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‘Farming looks mighty easy when your plough is a pencil and you’re a thousand miles from the corn field’

Dwight D. Eisenhower (1956)

Statement of originality

This thesis and the work to which it refers are the results of my own efforts. Any ideas, data, images or text resulting from the work of others (whether published or unpublished) are fully identified as such within the work and attributed to their originator in the text, bibliography or in footnotes. This thesis has not been submitted in whole or in part for any other academic degree or professional qualification. I agree that the University has the right to submit my work to the plagiarism detection service TurnitinUK for originality checks. Whether or not drafts have been so-assessed, the University reserves the right to require an electronic version of the final document (as submitted) for assessment as above.
Abstract

Greenhouse gas (GHG) emissions from agriculture and forestry account for nearly a third of anthropogenic emissions globally. The aim of this research was to explore how agri-food companies, including Unilever, manage and assess the GHG performance of the farmers in their supply chains. Certification schemes were identified as a key mechanism for GHG management at farm level and a structured framework was constructed to enable a transparent comparison of how current schemes address GHG management and performance. It revealed that most schemes are management oriented and few look to quantify the GHG emissions of farming systems or set GHG performance standards.

GHG calculators are an increasingly important tool to model and estimate farm GHG emissions. An in-depth comparison of three calculators revealed differences in methodology and in their underlying assumptions and data which have important implications when used by companies to assess farm performance and crops. GHG calculators are complex tools and, in four case studies using the Cool Farm Tool, the quality of the results was found to be highly dependent on the mode of implementation. Key factors included the level of support and verification provided by the company and the capability of the user. The GHG results obtained from the use of the calculator was shown to be sensitive to farm management practices and climatic conditions.

Findings of the research provided Unilever (and the wider agri-food sector) with insights on the effectiveness of key GHG management and assessment mechanisms being used across agri-food supply chains at the farm level. Moreover, it has provided Unilever with a robust basis in which to define their future strategy for managing/assessing GHG in their agri-food supply chains and has recommended some future areas of work that would help to advance the agenda further.
Executive Summary

Introduction

This research was initiated by the sustainability team at Unilever to explore the mechanisms that could be used to manage and assess performance of the GHG emissions from their agricultural food (agri-food) supply chains. Unilever is a large multi-national fast-moving consumer goods (FMCG) company who manufacture a number of products across the home care, personal care and food categories. In 2010 Unilever launched its Unilever Sustainable Living Plan (USLP) (Unilever, 2010) with the overarching aim of doubling the size of the business whilst halving the environmental impact. Environmental impact was predominantly focused on greenhouse gas (GHG) emissions, water use and waste and was to be assessed on a per consumer use basis, and moreover, it was aimed at reduction across the whole of Unilever’s supply chain. 50% of the raw material ingredients that Unilever source come from agriculture, thus the agri-food supply chain, and particularly the part of the supply chain that is most difficult to address and where (often) the largest proportion of GHG emissions are produced, farm level, was identified as an important focus for GHG emission reduction.

Agriculture, together with forestry, is responsible for approximately 30% of global anthropogenic GHG emissions (IPCC, 2007), and yet it is a sector with a significant mitigation potential (Smith et al., 2008). Consequently, pressures to reduce GHG emissions from farming systems and improve agricultural practices is high on political and consumer agendas (Weidmann and Minx, 2008). Improved farm management practices and increased carbon sequestration through the preservation and production of biomass could render agricultural systems carbon neutral over their life time (Noponen et al., 2012) or even a net sink. With this potential to reduce emissions, companies have begun setting targets to reduce their scope 3 GHG emissions (indirect emissions including those from agriculture), however, many are uncertain how this would be achieved. The research therefore focuses on the global challenge of reducing GHG emissions in the agri-food sector as exemplified by the interest of Unilever and related food and manufacturing companies.

The Engineering Doctorate Programme was well suited to this area of research as it aims to address the ‘relationship between the environment, technology and business’ (University of Surrey, 2011). This research was funded by the EPSRC and was undertaken in the context of and tailored to the approaches and needs of Unilever. However, it was intended to take on board the needs and activities of the wider agri-food sector to be useful outside of just Unilever.

The work is presented in the format of a portfolio, comprising a main thesis (Volume 1) documenting the key aspects of the research and the findings, and a compilation of the six month reports that were produced throughout the project duration (Volume 2). Additionally the publications produced throughout the research are available and are summarised in Appendix D of the thesis.
Research aim and objectives

The overall aim of this research was to:

- Improve the effectiveness of FMCG companies in managing, quantifying and providing evidence of performance of the GHG emissions in their agricultural supply chains and specifically up to the farm gate.

The specific research objectives to help to meet this aim were:

1. To review and summarise the approaches, standards and methodologies for GHG assessment at the farm level in the context of complete supply chains, and the company commitments being made.
2. To develop a framework to assess how agri-food certification schemes address the management of GHGs through to reporting of GHG emissions (outcome focused).
3. To explore the range of agricultural GHG modelling tools available and compare three important, widely used tools in order to clarify sources of methodological difference between them in order to evaluate their comparability for use in GHG reporting.
4. To understand how the mode of implementation of GHG calculators affects the quality of the GHG emission results from farmers, when used and interpreted by FMCG companies.
5. To use the insights gained to make recommendations for improved GHG assessment, management and reporting of farm level data for a supply chain company.

Research approaches

The research was conducted within the context of Unilever and thus observation and engagement in business activities formed a key part of shaping the research agenda. The majority of the research was desk based and involved a number of different approaches, including:

- Detailed literature reviews were conducted to inform the basis of the research area and keep pace with the evolving activities.
- Framework analysis combined with other dimensions of social research including thematic analysis and case study research.
- Quantitative analysis was performed through the use and assessment of GHG calculators and the results produced.
- Social research in the form of surveys and semi-structured interviews were also used to gather insights throughout the research and to strengthen some of the findings in particular areas.
Chapter summaries and key findings

Chapter 1 sets the scene by introducing the research context and providing more information on Unilever’s corporate GHG reduction targets and the approaches taken so far to enable the calculation of a baseline GHG footprint including agricultural production. Most of the GHG data used to calculate this part of the footprint was based on literature sources, modelled data and expert opinion when necessary, i.e. it was not specific to their supply chain. In order to manage and assess performance and be able to demonstrate improvement requires efforts focused at the farm level of the supply chain. This therefore provides the rationale for the research.

Chapter 2 provides a summary of agri-food supply chains and the many and various complex GHG emission sources (GHG drivers) from agriculture, thus demonstrating the difficulties for companies to manage and assess them. A brief overview of some of the approaches that companies can adopt to account and report their agricultural GHG emissions is presented. It shows that there are many approaches that can be adopted. Two important ones, environmental certification schemes and GHG calculators form the basis of the rest of the thesis.

The main feature of Chapter 3 is the development and application of a structured and transparent framework to compare ten important and widely applied agricultural environmental certification schemes for how they address GHG emissions. The chapter begins by presenting some of the background to certification schemes and infers the proliferation of schemes that has occurred over the last few decades, largely as a mechanism to bridge the gap in regulation, to provide assurance of environmentally superior, or more sustainable, production practices, and to differentiate products and communicate to consumers. An important finding of the research in this chapter is the limited evidence of the ‘impact’ of certification schemes on the environment across all environmental indicators and particularly GHG emissions. This is due to the expensive and high resource needs of such studies. The framework developed therefore aims to reveal how schemes address GHG emissions; it looks at three dimensions:

- The comprehensiveness of the schemes in terms of the number of GHG drivers (emission sources) they include
- The level of intervention at which each driver is addressed i.e. whether it is required to be managed, whether quantified input parameters are required that would enable a GHG estimation or ‘measurement’, or whether a GHG performance standard is set (e.g. an emission threshold)
- The stringency with which each GHG driver is imposed i.e. whether it is mandatory or optional.

The results of the framework reveal that most schemes are GHG management oriented, but few are beginning to require evidence of quantified farm inputs and/or GHG performance. This work is published in (Keller et al., 2013).
Chapter 4, then, is focused on a key mechanism by which to estimate GHG performance at the farm level, GHG calculators. It introduces and classifies a number of the plethora of calculators that have been developed in recent years and then conducts a detailed comparison of three internationally important GHG calculators that are being applied as part of certification schemes; the Cool Farm Tool within Unilever’s Sustainable Agriculture Code and in PepsiCo’s supply chain; PalmGHG specific to palm oil production and required within the Roundtable of Sustainable Palm Oil (RSPO) certification scheme; and the Bonsucro calculator for sugarcane that is used within the Bonsucro scheme. The comparison reveals the differences between the calculators in the methodologies, data sources, units and nomenclature used. It provides a structured and transparent comparison of the three calculators and also demonstrates the different results that each can produce when using the same input data. This work is published in (Keller et al., 2014).

To assess the potential of GHG calculators to ascertain good quality GHG results from farmers, Chapter 5 focuses on the implementation of the Cool Farm Tool through four case studies. It showed that the quality of the results was found to be highly dependent on the mode of implementation. Key factors included the level of support and verification provided by the company and the capability of the user. The GHG results obtained from the use of the calculator was shown to be sensitive to farm management practices and climatic conditions.

Finally, Chapter 6 summarises the key conclusions made throughout the research project. Most importantly, however, it focuses on a broader discussion of the observations, insights and findings made over the course of the research. Of particular note, are the many challenges and issues that companies may face in trying to manage and assess the GHG performance of their agri-food supply chains, particularly if trying to achieve results at scale and include smallholder farmers. Some important areas for further research are identified including validation of the framework developed in Chapter 3, the need for long term studies to assess and quantify the impacts (GHGs and others) of certification schemes, and the need for further work to understand the operationalisation and value of landscape based approaches.

**Contributions to knowledge**

This research has contributed to understanding and knowledge in four main areas:

1. A review of GHG accounting methods and standards employed in the agricultural sector, along with their associated challenges and uncertainties.
2. The development of a framework for assessing and comparing how agri-food certification schemes address GHG emissions. This work was published in Keller et al., (2013) together with a review of 10 widely used schemes.
3. An in-depth comparison of three of the key farm-level GHG calculators; this part of the work was published in Keller et al., (2014).
4. An overall improved understanding of GHG management in agri-food supply chains, some of the mechanisms available to ascertain GHG data from supply chain actors and the associated challenges in applying them.
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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AGB</td>
<td>Above ground biomass</td>
</tr>
<tr>
<td>B2B</td>
<td>Business to business</td>
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<tr>
<td>B2C</td>
<td>Business to consumer</td>
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<tr>
<td>BCI</td>
<td>Better cotton initiative</td>
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<tr>
<td>BGB</td>
<td>Below ground biomass</td>
</tr>
<tr>
<td>BSI</td>
<td>British Standards Institute</td>
</tr>
<tr>
<td>C</td>
<td>Carbon</td>
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<tr>
<td>CDP</td>
<td>Carbon disclosure project</td>
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<tr>
<td>CF</td>
<td>Carbon footprint</td>
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<tr>
<td>CFA</td>
<td>Cool farm alliance</td>
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<tr>
<td>CFT</td>
<td>Cool farm tool</td>
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<tr>
<td>CGF</td>
<td>Consumer goods forum</td>
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<tr>
<td>CH₄</td>
<td>Methane gas</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide gas</td>
</tr>
<tr>
<td>CO₂ₑ</td>
<td>Carbon dioxide equivalents</td>
</tr>
<tr>
<td>COCOBOD</td>
<td>The Ghana cocoa board</td>
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<tr>
<td>CPC</td>
<td>Crop protection chemical</td>
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<tr>
<td>CPO</td>
<td>Crude palm oil</td>
</tr>
<tr>
<td>CRC</td>
<td>Carbon Reduction Commitment</td>
</tr>
<tr>
<td>CRIG</td>
<td>Cocoa Research Institute of Ghana</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department for Environment, Food and Rural Affairs</td>
</tr>
<tr>
<td>DM</td>
<td>Dry Matter</td>
</tr>
<tr>
<td>EF</td>
<td>Emission Factor</td>
</tr>
<tr>
<td>EFB</td>
<td>Empty Fruit Bunch</td>
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<tr>
<td>EM</td>
<td>Extraneous Matter</td>
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<tr>
<td>EPD</td>
<td>Environmental product declaration</td>
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<td>EU</td>
<td>European Union</td>
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<td>EU RED</td>
<td>European Renewable Energy Directive</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation of the United Nations</td>
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<tr>
<td>FDF</td>
<td>Food and drink federation</td>
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<tr>
<td>FFB</td>
<td>Fresh fruit bunch</td>
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<tr>
<td>FMCG</td>
<td>Fast-moving consumer goods</td>
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<td>FSC</td>
<td>Forest stewardship council</td>
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<td>FT</td>
<td>Fairtrade</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
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<tr>
<td>Ha</td>
<td>Hectare</td>
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<tr>
<td>HCS</td>
<td>High carbon stock</td>
</tr>
<tr>
<td>HCV</td>
<td>High conservation value</td>
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<tr>
<td>IPCC</td>
<td>International Panel on Climate Change</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>IT</td>
<td>Information technology</td>
</tr>
<tr>
<td>K</td>
<td>Potassium (fertiliser)</td>
</tr>
<tr>
<td>Kg</td>
<td>Kilogram</td>
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<tr>
<td>Km</td>
<td>Kilometre</td>
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<tr>
<td>kWh</td>
<td>Kilo watt hours</td>
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<tr>
<td>LEAF</td>
<td>Linking environment and farming</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>LCA</td>
<td>Life cycle assessment</td>
</tr>
<tr>
<td>LU</td>
<td>Land use</td>
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<tr>
<td>LUC and iLUC</td>
<td>Land use change and indirect land use change</td>
</tr>
<tr>
<td>LULUC</td>
<td>Land use and land use change</td>
</tr>
<tr>
<td>MJ</td>
<td>Mega joule (energy)</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>N/A</td>
<td>Non applicable</td>
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<tr>
<td>N₂O</td>
<td>Nitrous dioxide gas</td>
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<tr>
<td>NGO</td>
<td>Non-governmental organisation</td>
</tr>
<tr>
<td>NR</td>
<td>Not relevant</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus (fertiliser)</td>
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<tr>
<td>PAS</td>
<td>Publically available specification</td>
</tr>
<tr>
<td>PCR</td>
<td>Product category rules</td>
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<td>PEFC</td>
<td>Programme for the endorsement of forest certification</td>
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<tr>
<td>PK</td>
<td>Palm kernel</td>
</tr>
<tr>
<td>PKE</td>
<td>Palm kernel expeller</td>
</tr>
<tr>
<td>PKO</td>
<td>Palm kernel oil</td>
</tr>
<tr>
<td>PO</td>
<td>Palm oil</td>
</tr>
<tr>
<td>POME</td>
<td>Palm oil mill effluent</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and development</td>
</tr>
<tr>
<td>RA</td>
<td>Rainforest Alliance</td>
</tr>
<tr>
<td>RA-CM</td>
<td>Rainforest alliance climate module</td>
</tr>
<tr>
<td>RED</td>
<td>Renewable energy directive</td>
</tr>
<tr>
<td>REDD</td>
<td>Reducing Emissions from Deforestation and Degradation</td>
</tr>
<tr>
<td>RSB</td>
<td>Roundtable of sustainable biofuels</td>
</tr>
</tbody>
</table>
CHAPTER I

BACKGROUND AND CONTEXT

‘Climate change is a terrible problem, and it absolutely needs to be solved. It deserves to be a huge priority’ (Bill Gates).

This introductory chapter provides the reader with an overview of the research area by highlighting the importance of Greenhouse Gas (GHG) emissions from agriculture and the challenges of managing and reducing them, particularly over supply chains which are commonly global. It presents the motive for the research and introduces the context in which it was conducted from the perspective of a global fast-moving consumer goods (FMCG) company, Unilever. This chapter presents the overall aims and objectives of the research set out in the succeeding chapters. Lastly, the contents and structure of the thesis are described to aid navigation.
1.1 Introduction

This Engineering Doctorate research project was initiated by the sustainability team within Unilever’s Safety and Environmental Assurance Centre (SEAC). SEAC are responsible for providing Unilever with scientific assessments on safety risks and environmental impacts of its ingredients, products and activities and for developing new capabilities in safety and sustainability science. The research project was co-funded by the Engineering and Physical Research Council (ESPRC) and Unilever in association with the University of Surrey Engineering Doctorate Programme in Sustainable Engineering and Energy Systems. The programme is designed to bring together academia and industry to help solve challenging business issues and to provide advanced post-graduate education and training.

The research focuses on the global challenge of reducing GHG emissions in the agri-food sector as exemplified by the interest of Unilever and related food and manufacturing companies.

Section 1.2 of this chapter provides an overview of the current global challenges that motivate the research, followed by section 1.3 that focuses on the role of agriculture in this context. Section 1.4 introduces and provides some background information on Unilever and explains some key features of their corporate sustainability plan and their sustainability commitments that shaped the research landscape. Following this, Section 1.5 presents some of the challenges of managing and reducing GHG emissions from agri-food supply chains and then goes on to define the overarching research aim and objectives and the structure of the thesis (Section 1.6).

1.2 The global challenge

Climate change is one of the biggest global challenges faced today (IPCC, 1990; Obama, 2015) and is the greatest and widest-ranging market failure ever seen (Stern, 2006). Climate change threatens global biodiversity and imposes a significant risk of extinction for many species (Thomas et al., 2004). It creates risks for human health (CCSP, 2008), threatens the functioning of fundamental ecosystem services such as provision of clean air and water (Mooney et al., 2009), and adds new pressures to global social systems (IPCC, 2007). One of the most profound and wide reaching impacts of climate change over the coming years, however, will be on agricultural food systems. Increasing temperatures, changes in the amount of carbon dioxide (CO₂) in the atmosphere, declining rainfall in semi-arid regions and changes in the frequency and intensity of extreme weather events such as

1 ‘Agri-food’ pertains to all food materials produced through agriculture including livestock, horticulture (plant based materials), aquaculture (fish farming) and can also include food and drink processing technologies. In this thesis, the focus is on the farming component of the agri-food supply chain. It also focuses predominately on food crop production and thus does not address issues associated with livestock production. It is, however, broader than food crop production, as some agricultural materials e.g. palm oil, are used not in food products but also in other products such as shampoos and detergents and as a source of fuel (biofuel). A further description of an agri-food supply chain will be presented in Chapter 2.
floods and droughts are likely to reduce the productivity of primary crops and livestock systems (Brown and Funk, 2008). These climate change induced impacts are likely to have substantial consequences for global food security and thus for human security. Compounding this issue is the need to feed a growing population of up to 9 billion by 2050 (Foley, 2011) and within this, a growing middle class with more wealth that creates a greater demand for a more varied and high-quality diet that requires additional agricultural resources to produce e.g. grain-fed meat products (Foresight, 2011). There will be increased competition for key resources (land, water, energy) on which agriculture and food production depend and which simultaneously, increased food production, exacerbates the competition (Foresight, 2011). Furthermore, there will be pressure for agriculture to play a role in decarbonising our energy supplies and bridging the ‘energy gap’ and the food vs. fuel debate (Graham-Rowe, 2011). All of these trends increase pressure on the agricultural sector to continue and increase production of healthy nutritious food, to substitute fossil materials as an energy source, whilst not expanding into high conservation value (HCV) and high carbon stock (HCS) areas (Wollenberg et al., 2011). For businesses that rely on agricultural raw materials, climate change poses serious risks both financially and operationally including risks to security of materials supply, increased volatility of commodity prices, stock damages (both to produce and infrastructure) and potential regulatory and reputational risks.

Climate change is caused by increasing concentrations of ‘greenhouse gases’ (hereafter GHGs) in the atmosphere that trap heat leading to global warming. CO$_2$ is the most important GHG and levels in the atmosphere are regulated by the carbon cycle. In the carbon cycle, CO$_2$ is generated by decaying plant matter, volcanic eruptions and animal respiration and it is removed through photosynthesis and dissolution in water (e.g. the oceans). However, an imbalance in the carbon cycle has been caused by man through the burning of fossil fuels and global warming has been exacerbated by the releases of other GHGs such as methane (CH$_4$), nitrous oxide (N$_2$O) and certain halogenated gases (which contain fluorine, chlorine or bromine). The importance of each individual GHG on climate change is dependent on their concentration, the longevity of the gas in the atmosphere and its potency to impact global temperatures. The latter two factors are combined to define the global warming potential (GWP) of each GHG. The GWP of CO$_2$ has been standardised to one and other GHGs are expressed in terms of their CO$_2$ equivalents (CO$_2$e).

Figure 1 shows an approximate breakdown of total global GHG emissions (in CO$_2$e) per sector and highlights the contribution of agriculture both through associated land use change, production of inputs used in agricultural systems, and the direct emissions from agriculture itself. There is global consensus among politicians, scientists and business that reducing GHG emissions is important, although agreement on the exact size of the target or how it should be met have not yet been reached (Nereng et al., 2009).

It is evident that agriculture is a potentially important sector for addressing climate change. Substantial reductions in GHG emissions from agriculture are required and the large multinational
food companies who source large volumes of agricultural materials as ingredients for their products have a key role to play. This thesis focuses on the different mechanisms available to agri-food companies to manage GHG emissions in their supply chains and specifically in activities up to the farm gate.

Figure 1: Breakdown of total global GHG emissions, the emissions associated with the food system, and those directly attributable to agricultural activities. [Image adapted from: (CGIAR and CCAFS, 2014)]
1.3 Agriculture: definitions, emissions and increased attention.

Agriculture may be defined as the deliberate use of land for the cultivation of edible plants or animals (Spedding, 1975). In fact, it is actually broader than this and includes the production of timber, fibre, feed and increasingly fuel crops (biofuels). The United Nations Food and Agriculture Organisation (UN FAO) defines agricultural land as land that is arable i.e. under temporary crops, meadows for mowing or pasture, under market or kitchen gardens and land that is temporary fallow; under permanent crops; and under permanent pastures. Under this definition agricultural land covers approximately 33% of the world’s land area (Nijs, 2014); in some countries the total area dedicated to agriculture is much higher e.g. in Bangladesh around 70% of land is under agricultural production and over 50% of France, whereas it is just 1% of the land area in Singapore (World Bank, 2015). The types of crop and farming system adopted in each of these countries differ considerably based on the local soil, climate and other factors.

Agriculture, together with forestry, is responsible for up to 30% of anthropogenic GHG emissions globally (IPCC, 2007), second only to the emissions produced by the energy sector including transportation (UNEP, 2012). It is also a sector with significant mitigation potential. Improved farm management practices, drastic reduction in deforestation, and enhanced carbon sequestration through maintenance of soils and increased biomass production could enable agriculture and forestry to facilitate emissions removals that outweigh releases and render agricultural production systems carbon neutral over their life span (Nooponen et al., 2012) or even a net carbon sink. The agricultural sector therefore has significant potential to not only eliminate its own GHG impact but to mitigate the GHG impact from other sectors (Paustian et al. 2006; Smith et al. 2007). (The sources and sinks, or ‘GHG drivers’ in agriculture will be described further in the following two chapters). Technological advances that lead to efficiency improvements and better management systems motivated by increased awareness, engagement and education on GHGs, and positive incentives to encourage behavioural changes, can help to reduce GHG emissions from agricultural activities. To be effective, approaches should be complementary, cost-efficient and simple to implement in order to increase uptake.

Given the significance of the emissions from this sector, it has attracted increasing political, media, academic, corporate and public attention. Politically, this has been reflected by the inclusion of agriculture and forestry within global and national GHG reduction programmes such as the UN-REDD and REDD+, (Reducing Emissions from Deforestation and forest Degradation), in projects under the CDM (Clean Development Mechanism), the 2008 UK Climate Change Act, and also by the debate surrounding how to include agricultural activities in other programmes including EU climate change commitments (Europa, 2014). Increased public attention and concern has been fuelled, in part, by increased media communication on the role of agriculture in tackling climate change, as well as through increased and more prominent communication and competitive claims by companies.
The size of the agricultural sector is vast and action to tackle GHG emissions must occur at multiple levels. ‘Macro’ level initiatives i.e. those at a large scale such as national or sector level, are important to influence agricultural production systems, however, for these broader changes to occur must be the sum of a number of individual changes/improvements at the more ‘micro’ level i.e. the farm, the most basic unit of management (van der Werf and Petit, 2002). Agri-food companies who are dependent on several individual farms and farming groups within their supply chain for the raw materials that make up their products, represent an important actor to influence and help to improve individual and collective farming units.

The overview above, has highlighted the concern of GHGs from agriculture that will be the focus of this thesis, but it is important at this stage to acknowledge that GHGs are just one part of the environmental impact story and there are many other environmental impacts at farm level that could be considered and in which trade-offs may occur. GHGs, however, have been one of the first environmental metrics to receive wide scale attention and efforts to manage and measure, yet significant challenges persist. They are usually a starting point for many organisations who want to reduce their environmental impacts and are often seen as a proxy for wider environmental impacts (UNFCCC, 2009; Trexler, 2011).

1.4 Introduction to Unilever

Unilever is a 40 billion Euro global FMCG company whose portfolio of products includes home care, personal care and food products. The home care part of the business includes laundry detergents and household cleaning products sold as well-known brands such as Persil, Surf and Domestos. Personal care covers skin and hair products, deodorants and oral care products, with brands such as Dove, Tresemme, Axe, Sure and Mentadent. Lastly, the food portfolio encompasses a diverse range of products: refreshment products including ice cream, beverages such as tea, spreads and savoury products such as soups, stocks, and sauces and brands like Flora, PG tips, Ben and Jerry’s, Walls, Knorr, Bertolli, and Hellmann’s. Unilever operates and sells products in over 170 countries, half of which are developing and emerging (D&E) markets. They employ over 160,000 people globally across core business functions including marketing, sales, finance and research and development (R&D). Unilever’s corporate mission is to make sustainable living common place and it is driven by the Unilever Sustainable Living Plan (Unilever, 2010a).

Unilever’s own operations include factories, office buildings, R&D sites (including laboratories), and some agricultural production sites e.g. tea estates in Kenya. Processes have been put in place to manage and reduce the environmental impacts of their own sites: in-company GHG emissions have been reduced by 62% relative to 1995, in absolute terms (Unilever, 2014a). Water use has been reduced by 74% in absolute terms since 1995, through implementation of monitoring and efficiency measures (Unilever, 2014b). Unilever also has a comprehensive Environmental Performance Reporting (EPR) system in place that captures data on energy and water use, waste and other
environmental impacts for their own business units (scope 1). Although this represents good progress in managing and reducing direct impacts, Unilever recognises the need to engage and manage impacts outside their direct control (scope 2 and 3).

Unilever has a long history of working on the sustainability of activities in supply chains but external to its own operations. The company works in partnership with several organisations and is part of many multi-stakeholder collaborative platforms across various dimensions of sustainability. Unilever, along with WWF (World Wide Fund for Nature), founded the MSC (Marine Stewardship Council) to improve fishery management; it took the lead in setting up the Roundtable on Sustainable Palm Oil (RSPO), an industry-led initiative to develop and promote global standards for sustainable palm oil as well as the Better Cotton Initiative (BCI) to address the negative impacts of mainstream cotton production; and is a member of various platforms including The Sustainability Consortium (TSC), the Roundtable for Responsible Soy (RTRS) and the Consumer Goods Forum (CGF). Unilever has also won several awards and has been recognised in several different rankings for sustainability including being named as the leader of the Food, Beverage and Tobacco Industry group of the Dow Jones Sustainability Indices; named as sector leader by the Carbon Disclosure Project (CDP) for their Forests programme in 2013; and ranked number one for sustainability leadership in a GlobeScan/SustainAbility survey in 2014.

As a responsible business, Unilever has embedded sustainability into its overall corporate strategy to ensure it is part of all business activities and that it spans the full value chain of their activities i.e. both direct and indirect emissions across scope 1, 2 and 3 of their impacts. This is elaborated on in the subsequent section.

1.4.1 Unilever as a sustainable business: the Unilever Sustainable Living Plan

In 2010 Unilever launched its Unilever Sustainable Living Plan (USLP) (Unilever, 2010a) which set out a ten-year plan (out to 2020) that would guide the business to achieve sustainable growth and double turnover whilst reducing the environmental impact. Unilever believes that growth must be sustainable and not come at a compromise to the health and well-being of the planet in which it operates. The USLP is therefore centred on three core targets:

1. To improve the health and well-being of over 1 billion people;

2 The GHG protocol differentiates between direct emissions, those from sources that are with direct control or ownership of the reporting entity (i.e. the reporting company), and indirect emissions, which are a consequence of the wider activities associated with the reporting entity but are owned or controlled by another entity (e.g. a supplier in the supply chain). Scope 1, 2 and 3 refer to the sub-classification of direct and indirect emissions. These are described further in Chapter 2.
2. To halve the environmental impact of Unilever products across the whole life cycle, specifically focusing on GHGs, water and waste;
3. To source 100% of agricultural raw materials sustainably.

The first target is about enhancing the impact that Unilever can have as a business on people’s lives. It includes encouraging over a billion people to improve their hygiene habits and the goal to bring safe drinking water to 500 million people. This is to improve quality of life and reduce the incidence of diseases such as diarrhoea (USLP, 2010). It also includes a focus on improving the nutritional quality of products to meet the highest standards according to globally recognised dietary guidelines, ultimately helping people to achieve a healthier diet. Upon review in 2013, the scope of this target was broadened to include targets to advance human rights across the value chain to help drive fairness in the workplace; provide increased opportunities for women; improve the livelihoods of smallholder farmers and the incomes of small-scale retailers; and provide increased opportunities for young entrepreneurs within the Unilever value chain (Unilever, 2014c). Therefore this overarching first target is focused on increasing Unilever’s positive social impact through its products, organisational behaviour, position in the supply chain and the campaigns it is involved with. Unilever believes that this is essential to help growth, reduce reputational risk and is part its duty within society.

The second target seeks to halve the environmental impacts of Unilever as a whole on a per consumer use basis. The environmental impacts are focused on GHGs, water and waste. To understand and demonstrate improvements against these metrics Unilever established baseline levels in 2010 by estimating the footprints for the full life cycle of approximately 1,600 stock keeping units (SKUs) representative of approximately 70% of the product volume sold (based on 2008 sales data) and based on 14 key countries (Franceshini et al., 2011; Unger et al., 2011). The countries were selected based on market importance, coverage of product formats, differences in products and consumer habits, and country infrastructure factors (e.g. GHG intensity of the grid). The footprint was recalculated in 2012 using slightly better data and improved methodology.

Figure 2 shows the GHG footprint and the relative contribution of each life cycle stage. It highlights that over 90% of the GHG emissions for the organisation are outside of Unilever’s own operations: the highest proportion is in the consumer use phase (68%), followed by sourcing of raw materials (23%) which includes both extracted minerals and agricultural materials.

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3 The target to halve the environmental footprint is on a per consumer use basis; i.e. the environmental (GHG, water and waste) impacts per single use, portion or serving of a product.
In addition to the three life cycle based metrics and targets, Unilever set a goal of sourcing 100% of the raw agricultural materials from sustainable sources. Over half of the raw materials purchased by Unilever come from agriculture and they include a diverse range of crops, livestock and commodity products including palm oil, other oil crops, sugar (both cane and beet), paper and board for packaging materials, tea, fruit and vegetables, dairy products and cocoa. To achieve sustainably sourced status, raw materials purchased must either be certified by an external certification scheme (e.g. Rainforest Alliance, Fairtrade etc.) or must comply with the Unilever Sustainable Agriculture Code (UL SAC).\(^4\) The UL SAC was launched in 2010 and requires suppliers and the farmers that supply them to comply with a number of good management practices and to provide quantitative data that enable the calculation of metrics by which to assess continuous improvement. There are eight metrics including a greenhouse gas (GHG) footprint, estimated using the Cool Farm Tool (CFT);\(^5\) water use efficiency and water quality; as well as others to assess the Nitrogen balance, biodiversity and land use (Unilever, 2010b). Table 1 indicates which of Unilever’s ten most significant materials are covered by either the UL SAC or a third party environmental certification scheme(s) and which schemes are included.


\(^5\) The Cool Farm Tool (CFT) is a GHG calculator developed by Unilever, University of Aberdeen and the Sustainable Food Lab. Available for download from: [www.coolfarmtool.org](http://www.coolfarmtool.org). It will be described further in Chapter 4.
Table 1: Certification schemes applied to Unilever’s top 10 raw agricultural materials.

<table>
<thead>
<tr>
<th>Agricultural Material</th>
<th>Certified through SAC</th>
<th>Certified with third party certification schemes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm oil</td>
<td>✓</td>
<td>✓ - RSPO, RFA</td>
</tr>
<tr>
<td>Sugar</td>
<td>✓</td>
<td>✓ - Bonsucro</td>
</tr>
<tr>
<td>Paper and board</td>
<td>✓</td>
<td>✓ - FSC, PEFC</td>
</tr>
<tr>
<td>Soy</td>
<td>✓</td>
<td>✓ - RTRS</td>
</tr>
<tr>
<td>Tea</td>
<td>✓</td>
<td>✓ - RFA</td>
</tr>
<tr>
<td>Fruit &amp; Vegetables</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Sunflower oil</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Rapeseed oil</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Dairy products</td>
<td>✓</td>
<td>✓ - Caring Dairy</td>
</tr>
<tr>
<td>Cocoa</td>
<td>✓</td>
<td>✓ - RFA, Fairtrade</td>
</tr>
</tbody>
</table>

*RSPO: Roundtable for Sustainable Palm Oil; RFA: Rainforest Alliance; FSC: Forest Stewardship Council; PEFC: Programme for the Endorsement of Forest Certification; RTRS: Roundtable for Responsible Soy

There are also more specific targets and time-bound commitments that form part of these three overarching targets. More detail can be found in the USLP (Unilever, 2010a) as well as the subsequent update reports (Unilever, 2013, 2012a). One additional important target is the commitment to include and improve the livelihoods of 500,000 smallholder farmers within the Unilever supply chain. This further demonstrates Unilever’s commitment to the sustainability, diversity and resilience of their supply chain.

This research project was motivated by the USLP target to halve Unilever’s environmental impact, specifically its GHG impact. It was undertaken to explore how far the GHG reduction might be achieved from the upstream sourcing of raw agricultural materials and promoted by the use of certification schemes. It is also linked to the sustainable sourcing target through the focus on many of the certification schemes that Unilever uses including the UL SAC.

1.4.2 Unilever’s assessment of GHG emissions from its agricultural supply chain

Figure 3 shows three levels of GHG assessment that Unilever (and other companies) have undertaken to begin to quantify the GHG impacts of agriculture and food production. The first level involves an assessment of the company’s own operations including manufacture and transportation i.e. Scope 1 and scope 2 emissions6 (more detail on emissions scopes is provided in Chapter 2). This

6 The GHG Protocol sets the global standard for how to measure, manage and report GHG emissions. It defines three scopes of emissions to aid with accounting and reporting and which delineate direct and indirect emission sources. More detail is provided in Chapter 2.
information can be collected through simple metering and activity measurements but typically does not cover agricultural GHG emissions (Russell, 2011).

For the second assessment level, own company operations plus supply chain activities (Scope 1, and 2/3) calculation of the GHG footprint was more resource intensive requiring additional data collection and analysis, and increased time and expertise. Individual product life cycle assessments had to be scaled up to portfolio level and then aggregated up to company level. Given the range and diversity of Unilever products, the footprint calculation process involved a combination of Unilever specific data such as energy consumption in offices and factories, supplier data, where available, for processing, and data from literature sources and life cycle databases and models. This presented a particular problem for calculation of the GHG impacts from agricultural materials sourced globally, for which data were particularly difficult to establish. Several literature data sources including detailed life cycle assessments (LCAs) of food products and raw materials were consulted but where no specific data existed, expert opinion was used based on estimates or surrogates as necessary (Unger et al., 2011).

GHG assessment of Unilever’s product portfolio took a full life cycle approach based on ISO 14040 standards (described further in chapter 2). Key features of the methodology included (adapted from Unger et al., 2011):

- GHG emissions were calculated in CO₂ equivalents over a 100 year time horizon.
- Land use and land use change GHG emissions associated with agricultural materials were partially included where the data was available (although this was limited).
- Published GHG data sources were used whenever possible.
- The generic life cycle was modelled using commercial life cycle assessment software provided by PE International (Gabi software and i-report).
- Where necessary, fixed assumptions were used for phases of the life cycle that constituted a small proportion of the overall footprint e.g. a single journey distance/mode of transport was used to describe product distribution from factory to retailer.
- GHG emissions from biodegradation of petrochemical ingredients were omitted.

The life cycle models were built in Gabi software and used all available ingredient inventories. GHG calculations were performed on a per consumer use basis for each product and the results were scaled up using sales figures for each product group in each country (Unger et al., 2011).

The third level is where many companies, including Unilever, are now looking to develop, namely to combine global average data with supplier specific GHG data that is representative of their own supply chain. This is necessary to inform better decision making by providing a more detailed understanding of the GHG impacts of suppliers, crops and sourcing regions, and thereby potentially to support decisions based on material/ingredient switching and supplier selection, as well as
enabling targeted improvement interventions. This forms an important motivation of this research project.

1. **Own operations**

   GHG assessments of own operations including manufacturing and transport. Agricultural GHGs were omitted.

2. **Own operations**

   Modelling tools and global average data representing global commodity market situation or company purchasing mix for assessment and increased understanding of GHGs from agricultural systems.

3. **Own operations**

   Combinations of modelled and global average GHG data with supplier specific GHG data from farmers in the supply chain across different crops and farming locations

Figure 3: Three levels of company GHG assessment of food products (up to the shop floor).

1.5 **Challenges of management and reduction of GHG emissions from agri-food supply chains**

There are some significant challenges for companies who want to move towards the third level shown in Figure 3 to understand the GHG impacts of the farms in their own supply chain. These include (adapted from Keller et al., 2011):

- **GHG accounting methodology** – there remains a lack of consensus on a whole farm GHG accounting methodology and so the distribution of possible GHG assessment results is large. This uncertainty is primarily due to incomplete scientific understanding of GHG emissions arising from biological systems and ecological interactions. Uncertainties exist at a fine-grained spatial scale, and are thus even greater when scaling up to the whole farm-level (Gibbons et al., 2006) and greater still at landscape or national level (IPCC, 2006a). Several GHG models exist which attempt to estimate emissions from biological sources including soils, biomass and other organic matter and also emissions arising from the contentious issue of land-use change (LUC). Most, however, fail to consider the dynamics of agricultural systems including weather variability, real-life yields and the impacts of different management practices, and so are of little use in calculating an accurate overall farm GHG balance. Some studies have begun to quantify the relative contribution of different farming management practices as part of the larger carbon footprint of different crop types (Smith,
but validation of these models against real in-field emissions, is limited.

- **On-farm emission estimation and data capture** – IPCC emission factors and GHG inventories have been developed using several datasets (IPCC, 2007, 2006b) (where available) to guide users to produce more accurate emissions estimates but farm-specific data is often lacking. (Some of the levels of data collection and methodologies defined in IPCC will be elaborated on in Chapter 2). Farmers may be familiar with monitoring and recording information for food safety and quality requirements, product liability, trade reasons and for tracking fiscal trends in the market (e.g. UK Government, Department for Environment, Food and Rural Affairs (DEFRA) farm surveys; United States Department of Agriculture (USDA) reporting requirements). However, GHG data requirements related to particular farm characteristic or management activities, are new in comparison, are often poorly understood (DEFRA, 2010) and the data-intensive tools may be seen as an additional or unnecessary administrative burden.

- **Interpretation and communication** - Acquiring good quality farm specific GHG information is important for companies wanting to compile detailed inventories for use in product assessments. Contextual information can make data interpretation more accurate and enable better understanding of the system and improved management. Vertical information sharing through supply chains brings its own challenges and as such GHG data sharing is generally not an integral part of agri-food chain communications.

In spite of the challenges and uncertainties companies are taking action and a number of approaches are being employed to capture farm-level GHG impacts and to support the tracking of this information up the supply chain. This research project aims to contribute to this area of knowledge.

### 1.6 Aims, objectives and structure of the thesis

The preceding sections have outlined the subject area, some of the gaps in the knowledge base and the company context for this project. The research was undertaken from the perspective of Unilever, but with relevance to the wider food supply chain and in particular other food manufacturing companies and retailers who are embarking upon a similar journey to understand, reduce and report the GHG emissions from their agri-food supply chain. The overarching aim of the research is therefore to:

- Improve the effectiveness of FMCG companies in managing, quantifying and providing evidence of performance of the GHG emissions in their agricultural supply chains and specifically up to the farm gate.
To meet this aim there is a need to identify and understand the current range of approaches and standards for GHG assessment and management and to recognise those appropriate for use within a supply chain context. This led to the first specific research objective:

1. To review and summarise the approaches, standards and methodologies for GHG assessment at the farm level in the context of complete supply chains, and the company commitments being made.

Findings from this review highlighted the main mechanisms that can be used to manage and quantify GHG performance and thus lead to the second and third research objectives:

2. To develop a framework to assess how agri-food certification schemes address the management of GHGs through to reporting of GHG emissions (outcome focused).
3. To explore the range of agricultural GHG modelling tools available and compare three important, widely used tools in order to clarify sources of methodological difference between them in order to evaluate their comparability for use in GHG reporting.

Moving beyond the technical exploration of these mechanisms it is important to understand how GHG data can be acquired from agri-food supply chains at the farm level, leading to the fourth research objective:

4. To understand how the mode of implementation of GHG calculators affects the quality of the GHG emission results from farmers, when used and interpreted by FMCG companies.

Finally, the ultimate aim of this research is to inform and improve GHG management and assessment, leading to the final research objective:

5. To use the insights gained to make recommendations for improved GHG assessment, management and reporting of farm level data for supply chain companies.

It is intended that this research will help FMCG companies, and Unilever in particular, to better understand how they may manage and reduce the GHG emissions of their agri-food supply chain and to guide them on the use of the data for GHG reporting (internally and externally) and in decision-making. Furthermore this research will contribute to Unilever’s external influencing as a leader in this space through the promotion of this work at different industry working groups (e.g. Food and Drink Federation (FDF) sustainable sourcing working group, RSPO carbon working group and in DEFRA’s food and agriculture GHG mitigation working group) as well as through scientific publication of some aspects of the work (Keller et al., 2014, 2011b, 2013).

1.6.1 Thesis structure

The thesis is structured in six parts: introduction, supporting literature and background information, three results and discussion chapters where the key GHG management and quantification
mechanisms are explored and assessed, and a final chapter to discuss overall findings and provide a future outlook for the topic area. The structure and content of the remaining chapters is as follows:

- Chapter 2 presents the current state of the science of GHG emissions and agriculture and the challenges pertaining to supply chain activities.
- Chapter 3 addresses objective 2 and focuses on certification schemes as a mechanism for management of the sustainability, and the GHG impact, of farmers and suppliers within a supply chain. In this chapter a framework to compare certification schemes for how they address GHG emissions, is developed and applied to a number of schemes used within Unilever’s supply chain. It is based on the publication (Keller et al., 2013) which was an outcome of this research project.
- Chapter 4 focuses on objective 3 and a comparative evaluation of three key GHG calculators. It is based on the publication (Keller et al., 2014).
- Chapter 5 addresses objective 4 and through four case studies surrounding the application of the Cool Farm Tool GHG calculator in different supply chain implementation modes combining an assessment of data quality as well user experiences.
- Chapter 6 is a wider discussion on some of the key insights and challenges as well as recommendations for future research.
CHAPTER II

AGRICULTURE AND GREENHOUSE GASES
AND AGRI-FOOD COMPANY
COMMITMENTS

‘For me context is key – from that comes the understanding of everything’ (K. Noland)

Greenhouse gases (GHG) are emitted from a diverse range of sources in agriculture. Managing and quantifying each of these sources involves numerous approaches and possible methodologies and is associated with many uncertainties and challenges. This chapter provides an introduction to agri-food supply chains, the sources of agricultural GHG emissions and the commitments of agri-food companies to sustainable sourcing and GHG targets.
2.1 Agri-food supply chains

In this thesis, ‘agri-food’ refers to ingredients and products that come from land-based agricultural production systems. Some agri-food materials, such as oil crops (e.g. palm oil, rape seed oil) are also used in non-food products such as home and personal care products and as biofuels in the energy sector.

Agri-food supply chains are inter-connected networks of agricultural and food related businesses through which agricultural ingredients and products move from growing/sourcing through to consumption. They include pre-production activities (land conversion for growing and manufacture of farm inputs e.g. fertilisers) and post-consumption activities such as waste management. The supply chain networks involve numerous inputs, processes and often many supply chain actors. As many of the world’s staple foods are traded internationally as commodities (Smith, 2008b) consumers in the developed world have come to expect constant availability, quality and of food products year round.

Figure 4 shows a schematic representation of a typical agri-food supply chain including the producers of agricultural inputs and the farmers through to the consumer use end of the chain where the product is consumed and waste is generated. Despite the use of the term supply chain, it is neither a linear nor a static entity. They are highly diverse, varying in structure, numbers of players, transport systems used, distance travelled, number of ingredients involved and the amount of processing undertaken.

Figure 4: Schematic representation of an agri-food supply chain (Matopoulos et al., 2007).
Some important factors that influence the length and complexity of various agri-food supply chains include:

- **Commodities** – standardized, bulked and mass traded on spot markets mainly based on price. These supply chains are usually organised as globally as a ‘set of inter-organisational networks clustered around one commodity or product’ (Gereffi, 1994) and may be either ‘producer-driven’ or ‘buyer-driven’ (Potts, 2006). Examples include palm oil, soy (beans, oil, meal), coffee and cocoa etc.

- **Value added** – characterises raw food products that provide ‘incremental value’ within the market place. This is generally through higher prices, expanded markets or through differentiation from similar products. Differentiation can be made through product functionality e.g. high in protein, increased food safety, the location of origin and environmental stewardship (Bender, 2003). Similarly, the word value in this context can also relate to the nature of the interacting parties and business relationships across the ‘value chain’, examples include:
  - *Organic* - uses fewer artificial chemicals, rears animals in more natural conditions and so is ‘more in harmony with the environment and local ecosystems’ (Seyfang, 2006) to the extent that proponents claim enhancement of biodiversity, soil quality and less pollution and land degradation (Seyfang, 2006). Organic farming emphasises knowledge-intensive farming as opposed to input-intensive farming (Blackmore et al., 2012) as it typically requires new skills and different farm management approaches. Organic production is not standardised globally, there are a range of different organic standards for the Japanese, U.S and European markets. Studies have shown that consumers generally view organic produce positively (Zanoli and Naspetti, 2002), believe that they taste better (Beharrell and MacFie, 1991; Fillion and Arazi, 2002; Lee et al., 2013), and believe that the practices of the producers of organic foods are more ethically sound (Harper & Makatouni, 2002).
  - *Local farm produce* – i.e. the notion of ‘local’ food has grown in prominence and appeal. It refers to food that has not moved long distances to get to market, that it is part of a short supply chain and has been grown within ~100 miles from its point of purchase (DeLind, 2011; Mount, 2012). Growing public concern regarding the provenance, manipulation and more recently, the sustainability of the food they are purchasing has increased the demand for ‘more natural’, ‘more local’ and often viewed and considered as healthier and ‘environmentally friendly’ food (Marsden et al., 2000; Murdoch et al., 2000). These, generally shorter supply chains, have the capacity to bring the consumer closer to the producer and re-socialise or re-spatialise food bringing greater value judgments and perceptions into the purchasing process (Marsden et al., 2000). Consumers therefore can experience a
sense of ecological citizenship (Seyfang, 2006) which Carter (2007) argues is an essential prerequisite of a sustainable society.

2.1.1 Traceability and consumer marketing

Many retailers and food companies have embraced the concept of traceability and have gone a step further to connect producers and consumers by defining foods by the locality or even the specific farm where they were produced. In doing so they attempt to enhance the ‘value’ and ‘market differentiation’ of the food product by creating a perception of greater quality, fairer practices, more environmentally sustainable practices and thus will often command a premium price. (What constitutes sustainable agriculture will be explored in the following section). Figure 5 exemplifies the information being communicated to the consumer on products irrespective of how locally they have been sourced. It is not the distance or number of exchanges of the product through the supply chain that is critical, but the successful translation of information that consumers consider valuable, that engenders the relationship from one end of the supply/value chain, to the other (Renting et al., 2003).

![Figure 5: Sourcing communications on packaging of food products. a) Picture of a famer on egg box to engender a connection between producer and consumer. b) Barcodes in Europe allowing consumers to trace the meat they purchase. c) Locally branded milk that increased a supermarket’s sales. (Images taken from: flickr.com).](image)

2.1.2 Sustainable agriculture

Sustainable agriculture is concerned with the ability of agro-ecosystems to remain productive in the long term (Van der Werf & Petit, 2007) and thus incorporates concepts of both resilience (to shocks and stresses) and persistence (capacity to continue to produce over time) (Pretty, 2008). Sustainability of the agri-ecosystem is very difficult to measure. These systems rely on a combination of natural capital inputs (solar energy, soil, rain etc.) and human-made capital (chemicals and equipment) which produce outputs or products that we want, but also outputs or impacts on the environment that we don’t.
Just as agricultural systems are complex and diverse, so is the understanding of what constitutes sustainable agriculture which itself is a term that defies definition (Pretty, 1995). Table 2 exemplifies some of the many definitions that have been proposed, highlighting how the focus can vary. However, regardless of the specifics of the definition used all emphasise the importance of addressing the system as a whole to ensure that trade-offs are managed acceptably and that the problems of conventional agriculture are not reproduced (Allen et al., 1991). Ultimately, the goal of sustainable agriculture is to remain productive in the long term (van der Werf and Petit, 2002) by conserving resources on-farm, minimizing adverse impacts to the immediate and off-farm environments whilst ensuring a sustained level of profit. Environmentally speaking, farming activities are sustainable if the inputs of natural and man-made resources are used to maximum efficiency so that the outputs of emissions and wastes are supported by the ecological system it is in, over the long term (Payraudeau & Van der Werf, 2005). Regardless of efficiency gains in production, the system will not be sustainable if consumption goes beyond the system’s carrying capacity; in this sense UNEP (United Nations Environmental Programme) and FAO have adopted a definition of sustainable food systems, beyond sustainable agriculture that considered production only (UNEP, 2015).

Table 2: Some definitions of sustainable agriculture featured in literature.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Source</th>
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<tr>
<td>The ability to maintain productivity, whether of a field, farm or nation, in the face of stress or shock (such as increasing salinity, or erosion, or debt, or a new pest, or a rare drought or a sudden massive increase in input prices).</td>
<td>(Conway and Barbier, 1990)</td>
</tr>
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<td>The three principles of sustainable agriculture are the interrelatedness of all parts of a farming system, including the farmer and his family; the importance of the many biological balances in the system; and the need to maximize use of material and practices that disrupt those relationships.</td>
<td>(Harwood, 1990)</td>
</tr>
<tr>
<td>A sustainable agriculture is one that equitably balances concerns of environmental soundness, economic viability and social justice among all sectors of society.</td>
<td>(Allen et al., 1991)</td>
</tr>
<tr>
<td>A management strategy whose goal is to reduce input costs, minimize environmental damage and provide production and profit over time.</td>
<td>(Francis et al., 1988)</td>
</tr>
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| An integrated system of plant and animal production practices having a site-specific application that will, over the long term:  
  - satisfy human food and fibre needs; | (Gold 1999 and 2007) (USDA Legal definition) |
• enhance environmental quality and the natural resource base upon which the agricultural economy depends;
• make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
• sustain the economic viability of farm operations; and
• enhance the quality of life for farmers and society as a whole.

Sustainable agriculture is a productive, competitive and efficient way to produce safe agricultural products, while at the same time protecting and improving the natural environment and social/economic conditions of local communities (SAI Platform, 2010)

Sustainable agriculture:
• production systems and the policies for global food security must be adequate
• facilitate healthy ecosystems and support the sustainable management of land, water and natural resources, while delivering world food security
• meet the needs of the present and future generations whilst ensuring profitability, environmental health and social and economic equity
• requires major improvements in resource use efficiency, environmental protection and systems resilience
• requires a system of global governance that promotes food security. (FAO, 2015)

The following points briefly describe some of the key concepts that are referenced as important activities/concepts to achieve sustainable agricultural systems:

• **Low carbon farming** - an entirely sustainable system would be one in which carbon (or carbon equivalents, CO₂e) released, are in balance with the carbon sequestered by the system. Some low GHG agricultural systems including some methods of organic farming show that when the system is in complete harmony with its environment, farming can be low impact or even climate neutral (Niggli et al., 2009). This balance, however, is rarely achieved in practice. Technically then, the mitigation potential of agriculture is large, estimated to be approximately 5500-6000 Mt CO₂e/year (Smith et al., 2008) and for which improved management practices e.g. effective nutrient management, soil and grassland management and the use of renewable energy on farm, plays a key part.
• **Sustainable intensification (SI)**—increasing food production from existing farmland but that is balanced with the optimal use of farm inputs so that it doesn’t reduce the capacity of the land to continue producing food in the future (Garnett et al., 2013). It is about closing the yield gaps to be able to get increased productivity and reduce the need for expansion onto new croplands (Foley, 2011; Foley et al., 2011).

• **No-till agriculture**—by minimising soil and crop residue disturbance no-till technologies result in reduced energy requirements and can also sequester C in the soil as long as practiced with use of crop residues (Lal et al., 2007). It often cited as a method of conservation agriculture, but other research disputes this due to its potential need for increased chemicals (Friedrich and Kassam, 2012).

### 2.2 GHG emissions from agriculture

As indicated in the previous chapter, agriculture and deforestation is responsible for approximately 30% of global anthropogenic GHG emissions (IPCC, 2007; Smith et al., 2008). The three important GHGs from agriculture are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Carbon dioxide is released from microbial decay processes and the burning of plant organic matter; it also comes from use the use of fossil energy and products in agricultural activities. Nitrous oxide is generated largely by microbial activity in soils, enhanced by the extensive use of nitrogen-based fertilisers, particularly when the available N exceeds the plant’s requirement. Methane is produced when organic materials decompose in anaerobic conditions i.e. without the presence of oxygen, particularly those associated with the rearing of livestock (enteric fermentation and stored livestock manures) as well as large amounts that are associated with rice production in paddy fields (Denef et al., 2011; IPCC, 2007; Smith et al., 2008). GHG emissions from agriculture are complex as they are highly dependent on the natural geophysical conditions, temperature, climate and inherent soil properties, as well as specific farming practices (Milá i Canals, 2003).

Figure 6 presents an overview of the main emission sources (releases) and emission sinks (possibilities for GHG sequestration and storage) from an agricultural system. These sources and sinks will be collectively referred to as ‘GHG drivers’ and a brief explanation of each is provided in the subsequent sections.
2.2.1 GHG drivers from agricultural crop systems

2.2.1.1 Fertiliser production

GHGs from fertiliser production are associated with three main industrial processes; ammonia, phosphoric acid and nitric acid production. These processes are extremely energy intensive, predicting to consume 1.2% of the world’s energy and generate 1.2% of global GHG emissions (Kongshaug, 1998). Of these processes, ammonia production is the most intensive, accounting for approximately 87% of the fertiliser production industry’s total energy consumption (FAO/IFA, 2001). Fertiliser production can therefore constitute a large proportion of the overall crop footprint depending on factors such as, the mineral composition of the fertiliser, the technology used and the energy sources used (Quirin et al., 2004). In conventional coffee production, for example, fertiliser production can contribute up to 50% of the overall agricultural footprint (Noponen et al., 2012) although there are often large uncertainties involved.

2.2.1.2 Fertiliser field emissions

Fertilisers have proved to be an important input to increasing food production in all regions of the world (FAO, 2000). Mineral fertiliser use, however, is an important source of N₂O emissions, often one of the most significant emission sources of the agricultural system (Hillier et al., 2009). Emissions are generated from the associated nitrification and de-nitrification processes in the soil. The quantity
of N₂O produced is influenced by the type, placement and amount of fertiliser applied, the climate conditions, soil type and tillage practices. Growing pressures to produce higher yields per unit of land has seen their use intensify, with resultant increases in fertiliser related emissions. These emissions, however, are argued to be more than offset through considerably greater production quantities than would have been achieved without them (Burney et al., 2010). A large proportion of emissions from fertilisers are believed to be due to the poor or inappropriate management of the fertiliser application method(s), the rate and timing of application, and the types of fertilisers used (Snyder et al., 2007). This constitutes not just a GHG loss but a financial loss also due to wasted inputs. Several studies for different crops under different management regimes highlight the importance of fertiliser application as an emission source including coffee cultivation in parts of Central America (Noponen et al., 2012), for sugarcane in Mauritius (Plassmann et al., 2010) and table potatoes in Sweden (Röös et al., 2010). This is despite of huge uncertainties that remain for quantifying this emission source (Bouwman et al., 2013, 2002; Philibert et al., 2012).

2.2.1.3 Crop protection chemicals

Crop protection chemicals (CPCs) are pesticides, including herbicides, insecticides and fungicides that are used in agricultural systems to avoid or control crop pests and diseases. Concern over their use is largely in regard to the potential for damage to ecosystem food webs both within the immediate and surrounding fields (Hawes et al., 2009). As with fertiliser production, the energy requirement for the manufacture of CPCs can be significant. Studies suggest it can consume about 9% of the energy use for arable crop production and represent about 3% of the global warming potential (GWP) of crops overall (over 100 years) (Audsley et al., 2009). The actual GHG impact of production of specific pesticides will vary as it does for fertiliser production, because it is dependent on the chemical ingredients involved, the energy requirements in the manufacturing processes and the state of the technology used. There is a lack of data available for the GHG emissions from pesticide production and many sources still rely on data from chemical engineering estimates of early 1980s technologies (Green, 1987). In many agricultural systems CPCs themselves typically afford a very small contribution to the overall GHG footprint (Hillier et al., 2009; Pandey and Agrawal, 2014) or none at all in many developing world systems or others where alternative biological controls are used.

2.2.1.4 Soil

Soils contain significant amounts of carbon and indeed are the largest terrestrial carbon pool in the world, containing more carbon than that stored in all plant biomass and in the atmosphere (Scharlemann et al., 2014). Debate, however, remains over how much carbon exactly this is, and how much is released each year (van der Werf, et al., 2009; Le Quéré et al., 2013). Good quality soils therefore contain high quantities of soil organic carbon (SOC) and soil inorganic carbon (SIC). Conversion of natural undisturbed soils into agricultural production land can deplete the SOC pool by
up to 60% in temperate regions and cause even greater losses, up to 75%, in tropical areas (Lal, 2004) and thus result in a considerable release of GHG emissions. Reduced carbon stocks lessen the productivity of the soil and can have further impacts on soil structure and water quality, thereby making it is less suitable for cultivation. GHG emission releases from soils can be reduced through good soil management practices including well-timed applications of fertilisers and CPCs (or elimination of chemical application entirely), as well as employing practices that cause minimal soil disturbance such as reduced or no-till management over the long term (conservation tillage practices) (Baker et al., 2007; McCarl et al., 2007; Six et al., 2004; Mangalassery et al., 2014). (See more in section 2.2.1.6.1).

In addition to emissions reductions from soil, the potential of soil to sequester carbon from the atmosphere can be enhanced through other management operations that improve soil quality, structure, nutrient cycling, and water retention and water quality. Such practices can include; adding substantial quantities of biomass to the soil, e.g. mulch farming; use of cover crops; agroforestry and intercropping; integrated nutrient management through incorporation of manure; composting; application of other bio-solids and improved grazing; and rotational and intercropping, that can enhance microbial activity and the species diversity of soil fauna (Lal, 2004; Lugato et al., 2014).

Emissions from soil can dominate a crop GHG footprint, particularly in a system which might involve the addition of agricultural by-products or wastes from other industries, e.g. in an organic coffee production system studied by Noponen et al., (2012) the soil N\textsubscript{2}O emissions made up to 92% of the total GHG emission footprint. This source of emissions is extremely difficult to quantify at a local level due to inadequate data for important parameters such as soil structure, SOC levels and their interaction with local weather conditions. In the absence of complex and often impractical and costly gas chamber based approaches (see section 2.3 for a brief overview of some of these) an IPCC tier 1\textsuperscript{7} approach is used (IPCC tiers are described further in section 2.4). Including an estimation of soil GHG emissions is an important impact criterion for GHG management on farms.

2.2.1.4.1 Peat soils

Peat soils contain large stores of organic matter and are the most efficient store of carbon globally (Hurgon et al., 2013). The carbon content of peat soils depends on the depth of the organic layer which in South East Asia a depth of several metres is common (Germer and Sauerborn, 2007a), typically between 5.5 – 7.0m on average (Page et al., 2011). Peat is typically waterlogged which prevents the microorganisms present from aerobic respiration thus preventing oxidation and the release of GHG emissions in the form of CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O. Cultivation on peat soils often requires

\textsuperscript{7} The 2006 IPCC Guidelines provide advice on emission estimation methods at three levels of detail starting with tier 1 which is the default approach and uses the most general data through to tier 3, the most detailed approach. Emission estimation accuracy and precision should improve from tier 1 to tier 3 and the different tiers enable users to use methods that suit their needs and resources. See section 2.3 for more detail.
that the land is cleared of vegetation (including forest) and is drained to enable planting. This drainage results in the aerobic decomposition of the stored organic material and significant CO₂ emissions. In addition, there is a significant reduction or cessation of any carbon sequestration by the peat by the addition of biomass and peat shifts from being a net sink of carbon to a source of CO₂ emissions. CO₂ is the most important GHG emission from peat soils comprising 98% or more of the total combined global warming potential from peat (Page et al., 2011). Emissions of CH₄ from peat drainage are insignificant in comparison to CO₂ and emissions from N₂O remain uncertain and so are not often quantified in many studies.

Peat is a particularly important consideration for some crops, such as palm oil, that is grown in tropical areas with large areas of peatland. Over 85% of palm oil is grown in southeast Asia (specifically Indonesia and Malaysia) (Fargione et al., 2008) which hosts approximately 56% of all tropical peatlands, estimated to contain around 70 Gigatonnes of carbon (Miettinen et al., 2012). This is equivalent to around eight times the annual amount of carbon released into the atmosphere globally by fossil fuel consumption in 2008 (Miettinen et al., 2012).

2.2.1.5 Energy use

Energy inputs are required throughout agricultural production from manufacture of mineral fertilisers and CPCs, the transport of materials to and off of the farm, on-site energy use in farm machinery and farm infrastructure as well as water management, land preparation, cultivation and harvesting operations. Globally, agriculture demands a relatively small proportion of total energy, between 3-8% (FAO, 2000), however, this is likely to increase as the developing world moves away from manual to mechanised labour and intensification practices increase. Agricultural energy demand can be divided into direct and indirect energy needs. The direct energy needs include energy required for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production, storage and the transport of agricultural inputs and outputs. Indirect energy needs are in the form of sequestered energy in fertilizers, herbicides, pesticides, and insecticides.

2.2.1.6 Land preparation/management activities

2.2.1.6.1 Tillage

Tillage is the preparation of soil, typically through mechanical agitation of various forms including digging, overturning and stirring of the soil. The tillage system employed in land preparation on the farm can have a significant impact on GHG emissions associated with the fuel energy use and emissions resulting from soil disturbance or compaction and associated yield declines (Mostaghimi et al., 1991). Both the type of tillage and the machinery or implement used is important, demonstrated by several studies (Baker et al., 2007; Clair et al., 2008; Lal, 2004) and therefore it is an important management practice to consider in regards to GHG emissions. No-till management can enhance the carbon sequestration potential of the soil and can also result in significant fuel
savings when compared with conventional tillage and can therefore be profitable if performed appropriately and in consideration with other local factors (Beck et al., 1998). Tillage practices can drastically reduce losses of SOC, and conservation tillage i.e. no-till, ridge-till or mulch-tillage which maintain higher levels of reside and disturb soils less than conventional tillage (Follett, 2001). The extent of the emissions reduction potential of these soil management practices, however, is still under debate in the literature. For example there are a number of recent studies that show that there may be a limit to soil storage capacity or a C-saturation which is often overlooked in studies estimating C sequestration under no-till (Corbeels et al., 2016) or that other factors such as the presence of earthworms might negate any CO2 and N2O savings gained from no-till rendering the emissions the same as a conventional tillage system (Lubbers et al., 2015).

2.2.1.6.2 Irrigation

Irrigation is the process of artificially applying water to land or soil that might otherwise receive inadequate rainfall and therefore be too dry for agricultural production. It is important for increasing crop yields and can also result in improved soil sequestration rates (Lal et al., 1998). Land can be irrigated in different ways; most utilise pumped irrigation systems whilst others may rely on gravity irrigation. The latter requires no energy inputs and thus has no energy associated GHG emissions. Energy associated emissions from irrigation can account for between 50 and 70% of all energy associated emissions in agriculture (Zou et al., 2013). Irrigation can also increase GHGs from soil by increasing the soil water availability, microbial activity and the mineralisation of carbon (C) and nitrogen (N) (Sainju et al., 2012). Predominantly, however, it is improvements in water use efficiency (crop biomass/unit of water), equipment efficiencies, and other improved technologies that can help to decrease the GHG emissions resulting from irrigation. Such technologies include rainfall monitoring and accounting and more detailed irrigation scheduling to help decrease irrigation water use; more efficient irrigation systems and improved electricity generation can reduce the energy associated emissions; and improved crop varieties (with reduced water requirements) and more optimal nutrient use can also help to reduce irrigation requirements (Follett, 2001).

2.2.1.6.3 On-farm combustion of crop residues

GHGs are released when crop residues are burnt. In India, burning of wheat and rice paddy straw contributes a large proportion of GHGs from the sector (Jain et al., 2014). Burning of crop residues is common practice in many production systems across the U.S including corn, cotton, rice, soybean, sugarcane and others and it typically takes two forms, a) post-harvest burning of dead or dying vegetation and crop residues, and b) pre-harvest burning, usually of crops such as sugarcane, in order to clear leaves and other biomass ahead of the harvest (and in other countries like Brazil, to clear out dangerous animals like snakes). A study on Brazilian sugarcane production systems found that residue burning was responsible for approximately 44% of the total emissions per tonne of sugarcane produced (Figueiredo et al., 2010). Most fires on crop/forest land are the direct result of
human activity (i.e. it is intended), this is estimated to be approximately 90% of incidences, and only around 10% are the result of natural causes, primarily lightening (Andreae, 1991; Lavorel et al., 2007).

Use of fire for land clearance prior to establishment of agricultural production is also frequently undertaken in areas of palm oil, soy or timber production. The burning process also emits other pollutant gases and consequently is banned or regulated in many countries, even though the practice may persist. Increased attention has been given to this agricultural land management practice, particularly in the wake of Indonesia’s recurring haze issue which leads to substantial GHG emissions as well as often severe health impacts on people/animals (Kunii et al., 2002; WRI, 2015).

2.2.1.7 Waste crop residue

Crop residues can help to enhance the soil organic carbon (SOC) which increases the physical, chemical and biological properties of the soil. Consequently, incorporation of residues can be a cost-effective and sustainable way to maintain/enhance SOC and increase soil fertility and ultimately improve yields and reduce GHG emissions (Smith et al., 2008). Removal of crop residues can therefore directly affect the soil carbon, can increase loss through erosion (the soil is likely to be more exposed), and through increase SOM decomposition (Kochsiek and Knops, 2012). Burning of waste crop residues is discussed in the preceding section.

2.2.1.8 Land use change (LUC)

LUC is the conversion of land, typically forest\(^8\), into agricultural land, therefore involving the removal of considerable amounts of standing biomass (e.g. trees) and soil disturbance, both of which can release significant GHG emissions (Agus et al., 2012; Fargione et al., 2008; Milà i Canals et al., 2006; Searchinger et al., 2008). Treatment of LUC is by far the largest aspect of variation in carbon footprints (CF’s) and Plassmann et al., (2010) demonstrated that the CF of 1kg of sugar can vary by up to 1900% depending on the CF method employed and whether LUC emissions are included or not. Similarly, Cederberg et al., (2011) showed how different the GHG footprint for beef that included emissions for LUC (annualised over 20 years) compared to the footprint of beef that had been produced on established pasture or non-deforested land. This is particularly an issue for agriculture and land conversion in developing countries where forest conversion may be high (Bessou et al., 2012; Flynn et al., 2012). (This will be covered more in Chapters 3 and 4). LUC emissions associated with food production are also an important consideration for looking at food-consumption impacts in countries that import a large amount of their agricultural ingredients. For UK food consumption, Audsley et al., (2009) found that inclusion of GHG emissions from food-consumption induced LUC, increased the total GHG footprint of food by 50%. This therefore made it

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\(^8\) There is a lot of debate about what constitutes ‘forest. The FAO definition of forest and forest types can be seen here: http://www.fao.org/docrep/006/ad665e/ad665e06.htm
a much larger GHG contributor to the overall UK consumption related impacts than previously thought (Audsley et al., 2009).

There are two categories of LUC; direct LUC in which GHG emissions can be directly attributed to a product following the conversion of a specific piece of land in order to produce that agricultural material; and indirect LUC where changes in global agricultural activity or total demand for an agricultural product induce land-use changes that cannot be associated directly with a specific product (Cederberg et al., 2011; Plevin et al., 2010).

2.2.1.9 Agroforestry

Agroforestry as a GHG driver and sink of carbon, is defined as a land-use that involves deliberate retention, introduction or mixture of trees or other woody perennials in crop/annual production fields to benefit ecological and economic interactions (Helms, 1998). Well managed agroforestry systems can play an important role in carbon (C) sequestration as they have the potential to be more efficient in resource capture and utilisation, resources including soil nutrients, light and water, in comparison to monoculture systems (Nair et al., 2008). As in other land-use systems, the extent of C sequestered depends on the amounts of C in standing biomass, recalcitrant C remaining the soil and C sequestered in wood products (Montagnini and Nair, 2004). As well as sequestering C, it can help landowners and society to address other issues facing land such as economic diversification, biodiversity pressures, water quality (Schoeneberger, 2009) as well as helping to reduce flooding. Establishment and management of agroforestry systems compatible with existing soil properties and climatic conditions can ensure that agroforestry systems can be significant sinks of carbon. Storage in trees and soils over decades to centuries as well as the potential for offset of immediate GHG emissions associated with deforestation and land use change due to shifting agriculture and expansion (Dixon, 1995). More broadly, agroforestry such as fuel wood plantations, shelterbelt/windbreak systems, buffer zones and woodlots can both sequester CO₂ from the atmosphere but also offset fossil fuel emissions through substitution with sustainably produced fuel wood and fodder (food and feed) etc. Agroforestry is particularly important in cocoa systems (Borg and Selmer, 2012; Ruf and Zadi, 1998) which will be explored further in Chapter 5.

2.2.2 Agriculture’s GHG mitigation potential

Both the preceding sections and content in Chapter 1 have referenced the significant GHG emissions that result from agricultural production, much of which could be avoidable, therefore highlighting the enormous role that agriculture could play in mitigating GHG emissions and reducing the impacts of climate change. Furthermore, with the appropriate context and economic incentives in place it could be done so cost-effectively (Golub et al., 2009; Smith, 2014). Much of the literature provides strong assertions in line with this (Cole et al., 1997; Paustian et al., 2006; Smith et al., 2007; Johnson et al., 2007; Beach et al., 2015) and points to many tens of possible individual mitigation activities which can be grouped into the following three broad categories (Smith et al., 2007; GIZ, 2014):
• Increasing CO2 storage in soils and biomass – increase soil C pools, avoiding emissions through reduced land conversion (particularly of high carbon land types e.g. forests) and strategic use of land that is set-aside i.e. not under agricultural production, restoration of drained soils and degraded land including maintenance and improvement of organic and peat soils.

• Enhancing GHG removal through management – zero-till, conservation till, fertiliser optimisation, improved crop and grazing land management including manure management and better feeding practices/feed ingredients and enhanced feed conversion rates.

• Indirect means to reduce the required volume of agricultural production – shifts from animal to plant based diets, reduced food loss and waste in the system, improved energy management (but with less demand for energy crops as this add to the demand for agricultural production).

The effectiveness of these activities depends on factors such as climate, soil type, and farming system as well as the socio-economic, political and cultural circumstances at local and global levels (Smith et al., 2008; Smith et al., 2009; Horowitz & Gottlieb, 2010).

Figure 7 shows the technical mitigation potential of 10 important agricultural management practices in MTCO2e/year up to 2030 considering no economic or other barriers. Actual emissions reductions that can be realised and that are economically feasible, however are highly dependent on the carbon price (Smith, 2014; Golub et al., 2009; ); at a low carbon price mitigation measures need to offer benefits beyond payment in order to facilitate their uptake by farmers. Other benefits might include yield increases, food security, or increased income through supply chain contracts (GIZ, 2014). Smith et al., (2007) calculate that the economic mitigation potential will be 73% of the technical potential when the carbon price is at 100 U.S dollars ($) per tCO2e, at 45% when the carbon price is $50 and just 28% of the technical mitigation potential when the carbon price is $20, by 2030. The current carbon price (in December 2015) is less than $10 per t. Consequently, current levels of GHG mitigation are below the proposed technical potential and without appropriate policy interventions it is projected that agricultural emissions of N2O and CH4 will increase by 35-60% and ~60% respectively, up to 2030 (Smith, 2014). This would be a more rapid increase in the observed non CO2 emissions rise of 14% between 1990 and 2005 (Smith, 2014). This rapid increase is largely driven by population increase and shifts in dietary patterns globally (Popp et al., 2010).
Many studies demonstrate the possible mitigation potentials using models to calculate mitigation potential globally and regionally (Beach et al., 2015; Meyer-Aurich, 2006; Henderson et al., 2015) and lots of research into the GHG mitigation contribution of different individual management practices on specific agricultural system types (Weiske et al., 2006; Schoeneberger, 2009; Paustian et al., 2000).

To balance this, however, there is a large body of literature that posits that some of the mitigation potential of different management practices and activities may be over-optimistic and in some cases unrealistic in light of what can technologically and economically be achieved. Some of these were already alluded to in the case of proposed soil carbon sequestration potentials, for example, no-till management (see section 2.2.1.6.1) (Neufeldt et al., 2015). Other management practices and agricultural mitigation options might also be over-optimistic, for example, the potential of agroforestry, and afforestation, given that it is highly dependent on land availability and political will to drive effective re-planting programmes, and can involve high transaction costs that may be a barrier to adoption, particularly when looking at the role of smallholders in carbon sequestration (Smith et al., 2007; Lasco et al., 2010; Luedeling & Neufeldt, 2012).

Figure 7: Global technical GHG mitigation potential of agricultural management practices by 2030 in MTCO$_2$e/year across three key GHG emission types (GIZ, 2014 and adapted from Smith et al., 2007).
2.3 Overview of experimental on-farm GHG measurement techniques

Field measurements of GHG emissions are important to understand different GHG emission profiles in different field conditions. It is important for the development and evaluation of GHG mitigation strategies and underpins the development of empirical GHG emission quantification models (Rosenstock et al., 2015). GHG fluxes can be defined as the flow of GHG emissions and GHG uptake across the soil surface i.e. the flow of GHG emissions between the terrestrial land surface and the atmosphere. Measuring GHG fluxes over time can help to determine whether a particular site acts as a GHG source or sink. Emission fluxes can be measured using a variety of techniques but the two most common approaches are described below (and images for each are shown in Figure 8):

- **Chamber-based methods** – one of the most standard and widely used methods for acquiring point measurements of GHGs in small scale field experiments. A chamber is set up to trap gases emitted from the soil surface. Chambers are placed in different locations across the agricultural site (taking into account different spatial considerations such as crop row spacing, plant height and fertiliser application bands) (Collier et al., 2014). An impermeable anchor is placed in the ground to stop the lateral flow of gases through the soil and a chamber lid is placed over the top. Air samples are physically extracted from the chamber at defined time intervals, using an air-tight syringe (optimal sample collection timings depend on the system under study and the chamber design being used). The air samples are run through a chromatograph and subjected to regression analysis to determine the changes in the concentration of GHGs of interest over time. This can be used to assess the different GHG fluxes from soils under different vegetation types or management practices. Results may also be compared across different fertiliser treatment regimes, soil tillage activities, or across seasons to explore system dynamics (Collier et al., 2014). Most chambers still rely on manual sample collection, but with the improvements in technology may also now be automated (Breuer et al., 2000) which can mean more data samples can be collected, but these should be moved regularly to minimise effects on soil conditions, particularly soil moisture (Yao et al., 2009).

A number of different gas chamber structures exist but to gain reliable results they should comprise: a sturdy non-reactive metal, reflective insulation to minimise the impacts of heat build-up during measurement, a sealing mechanism to prevent loss of gases, a septum to enable gas samples to be taken and a vent tube to prevent pressure changes during experimentation. Gas chamber methods are relatively inexpensive and consequently have been used in a number of studies across many years (Rochette, 2011). They can, however, be fairly resource intensive given the number and frequency of samples that may need to be taken and one of the main limitations of this approach is the temporal and spatial variability of GHG fluxes (Sapkota et al., 2014). Caution must also be exercised when comparing GHG results across different studies as chamber type (static, as described here, is
gas tight; or dynamic, which enable gas mixing in the chamber headspace), chamber design, sampling frequency and the analytical procedures used can have significant effects on the GHG emission results (Sapkota et al., 2014).

- **Eddy Covariance flux method** – this is a micrometeorological approach that is based on real-time and direct measurement of vertical gas fluxes within different atmospheric layers (Collier et al., 2014). It is also an effective method to evaluate how different climate conditions and management practices effect GHG emissions across a site. It measures the changing speed of ‘updrafts’ and ‘downdrafts’ in the air to calculate the net release and uptake of GHGs like CO$_2$. It utilises infra-red and ultrasonic soundwave technology. It can also measure other meteorological data such as temperature, relative humidity, solar radiation and light availability, wind direction and speed, and precipitation and additional probes in the ground can measure soil temperature and moisture (Waldo et al., 2012). Flux tower measurements collected over a year can provide information on the annual budget of GHG losses and gains from the environment. Use across a large area, can therefore, provide useful information on the impact of different climatic and environmental conditions and different management practices on GHG emissions. This method can also be used to look at the emissions of livestock systems as it can capture animal respiration on an outdoor grazing system.

It is a more costly method of quantifying GHGs from soils as it requires fairly complex technical equipment, needs a power supply and so is usually connected to batteries powered by solar panels. It is able to generate continuous measurements that can be spatially averaged over a large area from a few hectares to several kilometres and thus is better suited to larger sites (Baldocchi, 2003) such as for ecosystem-scale gas flux measurement. Its applicability for small-scale field sites and complex terrains are limited due to inherent assumptions, thus it works best with a minimum of 1ha of homogeneous flat terrain (Butterbach-Bahl et al., 2015).

The choice of approach will depend on resource availability, size of site under assessment and the specific research question or flux data of interest. There are other methods that vary on those presented above and might be more appropriate in different situations such as mass balance approaches, flux-gradient methods and others (Pattey et al., 2006; Denmead, 2008; Butterback-Bahl et al., 2011).
2.4 Standards, approaches and methods to estimate GHGs from agriculture

The following sections of this chapter intend to provide further important background information for the context of this thesis and in particular to fulfil objective 1 as defined in Chapter 1:

1. To review and summarise farm level GHG emission sources and the approaches, standards and methodologies for GHG assessment at the farm level in the context of complete supply chains, and the company commitments being made.

The complexities of agricultural and the interacting GHG drivers described above does not adapt itself easily to a life cycle assessment (LCA) approach (Lewis et al., 2008). A review by Foster et al., (2006) of LCAs for UK post-farm gate and imported pre- and post-farm gate agricultural commodities highlighted the gaps in data for conducting agricultural LCAs, the different system boundaries selected and the different methods used, rendering it very difficult to compare studies (Foster et al., 2006). Previous research (see e.g. (Brandão, 2013; Cowell, 1998; Mattsson et al., 1998a; Milá i Canals, 2003)) has provided detailed accounts of the key differences between agricultural and industrial systems, which explain the difficulties in applying life cycle assessment or LCA (a tool developed initially for industrial systems) to agriculture.

Despite the challenges faced it is still a commonly used approach to assess the environmental impacts of agri-food products (Brentrup et al., 2001; Haas et al., 2000; L. Milà i Canals et al., 2006; Nilsson et al., 2010) and it has formed the basis for many other approaches. A brief description of
LCA and some of the other key approaches and standards that can be used by companies to assess and report their GHG emissions from their supply chain, are below:

- **LCA** – Life cycle assessment is a ‘comprehensive method for analysis of the environmental impact of products and services’ (Baumann and Tillman, 2004) over their entire life, from ‘cradle to grave’ based on a functional unit basis e.g. per tonne. It attempts to measure all environmentally relevant inputs and outputs involved in the processes relation to the product being assessed. One of the key strengths and value of LCA is the breadth of product/environment relationships examined. It can reveal the environmental ‘hotspots’ i.e. specific activities in the life cycle that contribute disproportionately to impacts being assessed. It has four key stages, 1) goal and scope definition, 2) inventory compilation and analysis, 3) impact assessment, 4) interpretation and communication of results. LCA was first developed to understand the impacts associated with a single product; however, it has now been adapted so that it can be used to assess larger systems and to help in decision making. This has led to two distinct LCA approaches (Tillman, 2000; Schmidt, 2008; Brander et al., 2009):
  - **Attributional LCA** – also known as traditional or retrospective LCA, uses average or supplier-specific data to describe the environmentally relevant impacts of the processes used to produce, consume and dispose of a product. It does not consider any indirect effects that might arise from changes in the wider system in which the product is in e.g. changes in the output of a product. In this type of LCA, impacts of co-products are determined by applying specific allocation factors (types of allocation approach are briefly described below in section 2.3.1). Attributional LCA is useful for consumption-based GHG accounting and is the most commonly used LCA. It is the basis of the methodologies/standards below.
  - **Consequential LCA** - also known as prospective LCA, uses marginal data to provide information about the consequences of changes in the level of output of a product i.e. it describes how environmental impacts might change in relation to effects both inside and outside of the life cycle of the product. Consequential LCA deals with co-products through system expansion (where co-products are considered as alternatives to other products on the global market e.g. co-product of manure in a livestock system considered as an alternative to fertiliser on the market. It avoids some of the issues that can arise when trying to allocate impacts between multi-product systems). With its wider scope, consequential LCA can be used to inform policy makers on the impacts of policies which might change levels of production. Because of the inclusion of market data, this type of LCA is more sensitive to uncertainty.

- **GHG Protocol** – The GHG protocol recognises three scopes of emissions that cover both direct and indirect emissions from a company’s supply chain. Scope 1 covers all direct emissions i.e. those produced by the company’s own actions; scope 2 includes all indirect
emissions such as those from consumption of purchased energy; and scope 3 pertains to all
other indirect emissions, such as the extraction and production of purchased materials
(including agricultural materials) and fuels etc. Scope 3 therefore includes all emissions that
occur somewhere in their supply chain and that are not covered in scope 2, and this is what
is of interest relevant to agricultural production. Figure 9 summarises these GHG emission
scopes and indicates some of emissions that might be included across the value chain. The
GHG protocol standard for corporate value chain accounting and reporting standard and the
associated guidance are useful for companies to prepare and report on their supply chain

- **PAS 2050** - The British Standards Institute (BSI) has introduced a specification of assessment
  of GHG of goods and services based on LCA and ISO 14040 and ISO 14044 standards (PAS
  2050:2011). First developed in 2008 and a subsequent version released in 2011, the PAS
  (publically available specification) methodology describes how to manage the incremental
  addition of GHG emissions at different stages of the supply chain until the product is
  provided to the consumer (Nereng et al., 2009). When a product is transferred from one
  actor to another in the supply chain, the GHG emission assessment “shall include all
  emissions that have occurred up to, and including, the point where the input arrives at a
  new organization” (PAS 2050 2011), in other words it should include all upstream emissions.
  - **PAS Horticultural standard** – BSI developed a specific PAS 2050-1:2012 for the
    assessment of life cycle greenhouse gas emissions from horticultural products (BSI,
    2012). It is supplementary to the main PAS 2050 standard but with a horticultural
    focus which has particular challenges compared to other sectors (as described in an
    earlier section of this chapter).

- **ISO 14067** - Part of the ISO 1400 cluster of international voluntary standards by the
  International Organization for Standardization (ISO). It designed to help companies to
calculate the GHG emissions from their activities and measure their carbon footprint. The
standard ultimately aims to help companies to decarbonise their product supply chain and
lessen their impact. The standard focuses on setting out a comprehensive description
outlining a methodological framework for the quantification and communication of GHG’s
associated with the whole life cycle or specific stages of the life cycle of products. It has been
divided distinctly into two key focus areas, 14067-1: Quantification, and 14067-2: Communication.

- **Environmental Product Declarations (EPDs)** - An EPD is a standardised, independently
  verified tool that is used to communicate on the life-cycle based environmental performance
  of products. It has been standardised under the ISO system, specifically under ISO 14025,
  and is classified as a type III environmental declaration (ISO labelling classifications will be
  presented in Chapter 3). ISO defines a number of requirements for how the LCA should be
  conducted in order to be used as a credible basis for an EPD and include how the product
system should be modelled, what lies within the system boundary, the data use requirements and which environmental indicators should be reported (Del Borghi, 2013). As EPDs can be applied to a broad product range, product category rules (PCRs) that are relevant for specific product types. These have been developed to ensure comparability of the results between different producers/production systems for the same product.

**Figure 9: Overview of the GHG Protocol scopes of assessment and emissions across the supply chain. (Image taken from: GHG Protocol, 2012a).**

The GHG Protocol, PAS 2050 and ISO 14067 provide guidance and set standards for the collection of GHG data and its quality (data quality is looked at briefly in section 2.4.2). There are also other standards, approaches and guidance documents that many of these build on and that companies may also use to manage and assess GHG emissions. Most notably is the IPCC guidelines (IPCC, 2006b) for national level GHG inventory development and reporting. The IPCC guidelines are intended to provide a large scale average emission rate that can be used in national GHG inventories and so it does not take into account the more local GHG drivers of particular farming units that might be more interesting and important to companies assessing their supply chains. For context, it is useful to review the IPCC’s tiered classification of emission quantification; this is in Table 3 which follows.
Table 3: Summary of IPCC agriculture emission quantification levels.

<table>
<thead>
<tr>
<th>Level of complexity (tiers)</th>
<th>Data requirements</th>
<th>Uncertainty / scale</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1</td>
<td>Limited land use and management activity data.</td>
<td>Large spatial scales, usually national scale and annual resolution.</td>
<td>IPCC tier 1 default factors are suitable for general overviews where data is limited</td>
</tr>
<tr>
<td>Tier 2</td>
<td>Intermediate spatial and temporal scale input data. Region or technology specific data.</td>
<td>Finer spatial and temporal resolution than tier 1. Regional assessments.</td>
<td>May be suitable for project based GHG accounting. Suitable for collating to national scale.</td>
</tr>
<tr>
<td>Tier 3</td>
<td>Spatially explicit data, detailed land use and management histories; fine scale soil maps and daily/weekly climate data.</td>
<td>Finest spatial scale and level of detail (e.g. farm or field scale. Representation of detailed management variables.</td>
<td>Individual unit assessments. Useful in supply chain contexts.</td>
</tr>
</tbody>
</table>

2.4.1 Methodological challenges of agricultural GHG assessments

Specifically in relation to calculating the GHG footprint of an agricultural system, some of the key methodological challenges are:

- **System boundary** – clear indication of what is included and excluded in the system being assessed, i.e. where the boundaries of the system lie.

- **Direct and indirect impacts** – Direct inputs are those that are directly associated with the production of the crop such as the fuel and energy inputs, which may or may not take into account the efficiency of conversion from fuel to power and the energy consumed in initial production of the fuel source, usually gasoline and diesel), and fertilisers or other chemicals input into the system. Indirect inputs include for example, the energy required for the production of farm inputs including fertilisers, pesticides and other materials used. More controversially and typically in consequential LCAs indirect land use change impacts may be included as noted earlier (Russell, 2011).

- **Capital goods** – the carbon burden from the manufacture of infrastructure, such as a farm house; or machinery, such as tractors or other vehicles, that form part of the farm boundary are often excluded from LCAs (BSI, 2011) particularly in Europe, however some American studies include this source of emissions as does the Ecoinvent database (Ecoinvent, 2002).
• **Land use change** – the changes in carbon stock from the previous use of the land to its new use needs to be accounted for in the assessment and can be substantial if the previous land was a high carbon stock area such as a primary forest which has been cleared to become agricultural cropland or plantation. The allocation of the initial GHG emissions from the land use change over subsequent land uses may determine the results to a large extent (Searchinger et al., 2008; Cederberg et al., 2011; Flynn et al., 2012). Additionally, land use change may also result in a GHG reduction i.e. sequestration of carbon. This can happen when low carbon land areas such as degraded lands or low quality grasslands are converted to land uses with higher carbon stocks such as plantations or in the case of agroforestry systems. See for example: Post & Kwon, 2000; Silver et al., 2000; Chazdon, 2008).

• **Allocation and co-products** – crop production may lead to one or more products, typically the primary product is the reason the crop is being grown with the largest economic value and co-products are produced as a by-product, e.g. wheat grown for wheat products for consumption of further processing and the by-product of straw is also a product that can be sold but typically at a lesser value. Allocation of GHGs to different co-products is a highly contested issue (Hellweg and Milà i Canals, 2014; Luo et al., 2009) and allocation rules must be assigned, usually this is through either physical allocation of economic allocation as described in the example above, or through system expansion in consequential LCA.

• **Data** – primary data and direct measurements from the farm/field under assessment are preferable, however, are often difficult and unreasonable to acquire. Activity data combined with some emission factors are a next best proxy. In other circumstances it is often necessary to make some assumptions about the system. The data used and the source from which it is taken can have a significant influence on the modelled emissions.

### 2.4.2 GHG data and data quality

Data quality is often treated as an intrinsic concept, independent of the context in which the data has been produced and in which it is used (Strong et al., 1997).

Definitions of data quality and criteria by which to classify or rate its quality differ across sectors/fields of interest and for different types of data. One of the key characteristics for identifying data quality, however, is the perception or assessment how fit the data is for its purpose in a given context. This purpose may be decision making, management planning or for use in operations or assessments. Data are also said to be of high quality if they correctly represent the real-world construct to which they refer. In some contexts this may refer to an exact representative of the

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9 Physical allocation is where impacts are allocated between co-products based on a physical characteristic such as mass, dry mas, volume, energy content, exergy content etc. Economic allocation is where impacts are allocated between co-products in proportion to the economic value of the products.
situation e.g. Government databases of names and addresses, or may be modelled data to ‘represent’ the situation it is meant for, such as in the case of agricultural GHG data.

2.4.3 Data quality criteria

Defining data quality is not simple as there are a number of theoretical frameworks for understanding data quality applicable to different data types (Hansen, 1991; Kahn et al., 2002; Kristo, 1972). Essentially, data quality is the specific characteristic of data as expressed through information about the data (meta-data) (Weidema et al., 1996). There are nearly as many as 200 different data quality ‘criteria’ or attributes defined in the literature, however, some are used more widely as they can be used to assess data quality for data across various domains. Some of these data quality criteria or indicators of quality, and a brief explanation of what they constitute, include, but are not limited to (adapted from Weidema & Wesnæs 1996; Ciroth et al., 2013; Wang et al., 1995; Divorski & Scheirer 2001 and others):

- **Accessibility** – the data is accessible and available to the user. They have the means, the privilege and the necessary transparency required of the data.
- **Accuracy** – how close the recorded value is with the actual value. To aid accuracy, data should be recorded at the point of activity.
- **Reliability** – refers to the sources, acquisition methods and verification procedures used to obtain the data.
- **Validity** – how reasonable the data is e.g. numerical value where numerical data is required; wrongly spelt names; the data is within a reasonable expected range.
- **Correctness** – data may appear valid, accurate and consistent but still may be wrong and not represent the real data point.
- **Completeness** – data requirements should be specified based on the information needs and the data collection process(s) should be sufficient to meet this. It also relates to how representative the sample is of the population/market considered and whether it is over an adequate time period to even out normal fluctuations.
- **Relevance** – data captured should be relevant to the purposes for which it will be used. This may require periodic reviews of the data being collected to reflect changing requirements.
- **Consistency** – the representation of the data is the same across data sources
- **Timeliness** – data should be appropriate for the time of the study. Time can affect the relevance of the data, the data collection methods used, the state of the technologies that might be involved which will therefore affect the overall quality of the data. The temporal indicator, and also a geographical one (i.e. how close the area for which the data is from relates to the study area) may be relevant or not to the study for which the data is being used.
Depending on the aim of the study and the application of the data, the data quality goals will differ. Data quality goals might include the timeliness of the data, might require independent verification or peer review of the data, or might focus on the consistency of the data. The data quality goals define the desirable characteristics of the data and thus can influence the data collection and or verification procedures used (Weidema and Wesnæs, 1996).

The data quality criteria or indicators described above (as well as others) can be used to assess or describe both, a whole dataset or individual datum point and will typically be accompanied by a qualitative description for the extent to which it meets each criteria e.g. a dataset may be highly consistent but not relevant for the study. Comparing the quality of datasets or datum points in this way is difficult. A pedigree matrix is an effective means to enable the quantification of qualitative assessment results. It is a tool for the assessment and management of data quality, first introduced by Funtowicz and Ravez, (1990). The concept, first developed as part of uncertainty analyses, was designed to code qualitative expert judgement for a set of issue-specific ‘pedigree criteria’ into a simple numerical scale to create a quantitative indication of quality (Ciroth, 2009). Data quality indicators are specified in the matrix columns and the numerical codes in the rows along with descriptions of each criterion worthy of the coded scores. The main purpose of the matrix is to translate qualitative classifications of data attributes into quantitative values that can be assessed and compared. The indicators used to define data quality and the numerical rating scale can be determined based on the study requirements and for which there are no formal requirements. It has been fairly widely applied in LCA studies with different criteria and rating scales, see for example (Frischknecht et al., 2004; Weidema and Wesnæs, 1996; Weidema, 1998).

2.5 Corporate approaches to address and assess GHGs from agriculture

Companies don’t yet use a common approach or method to assess their GHG emissions (Hanifan et al., 2012) though they do recognise the importance of doing so. In a 2010 survey, Accenture questioned 700 member companies of the UN Global Compact on sustainable business practices and 96% of the CEOs interviewed said that sustainability should be integrated into all aspects of strategy and operations. In 2010 the Carbon Disclosure Project CDP started a supply chain initiative, where CDP reporting companies asked a number of their suppliers to respond to the questionnaire and to assess their climate risk and disclose their carbon emissions. In 2010 44% of the suppliers to the 50 CDP member companies responded to the information request and of those, only 28% said that they had received emissions reductions in comparison to the 43% of the reporting end customers who claimed emissions reductions (Hanifan et al., 2012). The number of member companies and thus supplier companies engaged increased in 2015, 75 member companies engaging with over 4000 suppliers, on disclosing their carbon emissions, yet those able to demonstrate progress was limited to a third of them and this covered mostly scope 1 and 2 emissions only (BSR, 2016). While it demonstrates a positive upward trend in companies addressing their emissions and in particular
their supply chain emissions, actual disclosure and improvement reporting remains limited, especially when it comes to addressing the upstream supply chain emissions from agriculture.

Companies face different challenges and opportunities when setting out to assess the GHG emissions from their supply chain (scope 3). Their different positions in the supply chain and the different types of relationships they have across a potentially large range of suppliers, can make engagement with suppliers and data collection more or less difficult in some cases. A global company like Unilever, has an extensive supply chain and will deal, on a daily basis, with thousands of suppliers ranging from large corporate companies to individual farms of varying size. Several retailers, for example, buy a number of ‘finished products’ i.e. manufactured products ready to sell, and so may be several steps removed from the raw material growers, processors and manufacturers in the supply chain, making it more difficult to engage and have influence over agricultural producers much further down the supply chain and indeed reduce the transparency on where raw materials are coming from.

This has led to a range of different ways that companies have gone about assessing their agricultural supply chain emissions. As mentioned in Chapter 1, Unilever conducted a number of LCAs of a large and representative proportion of their individual SKUs, in most cases based on a number of assumptions and often based on limited and/or unverified data. This information is extrapolated out to the wider supply chain and agricultural emissions calculations. Some research undertaken on PepsiCo’s supply chain, explored the potential of ‘fast carbon footprinting’ (Meinrenken et al., 2011) which built on available datasets, standardised approaches and some defined algorithms to generate carbon footprints of 1559 SKUs in approximately 1 minute or 10 minutes when some uncertainty analysis was incorporated. McDonalds worked with environmental consultants who used a hybrid LCA model that combined input-output and process LCA methods to assess their Scope 1, 2 and 3 emissions which revealed that 71% of their emissions were in the upstream agricultural supply chain, 41% of which were due to beef production (McDonalds, 2013).

Upon calculation of their carbon or GHG impacts and realisation that a considerable proportion lie upstream and therefore out of direct control, many companies turn the use of environmental certification schemes as mechanisms to manage their GHG emissions. These are usually targeted at the producer level and incorporate a wide range of sustainability criteria, including climate change and GHG emissions. Additionally, they are adopting GHG estimation tools such as GHG calculators to assess the GHG performance of the farms in their own supply chains. Both of these will be explored in greater detail in this research. Certification schemes often serve as the implementation mechanism of company sustainable sourcing commitments.

2.5.1 Company commitments

An increasing number of FMCG companies and retailers have committed to sustainable sourcing of agricultural ingredients and products. Table 4 summarises the commitments of some leading FMCG
and retailers involved in the agri-food sector in terms of sustainable sourcing as well as any targets for GHG reduction from their agricultural supply chains.

Table 4: Examples of some agriculturally related sustainable sourcing strategies, the targets set, programmes under development and their consideration of, or metric used for GHG measurement.

<table>
<thead>
<tr>
<th>Type</th>
<th>Company / (Year*)</th>
<th>Agricultural sustainable sourcing focus</th>
<th>GHG emphasis in agriculture</th>
<th>Metric (if any)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilever (2010)</td>
<td>Target: ‘source 100% raw agricultural materials sustainably by 2020’ and ‘halve the environmental impact by 2020’ Programme/document: Sustainable Agriculture Code (SAC)</td>
<td>Reduce GHG emissions by 50%. Management practices to encourage and driver better GHG performance.</td>
<td>Yes</td>
<td>GHG emitted from cropping = (sum of CO$_2$e x 1) + (sum of N$_2$O emitted x 296) + (sum of CH$_4$ emitted x 23) (Cool Farm Tool used)</td>
</tr>
<tr>
<td>PepsiCo (2010)</td>
<td>Target: ‘50 in 5’ aim to reduce GHGs and water use by 50% in 5 years (starting in 2010). Programme/document: Our Commitment to Sustainable Agricultural Practices (CSR report)</td>
<td>Reduce GHGs by 50% in 5 years. Policy and guiding principles to promote practices that reduce GHG emissions: - Energy management - Agrochemical management - Water management</td>
<td>Yes</td>
<td>CO$_2$e per tonne of product. (Cool Farm Tool used)</td>
</tr>
<tr>
<td>Retailers</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>---</td>
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</tr>
<tr>
<td><strong>Wal-Mart (2010)</strong></td>
<td><strong>Target:</strong> Sustainably source key agricultural products (Palm oil and beef).</td>
<td><strong>Programme/Document:</strong> Wal-Mart global sustainable agriculture goals.</td>
<td><strong>Cut 20m tonnes of emissions from its supply chain by 2015 (inc. agricultural supply chain).</strong></td>
<td><strong>Not defined</strong></td>
</tr>
<tr>
<td><strong>McDonalds (2012)</strong></td>
<td><strong>Target:</strong> certified sustainably sourced supply chain (beef, poultry, coffee, palm oil and packaging)</td>
<td><strong>Programme/document:</strong> Sustainable land management. McDonald’s Agricultural Assurance Programme (MAAP)</td>
<td><strong>Carbon footprinting activities to understand impacts.</strong></td>
<td><strong>Not defined.</strong></td>
</tr>
<tr>
<td><strong>Marks and Spencer (2010)</strong></td>
<td><strong>Target:</strong> Help suppliers cut their carbon footprint</td>
<td><strong>Programme/document:</strong> Gold/silver/bronze sustainability framework. Sustainable agriculture programme under development (at time of writing). Plan A. Leaf certification.</td>
<td><strong>Help suppliers cut their carbon footprint by 2015.</strong></td>
<td><strong>Not defined</strong></td>
</tr>
<tr>
<td><strong>Waitrose (2009)</strong></td>
<td><strong>Target:</strong> by 2010 all its fresh, prepared and frozen fruit, vegetables and flowers will either be organic, certified by the Soil Association, or have qualified for the LEAF marque.</td>
<td><strong>Programme/Document:</strong> Responsible sourcing</td>
<td><strong>15% absolute carbon reduction by end of businesses’ 2020/21 year.</strong></td>
<td><strong>Not defined</strong></td>
</tr>
<tr>
<td><strong>Starbucks (2010)</strong></td>
<td><strong>Target:</strong> Responsible sourcing (focus on ethical sourcing commitment).</td>
<td><strong>Programme/Document:</strong> Coffee and Farmer Equity (C.A.F.E)</td>
<td><strong>Not defined</strong></td>
<td><strong>Not defined</strong></td>
</tr>
</tbody>
</table>

*Year in which the commitment was made (where known).*

Sustainable sourcing strategies are in their infancy for many agri-food companies and despite being part of the same sector, the strategies being adopted vary considerably. Many companies’ strategies set out broad management goals with the aim to procure from sustainably certified sources but relatively few specify a GHG target.
The focus of this research is to explore the extent to which sustainable certification schemes address GHG management and the challenge of using GHG calculators to estimate and report GHG emissions from farming activities.

2.6 Chapter conclusions

This chapter provides an overview of the means in which to measure GHG emissions (experimentally and through use of defined standards/approaches) and some of the complexities involved in doing so. There is a vast body of literature on GHG emissions from agriculture and a very live and active debate about the potential mitigation potential of the sector and the different measurement approaches and appropriate data. This is because agriculture is a very complex and variable system for which to measure GHG emissions, with a huge amount of environmental factors and interactions to consider that can and do vary across time and space. Inevitably, therefore, this has led to some divergence in the details of the measurement approaches and the data sources to use in different situations.

For companies, there is increased recognition of the importance of understanding, assessing and addressing the GHG emissions from their agri-food supply chains and thus understanding the GHG emissions at crop/farm level. For most companies, however, it is not practical or feasible to undertake continuous measurement (experimentally) at farm level and so there has been a convergence towards using standardised approaches, whether this be a GHG accounting standard or the use of common tools or certification schemes (these will be explored further in the proceeding chapters of the thesis). Forming the basis of this convergence is the higher level of clarity and confidence at the level of farm management practices that can help to facilitate GHG emission reductions. The literature is a lot more aligned in this respect.

For emissions from agriculture to be adequately addressed and for companies to play a role in reducing their supply chain emissions there is a need for both continued research to better understand the science, the variability and the uncertainties in measuring GHG emissions at farm level across different geographies and different temporal scales, and for continued improvement of the common approaches and methods that can be used to more easily assess farm level emissions. The former, i.e. the data and measurement findings, underpin the latter i.e. the models, methods and management practice information that can be used by companies (and others) to practically address GHGs from their agri-food supply chains.
CHAPTER III

GHG MANAGEMENT AND CERTIFICATION

‘I didn’t want to know that it might not be safe, I just wanted to be reassured that is was. So instead of checking it myself, you see, I sent out one of the Electric Monks’ (Douglas Adams, 1979).

This chapter introduces the diversity and abundance of certification schemes used as mechanisms for management of agri-food systems. It starts by defining the different types of scheme that exist, the context in which they have been used and the potential role they can play in managing and mitigating GHG emissions. It explores some of the evidence for their ‘impact’, focusing on GHG emissions, i.e. evidence of GHG reductions delivered by certification schemes. Lastly, a framework is constructed to help identify how certification schemes consider/address GHG emissions and facilitate comparison between them.
3.1 Introduction to environmental certification schemes

Environmental certification schemes, standards, eco-labels, third party certification schemes (TPCs), assurance schemes, ‘electric monks’ (Clift et al., 2005) are some of the terms used to describe the diverse body of mechanisms that are used to ‘certify’ that production of a particular material/product or delivery of a particular service has complied with a number of defined principles and criteria, processes and practices that identify it as more sustainable than its non-certified counterparts. The literature on these certification schemes provides a number of different and sometimes confusing classifications; it is, however, useful to distinguish between three important terms:

1. **Standard (or specification)**\(^\text{10}\) – the set of requirements/principles and criteria/rules which a product, production practice or service must meet to become certified against the standard. The standard typically represents the requirements set by a single or consortium of stakeholders (Nadvi and Waltring, 2002).

2. **Certification** - the process of assuring that the subject has conformed to the requirements of the standard. This is often conducted and verified by a third party by way of an audit; however some standards may be self-verified.

3. **Certification label** – the associated label (often a logo or ‘stamp’, or ‘eco-label’) that indicates third party assessed conformance with the standard. Some labels are consumer facing, i.e. they are used for communication of environmental credentials from business to consumer (B2C), whilst others may be used for communications and transactions from business to business (B2B). The use of a certification logo depends on the activities, processes or materials being certified, the messages being communicated and the audience at which they are aimed.

Standards are enforced by certification processes of varying types by various bodies and may or may not have an associated eco-label. Further classifications are often made regarding their development or use in the market place (e.g. ISO 14020; see below). For example, standards may be classified as mandatory, such as those set by governments in the form of regulation which may affect trade flows.

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\(^\text{10}\) There are subtle differences between the terms standard and specification but they are often used interchangeably. To differentiate in this context a standard refers to either accredited standards that have been developed and adopted through an open consensus process under the guidelines defined by national or international standards bodies. An accredited standard will usually distinguish between requirements that must be met to conform, and descriptive, informative material that does not contain requirements. The ISO is an example of a national standards body that has developed a consensus based set of standards. Alternatively, de facto standards are often developed and owned by a single group, and they gain credibility due to the use of a critical mass, e.g. ISEAL standards. In contrast, a specification is usually developed by a specific industry group and sets a number of requirements for a specific set of industry practices. Specifications might form part of or be references in accredited standards. An example of industry specifications are the BREEAM (BRE Environmental Assessment Method) specifications that set out the requirements for the environmental performance of different types of buildings/materials/construction processes.
by stipulating that certain procedures have been undertaken (Giovannucci and Ponte, 2005); or they may be de facto mandatory as a pre-requisite to participating in a supply chain or as a ‘licence to operate’ (Kissinger et al., 2013). Many standards are a form of voluntary environmental regulations developed in response to gaps in the regulatory space to meet certain market requirements for good practice. They are often developed through collaboration between industry associations and/or non-governmental organisations (NGOs) seeking alignment on particular issues facing a sector, process or a particular product or commodity. These are perhaps the most common type of standard and are best recognised by consumers given their prominence on many products, particularly food products. They are viewed as having two complementary purposes: to promote more sustainable practices by “benchmarking” best practice (Busch and Bain, 2004; Haes and Snoo, 1996; Hatanaka et al., 2005); and to inform and influence consumer purchasing choices (Chkanikova and Lehner, 2014; Jaffry et al., 2004). Private or company-owned standards are a third class of scheme; these are standards that have been developed and are monitored and verified by individual enterprises (Giovannucci and Ponte, 2005) and may only apply to products/services within their own supply chain context. Compliance with private standards may also be communicated via a designated certification label or eco-label (the terms will be used interchangeably but do have distinct definitions in practice), as sustainability and environmental credentials are becoming increasingly important to many companies and core to their company mission, via their company logo e.g. the aim of Marks and Spencer’s Plan A (Marks and Spencer, 2015).

Eco-labels have proliferated in recent years and consequently have received much attention across academia, public media and also within government organisations. The increased number of labels has led to increased scrutiny of what they represent and what they deliver. This has been due, in part, to an increase in the number of company specific self-declarations that may be well intentioned but, in the absence of third party verification, provide no assurance on whether the claim is genuine and the company has conformed to a high standard of production. This is known as ‘greenwashing’ and has led to mis-trust of labels by consumers (Dahl, 2010; Newman et al., 2014). According to the Ecolabel Index (2015), there are approximately 459 ecolabels in existence in 197 countries and across 25 industry sectors (www.ecolabelindex.com); however, there are many more certification schemes that do not have an associated eco-label. Sectors using eco-labels include energy (e.g. EU energy rating label); construction and building sectors (e.g.s. BASS for product inventory, BASTA for hazardous substances); information technology (I.T) and computer manufacturing (e.g. 80 Plus for energy-efficient power supplies and the European Computer Manufacturers Association (ECMA)); and the agri-food sector with numerous ecolabels and certification schemes, explored further in the following section.

The International Standards Organisation (ISO) is a non-government membership organisation that is the world’s largest developer of voluntary international standards for products, services and systems to ensure quality, safety and efficiency and in many ways, sustainability. Their ISO 14000 series of
environmental standards includes the ISO 14020 family of standards that cover environmental labelling schemes specifically (ISO, 2000). ISO defines three classifications of environmental labelling (UNEP, n.d.). There are, however, other types that are hybrids of these and that don’t fit easily into the ISO classifications. For these labels, no ISO guidelines of use and/or assurance exist. They also make the landscape of eco-labels and environmental product labels somewhat difficult and confusing to navigate. The three ISO classifications and an example of a hybrid type are:

- **ISO Type I** - multi-attribute labels, often referred to as ecolabels, and are developed and awarded by an impartial third party to products that meet the criteria set out in the standard document. They are often based upon life cycle considerations and are particular to a specific product category. Examples include: Blue Angel (Germany); EU Ecolabel, otherwise known as the EU flower or ‘Eurodaisy’ (European Union); Ecomark (India); Nordic Swan (Scandinavian countries).

- **ISO Type I like labels** - share many characteristics with Type I but are focused on specific impacts and practices (e.g. energy requirements, agricultural production processes) and applied only to a specific sector (energy in buildings, agricultural commodities or agri-food products). These are better known as environmental certification schemes and examples include: Rainforest Alliance, Fairtrade, organic labels, Forestry Stewardship Council (FSC).

- **ISO Type II** - single-attribute and self-declared environmental labels and statements, commonly developed by an individual company and usually taking the form of a declaration or logo. Examples include Starbucks café practices, ‘made from recycled materials’, ‘biodegradable’ or ‘made with natural ingredients’.

- **ISO Type III** – environmental product declarations (EPDs) (briefly mentioned in Chapter 2) are based on full life cycle assessments and typically providing more detailed and quantitative information about the product. There are a number of different EPD schemes that have slightly different requirements, examples include Earthsure in North America that can cover a part or the whole of the life cycle of a product (IERE, 2015), the BRE global environmental profiles scheme for construction products EPD in Europe, as well as many of the carbon labels such as the Carbon Trust Footprint.

One of the first true ecolabels was Germany’s Blue Angel, initiated in 1978 to cover products and services globally that demonstrated strong environmental credentials whilst complying with high standards of industrial safety and health protection. Today approximately 3900 products and services across nearly 800 label users in Germany and internationally are certified as Blue Angel\(^\text{11}\).

The diversity and abundance of environmental certification standards, schemes and ecolabels are representative, overall, of mechanisms designed to improve the environmental performance of

\(^{11}\) [www.blauer-engel.de](http://www.blauer-engel.de)
goods and services; to distinguish them as environmentally ‘superior’ to their equivalent non-certified goods and services; and therefore to establish a market for environmentally sound/preferential products. To avoid confusion they will hereafter be referred to as ‘certification schemes’ or ‘schemes’ with further distinctions made as necessary or relevant.

3.2 Certification schemes in the agri-food sector

The global food market is flooded with schemes that certify agricultural products or farms/farm processing units (e.g. mills or factories) as adhering to a number of prescribed ‘good’ or ‘sustainable’ management practices. Successful compliance to a scheme’s requirements and subsequent use of its label (if relevant) therefore provides assurance that a specified level of management or good performance has been met. For agricultural systems, however, there is no universal definition of what is ‘good’ or constitutes ‘sustainable’ production (as indicated in Chapter 2). Different schemes therefore advocate different management activities based on how they perceive ‘good practice’ which in some cases may be those relevant to a particular type of production system or production country/region.

The scope and reach of agri-food certification systems and standards is diverse; some cover just one product type or group (e.g. UTZ KAPEH for coffee), while others are more generic and cover a whole sector (e.g. IFOAM for organic cultivation). Several are country specific (e.g. UK Red Tractor) while others cover farm systems across the globe (e.g. Sustainable Agriculture Network/Rainforest Alliance). Moreover, they are remarkably varied in the way they are developed, the stakeholders involved in their development, the companies that adopt them and the issues they address. As a result, they differ in their mission, scope, governance and in the socio-economic, legislative and environmental issues they cover and emphasise (Potts et al., 2010) and well as in the presentation format, stringency of compliance, flexibility and requirements for traceability (Lewis et al., 2008).

3.2.1 Proliferation of agri-food schemes

Food certification schemes arose initially as a way to bridge gaps in governance where governments had failed to keep pace with the evolving agricultural trade (Hatanaka et al., 2005) and following increased concerns from consumers for food safety and quality, particularly for fresh produce such as meat, seafood, fruit and vegetables (Unnevehr, 2000). A number of food scares in the 1990s (e.g. the 1998 meat and milk scare in Europe due to dioxins from citrus pulp in Brazil (Malisch, 2000); the BSE outbreak in the UK in 1996) also raised the profile of agri-food certification schemes to provide assurance that food had been produced and sourced to high standards. This, coupled with the increasing evidence and consumer awareness of the environmental impacts and financial and health costs associated with some agricultural production (Pretty et al., 2000), drove the diversification of
agri-food certification schemes. The Ecolabel index recognises approximately 150 ecolabels in the agri-food arena (www.ecolabelindex.com). De Battisi et al., (2009), however, acknowledged over 400 agri-food certification schemes in use globally, as the ‘personal’ nature of food and the diversity of produce and production system led this sector to experience a rapid increase in the number of environmental and sustainability initiatives (Tallontire et al., 2012). (The difference in the numbers is also indicative of the lack of clarity and definitions applied when looking at ecolabels or schemes). The proliferation of schemes includes those designed to certify both multi-product farming and specific crop or livestock production systems, and including individual producer and retailer schemes as well as multi-stakeholder initiatives (De Battisti et al., 2009).

The proliferation is due to a number of different factors, including:

- **Globalisation of food supply chains** – agri-food supply networks have become increasingly globalised, often involving long and complex supply chains. This makes the chain increasingly vulnerable to operational and resource risks inherent in international agricultural trade relations, particularly in high risk commodities. Joint standards to monitor the entire chain and all producers can be more effective than individual relationships with growers or suppliers (Roberts, 2003).

- **Consumer demands** – the informational needs of consumers has increased, driven in part by increased media attention following the food scares mentioned above as well as modern technology enabling easy and rapid access to all kinds of information through smartphones, computers and smartphone applications or apps. Consumers have become more aware of the socio-economic challenges faced by developing world farmers and that expansion of agricultural land and more intensive production is a major threat to global biodiversity (Giovannucci and Ponte, 2005).

- **Environmental pressure groups** – exposure of particular issues by environmental pressure groups and NGOs (such as Greenpeace, WWF and more recently the online campaign groups like sumofus.org or change.org) has fuelled the development of some standards, particularly for specific products. This shows the increased power and leverage of NGOs to influence industry actors (Baur and Schmitz, 2012; Burchell and Cook, 2006).

- **Individual Company values and risk management** - companies acting in their own self-interest to demonstrate the quality and stability of their supply chains (Bacon et al., 2008) have led to increased use of certification schemes and driven the rise of private company schemes. Certification schemes can be more prescriptive and more stringent than regulations; i.e. they can define not just what outcomes are achieved but also how they are achieved (Henson and Humphrey, 2010). Thus certification schemes can enable companies

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12 Ecolabel index defines ecolabels as ‘a sign or logo that is intended to indicate an environmentally preferable product, service or company, based on defined standards or criteria’. (www.ecolabelindex.com)
to demonstrate that they manage their supply chains to improve environmental and social performance as well as economic efficiency and impose their self-declared standards on their suppliers.

Because of the large number of schemes covering different aspects and components of the agri-food sector, there have been some efforts to harmonise schemes; for example, EUREPG.A.P is now GLOBALG.A.P, which has brought together various different standards; in the UK several schemes came together under the umbrella standard Assured Food Standards (AFS) (AFS, 2008) which appears on products as ‘Red Tractor’ certification (Lewis et al. 2008).

3.2.2 Industry use of certification schemes

Different food manufacturers and retailers adopt different approaches to ensuring and communicating the sustainability and environmental credentials of their products. Use of certification schemes is a common approach. Some organisations choose to partner with a single third party industry scheme and drive product differentiation through this - for example, Waitrose has teamed up with the LEAF Marque - whilst others utilise several different schemes depending on the product, the specific agricultural ingredients being certified and the brand messages they wish to communicate. For example, Unilever partners with Rainforest Alliance on its tea and cocoa products which tell the consumer a story about the environmental provenance of these ingredients, whereas for the dairy ingredients in Ben and Jerry’s ice cream products, Unilever work exclusively with Fairtrade to tell a very different (social) story to consumers. Like many other large companies, Unilever has also developed its own scheme, the Unilever Sustainable Agriculture Code (UL SAC), in particular to certify many of the agricultural materials it uses that are not adequately covered by external schemes. Figure 10 presents some of Unilever’s products that feature different eco-labels to certify different raw agricultural materials.

Figure 10: Examples of Unilever products displaying the Rainforest Alliance and Fairtrade certification scheme eco-labels.
3.3 Do certification schemes drive impact reduction?

As the number of certification schemes has risen, so too has the scepticism in what they deliver, by way of environmental improvements on the ground. Many schemes do not provide ‘hard evidence’ with regards to metrics or quantifiable improvements e.g. GHG emissions reduced, water use reduced/water quality improvements, or biodiversity loss avoided; hence they don’t validate the claims they make of being environmentally superior (Lewis et al., 2008; UNEP, 2005). The literature includes both compliments and critiques of certification schemes and their relative ‘impact’ at farm level, but either way, the evidence for environmental performance improvements is scant (Blackman and Rivera, 2010). This is due in part to their focus on the processes to drive environmental improvements i.e. the requirement of management practices (Henson and Humphrey, 2010) which are typically science-based measurable actions; thus have not been focused on evidencing the outcomes. Moreover, evidence is difficult to ascertain due to the complexity of collecting, monitoring and verifying this type of data and in attributing a causal link between the implementation of the scheme and any environmental benefits seen (Barry et al., 2012; Blackman and Rivera, 2010).

Much of the evidence that does exist has been anecdotal and focused on social impacts i.e. livelihood and welfare indicators such as income improvements through price premiums, improved access to clean water, hand-washing facilities, first aid etc., as these are typically easier to observe. Some of the key benefits arise through training, capacity building, record keeping (Borg and Selmer, 2012; Morris, 2000), as well as some improvements in overall quality of life from the organisational development that is supported by certification, particularly for smallholder farmers (Kamau et al., 2011; Riigaard et al., 2009; Ronchi, 2002). Conversely, there is evidence to suggest that certification has not led to any benefits. One study, for example, assessing animal welfare benefits, found that there was no difference observed across a number of indicators for RSPCA’s (Royal Society for the Prevention of Cruelty to Animals) Freedom Food certified farms when compared to non-certified farms (Main et al., 2003). Another study by Ruben & van Schendel (2008) found that Fairtrade certified banana producers in eastern Ghana received lower total salaries and their total family income was lower than comparable (a control sample was defined) non Fairtrade certified farmers. They found that though the Fairtrade farmers worked fewer hours and received more fringe benefits, the total expenditures and ratings of job safety, satisfaction and fairness, were not significantly different between the certified and non-certified groups (Ruben & van Schendel, 2008).

For environmental impacts, the evidence is even weaker and many argue that there is little conclusive evidence that schemes deliver environmental benefits (Lewis et al., 2008; Nilsson et al., 2004; UNEP, 2005). Some of the key challenges of trying to demonstrate benefits are the lack of data collected before a farm becomes certified, the time lag between becoming certified and the benefits seen and the resource and time costs involved in conducting such a study. Many studies (to date) have not been of a sufficient design or duration to properly assess and quantify environmental
improvements. Blackman and Rivera (2010) conducted an extensive review of the evidence base for the environmental and socio-economic impacts of sustainable certification across a select range of sectors including agricultural commodities, fish and forest products. Overwhelmingly, they found a very limited number of studies with a credible counterfactual to demonstrate real impact i.e. an estimate of the environmental or socio-economic outcomes for certified farms should they not have been certified; this could include the same farms pre-certification, or comparable non-certified farms (Blackman & Rivera, 2010). Of the studies identified, specifically those assessing environmental impacts, there was very weak evidence that certification had positive impacts.

The principles, criteria, management practices, indicators, actions etc. embedded within certification schemes have (typically) been carefully selected to ensure that a scheme is moving the production practices in the right direction, i.e. to be more sustainable. The criteria included, for the most part, will be underpinned by science and known best practice (FAO, 2004; WWF, 2014a) and in many cases will have the additional benefit of promoting practices that contribute or go beyond policy requirements e.g. restricted chemical lists, water quality legislation, child labour laws and more recently the modern slavery act etc. In addition, the range of criteria included (depending on the breadth of focus of the scheme) can help a company using the scheme to manage many of the interconnected risks in their supply chain (environmental, social, ethical) and can also help to forge improved trading relationships with suppliers which may also, in theory, improve the returns gained by the producers. Some studies are beginning to show some environmental improvements at producer level, some for reduced GHG emissions in some smallholder commodity systems (Gibbon et al., 2014), others showing biodiversity improvements and reduction in chemical usage (Haggar et al., 2012) and some more substantive studies in the seafood sector (Martin et al., 2012; MRAG, 2010).

Overall, there is a significant lack of evidence for the environmental impacts that certification schemes can have, particularly for GHG emissions, yet they remain one of the best and most widely used tools, they provide business with a credible reference point for credible action (Mak, 2012) and they raise the bar for the sustainability of agricultural systems. They are underpinned by science and experience of best practice where possible and can influence positive and more sustainable behaviour at different levels of the supply chain, from the producers through to the companies and ultimately (and ideally) to consumer purchasing behaviour. For the most part, it is a fair assumption that certification schemes lead to improved environmental performance of the system under certification and the surrounding area (as far as possible) despite the lack of comprehensive evidence. However, more quantified, empirical and robust evidence is needed if they are going to deliver and demonstrate environmental (and social, economic and ethical) improvements necessary to be a more sustainable system, and for certification to be adopted at scale and become the norm.
3.4 How agricultural certification schemes assess GHG emissions

Many agri-food certification schemes include management criteria to improve environmental, social and economic performance, and so include reducing GHG emissions. They therefore have the potential to play a role in mitigating climate change impacts by encouraging smart or low-carbon farming and prescribing management activities that reduce inputs whose production is associated with high GHG emissions. Because of the range of sources of GHGs in agri-food systems, many components of management must be addressed. Different schemes emphasise different components; therefore the extent to which different schemes address mitigation is not clear \textit{a priori}.

The ITC standards map\textsuperscript{13} is a useful tool that enables the identification of voluntary sustainability schemes relevant to any sector/commodity of interest. It provides an overview of the applicability and criteria of the main schemes and enables a level of comparison between them. The Standards Map includes an overview of climate and carbon-related criteria and thus provides a preliminary indication of whether and on what basis GHG emissions are addressed. The platform has developed to become increasingly comprehensive in the impacts it assesses and has continued to add schemes to its portfolio so that it now contains information on over 130 schemes across the agri-food sector.

Available literature and documentation to compare schemes in depth have increased in recent years; however, they still provide limited information on how and to what extent GHG emissions are addressed. The differences in structure, organisation, criteria and language between certification schemes make direct comparison difficult (Lewis \textit{et al.}, 2008). An important part of this research is to provide clarity and understanding on how certification schemes consider GHG emissions and hence on the role they can play in driving reductions as set out by research objective 2 in Chapter 1:

2. To develop a framework to assess how agri-food certification schemes address the management of GHGs through to reporting of GHG emissions (outcome focused).

The remainder of this chapter describes and applies the framework that was developed to enable systematic comparison for how a number of different agri-food certification scheme tackle GHG emissions.

3.5 Developing the framework

The framework has three aims:

1. To enable comprehensive and systematic comparison of the treatment of GHG emissions in different agri-food certification schemes;

\textsuperscript{13} www.standardsmap.org
2. To distinguish between schemes that are focused on GHG management requirements, those that require recording of farm inputs to enable a GHG estimate to be calculated, and those that set GHG performance standards;

3. To help users, such as food manufacturing companies, in selecting a scheme to use and partner with, when GHG emissions are an important consideration.

The framework should enable rigorous assessment of schemes; be repeatable so it can be used to assess schemes with different structures, scopes and formats; and be sufficiently comprehensive to provide a detailed overview of how GHGs are addressed but simple enough for users to apply and interpret.

To develop a framework to assess large amounts of qualitative data required the application of various social research methods. The main approach used was framework analysis (Ritchie and Spencer, 1994) which involves sorting data according to key issues and themes, following five different steps (Srivastava and Thomson, 2009). This approach was adapted and applied here. Other research approaches used in developing the framework included:

- **Thematic analysis** - used to identify patterns and themes within the data (Guest et al., 2012);
- **Content analysis** (Hodder, 2000) and explanatory analysis (Blaikie, 2003) - used to make sense of the framework and the outputs.

The qualitative data in this case were not generated by the researcher but pre-existed, in the form of published documents: i.e. the schemes’ standards. The process was iterative; it was based on a cyclic process of development and testing which enabled changes and refinements to be made until the framework met its aims. Additionally, the development of the framework required an inductive approach, whereby specific observations made through the review of each scheme were recorded and scaled up to a more general set of patterns and definitions. The sum of these observations enabled the generation of the framework components which then mounted to the broader and systematic framework linked to the research objectives (Thomas, 2006).

Development of the framework in this chapter was therefore built upon the five stages of framework analysis outlined below:

- **Familiarisation with the data** (Ritchie et al., 2003) - through thorough review of the scheme documents. A detailed descriptive sheet was constructed for each scheme to capture its approach to GHG assessment. During this stage the aims and objectives of the framework were refined.
- **Conceptual framework development** - using the familiarisation notes to identify and group the key features of each scheme.

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14 ‘Data’ here refers to the scheme documents and the textual information and criteria contained within them.
- **Indexing** (Ritchie et al., 2003) - the draft conceptual framework was applied to the certification schemes to assess how well it captures the distinctions between them and to build up an index of the criteria they cover. Given the diversity of the schemes, indexing involved making numerous judgements on the meaning and relevance of the data. Individual data points (scheme criteria) often contained numerous themes, each of which required separate or sub referencing according to the framework. This process also involved a degree of judgement and interpretation (Ritchie and Spencer, 2002).

- **Application and synthesis** - application of the framework to all the schemes, with outcomes compared between the schemes and sense-checked against the scheme documents. Some sub-categories defined in the first version of the framework were merged at this stage (Spencer et al., 2003).

- **Simplification and review** - review of the framework was conducted and validated based on expert judgement and other sustainability and LCA experts (members of SEAC at Unilever) and peer reviewed for publication (Keller et al., 2013).

### 3.5.1 Commentary on the framework development process

The above sets out the process that was undertaken in development of the framework but it is useful here to include some further comment on the process and in particular the significant changes or aspects that were discarded throughout the process, to add context and aid future researchers in this area.

As mentioned the approach taken was iterative. It started with a straight-forward review of the data (content of the schemes) to see if different GHG emission sources were included or not. During this initial analysis it became apparent that how GHGs were relevant in schemes was far more nuanced than this and the analysis would require greater distinction of the data. This led to the development of different ‘framework components’ or levels of analysis (which are described in detail in the subsequent sections). Delineation of these different framework components resulted from continual comparison of the data. This was conducted through making counts and documenting the frequency and forms of how GHG relevant data were included within the schemes. Brief descriptions of each of these instances of GHG relevant data were advanced and clustered into categories. The data was continually re-reviewed and all instances of data in each of the categories were compared until no new categories of data were identified and the three final framework components were defined.

Some of the noteworthy changes/discards made during development of the framework include:

- The way in which GHG emissions were considered within the schemes through the practices advocated and performance requirements stipulated was initially denoted as the ‘level of ambition’ but this was later discarded as it did not accurately reflect the activity related to GHG emissions that was being assessed. It was therefore changed to the ‘type of intervention’ in which to achieve less/improved GHG emissions, see Section 3.5.3.2.
In the early stages of data analysis, 5 categories ‘intervention’ of were defined, these were looking at whether GHGs were ‘mentioned’, ‘managed’, ‘measured’, ‘monitored’ and sought to be ‘minimised or mitigated’. Further data analysis showed that these were not appropriate and were not sufficiently distinct to enable clear classification of the differences between the schemes. These were then refined to three more distinct classifications described in Section 3.5.3.2.

The process of analysing the vast amounts of data was challenging and the iterative process adopted rendered it difficult to track all the changes and ensure fair comparisons were being made throughout. This led to changes in the analysis process which evolved from extensive documentation on each scheme and codification of the data through to the establishment of a replicable and transparent Microsoft Excel workbook detailing and calculating all of the scores awarded and the interpretations made. This is available in the supplementary material to this thesis.

3.5.2 Schemes reviewed

Ten prominent and therefore potentially influential schemes (Golden et al., 2010; www.ecolabelindex.com) were selected for review in development of the framework. All the schemes selected are used or recognised by Unilever as part of their sustainable sourcing requirements (Unilever, 2012). The overall aims and scopes of the schemes are summarised below.

Rainforest Alliance (RFA) is a broad coalition of conservation organisations, the certifying body for the Sustainable Agriculture Network (SAN). Rainforest Alliance works to conserve biodiversity and ensure sustainable livelihoods by transforming land use, business practices and consumer purchasing behaviour through certification of sustainable agricultural systems. The sustainable agriculture standard is designed to encourage sustainable farm management through adoption of best management practices across ten principles, each of which details a number of criteria for good environmental and social management. Certification requires monitoring of impacts and development of mitigation plans or projects and thereby promotes continuous improvement. In 2011, Rainforest Alliance released the new Climate Module; criteria for the mitigation and adaptation to climate change (Sustainable Agriculture Network, 2011) which is a voluntary add-on to the existing sustainable agriculture standard and cannot be a standalone award. The climate module aims to increase farmers’ awareness of climate change impacts through promotion of GHG reduction and sequestration while enhancing adaptation capacity.

Fairtrade (FT) comprises a number of standards, all certified under FLO-CERT. The fair-trade system focuses on the ways products are traded, aiming to improve the livelihoods and well-being of small-scale producers in developing countries by strengthening their business, improving market access and increasing profitability through fair pricing and improved production systems. It is limited to
smallholder farmers in listed countries across Africa, the Americas, Asia and Oceania (Fairtrade, 2011).

*The Roundtable on Sustainable Palm Oil* (RSPO) brings together the key stakeholders in the palm oil industry to develop and implement global standards for sustainable palm oil production and processing. RSPO promotes practices that reduce deforestation, preserve biodiversity and respect and enhance the living conditions and livelihoods of plantation workers and rural communities in palm oil producing countries. Certification is granted to the palm oil mill but all associated producers of palm oil fruits must also be certified.

*The Roundtable of Responsible Soy* (RTRS) standard promotes sustainable practices in soy production, including requirements to halt conversion of areas with high conservation value. In 2011, RTRS published a derivative of their production standard that was recognised as compliant with the sustainability criteria in Directives 2009/28/EC and 2009/30/EC of the European Commission for biofuels certification: the RTRS EU RED (Roundtable of Responsible Soy European Union Reductions of Emissions from Deforestation).

*Bonsucro*, formerly the better sugarcane initiative, is a private sector voluntary scheme created to drive more sustainable sugarcane production. A primary aim of Bonsucro is to promote measurable standards for environmental and social impacts of sugarcane production and to demonstrate the benefits of better production practices. The Bonsucro production standard was the first metric-based standard for an agricultural product and includes a detailed guidance document for GHG emissions calculations. Like the RTRS, the Bonsucro standard is formally recognised as compliant with EU sustainability criteria for EU RED.

*UTZ certified* sets stringent producer requirements for the sustainable production and sourcing of coffee, cocoa and tea. Each of these commodity crops has product-specific and chain of custody standards, with a key focus on traceability. The production codes of conduct are based on a model of continuous improvement in farm management, environmental protection and good social practices.

*GlobalG.A.P*, previously EurepG.A.P, is a private sector body that sets voluntary standards for certification of Good Agricultural Practices (GAP) globally. The GlobalG.A.P standards cover inputs and activities until the product leaves the farm. Initially the focus was on food safety but more recently the standards have expanded in scope to include environmental impacts. This is a B2B standard and thus has no consumer facing label.

*LEAF*, Linking Environment and Farming, is a charity registered in 1995, based in the UK but working with farmers and food related organisations globally. The LEAF standard is built around the principles of Integrated Farm Management (IFM); it takes a whole-farm approach to balance best available technology and sound agricultural management practices to ensure the environment is
maintained and enhanced. Achieving LEAF certification enables a producer to use the on-pack LEAF Marque consumer label.

Unilever released its Sustainable Agriculture Code (SAC) in 2010, as part of its commitment to sustainable sourcing. The code is designed to be applicable to all agricultural raw materials and details the practices and standards that suppliers are expected to meet, highlighting the need for continuous improvement. It is deployed on a self-assessment basis (2013) with independent verification to follow. Unilever also uses several external certification schemes (including some of those reviewed in this study) and has benchmarked the SAC against them to avoid duplicated or conflicting efforts.

The ten schemes under review have been broadly categorised into two groups: general schemes designed to be applicable to different farming systems; and system-specific schemes designed for one particular farming system or crop. The schemes are structured and organised differently; several include different standard documents that deal with different raw materials. Where possible, the most general production standard document was reviewed in this work; otherwise, one raw material standard illustrative of the scheme’s overall approach was assessed. Several schemes also have separate documents to provide further guidance to understand and interpret the control points in the standard document (e.g. National interpretations of the RSPO standard). Where appropriate, the additional guidance documents were consulted but they did not feature as a key part of the review.

Table 5 presents some basic characteristics of the schemes under review and also gives the source reference of the documents reviewed in the comparison process.
### Table 5: Overview of the certification schemes reviewed in the development of the framework.

<table>
<thead>
<tr>
<th>Type</th>
<th>Scheme</th>
<th>Establishment</th>
<th>Products certifiable</th>
<th>Scheme’s declared description and aim</th>
<th>Document(s) reviewed to assess scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>General schemes (Multi-system)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fairtrade (FT)</td>
<td>In 1997 FLO was established. First label in 1988.</td>
<td>Agriculture, composite and manufactured goods incl. bananas, cotton, coffee, flowers, juice, rice, spices, sport balls, sugar, tea, wine.</td>
<td>Fairtrade International (previously FLO – Fairtrade Labelling Organisation) unites all Fairtrade labelling initiatives. It aims to provide fairer terms of trade for farmers in the developing world through better prices, working conditions and local sustainability.</td>
<td>Fairtrade standard for small producer organisations, version 01.05.2011_v1.1 (2011). Explanatory document for the Fairtrade standard for small producer organisations (no date).</td>
<td></td>
</tr>
<tr>
<td>Linking Environment and Farming (LEAF)</td>
<td>1991</td>
<td>All agriculturally produced materials.</td>
<td>LEAF promotes environmentally responsible farming. It is built around whole-farm principles of integrated farm management (IFM) aiming to achieve a balance between modern technology and sound traditional methods to enrich the environment and produce good food products.</td>
<td>LEAF Marque global standard, Version 10.0 (2012). LEAF Marque standard additional guidance notes 2012 version 1</td>
<td></td>
</tr>
<tr>
<td>Sustainable Agriculture Network (SAN), Rainforest Alliance (RA)</td>
<td>1987 Rainforest Alliance was founded and the SAN group formally formed</td>
<td>Agricultural products incl. cocoa, coffee, tea, banana, flowers, pineapple, citrus fruits, avocado, grapes, plantain, rubber and</td>
<td>Aims to conserve biodiversity and ensure sustainable livelihoods by transforming land-use practices, business practices and consumer behaviour.</td>
<td>Sustainable agriculture standard (SAN), (2010).</td>
<td></td>
</tr>
<tr>
<td>Scheme</td>
<td>Year</td>
<td>Category</td>
<td>Description</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-------</td>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>SAN, Rainforest Alliance Climate Module (RA-CM)</td>
<td>2011</td>
<td>vanilla. Forestry products incl. timber &amp; paper.</td>
<td>The new climate module aims to increase farmers’ awareness of climate change impacts and promote adoption of good agricultural practices (GAPs) that reduce GHGs, increase carbon sequestration and enhance farms capacity to adapt. It is an add-on to the SAN standard enabling farmers to demonstrate use of climate-friendly agricultural practices.</td>
<td>SAN Climate Module: Criteria for the mitigation of and adaptation to climate change (2011).</td>
<td></td>
</tr>
<tr>
<td>Unilever Sustainable Agriculture Code (UL SAC)</td>
<td>2010</td>
<td>All agriculturally produced materials.</td>
<td>Unilever’s SAC prescribes the practices that all Unilever suppliers should strive to achieve. The code is applicable to all Unilever’s sourced raw agricultural materials globally.</td>
<td>Unilever sustainable agriculture code (Unilever 2010b).</td>
<td></td>
</tr>
<tr>
<td>Better Sugar Initiative (Bonsucro)</td>
<td>2010</td>
<td>Sugarcane</td>
<td>Bonsucro fosters the sustainability of the sugarcane sector through a metric-based certification scheme and by supporting continuous improvement. The scheme aims to provide a mechanism for achieving sustainable production from sugarcane products in respect of economic, social and environmental dimensions. In 2011 Bonsucro was recognised as meeting the sustainability criteria under Directives 2009/28/EC and 2009/30/EC of the European Commission for biofuel certification as part of the Renewable Energy Directive (RED).</td>
<td>Bonsucro production standard including Bonsucro EU production standard (2011).</td>
<td></td>
</tr>
</tbody>
</table>
| Roundtable on Sustainable Palm Oil (RSPO) | Formed in 2004. In 2005 the principles were set and the criteria and indicators followed in 2007. First certification granted in 2008. | Palm oil | The RSPO brings together stakeholders from seven sectors of the palm oil industry: producers, processors and traders, consumer goods manufacturers, retailers, banks and investors and environmental and developmental NGOs, to develop global standards for sustainable palm oil. Their aim is to transform the market and make sustainable palm oil the norm. RSPO was approved for biofuel production under RED in 2012. | RSPO- principles and criteria for sustainable palm oil production (2007).
Colombia’s national interpretation of RSPO (2010).
RSPO-RED requirements for compliance with the EU Renewable Energy Directive requirements. Version 4-10 February 2012. |
| --- | --- | --- | --- | --- |
| Roundtable of Responsible Soy (RTRS) | Roundtable formed in 2006. The standard was published in 2010 with first certifications in 2011. | Soy | Aims to promote responsible soy production, processing and trade worldwide. It is a multi-stakeholder initiative including industry, NGOs and producers. Countries are encouraged to create national interpretations of the core standard. In 2011 RTRS developed a derivative of their production standard that was recognised to be compliant with the sustainability criteria for biofuel certification under RED. | RTRS standard for responsible soy production, (2011).
| UTZ | 1997 | Coffee, cocoa, tea, palm oil, cotton. | UTZ promotes sustainable farming through assurance of GAPs and management, safe and healthy working conditions, and protection of the environment. UTZ seeks to create transparency along the chain and reward responsible producers. | UTZ certified ‘good inside’ code of conduct for cocoa for individual certification, version 1.0 (2009). |
3.5.3 Framework components

Different certification schemes require GHGs from farming activities to be managed and reduced in different ways: through efficient use of inputs and optimisation of farm conditions; through good soil management, increased stores of biomass etc.; and through changed management practices such as fuel switching (Smith et al., 2008). Schemes may be more or less ambitious in the type of intervention they advocate. They may also be stricter in their requirements to meet GHG-relevant criteria; i.e. adherence to a particular criterion may be a pre-requisite to receiving certification or may be more of a ‘nice to have’ requirement with farms able to receive certification without having met the particular requirement. The framework aims to capture and assess the schemes against all of these possibilities and generate an appropriate score for comparison. The following section describes each of the components included in the framework.

3.5.3.1 Component 1: GHG drivers (D)

Chapter 2 set out the range of possible GHG sources and sinks associated with agricultural production and the complex interactions between a farmer’s production practices, the geographical and geophysical state of the specific farming system in which they operate and other biotic and abiotic external environmental conditions (Milá i Canals, 2003; van der Werf and Petit, 2002). In this framework a GHG Driver is therefore defined as ‘a potential source or sink of GHG emissions associated with farm level agriculture’. Through stipulation of particular management practices, promotion of specific inputs or machinery operations and requirements for evidence of implementation of best practice, certification schemes could play an important role in improving farm practices and driving GHG reductions. The GHG drivers included in the framework were defined and limited to cover a comprehensive range of agricultural inputs, management practices and interactions based on the literature review in Chapter 2, including agricultural life cycle inventories and assessments, farm-level GHG assessments and footprinting activities (Brentrup et al., 2004, 2001; Fuller et al., 2003; Hillier et al., 2009; Olander et al., 2011; Pluimers et al., 2000; Roches et al., 2010; Roy et al., 2009; Smith et al., 2007). In addition a number of frequently used agricultural and crop-level GHG calculators were consulted, including some associated with biomass and biofuel materials, to ensure that all important management sensitive GHG drivers across a number of different farming systems, crop types and geographies were included. The calculators reviewed included the Cool Farm Tool (Hillier et al., 2011); Biograce (Neeft, 2011); Carbon Accounting for Land Managers calculator (CLA, 2009); C-Farm (Kemanian and Stöckle, 2010); PalmGHG (Chase et al., 2012) and C-Plan (Dick et al., 2008).

Several GHG drivers are common across all agricultural production systems; however their relative impact on the overall GHG profile of different systems can vary enormously. Briefly, Chapter 2 described the multiple and complex interactions that occur in an agricultural system rendering several GHG drivers inextricably linked. In this sense, managing one particular GHG driver, for
example land-use change (LUC), is inevitably linked to emissions arising from other drivers, i.e. soil GHG releases as well as sequestration and storage ability. The GHG drivers have been defined to ensure that the framework covers all possible sources and sinks. Due to the heterogeneity of farming systems, some drivers may be relevant to some production systems but not to others. The framework must be able to assess both generic and system/crop specific schemes and must therefore include all GHG drivers with the potential to result in GHG reductions under some circumstances. Soils, for example, can act as a source or a sink of GHG emissions according to the cultivation system (e.g. annual vs. perennial crops) with differences across different geographical biomes with differing soil characteristics. Carbon sequestration in perennial crops such as grasses and trees is much greater due to their longer-term carbon storage in both the soil and the crop biomass (Zan et al., 2001). In conventional coffee cultivation, fertiliser production can contribute up to 50% of the GHG footprint (Noponen et al., 2012) whereas in other systems, such as palm oil, the dominant GHG contributor is deforestation and expansion onto peat land (Germer and Sauerborn, 2007b; Murdiyarso et al., 2010). Conversely, use of crop protection chemicals (CPCs) typically affords a very small contribution to the overall GHG footprint of many agricultural systems (Hillier et al., 2009) or may have no impact at all.

The framework is not intended to be a footprinting exercise nor a reckoning of how a scheme could contribute to creating a GHG inventory; thus overlaps between GHG drivers or ‘double counting’ of GHG emissions are not of concern. The boundary is set at the farm-gate and the framework includes only those GHG drivers that occur upstream (manufacture and transport of specified inputs to the farm: drivers a-c) and on-farm up to the farm-gate (primary and some secondary but subject to some control by farmer: drivers d-t). Indirect GHG emissions arising from changes in product output, including effects from both within and outside the product life cycle, are excluded as they are outside the farmer’s control and are subject to greater uncertainty (Thomassen et al., 2008).

The GHG drivers considered for the framework:

- Can be influenced and assessed by the producer;
- Typically represent the principal influences on the GHG footprint of a crop/farm system;
- Apply up to the farm-gate (including some upstream drivers);
- Contribute to quantifying GHG emissions through activity or other data but are not necessarily intended to provide a detailed inventory of pre farm-gate GHG sources and sinks.

Some additional management practices that can contribute to the raw material GHG profile have been excluded from the assessment framework. These include: rotational cropping\(^\text{15}\); on-farm

\(^{15}\) Rotational cropping is a farming method which involves growing different successions of crops on the same area of land over a number of years. It is mainly practiced to help maintain and replenish soil nutrients and interrupt pest and disease cycles. Some of the key benefits are higher yields, improvements in soil quality and a reduced need for nitrogen fertilisers. Consequently crop rotations can lead to GHG benefits.
waste-water treatment\textsuperscript{16}; waste reduction; transport of farm staff to and from the farm; embodied energy in food intake of farm staff; and other indirect drivers such as indirect land-use change or other consequential impacts. These are commonly omitted from LCA studies and other GHG emission reporting protocols (e.g. (BSI 2011; WRI & WBCSD 2011; IPCC 2006) for several reasons, including complexity, uncertainty, difficulty of assessment or measurement, lack of available data or because their influence is nugatory.

Three additional GHG specific criteria - GHG specific commitments, carbon neutrality and carbon offsets, (drivers u-w) - have been included as part of the assessment framework so that schemes which include them explicitly can be scored. These are included because they may be relevant to users of the schemes, such as food manufacturers or retailers who wish to adopt standards best aligned with business agendas including one or more of these activities. GHG specific commitments can demonstrate that a scheme addresses GHG emissions and requires producers to show that they are setting targets or commitments to manage or reduce their own emissions. Similarly, carbon neutrality or offsetting offer opportunities for GHG reductions to be made in alternative ways, through set-asides and land regeneration activities or other sequestration activities on their own land or elsewhere. There is however much controversy and debate associated with each, particularly the latter which has been excluded from some important GHG assessment standards such as PAS 2050:2011 (BSI, 2011; Foucherot and Bellassen, 2011; Gaia, 2011).

Table 6 presents and describes each GHG driver included in the assessment framework and indicates which schemes are assessed for each. Some schemes are not assessed for particular GHG drivers because due to their irrelevance for the crops that can be certified under that scheme. For example GHG driver t, rice paddy cultivation is not relevant for several of the crop-specific schemes that do not certify rice production, thus just multi-crop schemes will be assessed for this GHG driver. The number of drivers assessed will be important to the total potential scores for each scheme (see section 3.5.3.4). The descriptor provides some examples of the type of activities and language used within a scheme that justifies inclusion of a GHG driver in the comparison even when the scheme does not include it explicitly for its influence on GHG emissions.

\textsuperscript{16} Waste water treatment converts waste water into an effluent that can be reused or released back into the water cycle with minimal environmental impacts. The process generates significant amounts of GHG emissions largely through the natural (aerobic and anaerobic) processes involved. Usually large quantities of methane and nitrous oxide are released though the quantity and types of GHGs released will depend on the treatment technology employed. Emissions can be reduced through operational efficiencies, energy recovery (methane capture) and use of improved treatment technologies.
Table 6: GHG drivers defined for the framework and the schemes that are assessed for their inclusion.

<table>
<thead>
<tr>
<th>ID</th>
<th>GHG Driver (D)</th>
<th>Descriptor (influences on GHG emissions)</th>
<th>Schemes assessed for the GHG driver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upstream GHG drivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>Fertiliser production</td>
<td>Energy requirement in the manufacture of synthetic fertilisers for use on farm; manufacture process e.g. ammonia; chemicals used.</td>
<td>All</td>
</tr>
<tr>
<td>b</td>
<td>Crop protection chemical (CPC) production</td>
<td>Energy requirement in the manufacture of synthetic CPCs for use on farm, including chemical feedstock used.</td>
<td>All</td>
</tr>
<tr>
<td>c</td>
<td>Transport of inputs to farm</td>
<td>Locality of input sources; energy requirement for travel; fuel combustion; distance travelled; mode of transportation.</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>On-farm GHG emission drivers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>Fertilisers</td>
<td>Fertiliser application; amount; types; timing; good practice; precision application; fuel combustion by application machinery.</td>
<td>All</td>
</tr>
<tr>
<td>e</td>
<td>Crop protection chemicals (CPCs) (pesticides, herbicides, insecticides etc.)</td>
<td>Pesticide application; amount; types; good practice; precision application; fuel combustion by application machinery.</td>
<td>All</td>
</tr>
<tr>
<td>f</td>
<td>Soil</td>
<td>Practices to maintain and enhance soil structure/quality; measures of soil quality/fertility and soil types.</td>
<td>All</td>
</tr>
<tr>
<td>g</td>
<td>Cropping operations</td>
<td>Good practice for machinery use for crop cultivation including but not limited to sowing, seed input, fertilisation, harvest, mechanical weeding; maintenance of machinery; use records; energy inputs and fuel combustion; machine efficiency.</td>
<td>All</td>
</tr>
<tr>
<td>h</td>
<td>Tillage machinery use</td>
<td>Good practice for machinery use for ploughing operations; maintenance of machinery; use records; energy inputs and fuel combustion.</td>
<td>All</td>
</tr>
<tr>
<td>i</td>
<td>Irrigation</td>
<td>Irrigation practices; water use efficiencies; records; energy use and fuel combustion.</td>
<td>All except RSPO 17</td>
</tr>
</tbody>
</table>

17 RSPO is excluded in this case because irrigation is not relevant to palm oil production systems certified under RSPO in Indonesia and Malaysia. This GHG driver may be included in future revisions of the RSPO standard as palm oil cultivation moves to drier regions such as Thailand or India.
<table>
<thead>
<tr>
<th>Column</th>
<th>Category</th>
<th>Description</th>
<th>Certification Bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td>j</td>
<td>Transport</td>
<td>Transport related energy of materials and inputs on farm; fuel use for transportation.</td>
<td>All</td>
</tr>
<tr>
<td>k</td>
<td>Non-specific energy use</td>
<td>General energy management; energy efficiencies; energy use records and fuel combustion.</td>
<td>All</td>
</tr>
<tr>
<td>l</td>
<td>Land use change</td>
<td>Transformation of land; expansion onto new land; deforestation.</td>
<td>All</td>
</tr>
<tr>
<td>m</td>
<td>Land Clearing</td>
<td>Land clearing practices; fire management; gas capture.</td>
<td>RSPO, RTRS, BonSucro, UL SAC</td>
</tr>
<tr>
<td>n</td>
<td>Organic soils</td>
<td>Cultivation and preservation of organic soils, especially peat soils.</td>
<td>All</td>
</tr>
<tr>
<td>o</td>
<td>Agroforestry</td>
<td>Conversion or enhancement of land into forest land; biodiversity enhancement; planting of trees; buffer strips; hedgerow maintenance; shade trees (where applicable).</td>
<td>All</td>
</tr>
<tr>
<td>p</td>
<td>Waste crop residue</td>
<td>UL SAC</td>
<td>All</td>
</tr>
<tr>
<td>q</td>
<td>Livestock</td>
<td>Livestock management practices; livestock health; feed records.</td>
<td>RA, RA-CM, UL SAC, LEAF</td>
</tr>
<tr>
<td>r</td>
<td>Manure</td>
<td>Manure/slurry incorporation; management practices; responsible disposal; quantity/use records.</td>
<td>RA, RA-CM, UL SAC, LEAF</td>
</tr>
<tr>
<td>s</td>
<td>On-site energy production</td>
<td>By-product material use for energy; combined heat and power on farm, etc.</td>
<td>All</td>
</tr>
<tr>
<td>t</td>
<td>Rice paddy cultivation</td>
<td>Rice paddy management practices; flooding; methane management/capture etc.</td>
<td>UL SAC, LEAF, GlobalG.A.P.</td>
</tr>
</tbody>
</table>

**GHG Specific criteria**

<table>
<thead>
<tr>
<th>Column</th>
<th>Category</th>
<th>Description</th>
<th>Certification Bodies</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>GHG commitments</td>
<td>Requirements specific to GHG emissions: carbon management; GHG emissions; climate change mitigation; targets; minimum requirements; calculations; default values; calculator use.</td>
<td>All</td>
</tr>
<tr>
<td>v</td>
<td>Carbon neutrality</td>
<td>Promotion of carbon neutrality; net GHG balance.</td>
<td>All</td>
</tr>
<tr>
<td>w</td>
<td>Carbon offsets</td>
<td>Requirements/calculations regarding carbon offsetting.</td>
<td>All</td>
</tr>
</tbody>
</table>
3.5.3.1.1 Consideration of GHG drivers in schemes

Table 7 provides an example of the type of nomenclature that may be used within a scheme that would warrant inclusion of a GHG driver; in some cases it is more obvious than in others.

Table 7: Examples of nomenclature used in a scheme that warrants consideration of a GHG driver.

<table>
<thead>
<tr>
<th>GHG driver</th>
<th>Scheme</th>
<th>Example criterion/language used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilisers (d)</td>
<td>Fairtrade</td>
<td>Measures to ensure that fertilisers are applied in amounts that respond to the nutrient need of the crop</td>
</tr>
<tr>
<td></td>
<td>Rainforest alliance</td>
<td>Soil or crop fertilisation program based on soil characteristics and properties</td>
</tr>
<tr>
<td></td>
<td>Unilever SAC</td>
<td>Fertilisers must only be applied to intended crop and avoid certain areas.</td>
</tr>
<tr>
<td>Irrigation (i)</td>
<td>UTZ</td>
<td>Water action plan to optimise irrigation use and water loss.</td>
</tr>
<tr>
<td></td>
<td>RTRS</td>
<td>Where irrigation is used, there is a documented procedure in place for applying best practices and acting according to legislation and best practice guidance (where this exists).</td>
</tr>
<tr>
<td></td>
<td>GlobalG.A.P</td>
<td>Justification of method of irrigation used in light of water conservation. System used should be efficient.</td>
</tr>
<tr>
<td>Land use change (l)</td>
<td>LEAF</td>
<td>Retain field boundaries, natural landscape features and other natural habitats such as rain forests and areas of high carbon stock, peatlands.</td>
</tr>
<tr>
<td></td>
<td>RSPO</td>
<td>New plantings since November 2005 have not replaced any primary forest etc.</td>
</tr>
<tr>
<td></td>
<td>Bonsuco</td>
<td>For greenfield expansion or new sugarcane projects, to ensure transparent, consultative and participatory processes that address cumulative and induced effects via an environmental and social impact assessment (ESIA).</td>
</tr>
</tbody>
</table>

3.5.3.2 Component 2: Types of intervention

The body of literature for GHG management in agriculture is broad and encompasses all activities from establishing good governance and management processes, through conducting detailed life cycle assessments (LCAs), to measuring point sources of GHG emissions and setting carbon budgets for particular operations. Each type of activity is important for GHG management, representing a means towards the goal of creating a more sustainable agricultural system with the lowest possible GHG impact and the maximum potential productivity. Arguably, some activities to drive lower GHG
emissions on-farm are more ambitious than others. They may involve more effort, resource or capability; it is important to assess how ambitious are the requirements of a particular scheme; specifically, what type of activity is required for each GHG driver. To understand this, the framework includes an assessment layer to classify the type of ‘intervention’ for each GHG driver encouraged or required to achieve certification.

A simple un-weighted classification system for the types of intervention (I) was constructed to differentiate how the schemes consider each GHG driver and enable transparent comparison. Intervention is defined as ‘the type of action or method of achieving less/improved GHG emissions’. Three types of intervention have been defined to classify whether each GHG driver is managed (I1), measured (I2) or if there is a performance standard (I3) in place. Any scheme may include more than one type of intervention (see section 3.5.3.2) The types of intervention deal with the various approaches that may be taken to drive good practices or change on farm, from implicit action requirements (manage) to performance based requirements (performance standards). A scheme is given a score of 1 for each type of intervention included (see section 3.5.3.4), so that there is no implication that one type is better than any other (i.e. interventions are not weighted). Similarly, there is no assumption that any of the intervention types are linked, e.g. that what is measured is necessarily also managed. Table 8 presents the three classifications of intervention (I). The definitions are based on the review of literature and guidance documents related to GHG management, measurement and mitigation as well as more general management literature (Eggleston et al., 2006; Herzog et al., 2006; Russell, 2011; Trexler, 2011; WRI and WBCSD, 2011). Alongside the definitions are some examples of the types of nomenclature on which the classification is based.

Table 8: Intervention (I) classifications defined for the framework and examples of the nomenclature that may be used.

<table>
<thead>
<tr>
<th>ID</th>
<th>Intervention Classification (I)</th>
<th>Definition</th>
<th>Examples of nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>Manage</td>
<td>The structures, policies and practices in place to manage GHG drivers and address GHG specific criteria. Requirements or instructions for result-oriented action; e.g. the implementation of good practices to address or control the GHG drivers, including training related to good management.</td>
<td>Management plans; policy; controls; design; training; knowledge generation; implementation of good practices; maintenance of good conditions; action.</td>
</tr>
<tr>
<td>I2</td>
<td>Measure</td>
<td>Requires measured and recorded performance related data e.g. through record keeping, assessments and</td>
<td>Monitoring and recording; documenting of quantitative data; energy</td>
</tr>
</tbody>
</table>
analysis. The measurement and recording of numerical activity data (such as litres of fuel used) or creation of an activity inventory that can be converted into GHG performance data using emission factors. Demonstrations of good management leading to GHG emission performance information.

<table>
<thead>
<tr>
<th>I3</th>
<th>Performance standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Requires an explicit reduction target or improvement of the GHG driver that will/is likely to result in associated GHG reductions. Explicit target to enhance sequestration of GHGs where applicable. Evidence of reduction/improvement or time-bound commitment; e.g. demonstrate an impact reduction through metrics, calculations with impact/use required to remain below a specified range or threshold.</td>
</tr>
</tbody>
</table>

3.5.3.3 Component 3: Stringency classification (S)

Each scheme sets its own rules for compliance the criteria it contains and schemes are very rarely structured or governed in the same way, and there is little commonality in their assessment criteria or compliance rules. Some schemes require full adherence to all criteria, whilst others offer some flexibility in achieving compliance. Flexibility may take the form of allowing some criteria to be met over a certain time period, or identifying some criteria as ‘recommended’ without enforcement, or mandating that a only a specified proportion of criteria within certain sections or chapters of the scheme must be met. Thus it is possible that a “compliant” farm may not address some GHG drivers at all. Differences in compliance requirements make comparing the treatment of GHGs in schemes more challenging.

For a fair and meaningful comparison, the framework uses a simple differentiation between the compliance requirements recognising three levels of stringency (S), defined as ‘how strictly a criterion is imposed for compliance to the scheme’. Each GHG driver, in each of the relevant intervention types (I), is classified at one of three levels of stringency: hard, medium and soft. The hard classification refers to those criteria that must be met immediately to receive certification; medium stringency describes criteria to be met under certain conditions; and the soft classification captures optional or recommended criteria for which no evidence of fulfilment is required so that
they may be omitted entirely. Table 9 defines these three stringency classification levels and provides examples of nomenclature pertaining to each.

Table 9: Stringency (S) classifications defined for the framework and example nomenclature used in various schemes.

<table>
<thead>
<tr>
<th>Stringency classification (S)</th>
<th>Definition</th>
<th>Nomenclature</th>
</tr>
</thead>
</table>
| **Hard**                     | Criterion must be met in order for the certification to be awarded. Immediate requirement without exception. | • Mandatory requirement  
• Propitiatory requirement  
• Critical Failure point  
• Critical criterion |
| **Medium**                   | Criterion must be met under particular conditions: specified percentage compliance of a chapter or section of the scheme; implemented in a specified time frame beyond the year of the audit. | • General criteria (percentage compliance)  
• Time bound requirement  
• Development requirement |
| **Soft**                     | Criterion is optional or voluntary or is recommended but with no evidence required for action or a time implementation deadline. | • Recommended requirement  
• Voluntary criteria |

Each GHG driver can receive a stringency classification for each type of intervention for which it is considered within a scheme. The three stringency classifications have an associated score which is outlined in the following section.

Table 10 depicts the compliance rules defined in each scheme and the associated stringency classification that would be assigned according to the framework.
### Table 10: Assessed schemes compliance rules and stringency classification.

<table>
<thead>
<tr>
<th>Type</th>
<th>Scheme</th>
<th>Criteria types</th>
<th>Compliance requirements</th>
<th>Stringency classification granted</th>
</tr>
</thead>
<tbody>
<tr>
<td>General (Multi-system schemes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fairtrade</td>
<td>Core</td>
<td>Compulsory compliance for certification (year 0 or year 1).</td>
<td>S1 - Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Development</td>
<td>Continuous improvements. Each has a specified time for compliance (1, 3, 6 years).</td>
<td>S2 - Medium</td>
<td></td>
</tr>
<tr>
<td>GlobalG.A.P</td>
<td>Major must</td>
<td>100% compliance is compulsory</td>
<td>S1 – Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minor must</td>
<td>95% compliance is compulsory</td>
<td>S2 – Medium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recommended</td>
<td>Non-compulsory and no minimum percentage of compliance</td>
<td>S3 - Soft</td>
<td></td>
</tr>
<tr>
<td>LEAF</td>
<td>Critical failure point</td>
<td>Full compliance for certification</td>
<td>S1- Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recommended</td>
<td>Non-compulsory additional requirements</td>
<td>S3 - Soft</td>
<td></td>
</tr>
<tr>
<td>Rainforest Alliance (RA)</td>
<td>Critical criteria</td>
<td>Compulsory compliance for certification</td>
<td>S1 - Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>General criteria</td>
<td>50% of applicable criteria per principle and 80% of total applicable criteria of the whole scheme must be complied with for certification</td>
<td>S2 - Medium</td>
<td></td>
</tr>
<tr>
<td>Rainforest Alliance Climate Module (RA-CM)</td>
<td>General criteria</td>
<td>Voluntary criteria as an add-on to RA. 80% compliance required to be RA-CM approved</td>
<td>S2 - Medium</td>
<td></td>
</tr>
<tr>
<td>Unilever Sustainable Agriculture Code (ULSAC)</td>
<td>Mandatory</td>
<td>Compulsory compliance for certification</td>
<td>S1 – Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Must</td>
<td>Obligatory compliance to receive certification unless an exception is granted by Unilever</td>
<td>S1 - Hard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Should</td>
<td>Non-compulsory and no minimum percentage of compliance</td>
<td>S3 - Soft</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Scheme</td>
<td>Criteria types</td>
<td>Compliance requirements</td>
<td>Stringency classification granted</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>----------------</td>
<td>------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>System specific schemes (crop specific)</td>
<td>Bonsuco</td>
<td>Core</td>
<td>Compulsory compliance for certification</td>
<td>S1 – Hard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>General</td>
<td>80% of indicators must be complied with</td>
<td>S2 - Medium</td>
</tr>
<tr>
<td></td>
<td>Roundtable on Sustainable Palm Oil (RSPO)</td>
<td>General criteria</td>
<td>100% compulsory compliance</td>
<td>S1 – Hard</td>
</tr>
<tr>
<td></td>
<td>Roundtable on Sustainable Palm Oil EU requirements (RSPO-EU)</td>
<td>General criteria</td>
<td>100% compulsory compliance</td>
<td>S1 – Hard</td>
</tr>
<tr>
<td></td>
<td>Roundtable of Responsible Soy (RTRS)</td>
<td>General criteria</td>
<td>100% compulsory compliance</td>
<td>S1 – Hard</td>
</tr>
<tr>
<td></td>
<td>Roundtable of Responsible Soy EU Requirements (RTRS-EU)</td>
<td>General criteria</td>
<td>100% compulsory compliance</td>
<td>S1 – Hard</td>
</tr>
<tr>
<td></td>
<td>UTZ</td>
<td>Mandatory control points yr 1</td>
<td>Mandatory control points for implementation in yr 1</td>
<td>S1 – Hard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mandatory control points yr 2, 3 or 4</td>
<td>Mandatory control points for implementation in yr 2, 3 or 4</td>
<td>S2 - Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Additional control points</td>
<td>Defined number of additional control points to be met per section of the scheme.</td>
<td>S2 – Medium</td>
</tr>
</tbody>
</table>

3.5.3.4 Scoring the schemes

Each scheme is scored according to the GHG drivers included, the intervention classifications (I) and the stringency classifications (S), leading to a unique total potential score (Table 11). The following section sets out the scoring rules and describes the different types of score that can be compared.

3.5.3.4.1 Scoring rules

One point is awarded for each relevant GHG driver (as defined in Table 6) included in the scheme at any intervention type and stringency level. The resultant total gives the comprehensiveness score. Two types of score are then awarded per GHG driver included. The first are the points awarded for
intervention (I): for each driver, 1 point is awarded per intervention type included so that the maximum intervention points that can be awarded per driver is 3. The second score is for stringency (S): stringency scores are awarded for each GHG driver and type of intervention included. Thus each intervention - management (I1), measurement (I2) or performance standard (I3) - receives an associated stringency score: S1, S2 and S3 respectively. Whereas each intervention type is only awarded 1 point for itself, levels of stringency are assigned scores of 3, 2 and 1 points according to whether they are hard, medium or soft so that S1, S2 and S3 can each have a score from 1 - 3. The maximum stringency points that can be awarded per driver is the sum of the points awarded for each intervention, i.e. 9. The maximum score that can be achieved per GHG driver is the sum of the intervention scores (I1+I2+I3) plus the sum of the stringency scores (S1+S2+S3) = 12. A total relative score is then calculated based on the total points awarded for each framework component; comprehensiveness, intervention type and stringency, as a proportion of the total potential score available for each scheme. Table 11 describes the different types of score that can be awarded upon application of the framework and how these are calculated.

Table 11: The types of score generated for each scheme under assessment and how they are calculated.

<table>
<thead>
<tr>
<th>Score</th>
<th>Descriptor</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensiveness</td>
<td>The proportion of GHG drivers addressed by the scheme.</td>
<td>(D score / Possible D score)*100</td>
</tr>
<tr>
<td>Intervention</td>
<td>The types of intervention for which GHGs are addressed within a scheme. A higher score indicates greater inclusion of more intervention classifications (I1, I2, I3). This score can also be divided to look at the intervention score at each type; I1 = management intervention; I2 measurement intervention; I3 performance standard intervention.</td>
<td>Overall Intervention score (I) = (D = GHG drivers; I = Intervention scores (I1, I2, I3); S = Stringency scores (S1, S2, S3) (D score / Possible D score)*3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I1 = ((∑ I1 score) / (Potential I1 score))*100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I2 = ((∑ I2 score) / (Potential I2 score))*100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I3 = ((∑ I3 score) / (Potential I3 score))*100</td>
</tr>
<tr>
<td>Stringency</td>
<td>The relative level of strictness for compliance to receive certification; a higher score indicates that a scheme is stricter in requiring compliance concerning GHG drivers.</td>
<td>((∑ S1 + S2 + S3) / possible S score)*100</td>
</tr>
<tr>
<td>Total relative score</td>
<td>The sum of all the above scores relative to the potential score that can be awarded for the scheme.</td>
<td>(Raw total score/potential total score)*100</td>
</tr>
</tbody>
</table>
3.5.4 Application of the framework

3.5.4.1 Assessment process

The assessment process and results per scheme was documented within an excel file so that all results, and judgements made are fully transparent. The results are available in the attached supplementary material.

There are several aspects of the assessment process that bear comment:

- **Type of intervention** - despite each component of the framework being clearly defined, to analyse qualitative data typically requires some level of judgement, which is of course subjective and is therefore open to differing interpretations (Ritchie and Spencer, 2002). In particular some degree of judgement may be required to decide which type of intervention best characterises criteria within a scheme. Where any ambiguity was found, arising in less than 5% of the interventions over all the schemes considered, the classification granted reflects consensus among the supervision team acting as an expert panel.

- **Double scores** - it is possible that one criterion in a scheme can be scored more than once within the framework. For instance a requirement to ‘manage all agrochemical applications’ will score for management (I1) in both the fertilisers (d) and pesticides (e) GHG drivers. Similarly this may occur if a criterion in a scheme can be categorised as including more than one type of intervention, i.e. management of and the setting of a performance standard within the same criterion.

- **Stringency scoring** - in the case that there are several criteria in the scheme that address one GHG driver with different stringency scores, the highest score takes precedence. For example, an optional criterion in scheme A might specify that ‘soil pH should be measured’ and thus be granted a stringency score of 1 (soft), while a subsequent mandatory criterion stipulates that records are kept including measurements of soil pH and so receives a stringency score of 3 (hard). In this case the higher score is recorded, i.e. 3.

- **GHG driver identification** - a scheme may feature the same GHG driver more than once in the context of different criteria. Biodiversity criteria for instance, may require tree or bush planting which is important for enhancing species diversity but also potentially increases carbon sequestration by increasing biomass and soil carbon. Schemes were assessed to recognise all GHG drivers wherever they are mentioned in the specifications of the scheme.

3.5.4.2 Scheme scores and results

Table 12 summarises the results from the application of the assessment framework to each of the schemes. Immediately, it is interesting to see that no schemes receive 100% in any scoring category. GlobalG.A.P receives the lowest comprehensiveness score, with just 38% of GHG drivers included in the assessment, in comparison to RA-CM which has a comprehensiveness score of 86%. The scores
for intervention and stringency fall in narrower ranges. The intervention scores range from 18% of the total available score for Fairtrade up to 58% for Bonsucro. GlobalG.A.P and Fairtrade score lowest on stringency with 13% each, while RTRS and RTRS-EU combined score highest at 46%.

Table 12: Score summaries of all the schemes assessed in the framework.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Potential score*</th>
<th>Total comprehensive-ness score (%)</th>
<th>Total intervention score (%)</th>
<th>Total stringency score (%)</th>
<th>Total relative score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairtrade</td>
<td>240</td>
<td>40</td>
<td>18</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>GlobalG.A.P</td>
<td>252</td>
<td>38</td>
<td>21</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>LEAF</td>
<td>276</td>
<td>65</td>
<td>45</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>RA</td>
<td>264</td>
<td>68</td>
<td>39</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>RA+RA-CM</td>
<td>264</td>
<td>86</td>
<td>50</td>
<td>35</td>
<td>38</td>
</tr>
<tr>
<td>UL SAC</td>
<td>276</td>
<td>78</td>
<td>48</td>
<td>39</td>
<td>41</td>
</tr>
<tr>
<td>Bonsucro</td>
<td>240</td>
<td>75</td>
<td>58</td>
<td>42</td>
<td>46</td>
</tr>
<tr>
<td>RSPO</td>
<td>228</td>
<td>63</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>RSPO+RSPO-EU</td>
<td>228</td>
<td>63</td>
<td>37</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>RTRS</td>
<td>240</td>
<td>70</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>RTRS+RTRS-EU</td>
<td>240</td>
<td>75</td>
<td>47</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>UTZ</td>
<td>240</td>
<td>50</td>
<td>28</td>
<td>23</td>
<td>24</td>
</tr>
</tbody>
</table>

*Number of GHG drivers included in assessment x 12 (max. score per GHG driver)

Figure 11 presents the relative total scores for each of the schemes assessed; that is, the total score across all framework components relative to the total potential score. This provides an initial overview and insight into how the schemes score for consideration of GHGs as assessed by the framework and serves as an initial comparison of the schemes. None of the schemes scored above 50% of their total potential score, indicating that there is the potential for further developments of the schemes to increase their consideration of GHG emissions. Figure 9 shows the schemes that scored highest overall, Bonsucro and RTRS+RTRS-EU, followed by the UL SAC and Leaf schemes. There are then several schemes that scored an overall score between 30 and 40% of their total. The
three lowest scoring schemes, UTZ, GlobalG.A.P and Fairtrade scored below 25% of their total potential score. It is interesting, in Figure 11, to observe which schemes appear to be very similar to each other e.g. there is only a 1% difference between the scores of Fairtrade and GlobalG.A.P rendering them almost the same for their consideration of GHG emissions. This is a similar case for RA+RA-CM, UL SAC and Bonsucro which scored 38, 41 and 46 % respectively and thus not a difference in score that would classify them as addressing GHG emissions in very different ways. To analyse and interpret the results further requires a more detailed look at the different scores generated and the relationships between them.

Figure 11: Total scores relative to the total potential score (%) for the schemes assessed in the framework.

Figure 12 a, b and c demonstrate graphically how the scheme scores compare for comprehensiveness, intervention and stringency, respectively. Two aspects of the results are of particular interest. The first is the percentage score on the y-axis where it can be seen that a greater percentage of the total possible score for comprehensiveness was reached. The comprehensiveness scores ranged from just 36% of GHG drivers included in the assessment for GlobalG.A.P in comparison to 86% for the combined score of RA plus RA-CM. Secondly, it is interesting to see how the schemes compare for the different score types and which is the top performer in each case. The intervention and stringency scores are highly dependent on the comprehensiveness score, so combining the results can provide greater insights on the results which is done in Figure 13.

The three graphs in Figure 12 helpfully provide an overview of how different the schemes are across the different scoring categories. It is interesting however to look closer to try and understand what difference in the % score would correspond to a considerable difference between the schemes. For
example, Rainforest Alliance (RA) and Rainforest Alliance inclusive of the climate module (RA+RA-CM) scored 68% and 86% for comprehensiveness respectively, a difference of 18%. This difference in scores pertains to a difference in the inclusion of 4 GHG drivers in the schemes, out of the 23 covered in this assessment. This therefore could mean the omission of some key GHG relevant management practices (the extent of which these would affect the emission performance is of course dependent on which 4 GHG drivers were omitted). For the intervention score the difference between the same two schemes is 11% which represents both the inclusion of the additional GHG drivers that must be managed as well as some GHG drivers that must be ‘measured’ in addition to being managed and thus has some further effort required. For the stringency score, the difference is just 7% because the stringency requirement for implementation of the criteria in RA were higher (i.e. more ‘hard’) than in the climate module which is a voluntary add on and so all criteria were deemed as medium. The addition of the climate module to the general RA standard therefore did not add much in terms of stringency. It seems that overall, a sensible rule of thumb that a difference in score of more than 15%\(^{18}\) in these three scoring categories in this framework is representative of a fairly substantial difference between the schemes for that individual particular aspect of the analysis.

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\(^{18}\) This 15% has been determined as a guiding rule of thumb for identifying where there may be considerable differences between the schemes within the different scoring categories. It remains, however, an arbitrary figure and has not been determined with statistical analysis so further investigation into the results would be required to ascertain the degree of the difference between the schemes.
Figure 12: Scores for the schemes assessed in the framework. a) comprehensiveness scores; b) intervention scores; and c) stringency scores.
Figure 13 shows the relation between the comprehensiveness score and the stringency score (S) for each scheme. The area of each bubble is proportional to the overall intervention score awarded. The figure therefore provides an initial indication of the extent to which a scheme might address all possible sources of GHG emissions relevant to the assessment. A perfect score of 100% for each of comprehensiveness, stringency and intervention would result in a large bubble in the top right hand corner of the graph. Conversely, low scoring schemes for each of the three possible score types would generate a small bubble in the bottom left hand corner. Fairtrade and GlobalG.A.P score very similarly and are clustered at the lower end of the score range. UTZ and RA score comparably for comprehensiveness but RA scores slightly higher for intervention and stringency.

Several schemes score similarly and are clustered at the top right of the graph some with larger area bubbles than others. RA, when combined with the climate module (RA-CM) moves upwards on the graph, as the comprehensiveness score increases; this is to be expected as the climate module specifies additional voluntary climate adaptation and mitigation criteria supplementary to RA. It does not move as significantly to the right as it potentially could because the RA-CM criteria are all medium stringency. RTRS however, when combined with the RTRS-EU module moves further to the right than it does upwards as the stringency score increases due to the RTRS-EU components being required for legal compliance. When RSPO is combined with the RSPO-EU additional compliance requirements it also moves to the right but less so than RTRS when combined with the RTRS-EU add-on. Three of the schemes assessed in the framework, RTRS, RSPO and Bonsucro, have been approved for assessing contributions to renewable energy targets in the EU (Europa, 2011) and are therefore beginning to cross the border between voluntary approaches for assurance of good practices into the regulatory territory. For biofuel products to be approved under the EU directive (2009/28/EC), these schemes must deliver ever increasing GHG benefits in comparison to conventional fossil fuels and so should score highly in this framework. Figure 13 also shows that LEAF and the UL SAC score very similarly for stringency and so are positioned close together along the x-axis, the UL SAC however, addresses more GHG drivers than LEAF and therefore scores higher for comprehensiveness in this framework as is indicated by its higher position up the y-axis on the graph.

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19 Biofuels used to achieve the EU target of 10% renewable energy in transport by 2020 must meet minimum sustainability requirements set by member states or by voluntary schemes approved by the European Commission. See: http://ec.europa.eu/energy/renewables/biofuels/sustainability_schemes_en.htm
To move towards the upper right hand corner of Figure 13, a scheme needs to be more comprehensive and impose stricter rules for compliance. No scheme scores above 50% for its total potential stringency score, as most do not address the full range of GHG drivers nor mandate compliance with all criteria. Doing so would likely make a scheme too difficult to achieve and could exclude a number of producers at different capacity levels, i.e. those unable to invest in particular management practices or undertake GHG measurement activities. Requiring such high levels of stringency might also be self-defeating, creating potential trade-offs by prescribing actions that may conflict, be unfeasible or not locally appropriate in certain contexts. Without detailed monitoring of all agricultural practices both in isolation and combined it is not possible to gauge the overall GHG impacts. For example Rosenstock et al., (2014) have highlighted the complexities associated with GHG impacts from agroforestry activities. In this case planting leguminous trees for their nitrogen fixing properties to improve soil quality and thus enhance yields was shown to increase the N$_2$O emissions from soils. This increase in emissions however was offset when considering the carbon sequestered in both the soil and the biomass, thus emphasising the importance of considering all GHG sources and sinks to understand the emissions from a system (Rosenstock et al., 2014).

Figure 14 shows how the schemes score for intervention and highlights some of the trends among the schemes assessed, with the three intervention scores (I1, I2 and I3) for each scheme shown.
(Figure 14a). For all but one scheme (Bonsucro), the score for management intervention (I1) was the highest, with most schemes awarded over 50% of their potential I1 score; lower scores are generally recorded for measurement (I2) or performance standards (I3). Bonsucro receives the lowest I1 score of all the schemes followed by GlobalG.A.P and Fairtrade, the two generally lower scoring schemes. The score for RA and RA-CM combined stands out with the highest I1 score, receiving 90% of its potential, 23% higher than the RA scheme alone. This is unsurprising as the climate module is designed to supplement the RA scheme through additional climate change adaptation and mitigation criteria. A general trend amongst most schemes becomes apparent from Figure 14a: schemes typically score most highly for “manage”, followed by their intervention score for “measurement”, with their lowest intervention score occurring for “performance standards” where nearly all schemes scored less than 30% (or even zero) of the potential total (Fairtrade and GlobalG.A.P). Bonsucro is highlighted as an exception here: it scores very highly for both “measure” and “performance standards” (I2 and I3) compared to the other schemes and also compared to its own I1 score for manage. This is more clearly seen in Figure 14b that presents a bubble chart of the three intervention scores. Here Bonsucro is positioned very differently from the other schemes as it is located much further along the x-axis for its I3 score for performance standards. This underlines the way Bonsucro positions itself as the first metric-based standard: it is heavily focused on measuring and setting performance targets and thresholds and requires a ‘verifier’ for evidence that a criterion or indicator has been met. In this way, it offers flexibility in the management approaches embarked upon, despite being highly prescriptive in the performance outcome required. Bonsucro is a relatively new scheme, developed in 2011, and appears to be taking a very different approach to several of the other more established schemes that tend to set a number of ‘management’ requirements that should lead to good performance, rather than setting performance targets and letting the farm decide how to achieve them. This may be the most appropriate approach for the types of farm that Bonsucro is designed to certify but whether the threshold approach is successful in driving continuous GHG reductions or inspires producers to go beyond the threshold required is yet to be seen. Second to Bonsucro for the I3 score was the UL SAC. Unilever designed this scheme to apply to their own supply-chain, to be specific to their informational needs, and therefore may be able to stipulate certain performance requirements as a condition of supply.

In Figure 14b, RA moves up on the graph when combined with RA-CM. It scores more highly for management requirements but there is no increase in the intervention score for performance standards: the climate module requires greater attention to management and measurement of GHG drivers but sets no performance requirements. As standards evolve and farmers become better acquainted with these practices, it is likely that this score distribution may change. This is true for all schemes: most are reviewed every 2 to 5 years, each time evolving to keep up with increasing informational requests, changing technologies, evolving legislation and new reporting requirements, as well as increased competition among schemes as they strive for further differentiation. It
therefore would be useful to re-apply the assessment framework following the update of a standard to see if the score(s) change.

Figure 14: Intervention scores awarded to the schemes, I1 (manage), I2 (measure) and I3 (performance standard). 14a shows a bar graph of the three scores for each scheme. 14b presents a bubble chart of the 3 intervention scores and highlights the patterns among the schemes; the area of the bubble is proportional to the I2 (measure) score.
Figure 15 shows the extent to which selected GHG drivers are covered by each intervention type, across all the schemes, including some drivers that are important in most agricultural systems (e.g. energy, fertilisers) as well as some that are more important in specific cases such as tropical cropping systems (e.g. LUC, agroforestry). This figure shows which GHG drivers are addressed most frequently and helps identify which GHG drivers lend themselves best to measurement and the establishment of a performance standard. For example, all the schemes require fertilisers and energy use to be measured whereas measurements associated with fertiliser production are included in very few. Farmers are likely to be able to measure and record the fertilisers they apply and energy they use more easily than they would be able to acquire information on the impacts of fertiliser production.

Several schemes receive scores for both managing and measuring use of crop protection chemicals (CPCs) as a GHG driver, though this was likely an unintended consequence as CPCs are more linked to other impacts such as eco-toxicity and chemical safety. The framework generates scores for some GHG drivers (as they are defined here) whether or not their inclusion is intended for GHG management or to achieve a GHG reduction; e.g. number of trees planted, which is recorded for biodiversity, counts as an I2 score i.e. measurement under the agroforestry GHG driver because as well as enhancing biodiversity it also affects GHG emissions. This approach has been adopted to provide a full assessment of all the GHG drivers included, in order to provide a complete picture of
the practices and emission sources that schemes address. The assessment framework does not apply a weighting to the different GHG drivers for their potential significance in a particular crop GHG footprint; therefore a scheme with a high comprehensiveness score may not have the biggest impact on the ground. For example a scheme that addresses less significant GHG drivers, such as CPCs and transport, but not fertiliser use might score higher for including more GHG drivers, but has potentially omitted a significant source of GHG emissions.

Over 60% of schemes explicitly reference GHGs or climate change and scored for this GHG criterion (u). Activities prescribed under this criterion range from raising staff awareness of climate change matters, to prescribing specific on-farm GHG mitigation activities.

3.6 Discussion

The beginning of this chapter provided a brief overview of some of the history, rationale and evolution of the development of certification schemes with a specific focus on the agricultural sector. Overwhelmingly in most cases, they arose due to market failures and a lack of regulation or control of some key issues or impacts. Initially the focus was on product/material safety and quality but they now cover a range of issues including environmental, social, ethical and economic (i.e. sustainability). Climate change is one issue they address that has become increasingly important and so certification schemes have become an important voluntary mechanism to guide and assess management practices that contribute towards reducing GHG emissions.

Evidence of the benefits, particularly the environmental benefits, of certification schemes is extremely limited and the evidence for positive impacts is weak at best. There is a need for well-designed and longer term studies of the causal impacts of environmental certification schemes and also for this process to be built into the certification process. This is important if certification schemes are going to continue to act as a mechanism to achieve more sustainable production systems as the need to demonstrate real impacts is more pertinent, particularly with the growing number of schemes on the market.

A detailed review of ten certification schemes was conducted using a framework focussing on how they address GHG management practices and GHG emissions. The following sections cover:

- Key findings and uses of the framework
- Limitations of the framework
- Further research areas and opportunities for validation of the framework.

3.6.1 Key findings and uses of the framework

The results do not show that one scheme is necessarily ‘better’ than any of the others but they demonstrate the differences in the ways in which GHGs are considered and addressed by the ten
certification schemes. The schemes can be differentiated by the number and range of GHG drivers considered, the level of intervention at which each GHG driver is addressed and whether the schemes are GHG management orientated or tend towards GHG measurement and performance standards.

The differences between schemes result from a number of factors, including the agricultural systems for which the scheme is intended; whether the GHG emissions from a particular agricultural system are a key concern compared to, for example, the primary processing supply chain stage; the capacity and capability of the target user (e.g. smallholders vs. large-scale farms); and the overall goals of the scheme. Some schemes were developed to focus on issues other than GHG emissions, or were established before climate change and GHGs became a key concern (e.g. Fairtrade focused on social issues).

Importantly, the analysis exposes the management bias of most schemes and identifies the performance-oriented approach of Bonsucro as an outlier. Within most schemes, therefore, the results indicate that there is scope to move towards GHG measurement and the setting of performance targets as they evolve over time. Current or future schemes may learn from or emulate the performance-oriented approach of Bonsucro, particularly as both the scientific and public debate on the need to quantify the impacts and benefits of certification intensifies (RESOLVE, 2012; SustainAbility, 2010).

The framework developed for this research will enable future users to identify the schemes that cover the widest range of GHG drivers and to determine which schemes address the GHG drivers that may be most important for any specific application. Furthermore, as the framework distinguishes how the GHG drivers are addressed, users are also able to select certification schemes most appropriate for the farms being certified. For example, a company seeking to certify a new group of smallholder farmers with less capacity for more difficult or expensive interventions, may choose to opt for schemes that are management focused rather than measurement oriented or that require performance standards. Differences identified between the schemes in their requirements or stringency (e.g. mandatory or optional) in managing GHG drivers could influence their potential effectiveness. The framework proposes a rating system to assess the stringency and in doing so provides an indication of the conditions under which particular criteria are imposed. The framework helps users to select a scheme that offers an appropriate level of flexibility in the way the GHG drivers are prescribed (managed vs. measured) or allows phased implementation of actions.

Although it was not the primary objective of the framework, the results show that several of the system- or crop-specific certification schemes scored more highly than multi-system schemes across the three scoring classifications. This may be indicative of the opportunity and potential benefits to be more specific and stringent in system-specific schemes compared with schemes applicable to multiple agricultural system schemes. It is also interesting that the results demonstrated that
schemes with add-on components, such as the climate module in SAN’s Rainforest Alliance or the RTRS and the additional EU component required for legal compliance to EU RED, score higher for comprehensiveness and stringency, respectively. It could be worth exploring the potential of add-on modules to enable lower-scoring schemes to achieve higher scores through inclusion of more criteria, more requirements for measurement and performance related information and increasingly strict compliance rules.

In conclusion the application of the framework is useful in a number of ways. For instance, it can:

- Help identify and demonstrate which GHG drivers are addressed and how so.
- Highlight which schemes are mostly GHG management oriented as opposed to those that set GHG related performance standards and require collection of GHG emissions data.
- Provide decision-support in selecting a scheme to use and partner with when GHG emissions are an important consideration.

The framework and its use should therefore be useful for different user groups, including:

- Supply chain companies that are using certification schemes to tackle GHG emissions from the agricultural production phase of ingredients/products.
- Standard developers and certification bodies - this work may help inform the evolution and development of schemes over time and guide which drivers should be included to address GHG emissions and encourage potential reductions. It may also be useful in assessing how the value (as scored in this framework) of a scheme might change following a review of the criteria included.
- Consumers with a concern for GHG emissions when they make a purchasing decision would benefit from increased understanding of the extent and reliability with which any certification label addresses GHGs.

As certification schemes become a more powerful force in agri-food supply chains globally (Ouma, 2010) and simultaneously the pressure on this sector to mitigate climate change increases, the need for schemes to effectively address GHG emissions and to be transparent in how they do so will become greater. This framework can contribute to informing this area.

3.6.2 Limitations of the framework

The intention was to create a framework to enable the assessment and comparison of agri-food certification schemes, albeit with a bias towards those schemes included in the detailed assessment. Whilst a range of schemes and crops have been considered, further work is required to assess whether the framework is applicable to all agri-food certification schemes. It is also important to acknowledge that the assessment framework includes a measure of subjectivity based on the user’s interpretation of the various schemes and their respective details. In the review of ten schemes, the
results were fully documented to ensure that they are transparent. In this way, others can see how the data were analysed and can challenge, check or test the judgements or assumptions made (Ritchie and Spencer, 2002).

The main limitation of the framework is that no weighting has been applied to the GHG drivers so that it provides no indication of the relative importance of each driver; a scheme could therefore receive a high score even if it does not incorporate the most significant GHG driver or drivers for a particular system or crop. For example, the omission of requirements to manage/measure LUC impacts on a palm oil plantation could potentially negate all the benefits resulting from other GHG drivers (Germer and Sauerborn, 2007a). Due to the range of agricultural systems covered by the schemes reviewed, it was not feasible to rectify this limitation nor was it an ambition of the exercise. It, therefore, remains an area for further research or an issue that future users could address by applying their own weighting criteria relevant to their specific concerns.

A second limitation of the framework concerns the possibility that, in some cases, the scores awarded may be too ‘optimistic’ by giving credit to a scheme for addressing a particular GHG criterion in a fashion which does not reflect the action actually taken. This is because some interpretation is required in the assessment of any criterion within a scheme for which the wording is broad or ambiguous. For example, RA specifies that the farmer should ‘select service providers that are climate friendly’. This criterion was scored for management of the three upstream GHG drivers including fertiliser and CPC production and transport of inputs to the farm (a-c) but, in reality, none may have been managed, not even the GHG footprint of the farm’s energy provider. In such cases the GHG driver scored more positively than in a more conservative approach; therefore some degree of caution is required. As this is a desktop exercise, future users of the framework need to validate their assumptions through consultation with the farmer/grower.

Finally, in scoring the schemes, the framework does not differentiate between schemes designed for different purposes; the only differentiation granted is the exemption from considering GHG drivers that are not within the remit of the scheme. It is, however, important to consider the original goal of the scheme. For example, the primary purpose of Fairtrade certification is to improve the livelihoods of farmers, whereas climate mitigation and GHG management is the focus of the RA-CM. This explains why these two schemes score so differently.

### 3.6.3 Further research and opportunities for validation

GHG emission is just one measure of environmental impact but the framework and its philosophy could be extended to include other important impacts or topics such as biodiversity or water use. This could provide some interesting results as the schemes may rank differently for different impact categories. Additional work would then be required to understand and represent potential trade-offs between different management practices. For example, some studies, particularly within the forestry sector, have developed methodologies and frameworks to compare and categorise
voluntary and regulatory standards for different social and environmental criteria (Mcdermott et al., 2008; Holvoet & Muys, 2004). An important follow-up to the framework presented here could involve comparing and reconciling these different approaches to help inform evaluation of schemes’ potential to drive improvement or potential development of better standards for particular impacts.

Importantly, greater understanding is needed of how qualitative information on farming practices, such as the identification of the management activities implemented by a farmer, can be used as a proxy or substitute for GHG emissions reporting and for understanding GHG performance (WRI, 2012). As demonstrated here, many schemes are management oriented and use information on the management practices as a proxy for good performance without quantitative supporting evidence. What is required are studies that compare GHG performance in terms of emissions from certified versus non-certified farms and also before and after certification from farms that have been assessed. Such studies are complicated and would require significant investment of resources, needing to be carried out over a number of years (e.g. 10-15 years to take into account crop rotation and time averaging of data). Such studies have been reported for some social metrics (Blackman and Rivera, 2010; Gabriel et al., 2010) but not for GHG performance.

There is a lively debate in the literature and also within the agendas of several certification bodies around the number of requirements within a standard, the difficulty of achieving them and the way in which they are mandated. External stakeholder NGO groups, such as WWF, Greenpeace and Conservation International, are pushing for a comprehensive set of requirements and stringent compliance requirements, to ensure that overall sustainability goals are met (Fischer and Lyon, 2014; Mongabay, 2013) yet at the risk that the schemes could become too difficult to implement. This in turn could exclude many producers and ultimately may reduce the market uptake of the schemes. On the other side, producer groups and other organisations may advocate fewer and less stringent requirements, to enable a greater number of producers to achieve certification. This, however, risks making certification too easy to achieve and setting a low performance baseline resulting in little or no real impact. Simultaneously, this risks the scheme losing credibility and trust, once again resulting in reduced market penetration. Such challenges are prevalent in the development and evolution processes of certification schemes and may explain some of the results in this study. In particular, it could explain why there are higher scores for comprehensiveness compared to the scores awarded for level of intervention and stringency, possibly because it is relatively easy to include a wide range of requirements or to phrase criteria so that they encompass many GHG drivers (and so score highly in this framework) but harder to prescribe higher levels of intervention (i.e. measurement data or performance standards) or to make these mandatory for certification. Further investigation into the uptake of all the schemes assessed and the trade-offs between comprehensiveness and stringency and/or levels of intervention, would provide further insights into the results from this study.
3.7 Chapter summary and key conclusions

The proliferation of agri-food certification schemes has accelerated over the last 10 years and they can differ significantly in their style, structure, focus and their compliance requirements. Much of the literature and reviews of their use present their potential benefits but also highlights their potential shortcomings.

A transparent and structured framework has been provided to enable comparison of agri-food certification schemes according to the GHG drivers considered, the level of intervention and the stringency of these requirements within the schemes. However, the comparison which results is multi-dimensional, not a simple ranking, so that the results still require interpretation to determine which schemes can be expected to deliver best on GHG reductions. Furthermore, the outcomes of this assessment still need to be validated against real GHG performance data. Indeed, an important follow up for this study would be to validate the scheme score against actual GHG performance for both non-certified and certified farms under similar conditions.

The ability of agri-food certification schemes to contribute to sustainable agriculture and lead to quantifiable impact improvements is an area of lively debate. The available evidence for their effectiveness is fragmented and largely anecdotal, focussing mainly on social metrics (Walter et al., 2003; Kamau et al., 2011); studies quantifying GHG emissions from certified farms and comparing them to non-certified farms are scarce. The approach developed here enables enhanced understanding of the content and activities prescribed within a scheme and the strictness with which they are imposed. It can therefore provide a first step towards ascertaining how different certification schemes address GHG emissions and show potential or reduced reductions through management and metrics. No current study has been found that shows this in a systematic and informative way; further application and validation of the framework will strengthen the findings and begin to contribute to the debates on how agri-food certification schemes should be constructed to drive potential GHG benefits.

The key conclusions from this chapter are:

- Agri-food certification schemes are and will continue to be important market mechanisms to achieve and provide assurance for more sustainable management practices, including but not limited to GHG emission reductions.
- Agri-food certification schemes have proliferated in the last decade and the diversity in the design, structure, language and implementation requirements render certification schemes difficult to compare directly.
- Of the certification schemes assessed, most are management oriented: they require farmers to adhere to a set of management practices and actions in order to achieve certification.
Fewer require measured (i.e. quantified) input data or modelled GHG emission values, and less still set GHG related performance standards such as emission thresholds.

• Adherence to a certification scheme is not necessarily synonymous with good GHG performance. Consequently, without detailed analysis, it is not possible to ascertain which schemes will lead to improved GHG emission performance of farms based on the requirements that they stipulate. Certification schemes are, however, one of the best available means of ensuring that production meets certain requirements and the increased uptake by large supply chain companies is testament to this.

• Evidence that certification schemes drive GHG emission reductions is lacking overall. The very limited evidence is inconclusive and anecdotal. Further work is necessary to validate the adherence to certification schemes against the real GHG performance of certified farms.

• To truly understand the impacts that certification can deliver on the farm, there is a need for it to build into the certification process, effective monitoring and evaluation to include a baseline or starting assessment (status quo) and then follow up evaluations as certification is achieved and then over time to see the impacts of continuous improvement.
Chapter four focuses on the modelling of GHG emissions from agriculture up to the farm gate using measured input parameters and GHG calculators. Numerous GHG calculators have been developed in recent years to estimate GHG emissions from agriculture and their applicability is summarised. The main focus of this chapter is an in-depth assessment of three GHG calculators selected on the basis of their use in agri-food certification schemes, their use by Unilever for assessing supplier performance and the insights gleaned from this comparison. Some aspects of this work have been published in Keller et al., (2014).
4.1 From GHG management to the estimation of GHG emissions.

Chapter 3 highlighted the proliferation of agricultural certification schemes, their prominence in supply chain relationships and the extent to which they address GHG management and performance through the reporting of GHG emissions. This chapter focuses on the modelling of farm GHG emissions, using agricultural GHG calculators. It is important at this point to distinguish between the measurement of actual released GHG emissions from an agricultural system and the estimation of GHG emissions through a combination of measured farm input/activity data and models (i.e. calculators). Chapter 2 briefly described the two most common on-farm experimental GHG measurement approaches that can facilitate a better understanding of GHG emissions from farming activities, together with the numerous standards developed by organisations such as IPCC to calculate GHG emissions from activity based measures. In most cases, on-farm empirical measurement of GHG emissions is impractical for farmers hence modelling of GHG emissions using scientifically agreed standards combined with measured farm activity data is universally accepted for estimating and reporting of GHG emissions at a farm level.

This chapter focuses on research objective 3, as defined in Chapter 1:

3. To explore the range of agricultural GHG modelling tools available and compare three important, widely used tools in order to clarify sources of methodological differences between them in order to evaluate their comparability for use in GHG reporting.

To do so, this chapter will introduce the concept of GHG calculators, how they work and the many sectors they have been designed for (4.2), specifically focusing on agricultural GHG calculators and the proliferation of these calculators in recent years (4.3). It will briefly look at some examples where calculators are being used (4.4) and some efforts that have been made to assess and compare them (4.5). The rest of the chapter will then compare three important GHG calculators that are used individually within specific certification schemes and simultaneously within Unilever’s agricultural supply chain (4.6). Finally, the results and insights will be discussed and summarised (4.7).

4.2 GHG calculators

Modelling GHG emissions, in many contexts, is a complex undertaking. GHG calculators exist to make it simple and accessible. They are intended to combine various forms of information about an activity, system or product and generate a single representative GHG footprint estimate. Scientifically derived and accepted GHG models and data sources are combined with user specified input data, characteristic of their circumstance, to model/estimate the GHG emissions of the activity, system or product under assessment.

GHG calculators are not unique to the agricultural sector and there are many examples across a range of sectors. There are, for example, personal GHG calculators to provide individuals with an
idea of the carbon intensity of their lifestyle (e.g. the UK governments ‘act on CO₂ calculator’\(^{20}\)); sector/activity specific GHG calculators such as those to assess the GHG impacts of buildings (e.g. construction carbon calculator\(^{21}\)) or more specifically to assess the waste management of bio-solids (Brown et al. 2010). GHG calculators exist in many formats but the core principles of how they work remain the same. Figure 16 provides a simple schematic to demonstrate this. Typically they require the user to enter fairly simple activity-based information that describes the system they are assessing. This information is then combined and modelled with underlying information and conversion factors embedded in the calculator to convert the activity data into an estimation of GHG emissions. The paramatisation of the model and the selection of the underlying data is determined by the developer of the calculator and is not necessarily transparent to the user. Many GHG calculators are designed to be simple and easy to use (particularly then they are targeted for use by the general public) and consequently, they often provide limited transparency on the calculations that have been performed or sources of the underlying data. The results from a GHG calculator are usually presented deterministically as a single GHG footprint number (mass of GHG emissions) without reference to the variability or uncertainty associated with the estimation. In some cases results are presented in terms of equivalents (e.g. hours of light bulb time or number of flights to the U.S) in order to aid communication. Figure 16 indicates which parts of the GHG calculation are usually seen by the user and require user interaction, and which components are in the background for calculation purposes.

Figure 16: Schematic representation of how ‘general’ GHG calculators work.

4.3 Farm GHG calculators

Agricultural GHG emissions are typically more difficult to model/estimate than many industrial processes due to the complexity and variability of natural systems (Clift et al., 2014). Agricultural

\(^{20}\) Act on CO₂ calculator can be found at [http://carboncalculator.direct.gov.uk/index.html](http://carboncalculator.direct.gov.uk/index.html).

\(^{21}\) The construction carbon calculator can be seen at: [http://buildcarbonneutral.org/](http://buildcarbonneutral.org/).
specific factors contributing to the complexity include: complex environmental interactions (e.g. soil and climate interactions), and variability between farms (e.g. size, location, farming practices), as well as some challenges associated with the GHG accounting principles of unique GHG emission sources such as those that arise from land use change (LUC). Farm GHG calculators need to model as many of these parameters as possible in order to provide a good estimation of GHG emissions. The IPCC has, as previously described in Chapter 2, identified different levels or tiers for estimating and reporting agricultural emissions. The tiers differ in terms of the level of detail and complexity of the data required (IPCC, 2006c). A tier 1 approach involves using emission factors based on global level data and this is considered too coarse for farm-based assessments. The IPCC encourages use of tier 2 approaches i.e. country or region specific emission factors based on representative measurements made in that country or region; or tier 3 methods which include higher resolution data and more detailed process based models specific to a country or region. However, due to the limited availability of tier 3 data, most farm GHG calculators use a combination of tier 1 and tier 2 data with farm specific activity data, for the majority of the GHG emission drivers modelled. Most agricultural GHG calculators do not require detailed field based measurements of actual GHG emissions.

Figure 17 schematically illustrates the operation of a generic farm GHG calculator. Building on Figure 16, it shows in more detail the most basic structure of many farm GHG calculators and the additional level of complexity to deal with environmental interactions.

Figure 17: Schematic representation of how agricultural GHG calculators work.

As well as using IPCC tier 1 and tier 2 emission factors, the underlying data elements and methodologies used in farm GHG calculators may be based on other data sources. Published literature data including life cycle inventory data and international guidelines and methodologies such as WRI (WRI, 2011) or PAS 2050 (BSI, 2011), which provide best practice guidelines for calculating an agricultural GHG footprint, may also be used within a GHG calculator. Despite the availability of these emission accounting guidelines and some agreed overall principles for agricultural GHG accounting, there is currently no agreed standard on how to construct a farm GHG calculator. Consequently, calculators may differ in aspects such as: format, scopes, geographical
boundaries, data requirements, methodological approach, and underlying datasets. These aspects are examined further in the following sections of this chapter.

Much like the increase in agricultural certification schemes described in the previous chapter, there has been a proliferation of agricultural GHG calculators over recent years. This has likely been, in part, due to both the diversity of agricultural systems and geographical conditions in which they can be applied as well as the diversity of methodologies and data sources that can be used. Potential user groups and calculator developers may therefore be incentivised to develop a ‘most appropriate’ GHG calculator, suited to their identified ‘need’. Table 13 presents an overview of agricultural GHG calculators. The table includes many of the publically available farm GHG calculators, including calculators for whole-farm GHG assessments as well as some that focus on more specific aspects of an agricultural system, but it is not intended to be an exhaustive list. The table includes an overview of each calculator, the developer(s) and year of development and how the calculator can be accessed. To illustrate the variability in scope and applicability of the calculators they have been classified as follows:

**By Geographical Scope (G):**

1. Geographically specific to one country or region of the world and thus the underlying data sources and emission factors used in the tool are specific to that particular area (G1).
2. Multi-location tools that can be used in more than one area or geography or those that are globally applicable (G2).

**By Farming System Applicability (S):**

1. System-specific tools that are designed specifically for one farming system or product type, either to a specific crop or a specific livestock type (S1).
2. Multi-system tools that can be applied to multiple farming systems, crop types and mixes of crop and livestock farming systems including forestry systems (S2).

For example, PalmGHG developed for palm oil is classified as G2/S1 based on the fact that it is intended to be used for all palm oil growing regions (e.g. SE Asia, Africa, Latin and S America) but is palm oil specific. In contrast, the Cool Farm Tool is classified as G2/S2 on the basis that it is a globally applicable multi-crop/farming system calculator.
Table 13: Overview of some publically available agricultural GHG calculators, classified by their geographical scope and system applicability.

<table>
<thead>
<tr>
<th>GHG calculator</th>
<th>Classifications</th>
<th>Overview</th>
<th>Developer; release year</th>
<th>Geographical scope</th>
<th>Applicable farming systems</th>
<th>Accessibility and Reference/link</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLA CALM (Carbon Accounting for Land Managers)</td>
<td></td>
<td>GHG balance of land based businesses. Assessment can be performed for whole farm, forestry activities and also enables the assessment of entry to the Environmental Stewardship(^{22})</td>
<td>Country Land and Business Association (CLA); (2008)</td>
<td>England and Wales</td>
<td>Several farm systems including cereals, horticulture, livestock, dairy, mixed farming systems and nature reserves</td>
<td>Free online access via website <a href="http://www.cla.org.uk/">http://www.cla.org.uk/</a></td>
</tr>
<tr>
<td>CPLAN Carbon Calculator</td>
<td></td>
<td>Carbon calculator for land based industries. Estimates the associated uncertainty by providing the average and upper and lower estimated GHG budgets for the system assessed.</td>
<td>CPLAN Consultancy; (2007)</td>
<td>UK</td>
<td>A range of UK crops and farming systems including livestock, horticulture, oilseed rape and sugar beet</td>
<td>CPLAN v.0 is freely available via the website <a href="http://www2.cplan.org.uk/">http://www2.cplan.org.uk/</a> CPLAN v.2 requires membership</td>
</tr>
<tr>
<td>Farm Carbon Calculator (formerly CFF calculator)</td>
<td></td>
<td>Farm carbon calculator developed by farmers for farmers to help them measure and take steps to reduce their GHG emissions.</td>
<td>Farm Carbon Calculator; (2009)</td>
<td>UK</td>
<td>A range of UK crops and farming systems including livestock systems</td>
<td>Freely available online via the website <a href="http://www.cffcarboncalculator.org.uk/">http://www.cffcarboncalculator.org.uk/</a></td>
</tr>
</tbody>
</table>

\(^{22}\) The Environmental Stewardship is an agri-environment scheme by Natural England to provide funding to farmers and land managers in England to encourage and deliver improved environmental management of farms. More information can be found here: http://www.naturalengland.org.uk/ourwork/farming/funding/es/default.aspx
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</tr>
</thead>
<tbody>
<tr>
<td>GHGFarm</td>
<td></td>
<td>Software tool to estimate and reduce new GHG emissions from Canadian farms. Designed for policy-makers, scientists and farmers to quantify, interpret and compare alternative farm management scenarios to encourage sustainable practices.</td>
<td>Academics, Newlands. N.K; (2007)</td>
<td>Canada</td>
<td>A range of Canadian crops and farming systems including livestock systems, canola, soybean.</td>
<td>Described in (Newlands, 2007)</td>
</tr>
<tr>
<td>Overseer</td>
<td></td>
<td>For farmers to manage their nutrient budgets to optimise production and environmental outcomes, the tool identifies potential risks through nutrient loss and GHG emissions and facilitates decision-support.</td>
<td>Overseer; Original development began in the early 1990s, GHG quantification was introduced in 2003</td>
<td>New Zealand</td>
<td>A range of New Zealand farming systems (9 system types are defined) and crops.</td>
<td>Freely available via website <a href="http://www.overseer.org.nz/">http://www.overseer.org.nz/</a></td>
</tr>
</tbody>
</table>
| ENZO₂          |                 | GHG calculator to facilitate compliance to sustainability certification schemes according to the Renewable Energy Directive (2009/28/EC); the Fuel Quality Directive (2009/30/EC); and others. Full production chain emissions accounted for. | Institut fur Energie-und Umweltforschung Heidelberg GmbH (IFEU); (2013) | Globally applicable | Specific to biofuels and bioliquids including vegetable oils, palm oil, biodiesel and ethanol from cereals, sugarbeet and sugarcane | Freely available online via the website http://www.ifeu.de/english/index.php?bereich=nac&seite=ENZO2
User manual: (Koppen et al., 2014) |
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</tr>
</thead>
<tbody>
<tr>
<td>Fieldprint</td>
<td>G1</td>
<td>Provides an estimate and scenario testing of field level performance for GHG emissions as well as other sustainability indicators including land use, conservation, soil carbon, irrigation water use, water quality and energy use.</td>
<td>Field to Market; (2009)</td>
<td>U.S</td>
<td>Specific crop systems including corn, cotton, rice, wheat and soybeans.</td>
<td>Freely available online via the website <a href="http://www.fieldtomarket.org/fieldprint-calculator/">http://www.fieldtomarket.org/fieldprint-calculator/</a></td>
</tr>
<tr>
<td>Comet-Farm</td>
<td>G2</td>
<td>Conservation planning tool to help agricultural producers to reduce the GHG emissions from farming and ranching. Enables scenario assessment of different management/conservation actions including future projections.</td>
<td>USDA, NRCS, Colorado State University; earlier versions of the tool e.g. comet 2.0 developed around 2011. Comet-Farm released later in 2013.</td>
<td>U.S.</td>
<td>Farming of various crops, ranching or pasture.</td>
<td>Freely available online via the website <a href="http://cometfarm.nrel.colostate.edu/">http://cometfarm.nrel.colostate.edu/</a></td>
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<td>Geographical scope</td>
<td>Applicable farming systems</td>
<td>Accessibility and Reference/link</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>HGCA carbon footprint decision support tool</td>
<td></td>
<td>Excel based tool to calculate the GHG footprint of cropping systems to facilitate decision support for farmers to manage their GHG impacts.</td>
<td>HGCA; (2012)</td>
<td>UK</td>
<td>Cereals and oilseed crops including wheat, barley, oats, rye, oilseed rape</td>
<td>Freely available for download via the website [link]</td>
</tr>
<tr>
<td>Climate Yard Stick</td>
<td></td>
<td>To raise farmer awareness of the GHG implications of their farming activities and possible reduction measures available. Whole farm assessment and it is possible to conduct scenario assessment.</td>
<td>CLM (Centre for Agriculture and the Environment); (2011)</td>
<td>The Netherlands</td>
<td>Calculators available for dairy, arable and pig farms</td>
<td>Available by request at the website [link]</td>
</tr>
<tr>
<td>HOLOS</td>
<td></td>
<td>Whole farm modelling software programme to help farmers calculate their GHG emissions and explore possible reduction options.</td>
<td>Agriculture and Agri-Food Canada in collaboration with Canadian farms; (2008), v2.2.1 released May 2014.</td>
<td>Canada</td>
<td>All Canadian system types including crops, grassland, livestock, dairy, tree plantings</td>
<td>Freely available online via the website [link]</td>
</tr>
<tr>
<td>DGAS (Dairy GHG abatement Strategy calculator)</td>
<td></td>
<td>For farm managers to calculate the impact of adopting different abatement strategies on their total farm GHG emissions. Scenario analysis can be performed to identify efficiency options.</td>
<td>Tasmanian Institute of Agricultural Research (TIAR); (2010).</td>
<td>Australia</td>
<td>Dairy farms.</td>
<td>Available upon request via the website [link]</td>
</tr>
<tr>
<td>GHG Calculator</td>
<td>Classification</td>
<td>Overview</td>
<td>Developer; release year</td>
<td>Geographical scope</td>
<td>Applicable farming systems</td>
<td>Accessibility and Reference/link</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
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<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<td>--------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Munton’s carbon footprint calculator</td>
<td>G1 S1 S2 S2</td>
<td>A simple crop specific calculator designed to assess key contributors for the GHG footprint. Specifically focusing on the impact of using N fertiliser sourced from carbon efficient producers and the gains that can be made from using green compost materials</td>
<td>Munton’s with the Centre for Low Carbon Futures; (2012).</td>
<td>UK</td>
<td>Specific to malting barley</td>
<td>Freely available for download at: <a href="http://www.muntons.com/calculator/">http://www.muntons.com/calculator/</a></td>
</tr>
<tr>
<td>European Carbon Calculator</td>
<td>G2 S1 S2 S2</td>
<td>To assess the life cycle GHG emissions from different farming systems across the EU. It quantifies direct and indirect GHG emissions, proposes mitigation options and sequestration actions suitable for individual farms based on their situation.</td>
<td>Solagro (contracted by the European Commissions’ Joint Research Centre); (2012)</td>
<td>European Union</td>
<td>All European farming systems including livestock systems, cereals, forage crops, vineyards, orchards, vegetable and industrial crops.</td>
<td>Freely available for download via the website: <a href="https://carbone.solagro.org/current/">https://carbone.solagro.org/current/</a></td>
</tr>
<tr>
<td>Cool Farm Tool</td>
<td>S1 S2 S2 S2</td>
<td>Provide decision support to farmers to enable management practice changes to promote GHG mitigation. Used for GHG reporting in supply chain contexts.</td>
<td>University of Aberdeen, Unilever and Sustainable Food Lab (SFL); (2011)</td>
<td>Global</td>
<td>All farming systems</td>
<td>Download from: <a href="http://www.coolfarmtool.org">www.coolfarmtool.org</a> Publication: Hillier et al., 2011.</td>
</tr>
<tr>
<td>GHG calculator</td>
<td>Classification</td>
<td>Overview</td>
<td>Developer; release year</td>
<td>Geographical scope</td>
<td>Applicable farming systems</td>
<td>Accessibility and Reference/link</td>
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</tr>
<tr>
<td>Bonsucro</td>
<td></td>
<td>Evaluate conformity against the maximum level of emissions set in the Bonsucro Production Standard for sugarcane, sugar and sugar based ethanol production and identify options for improvement</td>
<td>Dr P. Rein, University of Louisiana in collaboration with Bonsucro; (2012)</td>
<td>Sugarcane growing regions globally</td>
<td>Sugarcane, sugar, ethanol from sugarcane</td>
<td>No resources currently publicly available for the calculator. Some detail in Bonsucro production standard (<a href="http://bonsucro.com/site/production-standard/">http://bonsucro.com/site/production-standard/</a>)</td>
</tr>
<tr>
<td>Dairywise</td>
<td></td>
<td>A whole-farm GHG model for dairy farms. Includes economics</td>
<td>Wageningen UR Livestock Research; (2007).</td>
<td>The Netherlands</td>
<td>Dairy farms.</td>
<td>Model is described in (Del Prado et al., 2013).</td>
</tr>
<tr>
<td>GREET (GHGs, Regulated Emissions and Energy use in Transportation model)</td>
<td></td>
<td>Life cycle model for the greenhouse gas emissions of transportation fuels including those from agriculturally derived biofuels.</td>
<td>Argonne National Laboratory; (earliest version developed in 1996)</td>
<td>U.S.</td>
<td>Biofuel crops including corn, sugarcane, soybeans, and switchgrass.</td>
<td>Freely available for download via the website: <a href="https://greet.es.anl.gov/">https://greet.es.anl.gov/</a></td>
</tr>
<tr>
<td>GHG calculator</td>
<td>Classification</td>
<td>Overview</td>
<td>Developer; release year</td>
<td>Geographical scope</td>
<td>Applicable farming systems</td>
<td>Accessibility and Reference/link</td>
</tr>
<tr>
<td>--------------------------------</td>
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<td>---------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>DNDC (DeNitrification-DeComposition)</td>
<td>G1 G2 S1 S2</td>
<td>A computer simulation process-based model for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, N leaching and GHG emissions of agro-ecosystems.</td>
<td>University of New Hampshire; (2001)</td>
<td>Globally applicable</td>
<td>All farming systems</td>
<td>Freely available to download via the website: <a href="http://www.dndc.sr.unh.edu/">http://www.dndc.sr.unh.edu/</a></td>
</tr>
<tr>
<td>Dairywise</td>
<td></td>
<td>A whole-farm GHG model for dairy farms. Includes economics.</td>
<td>Wageningen UR Livestock Research; (2007).</td>
<td>The Netherlands</td>
<td>Dairy farms.</td>
<td>Model is described in (Del Prado et al., 2013).</td>
</tr>
<tr>
<td>GHG calculator</td>
<td>Classification</td>
<td>Overview</td>
<td>Developer; release year</td>
<td>Geographical scope</td>
<td>Applicable farming systems</td>
<td>Accessibility and Reference/link</td>
</tr>
<tr>
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<td>--------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>CQESTR</td>
<td></td>
<td>Process-based carbon sequestration model based on the balance of organic C added to soil and C lost to microbial oxidation. Aims to simulate the effect of agricultural management practices on short and long term trends of SOM to aid prediction and planning.</td>
<td>USDA ARS; (2001)</td>
<td>U.S</td>
<td>Field level applications for croplands</td>
<td>Model is described in (Rickman et al., 2001)</td>
</tr>
<tr>
<td>DairyGEM (development of DairyGHG)</td>
<td></td>
<td>Combination of process-based models, LCA and use of emission factors into a software tool that includes the GHG emission model of DairyGHG and adds further models for predicting ammonia and hydrogen sulphide emissions from manure.</td>
<td>USDA ARS; (2011)</td>
<td>U.S</td>
<td>Farm level for several livestock based systems including feed production (grain and grassland)</td>
<td>Freely available for download via the website: <a href="http://www.ars.usda.gov/Main/docs.htm?docid=21346">http://www.ars.usda.gov/Main/docs.htm?docid=21346</a></td>
</tr>
<tr>
<td>RSB biofuels GHG calculator</td>
<td></td>
<td>Lifecycle GHG calculator for biofuels to demonstrate GHG savings compared to fossil-fuel energy equivalents. Includes a module following the EU RED.</td>
<td>RSB with the Swiss Federal Institute for Materials Testing (EMPA), Quantis &amp; HTW Berlin; (2009)</td>
<td>Global</td>
<td>All biofuel feedstocks including soybeans, wood, wheat straw, waste wood, tallow.</td>
<td>Freely available via the website: <a href="http://rsb.org/activities-and-projects/greenhouse-gas-calculation/">http://rsb.org/activities-and-projects/greenhouse-gas-calculation/</a></td>
</tr>
</tbody>
</table>
4.4 Use of GHG calculators

Despite the large number of agricultural GHG calculators that have been developed, published examples of their use, and evidence of the influence they can have to improve GHG management and mitigation in practice, is limited. Some examples where GHG calculators have been applied or are beginning to play a key role include:

- Biofuel legislation – biofuels certified under the EU Renewable Energy Directive (2009/28/EC) must demonstrate a 35% GHG reduction compared to fossil fuels which increases to 50% in 2017 and 60% by 2018 (EU RED; UK, Renewable Transport Fuel Obligation (RFTO)). This must be demonstrated using an approved Biofuel GHG calculator to quantify the GHG emissions for the cultivation of the biofuel crops, the fuel processing and its transportation (e.g. Biograce; RSB calculator).

- Third party certification of agricultural materials – the Bonsucro scheme for sugarcane and RSPO’s certification scheme for palm oil have each developed and require the use of a GHG calculator as part of their principles and criteria for certification (e.g. Bonsucro calculator within Bonsucro certification and PalmGHG within RSPO certification) and to demonstrate continuous improvement.

- Industry sourcing activities/certification – Unilever’s self-verification certification scheme (the UL SAC), prescribes the use of the Cool Farm Tool GHG calculator as part of the crop and supplier assessment.

- Supply chain management – PepsiCo have been using the Cool Farm Tool to measure progress against their GHG commitment to ‘50 in 5’ to reduce GHG emissions by 50% over 5 years (PepsiCo, 2010) and to develop farm management plans for their potato growers.

4.5 How do GHG calculators compare?

There have been a limited number of studies comparing farm GHG calculators, those conducted, however, have used a variety of comparison approaches and focusing on distinctive aspects of the construct and use of the calculators. Studies focused on:

- Identifying which tool would be most suitable for use by farmers in a particular country (Laurence Gould Partnership & Best Foot Forward, 2010).

- Providing guidance on the decision process for how to choose the most appropriate tool for a particular use (Colomb et al., 2013, 2012).

- Ranking tools designed for certain crop types based on specified criteria including comparing the results produced for a particular crop (Whittaker et al., 2013).

- Comparing two biofuel GHG calculators designed under the same methodology specified under the Directive 2009/28/EC on the promotion of the use of energy from renewable
• Understanding which calculator is the most appropriate option for GHG calculation and mitigation based on the user experience and results generated by a single user (Harper Adams, 2011).
• Providing an overview of several of the GHG accounting tools for agriculture and forestry, describing their purpose, general methodology as well as their targeted user group (if applicable) and any applications of the tool (Denef et al., 2012).
• Classifying and benchmarking GHG quantification tools, including standard and guidance documents and protocols (see Chapter 2) based on the tool type and sub-type defined to identify which are appropriate as carbon market access mechanisms (Driver et al., 2010).

The above studies provide some insights on the differences between calculators in regards to their intended use, their user-friendliness, the transparency of the data sources and calculation methods employed, the differences in farm boundary defined, their scope (global, regional or local), and the different coverage of GHG emission sources included. In some cases the authors have also provided guidance on selection of the appropriate a GHG calculator to use given a particular context and purpose. However, few studies have systematically assessed GHG calculators in terms of the consistency of the models and the level of transparency and supporting documentation. These two factors are critical if the results from different GHG calculators are used for assessments outside of their current scope such as scope 3 GHG reporting by companies with mixed agri-supply chains or if multi-crop assessments are used for landscape level initiatives. To understand the implications of the use of farm GHG calculator data for such purposes requires a more detailed and systematic analysis of farm calculators than is currently available. Therefore, research was undertaken on three GHG calculators based on two paired comparisons and this is described in the following sections. It is based on work published in Keller et al., (2014) and Clift et al., (2014).

4.6 GHG calculators: Paired comparisons of the Cool Farm Tool with Bonsucro (sugar cane) and with PalmGHG (palm oil)

The CFT, a globally applicable multi-crop tool is compared against PalmGHG that is specific to the assessment of palm oil production and against the Bonsucro calculator that is specific to sugarcane production. The goals of the comparison are to:

1. Assess the consistency of the model structure, functionality and data used as part of the architecture of the calculators and highlight differences between them.
2. To perform a paired comparison between CFT and the relevant crop specific calculator to identify/quantify differences in their respective GHG assessments.
These three calculators were selected because of their wide-scale use in current supply chains or likely future adoption. The CFT can be applied to many different crops and is supported by a number of major food and retail companies and certification schemes, including Unilever’s Sustainable Agriculture Code and pilot tests with Coffee and Soy (Y. Faber, personal communication, November 10, 2013). Bonsucro and PalmGHG have been developed to support two globally important commodity crops (OECD and FAO, 2011) and certification schemes. In addition, the three calculators are being used within Unilever’s supply chain and the results will be incorporated into scope 3 reporting and footprinting activities. Finally the three tools may all be used in regions where the development of landscape initiatives is anticipated.

The following section provides a description of the agricultural practices typical of palm oil and sugar cane and the three GHG calculators.

4.6.1 The three calculators for comparison

The three calculators are designed to generate a GHG footprint for the cultivation of an agricultural material (up to the farm gate) as well as primary processing i.e. conversion of the agricultural material into a finished product or products. For the comparative assessment the modelling of primary processing was excluded as it generally occurs off-site. The three calculators are currently available in Microsoft excel but efforts are underway to develop online versions of the CFT and PalmGHG (at the time of writing). Each calculator requires the user to input information to characterise their farm practices and they include the option to model GHG emissions from direct land use change (LUC). Background to the three calculators is described below a comparison of them is presented in Table 14.

4.6.1.1 The Cool Farm Tool (CFT)

The Cool Farm Tool was developed in collaboration between Unilever, the University of Aberdeen and the Sustainable Food Lab. The original version was produced in 2010 and the model is described in Hillier et al., (2011). It was intended to be a ‘farmer-friendly’ way to help the farmers in Unilever’s supply chain to understand the GHG impacts of their farm management practices and to provide decision support in helping them to mitigate these emissions. At the same time, the CFT was intended to help Unilever to gather data and understand the GHG impacts of their agri-food supply chain. To be ‘farmer friendly’ the CFT was designed to utilise on-farm activity information that was familiar to the farmer or that could be easily ascertained whilst in the field. It was designed to enable a farmer to input information specific to their own farm system and to be able to manipulate the data entry for scenario analysis where they can begin to ask ‘what if’ questions and gain insight into the potential emissions reductions that can result from management practice changes (Keller et al., 2011). Given the diversity of agricultural materials in Unilever’s supply chain, the CFT was designed

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23 See www.coolfarmtool.org
for a wide range of farming systems, globally. The tool was therefore constrained, in part, by the need to provide a simple yet comprehensive GHG footprint for a specific farm, whilst remaining generic across crops, livestock and geographies (Keller et al., 2011b). The global applicability of the CFT has been a strong selling point of the tool and has led to the adoption of the CFT in several supply chains by a variety of industry players to assess the GHG footprint of different agricultural materials across different countries. It has also led to the development of a dedicated alliance to house, develop, promote and deploy the tool, the Cool Farm Alliance (CFA).24

The CFT utilises both numerical data input fields as well as a range of pre-defined drop-down menu options. Some default data inputs are also pre-set within the tool for certain activities where the farmer may be unsure; these can be over-written if more precise information is known. For example, a default crop residue quantity is provided based on the crop type, yield and location specified.

The CFT also includes some features designed to aid farmers in data entry. For example, GHG emissions from energy use can be modelled as a function of machinery operations for various cropping practices. The user can select the ‘number of operations’ of a particular piece of equipment used in a certain management activity, e.g. a chisel plough used for tillage practices, and the CFT will provide an estimate of the fuel quantity used dependent on soil type and crop yield where relevant. The default fuel use for a range of operations are derived from a simplified model developed from ASABE technical standards (ASABE, 2006a, 2006b). This functionality may be useful to users who are unable to ascertain their various energy records but know the details of the farm machinery used; it is likely to be more useful in a European farming context where high levels of mechanisation are present (Cole & Cole, 1997).

4.6.1.2 The Bonsucro calculator

The Bonsucro GHG calculator was designed specifically for the quantification of GHG emissions from sugarcane, sugar and ethanol production and is used to assess compliance with criterion 3.2 of the Bonsucro Production Standard (Bonsucro, 2011). The calculator was developed by Dr. P Rein at Louisiana State University using supporting life cycle information for the sugarcane industry (Macedo et al., 2008; Wang et al., 2008). It is intended to help users to identify GHG hotspots and design effective mitigation strategies to ensure their emissions do not exceed the GHG threshold set by the standard. It was originally designed to be used by operators of sugarcane mills and their supply base whereby data from multiple farms are collated to provide an aggregated emission estimate per mill. The underlying data used in the tool calculations is presented at the point of data entry, making the

24 The Cool Farm Alliance or CFA was formed by a coalition founding companies who believed in the need and use of the CFT as an easy to use GHG calculator to help farmers to reduce their emissions. The alliance was set up to build on the development of the original CFT and to foster a platform for information sharing and collaboration. It now (at the time of writing) has 9 founding partners and 20 member organisations. More information can be seen at www.coolfarmtool.org.
tool highly transparent in the calculations performed. It is not always entirely clear, however, where the data values have been sourced from.

Bonsucro requires numerical data inputs specified by the user. Some defaults are provided by the tool based on literature values (Macedo et al., 2008; Wang et al., 2008) if the user is unsure. Bonsucro is not yet publicly available (at the time of writing) and can only be accessed through the Bonsucro certification process.

4.6.1.3 PalmGHG

PalmGHG is specifically for the assessment of palm oil production systems. It is an evolution of the GWAPP model (Global Warming Assessment of Palm oil Production) created by Chase & Henson, (2010), which was further developed by members of GHG Working Group 2 of the RSPO (Chase et al., 2012; Bessou et al., 2014b). PalmGHG was developed specifically to quantify the net GHG emissions allowing for carbon sequestration, for individual palm oil mills and their supply base. Like Bonsucro, PalmGHG enables GHG emissions to be calculated based on an aggregation of several plantations including out-growers, or smallholder farmers (typically farms less than a few ha in size) that are associated with one mill. The tool is intended to inform management decisions to help to reduce GHG emissions. In addition, PalmGHG may be used to monitor and report progress in GHG reduction. Like the other two tools, PalmGHG requires numerical data inputs. Some default data entries are also provided based on common practices and literature sources (Chase et al., 2012).

An overview summary of the three tools and the GHG emission sources they include is provided below in Table 14.

Table 14: Summary of the three GHG calculators for comparison and the GHG sources they include.

<table>
<thead>
<tr>
<th></th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cool Farm Tool</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Open access – available online for download</td>
</tr>
<tr>
<td>Applicability</td>
<td>Multi-crop; globally relevant</td>
</tr>
<tr>
<td>GHGs considered</td>
<td>CO₂, CH₄, N₂O</td>
</tr>
<tr>
<td>Units of measurement</td>
<td>Whole farm, on-site activities</td>
</tr>
<tr>
<td></td>
<td>Per unit production (kg CO₂e/tonne crop) or per land area (kg CO₂e/ha)</td>
</tr>
<tr>
<td>Allocation method(s) employed</td>
<td>Economic allocation of co-products, details specified by the user</td>
</tr>
<tr>
<td>Current usage</td>
<td>Several examples of use within supply chain companies and other wider initiatives to engage with and collect data from farms</td>
</tr>
</tbody>
</table>

### GHG Emission sources included

<table>
<thead>
<tr>
<th>Source of Emission</th>
<th>Tool A</th>
<th>Tool B</th>
<th>Tool C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser production</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Transport of fertilisers to farm</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>(Direct fertiliser emissions) Soil N(_2)O emissions from fertiliser application</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Indirect N(_2)O from soils from fertiliser application</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Pesticide production <em>(includes herbicides, fungicides, insecticides etc.)</em></td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Fossil fuel</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Electricity</td>
<td>Y</td>
<td>Y</td>
<td>N (considered in the mill phase only)</td>
</tr>
<tr>
<td>Renewable energy generation</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Crop/mill residues</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>NR</td>
<td>Y (C and N related emissions due to peat oxidation; not included for mineral soils)</td>
</tr>
<tr>
<td>-----------------------</td>
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<td>----</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Enteric CH₄</td>
<td>Y</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Manure CH₄</td>
<td>Y</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td>Biomass burning</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Change in soil C stock from direct LUC</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Change in biomass C stock from direct LUC (sequestration in above and below ground biomass)</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Indirect LUC</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Peat soils</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Soil C changes due to management changes (tillage, composts etc.)</td>
<td>Y</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Transport of workers/materials on farm</td>
<td>Y</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

*Y = Yes it is included; N = No it is not included; NR = it is not relevant to the crop specific system and is therefore not included.

¹ = Emission sources from processing may be included in the calculator but are not demonstrated in the scope of this assessment.
4.6.2 *The sugar cane and palm oil agricultural production systems*

The two crop systems that were compared, sugarcane and palm oil, are briefly described in the following sections respectively (4.6.2.1 and 4.6.2.2).

4.6.2.1 *Sugarcane cultivation*

Sugarcane is grown in nearly all tropical and sub-tropical regions of the world occupying an area of approximately 26 million hectares (ha) across more than 90 countries with a total global production of over 1.83 billion tonnes (FAO, 2012). Brazil is, by far, the largest sugarcane producing country, accounting for approximately 35% of global production and occupying about 2.5% of Brazil’s arable land. Sugarcane is an important commodity crop constituting around 80% of the global demand for sugar, the rest being met by sugar beet crops. Sugarcane production also produces useful and valuable by-products including, and increasingly, biofuel materials (Boddey, 1995; Goldemberg, 2008); fibre; fertilizer (sugarcane straw can be used as mulch and other by-products from the processing of sugarcane can be used as organic fertilisers i.e. filter cake and vinasse); bagasse used as a biofuel in the paper and building industries; and sugarcane molasses which are a key raw material for alcohol production.

The sugarcane crop cycle lasts for on average between 5 and 6 years before the crop requires replanting. The sugarcane variety planted is usually selected based on the specific soil properties and climate conditions of the growing area in order to maximise productivity and resistance to pests and disease. Use of synthetic fertilizer is often limited as sugarcane systems can make use of the crop and mill-processing residues (which are often analysed for nutrient contents to ensure efficient use). Additionally, use of biological control through the introduction of natural pest enemies is common, particularly in Brazil, thereby reducing the requirement for chemical pesticides. Traditionally the sugarcane crop was burnt before harvest to remove the excess foliage to increase accessibility and also to remove hazards such as snakes and other poisonous animals. Mechanisation, however, is becoming increasingly common, particularly in Brazil, which eliminates the need to burn the cane and enables the straw to be left on the field as mulch, thereby re-introducing nutrients to the soil and protecting it from erosion. Manual harvesting is being phased out in several growing regions due to rising concerns over associated environmental and health issues (i.e. GHG emissions from sugarcane combustion and air pollution leading to respiratory conditions and increased incidence of lung cancers (Ribeiro, 2008), respectively). An agreement signed in 2007 between the sugarcane industry and the Sao Paulo state government for example, will see an end to manual harvesting in the state by 2017 (Unica, no date). Additionally, for an increasing number of mills, some of the straw that remains through mechanised harvesting, is beginning to be removed and used for bio-energy and in time may also be used for second generation biofuels (Kim and Dale, 2004). Figure 18 demonstrates the activities and inputs required in sugarcane cultivation including the pre-farm activities, land preparation and cultivation.
4.6.2.2 Palm oil cultivation

Palm oil is a versatile edible vegetable oil that can be used as an ingredient within both food and non-food products. Global demand for edible oils has increased in the past decade and as one of the most high yielding and efficient oil crops (palm oil requires nearly a tenth of the land area of other oil-producing crops (GreenPalm, no date; Nilsson et al., 2010)); palm oil production has expanded rapidly to meet this demand. In 2008 global palm oil production was about 48 million tonnes or 30% of the total oil and fats production (Oil World, 2013). Palm oil trees grow in the tropics, across parts of Asia, Africa and South America. Malaysia and Indonesia are the two largest producers of palm oil, together they account for up to 85% of palm oil production globally (GreenPalm, no date). The two main species of palm oil tree are *Elaeis guineensis*, native to Western Africa and *Elaeis oleifera* which is native to Central and South America, yet the former is most frequently grown.

Palm oil seedlings are cultivated in a nursery until they are ready to be planted into the field. Land preparation, ahead of planting, may involve removing the tree stumps of the previous plantation trees or other previous land uses (which can include forest in some cases). Fertilisers and some pesticides are required to nurture the young oil palms. Oil palm trees have a life span typically between 25 – 30 years, and they start producing fresh fruit bunches from three years of age. The oil is obtained from the palm fruit of the oil palm tree, each fruit containing about 50% oil. In a productive year each palm tree can produce between 8 and 12 bunches of fruit, each bunch containing between 1000 and 3000 individual fruit, particularly in the higher yielding production
areas of South-East Asia. Yields are highest between the 6th and 20th years of cultivation before a decline in productivity is observed. Palm trees typically grow up to about 20m tall and a well-managed plantation will plant approximately 142 trees per hectare on average (Liedke et al., 2013). As a tree crop, there is therefore, some carbon sequestration that occurs in the palm tree biomass over their lifetime. Palm trees are usually cleared after 25-30 years due to yield decline but also because the trees grow to a height at which (manual) harvesting becomes challenging and because a proportion of the trees begin to die e.g. through lightning strikes. Palm oil plantations are typically located in tropical regions and may also be grown on peat soils despite peat soils not usually as high yielding and present risks of subsidence etc.

Figure 19 presents and summarises the key stages for palm oil cultivation and shows the main inputs to the system to produce the palm oil fruit products.

![Figure 19: Palm oil cultivation activities and GHG related input requirements at each stage.](image)

**4.6.3 Methodology for comparison**

To explore the differences between the Cool Farm Tool (CFT) and the two crop-specific calculators and to provide increased transparency on the underlying workings of the tools, two types of comparative assessment were conducted. The first was a detailed assessment into the underlying data sources, models and methodologies used within the tools for three important categories of GHG drivers: agrochemical inputs, energy, and land use and land use change (LULUC). The second
The type of assessment conducted was an ‘output based assessment’ to compare the consistency of the results produced by the calculators given the same crop input data, explicitly comparing the two crop specific tools with the CFT. The system boundary for the assessment and the two types of comparative assessment are described further in the following sections.

4.6.3.1 System boundary for the assessment

The comparison of the three tools focused on GHG assessment up to and including the harvesting of the crop (i.e. to farm gate). It excluded any subsequent steps such as drying, storage, processing and milling. Consequently, the comparison did not include any allocation of emissions to any co-products that might be produced and it modelled the emissions for production of the primary crop only. Also omitted from the assessment were some of the GHG emission sources that remain uncertain and too complex to model or are not yet modelled by the tools (Plevin et al., 2010; Melillo et al., 2009; Searchinger et al., 2008; Al-Kaisi & Yin, 2005). This includes any embedded emissions associated with infrastructure or capital machinery (BSI, 2011) and emissions from indirect land use change (iLUC). Furthermore, as well as the GHG emissions emitted from crop production, there is also some carbon sequestration that occurs within the crop biomass, however, this GHG emission sink was omitted from the assessment due to lack of accurate data to model it. Consequently some of the functionalities of the tools are not utilised in the assessment and thus are not compared (in the output based assessment specifically).

Figure 18a and b present schematics of the GHG emission sources included in the assessment of the sugarcane and palm oil systems respectively. The results are presented on a per land area basis (kg CO\textsubscript{2}e per hectare (ha) cultivated).
Figure 20: Schematics of the GHG emission sources included and excluded from this study assessment for sugarcane (a) and for palm oil (b) systems.
4.6.3.2 Assessment of GHG drivers

The assessment of GHG drivers aims to provide increased transparency of the underlying components of the calculators including the underlying data sources, models, activity data requirements and methodological approaches employed. The assessment focuses on the three categories of GHG drivers that are relevant to the two crop systems. The three categories of GHG emissions are: 1) agrochemical inputs including organic materials, 2) energy use, and 3) land use and land use change. These three categories of GHG drivers were selected because they contribute the majority of most plant-based agricultural GHG emissions (Roches et al., 2010; Hillier et al., 2009; Smith et al., 2007) and because they represent significant potential for increased efficiencies and mitigation activities by producers. The assessment was performed by conducting an in-depth review of the calculator spreadsheets, the background calculations and embedded data sources and the supporting documentation available (as indicated in Table 14). The 3 categories of GHG drivers are described briefly in the following sub-sections.

4.6.3.2.1 GHG Driver 1: Agrochemical inputs

Figure 18 and Figure 19 show the agricultural activities involved in the sugarcane and palm oil production systems, respectively, and indicate some of the key agrochemical inputs. In sugarcane cultivation these include mineral fertilisers, crop protection chemicals (CPCs) or pesticides, and crop residues. Crop residues include extraneous matter, which is all the other plant material following harvesting that is left on or returned to the field such as leaves and stalks; filter cake (rich in phosphorus) which is the residue from cane juice filtration, a by-product of sugar production in the mill; mud; and vinasse (high in potassium), another by-product of the mill. Use of these residues and by-products enables the recycling of carbon and other mineral elements which contribute to the conservation of resources (Prado et al., 2013). In palm oil production it includes mineral fertilisers and pesticides, as well as organic inputs; the empty fruit bunches (EFB) that are returned to the field from the mill after fruit extraction; and palm oil mill effluent (POME), an organic waste material generated from palm oil processing (approximately 0.5-0.75 tonnes for every tonne of fresh fruit bunch (FFB) (Yacob et al., 2005)).

In most agricultural systems mineral fertilisers are a significant contributor to the overall GHG footprint (Hillier et al., 2009; Johnson et al., 2007). GHG emissions arise from the high energy demands involved in their production (particularly in the case of N fertilisers derived from the Haber process); their transportation, often over large distances, from the source to the farm; and most importantly N₂O emissions associated with the use of N fertilisers. N₂O emissions occur, as a consequence of the biophysical interactions and microbial processes in the soil, both directly, at the time of application, and indirectly, after application, from the transport of reactive N compounds into ground and surface waters through leaching and surface runoff. Nitrogen may also be emitted as ammonia (NH₃) or as nitrogen oxides (NOx) (IPCC, 2006a). Nitrogen application in sugarcane
production systems is usually in the form of ammonium nitrate (AN) or urea. There is some evidence to suggest that AN promotes more intense and faster N₂O emissions than urea, and that urea could reduce the activity of N₂O producing organisms in the soil (Signor et al., 2013). On mineral soils, N₂O emissions from fertiliser use in palm oil cultivation are second only to GHG emissions from land use change (Chase & Henson, 2010) and they are also an important contributor in sugarcane production (Rein, 2011).

Other agrochemical inputs, particularly relevant to sugarcane production, include lime which is often applied as a soil enhancer or stabiliser. Estimates of GHG emissions from the application of lime are very uncertain (Graboski, 2002) and lime addition can result in an uptake of CO₂ depending on soil conditions and the application of other fertilisers (West & McBride, 2005). GHG emissions from pesticides occur during their production (i.e. from energy use) and, in many agricultural systems, they represent only a small fraction of the overall GHG footprint (Hillier et al., 2009). For the agricultural inputs, the key parameters that will influence the calculators’ results are therefore; the data sources and assumptions describing fertiliser production and the models applied for N₂O emissions.

4.6.3.2.2 GHG Driver 2: Energy

Energy is required for the transport of materials and workers around the farm, for the general operation of site infrastructure, as well as for farm operations such as irrigation and land preparation e.g. tillage practices, cultivation and harvesting operations. The type of energy source(s) used on a farm site depends upon the location, activity type and level of mechanisation on-farm. The primary fuel used in many Brazilian sugarcane and Indonesian palm oil systems is diesel, used in transport vehicles and machine operations. Grid electricity may also be utilised for various infrastructure functions and irrigation and country or regional specific energy mixes will determine the associated GHG burden from electricity.

4.6.3.2.3 GHG Driver 3: Land Use and Land Use Change (LULUC)

As described in Chapter 2, Land use change (LUC) involves the conversion of one land use type e.g. from forest to agricultural land. It can be a significant source of GHG emissions and often dominates the GHG footprint of production systems due to substantial changes in carbon stocks (Searchinger et al., 2008; Fargione et al., 2008; Cederberg et al., 2011). This is particularly true in tropical areas where deforestation occurs to make way for monoculture plantations such as sugarcane and palm oil. LUC remains a topic of scientific debate due to several associated uncertainties in the calculation of carbon stock changes from soils and biomass and the amortisation of emissions over time. LUC

26 The idea of amortisation in financial accounting is the routine decrease in value of an intangible asset over time or the spreading of the cost of an asset of the period of its ‘useful life’. In this context, of GHG emissions from land use/land use change, amortisation is the spreading of the emissions burden over a (fixed) time
GHG emissions are typically based upon IPCC LUC classifications and default factors (IPCC, 2006). Differences in the consideration and treatment of the various carbon stocks including; biomass, both above and below-ground; dead organic matter contained in dead wood and leaf litter; soil organic matter contents including high carbon stock soils such as peat soil; as well as the amortisation period modelled, can influence the GHG emission results from LUC generated by the calculators (see e.g. Flynn et al., 2012). Moreover, despite some agreements on the accounting of provisional biogenic carbon storage notably in perennial crops (IPCC, 2006; BSI, 2011), the debate is still ongoing.

Pre-harvest burning is a practice common in sugarcane cultivation (see Figure 18) and it can be a significant contribution of the GHG emissions (De Figueiredo & La Scala, 2011).

GHG emissions from peat soils are particularly important for palm oil production due to the prevalence of peat soils in some areas where palm oil is grown. Emissions arise from the preparation of the peatland during clearing the land and draining and from the continuing emissions resulting from cultivation on peat i.e. from oxidative peat decomposition (Fargione et al., 2008; Germer & Sauerborn, 2008). The scale of the on-going emissions are influenced by the management practices of the land and of the water table, specifically the depth of the water table and the aerobic layer (Moore & Knowles, 1989).

4.6.3.3 Output based assessment

For the second type of assessment of the calculators two datasets were entered into the tools to compare the results generated. One dataset for sugarcane production in Brazil (described by Bonsucro) was entered into the CFT and Bonsucro and a second dataset for palm oil cultivation in Indonesia (described by PalmGHG) into the CFT and PalmGHG. The datasets for the two crops were provided by the sugarcane and palm oil commodity roundtables (Bonsucro and RSPO, respectively) (N. Viart, 2012; M. Chin, 2013) unless otherwise specified and they are summarised in Table 15 and Table 16. They are representative of farms within the specific crop system but not of the whole sector. The data in Table 15 and Table 16 represent the ‘base case’ data used for the primary comparison of the calculators. Additional analyses were performed to model different farm scenarios and to assess the influence of some of the different user options available in the calculators on the GHG emission results.

horizon so that emissions from this activity will be spread over multiple accounting years/inventories. There are different approaches to do this each with a number of assumptions (see Russell, (2011) for more). The default amortisation time period for carbon stocks to reach a steady state is 20 years, though in reality reaching steady state is dependent on a number of variables. Some implications of different amortisation approaches/time periods are explored in section 4.6.4.2.
Differences in data input requirements and the formats of the calculators make direct comparison of the results difficult and in some cases directly equivalent data inputs were not possible. For example, the CFT requires the specification of the soil properties whereas this information is not required for the Bonsucro calculator or PalmGHG. Also some minor amendments to the underlying formulae and algorithms in the calculators were made in order to render the calculations more directly comparable. For example, the amortisation period for land use change emissions was standardised for the calculators for each crop system. Furthermore some small adaptations to the Bonsucro calculator and PalmGHG were necessary to calculate the agricultural phase emissions only and to exclude emissions arising from processing or milling operations. Amendments or adjustments made to the tools to harmonise and align the calculations for the purpose of comparison are summarised in Table 17.

To facilitate the comparative assessment the results from the calculators were extracted from the calculator spreadsheets and recorded separately in a summary spreadsheet. For some calculations it was necessary to extract results from several output spreadsheets. This was particularly the case for the CFT, for which slight differences in background farm characteristics specified could result in very different emission estimates, given all other inputs remaining constant. It was in these instances that some scenario analysis was performed to explore the range of possible outputs (see the results section).

Table 15: Input data for sugarcane assessment (base case).

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Input</th>
<th>Data entry/quantity</th>
<th>Units</th>
<th>Source/reference</th>
<th>Tool(s) using the data</th>
</tr>
</thead>
<tbody>
<tr>
<td>General information</td>
<td>Crop type</td>
<td>Millet (proxy)²⁷</td>
<td></td>
<td>Closest representation to sugarcane as an option in the CFT</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Country</td>
<td>Brazil</td>
<td></td>
<td>Specified by N. Viart, personal communication (2012)</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>1700372</td>
<td>Tonnes</td>
<td></td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Production area</td>
<td>27231</td>
<td>Ha</td>
<td></td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>Tropical: annual average temperature = 18 °C</td>
<td></td>
<td></td>
<td>CFT</td>
</tr>
</tbody>
</table>

²⁷ Sugarcane was modelled as millet in the Cool Farm Tool because there is no option for sugarcane but it acts as a next best proxy as they are both grasses.
<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Soil type</th>
<th>Soil organic matter content</th>
<th>Specified by N. Viart, personal communication (2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medium</td>
<td>1.72 &lt; SOM &lt;= 5.16</td>
<td></td>
</tr>
<tr>
<td>Soil moisture</td>
<td>Dry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil drainage</td>
<td>Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil pH</td>
<td>&lt;= 5.5</td>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>Fertilisers applied</td>
<td>Nitrogen (N) [as urea in CFT]</td>
<td>65.7 kg/ha</td>
<td>Specified by N. Viart, personal communication (2012)</td>
</tr>
<tr>
<td></td>
<td>Phosphorus (P) [as triple super phosphate in CFT]</td>
<td>39.5 kg/ha</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Potassium (K) [as potassium sulphate in CFT]</td>
<td>65.9 kg/ha</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Lime [as limestone in CFT]</td>
<td>236.7 kg/ha</td>
<td>Both</td>
</tr>
<tr>
<td>Fertiliser related information</td>
<td>Fertiliser application method</td>
<td>Incorporate</td>
<td>CFT</td>
</tr>
<tr>
<td></td>
<td>Emissions inhibitors in fertilisers</td>
<td>None</td>
<td>CFT</td>
</tr>
<tr>
<td></td>
<td>Fertiliser production technology</td>
<td>Current technology</td>
<td>CFT</td>
</tr>
<tr>
<td>Organic inputs</td>
<td>Filter cake [as zero compost emissions in CFT]</td>
<td>3400 kg/ha</td>
<td>Both</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Herbicide</td>
<td>3.96 kg/ha</td>
<td>Specified by Viart, N (2012)</td>
</tr>
<tr>
<td></td>
<td>Insecticide</td>
<td>0.71 kg/ha</td>
<td>Bonsucro</td>
</tr>
<tr>
<td></td>
<td>Number of applications</td>
<td>4 Applicati ons/ yr.</td>
<td>CFT</td>
</tr>
<tr>
<td>Energy use</td>
<td>Gasoline</td>
<td>100 l/ha</td>
<td>Authors’ assumptions</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>7212659 litres per ha (264.87 litres per ha)</td>
<td>Specified by Viart, N (2012)</td>
</tr>
<tr>
<td></td>
<td>Natural Gas</td>
<td>50 kWh/ha</td>
<td>Authors’ assumptions</td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>90 kWh/ha</td>
<td>Both</td>
</tr>
<tr>
<td>Crop residue</td>
<td>Extraneous matter quantity</td>
<td>3126 Kg/ha</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>Left on field; incorporated or mulch</td>
<td>Specified by Viart, N (2012)</td>
</tr>
<tr>
<td>Land clearing</td>
<td>Sugarcane burnt</td>
<td>48.05 % of crop</td>
<td>Bonsucro</td>
</tr>
<tr>
<td>Land use change Scenarios modelled</td>
<td>Forest to arable cropland</td>
<td>%</td>
<td>Authors’ assumptions for comparison purposes only</td>
</tr>
<tr>
<td></td>
<td>Forest to perennial cropland</td>
<td>100% land conversion</td>
<td>Bonsucro</td>
</tr>
<tr>
<td></td>
<td>Forest to grassland</td>
<td></td>
<td>CFT</td>
</tr>
</tbody>
</table>
### Table 16: Input data for palm oil assessment (base case).

<table>
<thead>
<tr>
<th>Information Category</th>
<th>Input</th>
<th>Data entry / quantity</th>
<th>Units</th>
<th>Source / reference</th>
<th>Tool(s) using the data</th>
</tr>
</thead>
<tbody>
<tr>
<td>General information</td>
<td>Crop type</td>
<td>Tree crop</td>
<td></td>
<td>Closest representation to palm oil as an option in the CFT.</td>
<td>CFT</td>
</tr>
<tr>
<td></td>
<td>Country</td>
<td>Indonesia</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>195333 tonnes</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Production area</td>
<td>6822 ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Climate</td>
<td>Tropical: annual average temperature = 18 °C</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td>Mineral soil properties</td>
<td>Soil type</td>
<td>Fine</td>
<td></td>
<td>Specified by M. Chin, (2012).</td>
<td>CFT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mineral soil</td>
<td></td>
<td>PalmGHG</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil organic matter content</td>
<td>1.72 &lt; SOM &lt;= 5.16 %</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil moisture</td>
<td>Moist</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil drainage</td>
<td>Good</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil pH</td>
<td>&lt;=5.5 pH</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td>Peat soil properties</td>
<td>Soil type</td>
<td>Fine soil</td>
<td></td>
<td>CFT</td>
<td>PalmGHG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Peat soil</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil organic matter content</td>
<td>10.32 &lt; SOM</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil moisture</td>
<td>Moist</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil drainage</td>
<td>Poor</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil pH</td>
<td>&lt;=5.5 pH</td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water table</td>
<td>Actively managed</td>
<td>Y/N</td>
<td>(Defaults: not actively managed = 80cm; actively managed = 60cm) RSPO PLWG 2012</td>
<td>PalmGHG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Depth of water table</td>
<td>cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilisers applied</td>
<td>Ammonium nitrate</td>
<td>80 kg/ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Urea</td>
<td>20 kg/ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Kierserite</td>
<td>70 kg/ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Murate of Potash</td>
<td>200 kg/ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Triple super-phosphate</td>
<td>70 kg/ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Ammonium sulphate</td>
<td>80 kg/ha</td>
<td></td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>Organic</td>
<td>Fresh Fruit Bunches (FFB)</td>
<td>0.22</td>
<td>Specified by M. Chin, (2012).</td>
<td>Both</td>
</tr>
<tr>
<td>inputs</td>
<td>Palm Oil Mill Effluent (POME)</td>
<td>0.5</td>
<td>t/tFFB</td>
<td>Both</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>-----</td>
<td>--------</td>
<td>-----------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Pesticides</strong></td>
<td>Number of applications</td>
<td>3</td>
<td></td>
<td>I. Henson, personal communication May 2013</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Applications per year</td>
<td></td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td><strong>Energy use</strong></td>
<td>Diesel</td>
<td>388333</td>
<td>65.924</td>
<td>Specified by M. Chin, (2012)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Litres per year</td>
<td></td>
<td></td>
<td>Both</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Litres per ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Crop residue</strong></td>
<td>Frond piles and plantation litter (residue)</td>
<td>8.54</td>
<td>t biomass/ha</td>
<td>I. Henson, personal communication May 2013</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td><strong>Land use change Scenarios modelled</strong></td>
<td>Forest to plantation</td>
<td>100% land conversion</td>
<td>%</td>
<td>Authors’ assumptions for comparison purposes only.</td>
<td>PalmGHG</td>
</tr>
<tr>
<td></td>
<td>Forest to arable cropland</td>
<td></td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forest to grassland</td>
<td></td>
<td></td>
<td>CFT</td>
<td></td>
</tr>
</tbody>
</table>

Table 17: Assumptions and edits made to the tools in the comparison.

<table>
<thead>
<tr>
<th>GHG Source (crop system)</th>
<th>Issue</th>
<th>Tool</th>
<th>Assumption and justification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land Clearing (Sugarcane)</strong></td>
<td>No specific data input option for land clearing by combustion</td>
<td>CFT</td>
<td>Modeled under residue management functionality, ‘burned’. Residue quantity equated to the amount of dry matter burnt per hectare</td>
</tr>
<tr>
<td><strong>Pesticides (sugarcane)</strong></td>
<td>Quantity of different pesticide types present for Bonsucro. Unknown number of applications per year for CFT data entry</td>
<td>CFT</td>
<td>Assumed 4 applications including one application prior to planting (N. Viart, personal communication, September 2013)</td>
</tr>
<tr>
<td><strong>Residual extraneous matter (EM) (Sugarcane)</strong></td>
<td>Quantity of extraneous matter is calculated within Bonsucro but unavailable for the CFT. A calculation was performed external to the tools: KgDM/t left in field (104.25) x Yield (62.4t/ha) x Cane burnt (48.05%) = ~3126 kg/ha</td>
<td>CFT</td>
<td>Estimated 3125.75 kg/ha residue left in field/incorporated or used as mulch</td>
</tr>
<tr>
<td><strong>Transport of fertilisers (Sugarcane)</strong></td>
<td>Information on; distance of fertiliser production to farm; mode and type of</td>
<td>CFT</td>
<td>Distance: 200km Mode: Road Vehicle: heavy goods vehicle</td>
</tr>
<tr>
<td>Table Title</td>
<td>Description</td>
<td>Tool</td>
<td>Details</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Vehicle</strong></td>
<td>if (for road) it returned empty or not, unavailable.</td>
<td></td>
<td>Return: returning empty</td>
</tr>
<tr>
<td><strong>Fertiliser production technology</strong> (Sugarcane; Palm oil)</td>
<td>Unknown state of technology</td>
<td>CFT</td>
<td>Current technology (default option in CFT)</td>
</tr>
<tr>
<td><strong>Fertiliser equivalents</strong> (Palm oil)</td>
<td>The palm oil dataset includes six specific mineral fertilisers used in palm oil production systems. Some of which are not modelled (by default) within the CFT.</td>
<td>CFT</td>
<td>Where an exact match between the fertiliser featured in PalmGHG to be modelled in the CFT was not possible, the closest equivalent (based on nutrient content) was modelled. This was in the following cases: • Kieserite in Palm GHG - modelled as muriate of potash in the CFT.</td>
</tr>
<tr>
<td><strong>Amortisation of carbon stock biomass loss</strong> (Sugarcane; Palm oil)</td>
<td>GHG emissions for biomass loss are accounted for in the year they are lost and not amortised (this is based on IPCC accounting for national inventories)</td>
<td>CFT</td>
<td>A 20 year amortisation period was applied to the biomass loss GHG emissions for sugarcane. Both 20 and 25 year amortisation periods were used for the palm oil assessment</td>
</tr>
<tr>
<td><strong>EFB and POME (Palm Oil)</strong></td>
<td>No equal or closely equivalent fertilisers included in the CFT</td>
<td>CFT</td>
<td>Modelled under zero emissions compost (1% N) and cattle slurry (0.26% N) as the closest fertilisers with a low N content to reflect that of EFB and POME</td>
</tr>
<tr>
<td><strong>Farm type</strong> (Palm oil)</td>
<td>Able to model different palm oil plantation types.</td>
<td>PalmGHG</td>
<td>One plantation modelled, under ‘own crop’ functionality (no out-growers modelled), mineral soils only (no peat modelled, unless specified in the scenarios)</td>
</tr>
<tr>
<td><strong>Three year rolling average</strong> (Palm oil)</td>
<td>PalmGHG requires three years of data input and uses the average value to calculate the GHG footprint</td>
<td>PalmGHG</td>
<td>The same dataset was entered for each of the three years to ‘force’ the tool to use the 1 year data value as the average</td>
</tr>
</tbody>
</table>

### 4.6.4 Results

The following sections present the results of the GHG driver assessment, comparing the tools on their underlying methodologies, calculation approaches and data sources used, to highlight where differences may arise. Following this, the results of the output-based assessment for the general vs.
the system specific tools are presented, specifically comparing the CFT and Bonsucro for sugarcane production and the CFT and PalmGHG for palm oil production.

### 4.6.4.1 Results of GHG driver assessment

Table 18, Table 19 and Table 20 present the results of the 3 GHG driver assessments. The tables compare the three calculators directly and describe the general approach taken, some of the default values used in calculations (e.g. the emission factors (EFs) including the global warming potential (GWP) values (see Table 18)) and some of the reference sources for the underlying data.

The analysis of the calculators highlighted the following:

- **Transparency** - the calculators have differing degrees of transparency regarding the background data present in the calculator spreadsheets and in their supporting documentation. In Bonsucro much of the background data used is presented at the data entry stage although it is not always clear where the data has been sourced from. In the CFT and PalmGHG a large proportion of the underlying data and models are contained in background calculation sheets, rendering them difficult to decipher. This is more pronounced in the CFT due to its more extensive modelling options and broader coverage of different farming systems.

- **Complexity GHG emission sources** - the CFT is designed to cover a wide range of farming systems and therefore it includes a wider range of GHG emission sources and user options than the two crop specific calculators. For example, electricity, natural gas and some other energy types are not included in PalmGHG within the agricultural assessment (see Table 14), as they are not typical energy sources used in cultivation of palm oil production (electricity is included in the tool for mill operations).

- **Specificity** - the CFT requires the user to enter a number of parameters to define their system including descriptors of the climate and a number of soil properties. The CFT employs a number of extensive datasets and algorithms that will incorporate the user’s information to be able to model multiple system types. In addition, only the CFT contains the functionality to model the GHG impacts of different field management practices including different tillage intensities. Currently, Bonsucro and PalmGHG do not require specification of these parameters.

- **Relevant data** - Bonsucro and PalmGHG include a number of ‘system specific’ datasets appropriate to the sugarcane and palm oil systems, respectively, whereas the CFT includes some more general datasets (e.g. an average for pesticide production emissions) applicable to all systems modelled. Bonsucro and PalmGHG do not require specific climate or soil descriptor information; it may be that this level of data specificity is already built-in to the tools for the user as the tools are designed to be used in specific contexts.
Table 18 also shows the GWP values used by the three calculators. The version of the CFT used in this assessment (version 2.0) erroneously uses a GWP of 296 for nitrous oxide (N$_2$O) based on IPCC (2001) (TAR) whereas the original tool description (Hillier et al., 2011) references a GWP value of 298 (IPCC 2006). This may be illustrative of the challenges associated with version control of the calculators and the requirements for manual updates when developing and using Microsoft excel spreadsheet based GHG calculators.
Table 18: GHG driver 1: Agrochemical inputs.

<table>
<thead>
<tr>
<th>GHG driver 1: Agricultural inputs</th>
<th>Cool Farm Tool</th>
<th>Bonsuco</th>
<th>PalmGHG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General approach</strong></td>
<td>CFT combines several empirical models for GHG emissions from agricultural inputs including a fertiliser model based on over 800 datasets (Bouwman et al., 2002) with IPCC tier 1 inventory methods and emission factors (EFs).</td>
<td>The calculation approach is similar to and adapted from the EBAMM model (Farrell et al., 2006), which itself is similar to the GREET model (Wang et al., 2008), modified for sugarcane. The calculator uses IPCC emission factors (EFs).</td>
<td>PalmGHG is based on an earlier model, GWAPP developed by Chase and Henson (2010). It is based on a life cycle approach specific to global warming impacts. The tool uses both literature data sources and IPCC emission factors (EFs), combined with oil palm growth models to simulate C sequestration by the crop.</td>
</tr>
<tr>
<td><strong>Fertiliser production (kg CO₂e/kg)</strong></td>
<td>Fertiliser production emissions are specified for a range of fertiliser types (35 fertilisers modelled). Four options are specified for fertiliser production technology used: current, new, old, and older tech.</td>
<td>Production of N fertiliser is specified, and production and transportation of lime.</td>
<td>Fertiliser production emissions are specified for 9 synthetic fertilisers.</td>
</tr>
<tr>
<td></td>
<td>Key fertilisers modelled: (kg CO₂e/kg) Limestone: 0.006 Ammonium nitrate (35%N): 3.042 Muriate of potash (60% K₂O): 0.265 Urea (46.4% N): 2.551</td>
<td>Key fertilisers modelled: (kg CO₂e/kg) N fertiliser production: 3.99 P fertiliser production: 0.714 K fertiliser production: 1.61 Lime production and transportation: 0.065</td>
<td>Key fertilisers modelled: (kg CO₂e/kg) Ammonium nitrate (34%N): 2.380 Muriate of potash (60% K2O): 0.2 Urea (46% N): 1.34</td>
</tr>
</tbody>
</table>
### Fertiliser application, direct and indirect N\textsubscript{2}O emissions

Multivariate empirical model of Bouwman *et al.*, (2002) is used to calculate nitrous oxide (N\textsubscript{2}O) and nitric oxide (NO) emissions associated with fertiliser application. Emissions from fertiliser application differ for different types of fertilisers applied. Option for user to define own fertiliser blend using a base fertiliser.

Ref(s): Bouwman *et al.*, (2002); FAO/IFA (2001) (for ammonia).

Fertiliser application emissions differentiated between N, P, K\textsubscript{2}O and lime with specified emission factors for per kg applied.

Lime: 0.44 kg CO\textsubscript{2}e/kg lime (assumes all C in lime becomes CO\textsubscript{2})

Ref(s): IPCC (2007)

Direct and indirect fertiliser induced emissions are calculated according to IPCC Tier 1 and are differentiated between 9 widely used synthetic fertilisers in palm oil cultivation. Additional fertilisers can be included if the user requires.

Ref(s): IPCC (2006); Jenssen & Kongshaug (2003); Ecoinvent (2010); Chase & Henson (2010).

### Crop residues and organic inputs

Able to model:
- Compost: as zero emissions or aerated or non-fully aerated production.
- Slurry: from livestock types
- Straw

Residue N content dependent on crop type under assessment.
- Sugarcane (Millet): 0.7%
- Palm oil (tree crop): 0.0123%

Various residue treatment options modelled.
Assumed 1% N in residue is converted to N in N\textsubscript{2}O

Ref(s): IPCC (2006); Smith *et al.*, (1997)

Models:
- Cane residue left in field post burning: N content 0.5%
- Filter cake: N content 12.5%
- Vinassee: may be applied as a fertiliser

Assumed 1.225% of N in the residue is converted to N in N\textsubscript{2}O

Ref(s): Macedo (2008)

Models:
- Empty fruit bunces (EFB): 0.22t/t Fresh fruit bunch (FFB), N content 0.32%*
- Palm oil mill effluent (POME): 0.5t/t Fresh fruit bunch (FFB), N content 0.045%*

*N content and production rates can be modified by the user

Ref(s): Yacob *et al.*, (2005); Singh (1995)
| **N run off, leaching rate** | 30% for moist soils, none for dry  
Ref(s): IPCC (2006) | Not specified | 30%  
Ref(s): IPCC (2006) |
|-----------------------------|-------------------------------------------------|----------------|------------------|
| **CPCs (Pesticides)** | Average EF for all pesticides (based on production emissions) are included per application dose: 20.5 kg CO\(_2\)e.  
Ref(s): average generated from: Audsley (1997); Green (1987). | Insecticide EF: 29.09 kg CO\(_2\)e/kg  
Ref(s): Macedo et al., (2008) | Not included |
| Management inputs | IPCC tier 1 method is used to estimate soil C stock changes and the changes due to management practices are defined by Ogle et al., (2005). They are modelled on an annualised basis and are dependent on several farm characteristics including climate. | Not included | Not included |
| **Global warming potential (GWP) values** | N\(_2\)O: 296  
CH\(_4\): 25  
CH\(_4\): 25  
CH\(_4\): 22.25 (bio-methane e.g. from POME)  
Ref(s): IPCC AR4 (2007); Chase & Henson (2010); (Muñoz et al., 2012) |
Table 19: GHG driver 2: energy.

**GHG driver 2: Energy**

<table>
<thead>
<tr>
<th>General approach and activity data required</th>
<th>Cool Farm Tool</th>
<th>Bonsucro</th>
<th>PalmGHG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reported on a total annual consumption basis per fuel type used with the option to specify several fuel types. Alternatively/in addition, emissions arising per machine operation for various practices can be calculated based on number of operations, fuel used and other farm characteristics stated.</td>
<td>Total annual fuel use per fuel type across all agricultural activities is reported. Electricity used in irrigation is reported separately.</td>
<td>Recorded as total fuel consumption (of diesel and petrol) in one year of plantation lifetime. It includes emissions due to field operations that arise from fossil fuel consumed by machinery for transportation and other field operations.</td>
<td></td>
</tr>
</tbody>
</table>

### Fuel emission factors (EFs)

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Cool Farm Tool</th>
<th>Bonsucro</th>
<th>PalmGHG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline/petrol (kg CO(_2)e/ L of fuel)</td>
<td>2.32 (Reference(s): GHG Protocol (2003))</td>
<td>2.81 (Reference(s): Farrell <em>et al.</em>, (2006); Shapouri <em>et al.</em>, (2004); Graboski (2002); Macedo <em>et al.</em>, (2008)).</td>
<td>3.12 (Assumed as diesel) (Reference(s): JRC <em>et al.</em>, (2011))</td>
</tr>
<tr>
<td>Diesel (kg CO(_2)e/ L of fuel)</td>
<td>2.68 (Reference(s): GHG Protocol (2003))</td>
<td>3.46 (Reference(s): Farrell <em>et al.</em>, (2006); Shapouri <em>et al.</em>, (2004); Graboski (2002); Macedo <em>et al.</em>, (2008)).</td>
<td>3.12 (Reference(s): JRC <em>et al.</em>, (2011))</td>
</tr>
<tr>
<td>Fuel oil (kg CO(_2)e/ MJ)</td>
<td>0.0784 (Ref: GHG Protocol (2003))</td>
<td>0.096 (Ref: Farrell <em>et al.</em>, (2006) [EBAMM])</td>
<td>Not included</td>
</tr>
<tr>
<td>Natural gas (kg CO(_2)e/MJ)</td>
<td>0.0628 (Ref: GHG Protocol (2003))</td>
<td>0.066 (Ref: Farrell <em>et al.</em>, (2006) [EBAMM])</td>
<td>Not included</td>
</tr>
<tr>
<td>Coal (kg CO(_2)e/MJ)</td>
<td>0.0927 (Ref: GHG Protocol (2003))</td>
<td>0.107 (Ref: Farrell <em>et al.</em>, (2006) [EBAMM])</td>
<td>Not included</td>
</tr>
<tr>
<td>Topic</td>
<td>Description</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Electricity (kg CO₂e/MJ)</strong></td>
<td>Country specific values for kg CO₂e/MJ grid electricity are included in the tool. Value for Brazil: 0.02 value for Indonesia: 0.21 Ref: IEA (2009 figures) Country specific values for kg CO₂e/MJ grid electricity should be specified. Values stated in Bonsucro production standard. Value for Brazil: 0.02 Value for Indonesia: 0.22 Ref: RFA (2008)</td>
<td>Not included in the agricultural phase</td>
<td></td>
</tr>
<tr>
<td><strong>Renewable electricity sources (kg CO₂e/MJ)</strong></td>
<td>Option to include emissions generated from use of renewable electricity sources: Hydro: 0.0017 Wind: 0.033 Photo-voltaic: 0.01972 Reference: Ecoinvent (2007)</td>
<td>Not included</td>
<td></td>
</tr>
<tr>
<td><strong>Specific machine operation energy consumption</strong></td>
<td>Simplified model for fuel use as a function of machinery operations for basic farm management practices (tilling, harvesting etc.) for differing soil types and yields. Ref: ASABE 2006 a, b</td>
<td>No specific machine operations included.</td>
<td></td>
</tr>
<tr>
<td><strong>Energy used in transportation of inputs to farm</strong></td>
<td>Calculated based on quantity transported, distance travelled and mode of transport and vehicle/vessel type. Option for weight of vehicle to be included also. Transport emissions calculated as 0.05 kg CO₂e / kg input material transported. Ref: Wang et al., (2008)  Transport of fertilisers from production sites to field are included based on shipping and motor vehicle emissions. Assumed shipping distance 4000km Assumed motor vehicle distance 50km, 0.31kgCO₂e/km.t (assumes 2l diesel/km at 20t per trip) Ref: <a href="http://www.searates.com">www.searates.com</a>; Chase &amp; Henson (2010).</td>
<td>No other specific machine operations included.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 20: GHG driver 3: land use and land use change (LULUC).

**GHG driver 3: Land Use Change (LUC)**

<table>
<thead>
<tr>
<th>General approach</th>
<th>Cool Farm Tool</th>
<th>Bonsucro</th>
<th>PalmGHG</th>
</tr>
</thead>
<tbody>
<tr>
<td>User specifies broad category of LUC that has occurred, with more specificity if forest land; how long ago the change occurred and the percentage of the total land area converted. If converted from forest the user can state the age of the forest when felled.</td>
<td>Emissions from any land use change are calculated outside of the tool using IPCC values given in: <a href="http://shop.bsigroup.com/upload/Shop/Download/PAS/PAS2050.pdf">http://shop.bsigroup.com/upload/Shop/Download/PAS/PAS2050.pdf</a> Emissions from land clearing by burning are calculated based on user-specified percentage of crop burnt.</td>
<td>Emissions are calculated for land clearing each year and averaged over the full crop cycle. ‘Own crops’ and ‘out-growers’ can be modelled separately, as can emissions arising from mineral soils and peat soils. The user is required to specify how much land area was changed from different previous land use types at planting and the amount of C lost is then amortised over the expected crop cycle.</td>
<td></td>
</tr>
</tbody>
</table>

| Previous land use types included: | Forest land (several types)  
- Tropical forest  
- Tropical moist deciduous forest  
- Tropical dry forest  
- Tropical shrubland  
- Tropical mountain system  
- Sub-tropical humid forest  
- Sub-tropical dry forest  
- Sub-tropical steppe  
- Sub-tropical mountain system  
- Temperate oceanic forest  
- Temperate continental forest  
- Temperate mountain system  
- Boreal coniferous forest  
- Boreal tundra forest  
- Boreal mountain system  
Grassland / Arable | Forest land  
Grassland  
Crop land | On mineral soils:  
Primary forest  
Logged forest  
Coconut  
Rubber  
Cocoa under shade  
Oil palm  
Secondary re-growth  
Shrubland  
Food crops  
Grassland  

| On peat soils:  
Logged forest  
Food crops  
Secondary re-growth  
Oil palm |
<table>
<thead>
<tr>
<th>Land use carbon stocks</th>
<th>IPCC PAS 205 default values used</th>
<th>IPCC PAS 205 default values used</th>
<th>Defined in: Agus et al., (2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat soil emissions</td>
<td>Not included specifically (soil characteristics can be modified to be more representative of peat soil).</td>
<td>Not included</td>
<td>Emissions from oxidation of organic carbon and associated N\textsubscript{2}O emissions from peat cultivation based on water table depth and management. Calculation: 0.91 (t CO\textsubscript{2}e/ha/yr) x cm drainage depth. Ref(s): Hooijer et al., (2010)</td>
</tr>
<tr>
<td>Burning/combustion (pre or post crop harvesting)</td>
<td>Not included specifically (however can be modelled through specifying burning as the treatment of crop residue).</td>
<td>Emissions from cane burning are based on IPCC emission factors for burning biomass (0.07kg N\textsubscript{2}O/t dry matter and 2.7 kg CH\textsubscript{4}/t dry matter). Ref(s): IPCC (2006)</td>
<td>Not included</td>
</tr>
<tr>
<td>C stock changes related to management practices (e.g. tillage, composting, planting preparation etc.)</td>
<td>IPCC tier 1 method employed for estimating soil C stock changes. Changes determined by Ogle et al., (2005) for a period of 20 years.</td>
<td>Not included. (changes in C content of soils other than those from direct land use change are excluded)</td>
<td>Not included</td>
</tr>
<tr>
<td>LULUC induced soil C stocks</td>
<td>Defined by Ogle et al., 2005</td>
<td>Not included</td>
<td>Not included (for mineral soils)</td>
</tr>
<tr>
<td>Amortization</td>
<td>20 years (for soil carbon only) Ref(s): IPCC (2006); BSI (2011)</td>
<td>Not included within the tool</td>
<td>Default is 25 years (but can be modified by user). Ref(s): Chase et al., (2010)</td>
</tr>
<tr>
<td><strong>Crop sequestration in assessment crop</strong></td>
<td>Not included (unless modelled specifically under crop sequestration tab).</td>
<td>Not included (biogenic sources of carbon are excluded except those resulting from direct LUC).</td>
<td>Direct measurements preferable otherwise modelled data are used based on Southeast Asian conditions to produce annual values for standing biomass (above and below-ground), ground cover, frond piles and other plantation litter.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
| **Carbon content of biomass** | 50% | Not included | 45 or 46%  
Ref: Chase *et al.*, (2012) |
| **Sensitivities** | Unable to model different land use change scenarios in the same spreadsheet. | NA | Differences in crop ages throughout the plantation are captured. |
| **Underlying models incorporated** | Several datasets and allometric growth models from IPCC (2006) to model carbon storage in tree crop systems. | Not included | Palm oil specific crop sequestration models: OPRODSIM and OPCABSIM (vigorous growth for own crops and average growth for outgrowers).  
Ref(s): Henson, (2005); Henson, (2009) |

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28 An outgrower is usually a contract farmer; agricultural production is undertaken on the basis of an agreement between the buying entity and the farm producer. The contract may define the conditions for which the agricultural material is produced, the quality of the material and the delivery to the buyer’s premises.
4.6.4.2 Output based assessment results

4.6.4.2.1 Sugarcane assessment (CFT vs. Bonsuco)

Figure 21 presents the results for each GHG emission source assessed for Bonsuco and the CFT, reported in kg CO$_2$e/ha. The total GHG footprint for sugarcane cultivation from the two calculators was 2407 kgCO$_2$e/ha for Bonsuco and 2229 kgCO$_2$e/ha for the CFT, a difference of 8% (LUC excluded). However, there are more significant differences between individual emission sources. The CFT includes an additional GHG emission estimate of ‘background’ GHG from the soil, based on the farm conditions specified which are independent of the rate of N application i.e. they are a function of the climate and soil properties, deduced from the Bouwman model (Bouwman et al., 2002). In Bonsuco it is not possible to ascertain if these ‘background’ emissions are included within the tool as part of the fertiliser emissions or across various GHG emission sources. The main differences in results per hotspot range from a 12% difference for emissions associated with lime production and application up to a 42% difference for mineral fertiliser induced emissions with Bonsuco generating larger values for each GHG emission source apart from extraneous matter (EM) residue management.
Figure 21: GHG emissions for sugarcane production (excluding land use change (LUC)).

4.6.4.2.2 Sugarcane and GHG emissions from agrochemical inputs (GHG driver 1)

Fertiliser production emissions for Bonsucro were 30% greater than those produced by the CFT (Figure 21) due to differences in the emission factors used for N, P and K fertiliser production and specifically the higher emission factor for N-fertiliser production used in Bonsucro. The fertiliser production emission values used in Bonsucro are taken from the EBAMM model which is itself based on the GREET life cycle model for transport fuels in the U.S (Macedo et al., 2008; Wang et al., 2008; GREET 1.6). In comparison the CFT is largely based on European fertiliser manufacture data which is among the world’s most efficient and in some cases is close to the technological limit of efficiency (EFMA, 2008). The CFT includes provision to specify the fertiliser production technology employed, if known, based on four classifications of the technology used: old, older, new and current technology.
Each represents a different fertiliser production dataset that contains different production factors. In this assessment the default dataset was used (EFMA, 2006), described as ‘current technology’. Figure 22 demonstrates the influence of the choice of fertiliser production technology on the GHG emissions calculated by the CFT when all other inputs stay the same, in comparison to the default fertiliser production dataset (which cannot be user-specified) in Bonsucro.

Interestingly, Figure 22 shows that the GHG emissions for ‘old technology’ taken from Ecoinvent (2002) are the highest, even higher than ‘older technology’ which might be expected to result in increased GHG emissions due to less efficient production mechanisms and more GHG intensive fuels used. The data for the ‘older technology’ fertiliser production dataset was based on a publication by Kongshaug (1998), who worked for the fertiliser company Yara29. This publication was used to inform future fertiliser production datasets for the ‘current’ and ‘new’ technology parameters developed by Brentrup (unpublished data), also an employee of Yara, and based on European data (EFMA). The data for ‘old’ technology came from Ecoinvent (2002) which appears to be based on very different data and assumptions to the other three datasets used. The implications of using alternative datasets are explored further in the palm oil assessment.

![Figure 22: Fertiliser production emissions for different production technologies in the CFT compared to Bonsucro (kg CO₂e/ha).](image)

Calculation of field based fertiliser emissions are treated very differently by the two tools. Bonsucro requires the user to describe fertiliser application rates based on the quantity of nitrogen (N) applied and the GHG emissions are calculated based on one specific GHG emission factor per unit of N (6.2kg CO₂e/kgN (IPCC, 2006b)). In contrast, the CFT contains a range of fertilisers of different nutrient blends that the user can select. It also includes additional parameters that can be specified to

provide further detail of the on-farm application of fertilisers including the application type and
method employed. The CFT calculates the direct and indirect emissions using different emission
factors for each fertiliser blend and integrates the various degradation and transfer process
pathways for reactive nitrogen (Nr) compounds (i.e. nitrification, denitrification, volatilisation,
leaching and run-off) based on a global dataset (Bouwman et al., 2002). To compare the fertiliser
induced emission results produced by the two tools urea was selected in the CFT to represent the N
input as it is a fertiliser high in N and also is the most likely in the Brazilian context (FAO, 2004;
Macedo et al., 2008). In the CFT the user has the option to specify whether the fertiliser was applied
on a ‘nutrient’ or as a ‘product’ basis (application type), the former referring to the specific
application rate of the nutrient (N, P, K, Ca etc.) and the latter concerning the volume of product
applied in total. A wrong selection of the application type can result in a mis-reporting of emissions.
Figure 23 for example, demonstrates the sensitivity of the GHG emissions for two N containing
fertilisers, urea and ammonium nitrate, to the application type, nutrient or product, calculated with
the CFT for the same fertiliser application rate. An over-estimation of more than 77% for urea is
possible if the incorrect option is selected.

![Figure 23: The sensitivity of GHG emissions in the CFT from different fertiliser application types for two N containing fertilisers given the same application rate.](image)

In Bonsucro the soil properties are fixed whereas in the CFT the user must specify the relevant soil
properties (soil type, soil organic matter (SOM), soil moisture, drainage and soil pH (derived from
Bouwman et al., 2002)) from a selection of drop-down menus. Keeping all other data inputs the
same (as per Table 15), Figure 24 shows the effect of varying the soil properties in the CFT for four
different soil type scenarios (S1-4), on the GHG emissions for the same amount of urea (N)
application compared to the single value obtained from Bonsucro. A difference of 99% between the
base case soil properties (provided by N.Viart, 2012, and indicated in Table 15) and scenario 4 (S4),
highlights the sensitivity of the CFT to different soil parameters. Figure 24 shows that the base case
specified by Bonsuco is closest to scenario S1, whereas the output for Bonsuco is greater and closer to scenario S2.

Figure 25 shows the influence of different soil parameters in the CFT on the resulting GHG emissions from N, compared to the GHG emission output from Bonsuco. Each GHG emission output for the CFT shown in Figure 25 is the result of altering just one soil property option from the base-case soil properties. It demonstrates that some soil property selections can influence the GHG result more considerably than others. For example increasing the soil organic matter (SOM) to >10.32 drives an emission increase beyond both the base-case and the result from Bonsuco. This increase in emissions is also seen with other soil property amendments, for example changing the soil moisture from dry to moist soil. In the latter case, this is due to the potential for more of the N fertiliser to be lost from the soil as N\textsubscript{2}O through leaching, this emission pathway in particular is based on data from IPCC (Eggleston et al., 2006). In Bonsuco, it is not clear what the modelled soil properties are, whether they are implicitly representative of the production of a specific country, or whether considered at all; they are not described in the model or the reference literature cited.

![Figure 24: Fertiliser induced GHG emissions given different soil properties in the CFT.](image)
Figure 25: Fertiliser induced GHG emissions from different soil property combinations in the CFT compared to Bonsucro.

In the CFT the user can select from a range of different fertiliser application methods that may be used in a mechanised farming system. Figure 26 shows the influence of different fertiliser application methods on soil GHG emissions. In the CFT, the application method employed influences the amount of N lost as ammonia through volatilisation. This is taken from Bouwman et al., (2002). Only a small amount of the ammonia emissions ends up as N\textsubscript{2}O thus it doesn’t have a significant effect on the GHG emissions, so this parameter is clearly less significant than varying soil properties seen in the previous figures (Figure 24 and Figure 25). Here the N fertiliser induced GHG emissions (modelled as urea\textsuperscript{30}) given the various fertiliser application methods\textsuperscript{31} in the CFT are compared to the default N fertiliser induced emissions in Bonsucro which are not specified.

\textsuperscript{30} Ammonia volatilisation is higher for urea than for other nitrate based fertilisers (e.g. ammonium nitrate (AN)) (Titko et al., 1987) thus resulting in higher GHG emissions as seen in Figure 23, however the differences between the GHG emissions of these two fertilisers was outside the scope of this assessment.
Both tools model lime application input as limestone and they use the same tier 1 IPCC factor that assumes that all the carbon (contained as carbonate, CO$_3$) is released as CO$_2$. The emissions profile for lime from Bonsucro, however, is 12% higher than for the CFT due to differences in the modelling of lime production emissions. Bonsucro uses U.S data compared to European production data used in the CFT.

The differences in the emissions for crop residue management (Figure 21) are due to a combination of factors. Firstly, the two tools assume different N contents for the crop residue; in the CFT it is 0.7%N (IPCC, 2006d) for the crop residue$^{32}$ compared to the more specific N content of sugarcane extraneous matter, 0.5%N (Hassuani et al., 2005; Macedo et al., 2008) that is used in Bonsucro. Secondly, the CFT models 1% conversion of N to N$_2$O based on IPCC tier 1 (IPCC, 2006b) whereas Bonsucro employs a different conversion, assuming that 1.225% of N is released as N$_2$O (Macedo et al., 2008). Finally, the slight difference in the GWP of N$_2$O between the two tools, 296 in CFT and 298 in Bonsucro (see Table 18), contributes to the difference in emissions seen. Given the same quantity

Figure 26: GHG emissions for different application methods of N fertiliser (urea) in the CFT compared to the default N fertiliser induced emissions for Bonsucro (not specified).

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$^{31}$ NB: fertilisers come in different forms such as solid granules or liquid form. Different application methods may be more appropriate for different forms of fertiliser i.e. liquid fertilisers are typically sprayed or injected, whereas granular fertilisers may be broadcast or placed. Urea may be applied in liquid or granular form and it is has been indicated that volatilisation of N to N$_2$O may be greater upon liquid application (Titko et al., 1987), although there are a number of factors that influence ammonia volatilisation, exploration of which is beyond the scope of this assessment.

$^{32}$ Residue N content is assumed based on the crop type. Sugarcane was modelled as Millet in the Cool Farm Tool because there is no option for sugarcane.
of crop residue, the linear relationship between the different factors used in the two tools are responsible for the 12% difference in GHG emissions.

4.6.4.2.3 Sugarcane: GHG emissions from energy use (GHG driver 2)

The GHG emissions from energy use presented in Figure 21 are based entirely on the emissions from diesel use in farm operations. The CFT uses an emission factor for diesel taken from the GHG Protocol (GHG Protocol, 2012) (www.ghgprotocol.org) of 2.68 kg CO₂e/litre of fuel which includes the direct emissions only i.e. those from the combustion of the fuel and not the full life cycle emissions of the diesel. In contrast Bonsucro uses an Emission Factor of 3.46 kg CO₂e/litre of fuel based on the GREET life cycle model for energy use in transportation (Wang et al., 2008). It includes both the direct emissions from fuel combustion as well as the indirect emissions from oil extraction and production of the fuel.

In addition to diesel related GHG emissions, both Bonsucro and the CFT include GHG emissions for other possible types of energy use, in particular, gasoline (petrol), natural gas and electricity. The EFs associated with these various energy types are shown in Table 19. To assess the influence of energy type on the GHG emissions for sugarcane a scenario analysis was performed. Table 21 lists the input energy types and quantities for the scenario assessment and the GHG emissions outputs for each energy type (including diesel), re-presents the corresponding emission factor and shows the percentage difference between the tools for both the emission result and the emission factor used. The amount of energy modelled in each scenario were selected to be representative for Brazilian sugarcane production (Macedo et al., 2008; Rein, 2010).

It can be seen from Table 21 that the differences in GHG emission outputs for diesel, gasoline and electricity generated by the two tools correspond directly to the differences in the emission factors used. For natural gas the difference in GHG emission output is not directly related to the difference in the GHG emission factor. The CFT uses an emission factor for liquid petroleum gas (LPG) from the GHG protocol (2003) which only includes direct emissions from fuel combustion. Bonsucro, in contrast, uses an energy demand factor and the GHG emission factor for natural gas from the EBAMM model based upon the GREET model (Wang et al., 2008) which includes the life cycle emissions for production and transportation as well as fuel combustion. (Macedo et al., 2008).
Table 21: GHG emission outputs and emission factors for various fuel types included in Bonsucro and the CFT.

<table>
<thead>
<tr>
<th>Energy Type and Input</th>
<th>Calculation factors</th>
<th>Bonsucro</th>
<th>Cool Farm Tool</th>
<th>Percentage Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GHG emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel (7212659 litres per year)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Emission factor (kg CO$_2$e/l fuel)</td>
<td>3.46</td>
<td>2.68</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>GHG emissions (kg CO$_2$e/ha)</td>
<td>916</td>
<td>709.9</td>
<td>25.4</td>
</tr>
<tr>
<td>Gasoline (100 litres/ha)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Emission factor (kg CO$_2$e/l fuel)</td>
<td>2.81</td>
<td>2.32</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>GHG emissions (kg CO2e/ha)</td>
<td>281.16</td>
<td>232</td>
<td>19.2</td>
</tr>
<tr>
<td>Electricity (90 kWh/ha)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Emission factor (kg CO$_2$e/MJ)</td>
<td>0.022</td>
<td>0.018</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td>GHG emissions (kg CO$_2$e/ha)</td>
<td>7.13</td>
<td>5.75</td>
<td>21.3</td>
</tr>
<tr>
<td>Natural Gas (50 kWh/ha)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Emission factor (kg CO$_2$e/MJ)</td>
<td>0.0662</td>
<td>0.0628</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>Energy demand factor</td>
<td>1.12</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>GHG emissions (kg CO$_2$e/ha)</td>
<td>10.64</td>
<td>11.3</td>
<td>6.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> base case dataset (from Table 15);<sup>b</sup> authors’ assumed quantity;<sup>c</sup> taken from Rein (2010).

4.6.4.2.4 Sugarcane and GHG emissions from Land Use (LU) and Land Use Change (LUC) (GHG Driver 3)

4.6.4.2.4.1 Land use

In Bonsucro the GHG emissions for pre-harvest combustion of sugarcane are calculated based on the dry matter (DM) content of the crop burnt. In contrast, the CFT has no specific functionality to calculate GHG emissions for pre-harvest combustion, but it is possible to model it using the ‘crop residue management’ function and selecting the ‘residue burning’ option. To input the correct residue quantity burnt in the CFT requires the user to perform some calculations external to the tool which may not be obvious or intuitive to a non-expert user. Both calculators use the same biomass burning factors from IPCC (IPCC, 2006b) and so the GHG emission outputs for pre-harvest
combustion are comparable (Figure 21). This illustrates an important requirement of more multi-crop calculators such as the CFT, namely the need for more knowledge or expert user status in comparison to the simpler single crop calculator.

4.6.4.2.4.2 Land use change

The two tools calculate GHG emissions from LUC differently. Bonsucro requires direct entry of the LUC GHG emissions calculated by the user using the IPCC default values specified in PAS 2050 (BSI, 2011), relevant to the country being modelled. The CFT calculates LUC GHG emissions within the calculator and the user must specify the land use changes via a combination of drop-down options and data entry fields. The user must identify the type of LUC from a pre-defined list (involving forest land, grassland and arable cropland (see Table 20)); when the land use change occurred (up to a maximum of 20 years); and the type of forest converted from or to (if any) with the choice of a number of forest types.

In the CFT LUC emissions include both carbon stock changes in the soil as well as above ground biomass changes. Changes in soil organic carbon (SOC) storage are derived from the IPCC (2006a) method which is based upon (Ogle et al., 2005). It incorporates several factors including the relative C storage factor compared to the native system along with factors for tillage and other inputs such as manure or compost. In addition, C stocks in biomass are taken into account based on the gains or losses due to land use change practices. The CFT uses IPCC Tier 1 methodology as described in IPCC (2006a) in which the amount of above ground biomass gain (in kg/ha/year) (e.g. for afforestation) and biomass loss (in kg/ha) for the area where LUC has occurred are calculated with respect to the root to shoot ratio and the carbon fraction of the dry matter (DM) of the biomass for the land use type (in t of C). In the CFT the above ground biomass loss is calculated in kg/ha and reported in the year in which the biomass loss occurs. It is not amortised over a period of 20 years as in is the convention in many GHG calculators including Bonsucro. The effects of this difference are explored in the comparison between the CFT and PalmGHG for palm oil and so for this comparison the CFT was amended to amortise AGB carbon loss over 20 years (see Table 17).

To compare the results from the two calculators, different LUC scenarios were specified. For Bonsucro the GHG emission values for Brazil, for forest conversion to perennial cropland and to arable cropland were taken directly from the PAS 2050 (BSI, 2011) and entered into the tool. The CFT does not include an option to model perennial cropland and so conversion from forest to arable cropland and from forest to grassland, were used as proxies with varying types of forest.

Figure 27 shows the sensitivity of the LUC results for different forest and land types. The GHG emissions for LUC are ca. 2 orders of magnitude higher than the contribution from fertilisers (Figure 21). Figure 27 shows the GHG result for Bonsucro when LUC is modelled from forest to arable
cropland (Bonsucro 1) and from forest to perennial cropland (Bonsucro 2). The GHG emissions for LUC from the CFT range from 13% higher (CFT 1) to 46% lower (CFT 3) than Bonsucro 1 when comparing forest to arable conversion scenarios, or 44% higher (CFT 4) to 17% lower (CFT 6) Bonsucro 2 (i.e. conversion from forest to grassland). Figure 27 therefore shows the sensitivity of the results to forest type and the corresponding above ground carbon stocks (from IPCC, 2006), which may be important for users to better represent their site situation.

Figure 27: GHG emissions from various land use change (LUC) scenarios for sugarcane modelled in Bonsucro and the CFT.
Table 22 compares the results for conversion from forest to arable cropland for both Bonsucro and CFT, given different specified soil parameters in the CFT, where results range from a 2% to a 16% difference. These differences are driven by the changes in soil carbon stocks and demonstrate some important differences between the tools, particularly given the significance of LUC emissions to the overall footprint.
Table 22: GHG emissions for LUC from forest to arable given different soil properties in the CFT.

<table>
<thead>
<tr>
<th>Tool Scenario</th>
<th>LUC Type Specified</th>
<th>Soil Property Amendment (from base case, Table 15)</th>
<th>GHG output (kg CO₂e/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonsucro 1</td>
<td>Forest to arable</td>
<td>----</td>
<td>37000</td>
</tr>
<tr>
<td>Cool Farm Tool 7</td>
<td>Tropical rainforest to arable</td>
<td>Soil type: fine</td>
<td>37803</td>
</tr>
<tr>
<td>Cool Farm Tool 8</td>
<td>Tropical rainforest to arable</td>
<td>Soil type: coarse</td>
<td>43472</td>
</tr>
<tr>
<td>Cool Farm Tool 9</td>
<td>Tropical rainforest to arable</td>
<td>Lower SOM: &lt;=1.72</td>
<td>39892</td>
</tr>
<tr>
<td>Cool Farm Tool 10</td>
<td>Tropical rainforest to arable</td>
<td>Higher pH: &gt;8.5</td>
<td>37746</td>
</tr>
</tbody>
</table>

4.6.4.3 Palm oil results (CFT vs. PalmGHG)

The results for palm oil production modelled with PalmGHG and CFT for the three categories of GHG emissions are shown in Figure 28. The total GHG footprint of these GHG emission sources, excluding LUC and peat, was 1211 kgCO₂e/ha from PalmGHG compared to 1579 kg CO₂e/ha calculated by the CFT, a difference of 26%. Even though PalmGHG generates results higher than the CFT for all emission sources except for those from pesticide production (which are omitted entirely from PalmGHG) and those associated with mineral fertiliser production, it has a higher overall footprint due to the inclusion of a reported quantity of ‘background’ emissions based on the site-specific conditions (soil and climate), as in the sugarcane assessment. Some of the differences seen in the results for the individual GHG sources, are directly associated with different GHG emission factors used e.g. diesel energy use (see Table 19), whereas others are due to more substantive differences between modelling approaches and different background data. These will be explored further in the following sections.
4.6.4.3.1 Palm oil and GHG emissions from agrochemical inputs

Figure 28 shows the GHG emission results for field based mineral fertiliser emissions and those associated with organic fertiliser inputs, namely empty fruit bunches (EFB) and palm oil mill effluent (POME) that are returned from the mill to the field which are 8%, 56% and 192% higher respectively, in PalmGHG compared to the CFT. The differences in results reflect different underlying data sources or emission factors used in the two tools and also reflect the limitations of the CFT to model the organic inputs specific to palm oil production as adequately as PalmGHG. In the CFT, EFB (0.32% N) and POME (0.045% N) (Singh, 1995) were modelled based on ‘zero emissions compost 1% N’ and as ‘cattle slurry 0.26% N’, respectively to reflect the composition of these organic inputs as proxies in the CFT in its available form.

Figure 28: GHG emission outputs for palm oil generated by PalmGHG and the CFT across different GHG emission sources (kg CO2e/ha) excluding land use change (LUC) and peat.
PalmGHG can model the production and application of nine specific mineral fertilisers that are commonly used in palm oil cultivation. Six fertiliser combinations were modelled in this assessment as described in Table 16. The six fertiliser combinations were also modelled in the CFT and where an exact match was not possible, the closest equivalent fertiliser, with regards to nutrient content, was modelled (see Table 16). In the modelled system, the fertiliser production GHG emissions produced by the two tools differed by 13% due to differences in the GHG emission factors from different data sources. Figure 29 presents the GHG emission results for fertiliser production from PalmGHG compared to the CFT and it highlights the sensitivity of the results to the choice of fertiliser dataset in CFT. For example, GHG emissions for the Ecoinvent (2002) fertiliser production dataset (CFT C) is more than double that of PalmGHG. However, there is only a 1.5% difference between the two calculators for scenario CFT D), a dataset that is used in PalmGHG also.

Figure 29: GHG emission outputs for fertiliser production for a palm oil production system generated by PalmGHG and the CFT based on different datasets within the tools (Fertilisers modelled are indicated below the graph and in Table 16).
4.6.4.3.2 Palm oil and GHG emissions from energy use

The results for energy use are 15% higher for PalmGHG compared to CFT and this is due to a difference in GHG emission factors.

The GHG emission factor used in PalmGHG of 3.12 kg CO$_2$e / litre of diesel fuel used (JRC et al., 2011) includes life cycle emissions from fuel production based on automotive fuels in a European context. This value is therefore higher than the diesel emission factor used in the CFT (2.68 kg CO$_2$e/litre of fuel) which is also based on European data (GHG Protocol, 2003), but as described previously, is based on combustion emissions only.

4.6.4.3.3 Palm oil and GHG emissions from land use change (LUC)

PalmGHG includes a comprehensive approach to modelling of LUC over the first crop cycle which is generally between 20 and 27 years (Chase & Henson, 2010; Chase et al., 2012) after initial land conversion. PalmGHG enables the user to specify LUC to palm oil plantation from several previous land use types including primary forest, logged forest, grassland, cocoa and coconut plantations, arable food cropland, or from secondary re-growth; each with a specified carbon stock (Agus et al., 2012). The tool allows the user to specify both the area of cleared land from each LU type and when it occurred, therefore enabling the user to model multiple LU conversions from multiple previous LU types. The CFT provides a simpler approach with less specificity. It includes a narrow range of LUC categories that occurred within a farming system over 20 years, as recommended by IPCC (2006a) but including some complex calculations of soil carbon change based on soil parameter specified.

To compare the two calculators some standardised LUC scenarios were modelled; 100% LUC from forest to plantation in PalmGHG and 100% from forest to arable land and to grassland in the CFT (as there is no option to model plantation or perennial cropland in the CFT) and no edits/amendments were made to the tool(s). The results for the comparison are shown in Figure 30. The difference in results between the tools is considerable and more than would be expected given the differences in the final land use and their associated carbon stocks. The reason for this difference seen in Figure 30 in the first instance is due to the fundamentally different ways the tools treat emissions from LUC. In the CFT the below ground biomass (BGB) i.e. the soil carbon loss, from mineral soils is amortised over a period of 20 years as this is the duration at which soil carbon emissions reach equilibrium (IPCC, 2006). The carbon lost from above ground biomass (AGB), however, is not amortised at all and the GHG emission burden incurred from land clearing (e.g. deforesting) is accounted for in the year that the LUC occurs. In the calculations performed by the CFT therefore, GHG emissions (carbon loss) from AGB may not be accounted for at all, particularly if the LUC and clearance of AGB occurred prior to the year of reporting, which is often the case. Therefore the difference seen between the GHG emissions reported by PalmGHG and the CFT in is because no carbon loss from the AGB was
included in the calculations made by the CFT. This approach follows the IPCC methodology that is
designed for national inventory level reporting and not necessarily product or ingredient level
reporting that these tools may be used to inform. There is much debate both within the scientific
and policy communities about the appropriateness of this approach and the implications of different
amortisation periods. Amortisation is discussed further in the discussion section of this chapter.

![Diagram](image)

**Figure 30:** GHG emissions from LUC (kgCO₂e/ha) (no edits to CFT made and so no AGB C
loss is included, results are for SOC loss only).

The CFT was amended to enable amortisation of the above ground biomass (AGB) C stocks and make
the LUC calculations more comparable with those performed in PalmGHG. These results are shown
in Figure 31. The differences in the GHG results are driven by two key aspects of the tools
approaches and data sources for LUC. Firstly, the different carbon stock values incorporated for the
land use classifications; PalmGHG includes carbon stocks in below and above ground-biomass taken
from a variety of sources (Chase et al., 2012), whilst the CFT uses values from tier 1 IPCC (2006) data
and soil carbon stock changes from Ogle et al., (2005). The ‘tropical rain forest’ LU category in the
CFT was modelled as equivalent to the ‘primary forest’ category in PalmGHG (to represent the
higher C stock land uses present in the tools, although these values differ; 350 t C/ha in CFT
compared to 225 t C/ha in PalmGHG). The second key difference is the amortisation period and
approach used (the CFT was adapted to facilitate amortisation of above ground biomass losses (see
Table 17)). Figure 31 shows the GHG emissions from LUC for PalmGHG and CFT for different
amortisation periods, 20 years and 25 years and for conversion to both arable and grassland
modelled in the CFT, highlighting the influence of the amortisation period used. There is a difference
of 22% in the results from PalmGHG for 20 and 25 years amortisation, which, given the importance of LUC as an emission source, can have a significant impact on the overall GHG footprint.

An additional influence on the GHG results for land use change that was omitted from the assessment was the consideration of carbon fixation or sequestration in the palm tissues. An estimation for the carbon sequestration in the palm biomass is inherent within the calculations in PalmGHG under an assessment of a palm plantation, but is not within the CFT crop production assessment (i.e. no carbon sequestration is included through the assessment of a tree crop system). In PalmGHG, the carbon fixation in the palm tissues is calculated, preferably through direct user-specified measurements, but alternatively with modelled data from OPRODSIM and OPCABSIM (Henson, 2009, 2005). These are modelled palm oil growth curves based on climate and soil data primarily based on Malaysian conditions.

Providing an additional layer of transparency to the tools, Table 23 and Table 24 detail some of the key carbon stocks and factors used in the LUC calculations of PalmGHG and the CFT within this assessment, respectively. These tables illustrate the differences in the type of background data embedded within the tools. The data used in PalmGHG is specific to tropical systems and the LU types and their associated carbon stocks that will be found in these areas, i.e. the data has come from specific and sources directly related to palm oil systems in tropical countries (Table 23). The CFT on the other hand, incorporates the Tier 1 method and data detailed in IPCC (2006) which includes broad classifications of data for different regions of the world, different forest types and different ages of forest specified, which are used to calculate the GHG emissions based on the information provided by the user. This enables the CFT to be able to include LUC emissions relevant for multiple systems and LU types, globally.

Table 24 also demonstrates the differences in carbon stocks used by the tool for two geographical areas, Asia insular and Asia continental in this case, showing how important it is for the user to enter the most accurate information (Asia insular was used to represent Indonesia in this assessment).

Another important land use factor for palm oil is cultivation on peat soils. PalmGHG has provisions to model GHG emissions from peat under managed and unmanaged scenarios (based on the depth of the water table). There is no special provision for peat soil in the CFT but a pseudo-peat soil can be modelled through specification of representative (high carbon content) soil properties (described in Table 16), although the management aspects in relation to the water table cannot be modelled. Figure 32 shows the results for managed and unmanaged water tables for peat soils in PalmGHG and the equivalent representation of pseudo-peat soil in CFT for the two LUC scenarios, tropical rainforest converted to arable land and to grassland. The GHG emissions are substantial and Figure
32 indicates the range of results that may be generated (NB. The GHG emissions from LUC and cultivation on peat are several orders of magnitude larger than many of the other GHG hotspots and thus are important GHG emission sources to model).

Table 23: Carbon stocks in above-and below-ground biomass for some land uses included in PalmGHG (adapted from: Chase et al., (2012)).

<table>
<thead>
<tr>
<th>Land use type</th>
<th>AGB and BGB carbon stock (tC/ha)</th>
<th>Reference / source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary forest</td>
<td>225</td>
<td>Mean of 62 values* (Henson, in prep).</td>
</tr>
<tr>
<td>Palm oil plantation</td>
<td>≥ 50</td>
<td>Calculated with OPRODSIM and OPCABSIM models (Henson, 2009, 2005). Dependent on the crop cycle length and growth type (vigorous, for own crops; or average for outgrowers)</td>
</tr>
<tr>
<td>Food crops</td>
<td>9</td>
<td>Average of annual and perennial crops in Papua New Guinea.</td>
</tr>
<tr>
<td>Grassland</td>
<td>5</td>
<td>(Henson, 2009)</td>
</tr>
</tbody>
</table>

*62 values with a coefficient of variance of 26% from a LUC database in preparation by Henson.

Table 24: Carbon stocks and key factors in the CFT for forest lands over 20 years old (relevant to this assessment).

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Location</th>
<th>Above ground biomass (t DM/ha)*</th>
<th>Root to shoot ratio</th>
<th>Reference/source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical rain forest</td>
<td>Asia, insular</td>
<td>350</td>
<td>0.37</td>
<td>(IPCC, 2006a) Chapter 4</td>
</tr>
<tr>
<td></td>
<td>Asia, continental</td>
<td>280</td>
<td>0.37</td>
<td>(IPCC, 2006a) Chapter 4</td>
</tr>
<tr>
<td>Tropical moist deciduous forest</td>
<td>Asia, insular</td>
<td>290</td>
<td>0.2</td>
<td>(IPCC, 2006a) Chapter 4</td>
</tr>
<tr>
<td></td>
<td>Asia, continental</td>
<td>180</td>
<td>0.24</td>
<td>(IPCC, 2006a) Chapter 4</td>
</tr>
<tr>
<td>Tropical dry forest</td>
<td>Asia, insular</td>
<td>160</td>
<td>0.28</td>
<td>(IPCC, 2006a) Chapter 4</td>
</tr>
<tr>
<td></td>
<td>Asia, continental</td>
<td>130</td>
<td>0.28</td>
<td>(IPCC, 2006a) Chapter 4</td>
</tr>
</tbody>
</table>

*t DM/ha refers to the tonnes of dry matter per hectare of land.
Figure 31: GHG outputs for LUC scenarios for palm oil as modelled in PalmGHG and the CFT (kg CO$_2$e/ha) (including AGB in the CFT).

Figure 32: GHG outputs for LUC scenarios for palm oil on peat soils as modelled in PalmGHG and the CFT (kg CO$_2$e/ha).
4.7 Discussion

Short of empirical field measurements of GHG emissions from farming activities, modelling of GHG emissions through the use of GHG calculators is a practical and increasingly important approach for assessing the GHG performance of farms. The methodological approach selected, underlying data and embedded models constitute a GHG accounting framework applicable to a specific system or a range of farming systems and geographical scopes. This chapter has explored the range and diversity of agricultural GHG calculators that have been developed by different groups for different purposes; it has provided some examples of the context in which they are used; and it has briefly summarised some studies undertaken to assess and compare them. Three internationally important and influential GHG calculators have been compared in detail, addressing the architecture of the calculators, the consistency of the data sources and methods used and, ultimately, the GHG emission estimates of the calculators. This discussion section is structured as follows:

- Proliferation of GHG calculators.
- The results and insights gained from the calculator comparison.
- The uses and future of GHG calculators, their scalability and additivity at a landscape scale and whether there is a need for harmonisation or standardisation of calculators.

4.7.1 Proliferation of GHG calculators

The large increase in the number of agricultural GHG calculators is indicative of the increased desire and need to model on-farm GHG emissions and to assess performance. However, the proliferation of different agricultural GHG calculators can create challenges. For example, the availability of a number of ‘slightly different’ calculators can lead to confusion and mis-trust and to greater challenges in comparability and communication of results.

4.7.2 Calculator comparison: results and insights

The structured assessment of the underlying features and data sources provided insights into the architecture of the calculators that are not evident from the calculators’ published descriptions. The assessment highlights the difficulty of making direct comparisons between the tools, due to their different modelling approaches, structures, data input requirements and units and nomenclature.

As well as demonstrating how and why the tools differ in the results they produce, the comparison highlighted some of the advantages and shortcomings of each:

- PalmGHG handles LUC more comprehensively than Bonsucro or the CFT but as a consequence it is relatively data intensive. This reflects the higher importance of LUC in the palm oil system.
• The CFT, in its current state, is not well suited to modelling perennial crop systems or systems for which LUC is an important GHG hotspot.

• PalmGHG could be improved to include coverage of some other GHG sources, such as pesticide use.

• In Bonsucro, the assumptions and references for data sources are not always clear. In general there is a need for increased transparency of the underlying data values and sources both in the tool software and in the accompanying user guidance/documentation.

• Calculation of some GHG emissions requires the user to perform some calculations or assessments outside of the tool; in Bonsucro, LUC emissions must be obtained from PAS 2050; and in the CFT the user must calculate separately the amount of crop residue burnt. Drop-down menus such as those in the CFT may help tool users to characterise their system, though the broad classifications may result in variability as two different users might characterise the same system differently.

• The simple data entry structure in Bonsucro renders it the easier tool to use.

• None of the tools currently includes any estimate of uncertainty of the emissions estimates generated.

One of the key insights that arose throughout the calculator comparison was the issue of amortisation (briefly described earlier in section 4.6.3.2.3). Amortisation is important when there has been a management practice change during the reporting period that will have a longer term effect on the GHG emissions (or carbon pool) way beyond the reporting period (i.e. 1 year). For example, if a farmer adopts conservation tillage practices that will change the soil carbon content by a certain tonnage over a specified number of years, this carbon change should be amortised over multiple reporting inventories as the emissions profile changes over time (Russell, 2011). Amortisation is also important (as shown in this research) for the ways in which the emissions from land use change are reported. If land is converted from forest to crop land, thus considerably reducing the carbon stock of the land area (immediately in the year of conversion), and changing the GHG emission profile of the soil (which will change over a number of years into the future); the way in which these impacts are apportioned in different reporting contexts, e.g. national inventory reporting vs. product level reporting, needs careful consideration.

This research, in particular, highlighted that the different amortisation approaches used in a GHG calculator for the GHG emissions resulting from land use change, can have a considerable impact on the end GHG emission result of an agricultural crop. The results here revealed two categorically different ways of accounting for the GHG emissions of direct land use change, one in which the emissions (for above ground biomass clearance i.e. forest clearance) were calculated in a single year, and one in which the emissions were amortised at a fixed rate over a defined number of years. These two approaches are depicted in Figure 33.
Allocation of emissions to the year in which the LUC occurred (Figure 33a) bears no consideration for the ultimate duration of agricultural production of the land (which may be unknown). It may be justified because LUC causes largely irreversible damage and so its impacts should not be amortised over a long period of time (Jungbluth et al., 2007). For national inventories it may be appropriate to account for the emissions in this way as it reflects the large release of emissions that, in reality, occurs when biomass is removed and burnt or left to decay (Ramankutty et al., 2007). If, however, the GHG impacts are allocated to the agricultural produce in that year, they would have a disproportionately high GHG impact, particularly compared to subsequent years of agricultural production which would not carry any of the GHG burden from the previous land conversion and thus would be ‘free-riding’. If the GHG impacts were monetized, this issue would be more pronounced.

In Figure 33b the emissions are amortised or dispersed over a longer time horizon (20 years is the IPCC default) and therefore the GHG ‘cost’ of LUC is allocated to crops produced on that land over several successive years of production thus no one year of crop production takes on the GHG burden of the conversion event. For national reporting inventories this approach may not be appropriate as it does not reflect the ‘true’ release of emissions in the year they actually happen. For product GHG footprinting, however, it provides a ‘fairer’ emission estimate as it allocates a consistent GHG burden across several years of production. Of course, issues arise when the land ownership or use is changed during this period.

As well as the single year and fixed over time amortisation approaches, there are others which include (Russell, 2011):

- **Variable** – different amounts of GHG emissions are allocated across different years of the specified accounting period, until the total carbon change has been amortised. This may be able to better reflect actual patterns of change, particularly for soil carbon changes (BGB)
but is much more complicated to apply and requires site-specific information on the likely
rates of change which is usually not available.

- **Partial** – only a percentage of the total GHG emissions are reported over a defined time
  period. This does not usually reflect actual emissions releases over time and inevitably
  results in under-reporting of emission releases.

- **Hybrid approaches** – that combine various aspects of the approaches described above for
  improved applicability in different contexts e.g. allocation of producer and consumer
  responsibility for GHG emissions from agricultural produce (Zaks et al., 2009); net committed
  emissions approach where GHG emissions are calculated on the basis of the net difference
  in carbon stock between the original land use and the replacement use and also including
  emissions from decay of residual biomass over time, see Cederberg et al., (2011).

When each approach should be used is neither well defined nor universally agreed. There is not even
a consistent internationally accepted standard for land use classification and companies reporting
LUC emissions with operations in multiple countries may have to use several different internationally
recognised classification systems, further adding to confusion and complexity. It is outside the scope
of this research to delve further into different allocation approaches and advocate for one or the
other in different supply chain reporting contexts but it does highlight the need for clarity over
which approach is being used and specifically relevant to this research, which approach is
incorporated into a GHG calculator, and that this should be accompanied by clear documentation of
the assumptions made and the reporting implications. This is especially important as GHG emissions
from LUC become more routinely included in crop GHG footprints and in order to be able to
adequately inform policy making and improve supply chain management to ultimately reduce the
GHG emissions of agricultural production.

### 4.7.3 Calculator use, scale and standardisation

The three calculators are designed to enable the generation of a GHG footprint using data collected
from the respective agricultural system. For the farmer, the use of a calculator can help guide farm
management decisions and investments, increase awareness and knowledge of GHG emissions and
enable the assessment and monitoring of progress over time. However, in the context of the use of
the results by companies for measuring and reporting on their supply chains and for landscape level
assessments, the comparability and/or differences between calculators is a critical issue. It is,
therefore, useful to explore the implications of the design and use of calculators at three levels or
scales, namely:

- **Micro**: assessment of a crop product at an individual farm;

- **Meso**: assessment of equivalent crop products from a range of locations;
Macro: assessment of GHG performance within a contiguous area of land or landscape, with a number of different land types, land uses and crop products.

At the meso level, the findings of this research support the use of a single calculator if equivalency of data is required; e.g. for reporting, ranking farmers or suppliers, or comparing ingredients, products or diets. Use of a single calculator should be mandated as a requirement for certification (e.g. Bonsucro). However both RSPO certification and the UL SAC recommend use of a single calculator but allow the use of “equivalent calculators”; limited or no guidance is provided on how equivalency is to be established and the findings of this research indicate that differing levels of equivalency are possible. If it is not possible to use the same calculator for the cases to be compared, then it is critical to understand the comparability of the calculators.

Macro level use of farm-level GHG data may be required for national GHG reporting, to support or inform policy development and for use within programs such as the UN-REDD and REDD+. Interest in landscape scale assessments is increasing both as a means of managing landscapes and to overcome some of the barriers and costs of certification. Several certification schemes have joined the Committee On Sustainable Agriculture (COSA) which seeks to analyse the impacts of agriculture at a larger scale, particularly those impacts associated with the implementation of sustainability initiatives (COSA, 2013), and to assess whether the management practices advocated by the schemes do lead to a GHG benefit. This could involve scaling up of the micro level assessments. Therefore more effort is required to guide thinking and to reconcile different calculators, to reduce the potential for misguided actions or investments.

Given the diversity of calculators and the different levels at which they may be used, there is a need for agreement on appropriate methodology and background data and on the necessary level of standardisation or harmonisation between calculators. Issues to be addressed include: consensus on methodological approaches; agreement on and definition of emission factors; guidance on selection and use of underlying data; coverage of environmental impacts or reporting outputs; and collaboration between multiple stakeholders and administering bodies. There have been numerous efforts to standardise GHG accounting and reporting in other areas; examples are ISO guidance, the GHG protocol, PAS2050 and the establishment of IPCC methodologies for national reporting and accounting. Whilst these provide detailed guidelines and frameworks, most offer considerable flexibility for users to account for GHG emissions given their particular situation, level of capability, data availability and required level of detail. For GHG calculators, there is currently no standard or guidance on how they should be constructed, or on referencing and documentation. Most of the calculators reviewed in this research apply many of the standardised approaches defined within the boundaries of IPCC tier 1-3 (IPCC, 2006) but they apply them in different ways; this can lead to a lack of comparability. This is exemplified by the treatment of LUC in the three calculators compared in detail in this work.
Consequently greater understanding is required of the intended application of the calculators, the representativeness they offer in any particular system and increased transparency into their workings and results. While it may not be appropriate to standardise GHG calculators or advocate the establishment of a ‘de facto’ standard, improvements in the reporting outcomes with full transparency of the assumptions and data used in the calculations will help to provide the best results and use them to support the ultimate aim of these calculators: to inform, guide and encourage GHG mitigation from agricultural systems.

As calculators continue to be developed, the implementation of new science and insights could result in further inconsistencies between them. This is further justification for transparency and documentation. It will also aid version control of the calculators e.g. the difference between a v.1 of a tool and subsequent versions which may have improved emission factors or corrections made. The advent of tools available ‘online’ may provide an opportunity for greater transparency and management across calculators than was feasible for standalone versions.

Looking forward, there may be important opportunities for GHG calculators to play a role in informing policy development, contributing to scientific debates and potentially to demonstrate benefits and form part of a business case to farmers for change. One such are that is becoming increasingly important is the discussion around sustainable intensification (SI) (mentioned briefly in Chapter 2), particularly as the pressure to reduce GHG emissions and the impacts of climate change, to relieve the pressure on land and to contribute to increased food security, have risen on the political agenda. Garnett et al., (2013) posit that SI involves increasing the amount of food produced from existing farmland through management practices that have lower environmental impacts and which do not compromise the capacity of the land to continue producing food long into the future. It really refers to the optimisation of current production areas (intensification) and not opening up new land areas for agriculture (extensification). As a concept, SI goes further than simply making current production systems more sustainable, rather it is a radical rethinking of food systems to deliver a wide array of benefits including reduced environmental impacts, improved animal welfare and human nutrition as well as providing improved livelihoods and support for rural and developing economies (Garnett et al., 2013). Burney et al., (2010) estimated the GHG savings of historical agricultural intensification between 1961 and 2005 to be up to 161 gigatons of carbon (590 GtCO$_2$e), despite emissions from fertiliser production and application increasing over this time period, the savings were borne out of the yield gains made. They estimated that every dollar invested in agricultural yields has resulted in avoided emissions of 68kgC (249 kgCO$_2$e) relative to 1961 technology (Burney et al., 2010).

Much of the literature is in broad agreement of the benefits of SI to reduce GHG emissions and contribute to mitigating climate change in a cost-effective way, as well as potentially providing a broader suite of positive impacts related to reduced land clearing and biodiversity loss, improved food security and provision of ecosystem services and positive impacts on our water resources.
(Burney et al., 2010; Garnett et al., 2013; Campbell et al., 2014; Tilman et al., 2011). It does, however, stress that consideration must be taken for the system type, the location, the technology option and investment made in order to minimise/eliminate any potential negative trade-offs that could result (Valin et al., 2013; Garnett & Godfray, 2012). GHG calculators could be used to demonstrate the GHG impacts of SI and if combined with an economic assessment of the farmers’ inputs vs. outputs, could help support a farm by farm case for changing their management practices. This is particularly important in an EU context and one in which many GHG calculators, including the CFT, are well suited for.

4.8 Chapter summary and conclusions

A large number of agricultural farm-based GHG calculators are available and they can differ in many respects. This chapter has provided a structured assessment of three key GHG calculators and provided transparency on differences between them. The calculator comparison was not designed to test the accuracy of the calculators but rather the consistency of the results they produce. It has demonstrated how these calculators can generate different, but typically not perverse, GHG outputs when using the same core input data.

The key conclusions taken from this chapter are as follows:

- Proliferation of agricultural GHG calculators indicates increased interest and need for farm GHG emission estimates; however too many calculators leads to lack of consistency, confusion and challenges in comparability and benchmarking of results. In some cases it may also lead to perversities and mis-information and mis-communication.

- GHG calculators vary considerably in a number of aspects including format, scope, data sources, methodologies and nomenclature and units, making direct comparison difficult.

- The three tools compared in this study were shown to be in broad agreement regarding the GHG emission assessment methods used to estimate farm GHG emissions. However, results can differ by considerable margins when using the same input data, although the results are rarely perverse.

- Differences between the results generated by the different GHG calculators compared in this research are of comparable magnitude to the differences between individual farms. Comparison between farms therefore cannot be based on the results from different calculators.

- With no consensus on GHG emission accounting for agricultural systems, there is considerable flexibility on the values used within a GHG calculator. Key differences between
GHG calculators lie in the underlying data sources, differences in the calculation methodologies employed and overarching differences in approaches.

- Greater flexibility of the user options provided in the tool can enable greater site specificity, but at the potential trade-off of user-friendliness and reliability of results.

- For comparative assessments for a single-crop system or within one supply chain, the same GHG calculator should be applied; otherwise full transparency and detailed understanding of the underlying differences between the calculators are necessary to aid interpretation and comparison of results.

- There may be an important opportunity for GHG calculators to play a role in informing future science or policy debates and potentially in helping to demonstrate the GHG benefits of practice changes e.g. within the sustainable intensification debate.

- There is an opportunity to compare the results of GHG calculators to empirically measured emissions in the field to both a) verify the results being produced by the calculators and b) to continue to improve GHG calculators and the models within them to be more reflective of actual empirical emissions releases. (Such as work that was done involving the CFT towards the end of this project in Richards et al., 2016).
CHAPTER V

FROM FARM LEVEL MANAGEMENT AND ESTIMATION OF GHG EMISSIONS TO PERFORMANCE ASSESSMENT

‘However beautiful the strategy, you should occasionally look at the results’ (Winston Churchill)

This chapter focuses on four case studies which use the Cool Farm Tool (CFT), a GHG calculator, to estimate GHG emissions by farmers, specifically on how the mode of implementation by two FMCG companies affects the ‘quality’ of the results. Some of the views of the farmers and other stakeholders involved in the case studies are included to provide insights into the experiences of different CFT users.
5.1 Introduction

Given that companies are beginning to use GHG calculator(s) within their supply chain to assess performance and to track GHG emissions, this chapter addresses research objective 4, set out in Chapter 1:

4. To understand how the mode of implementation of GHG calculators affects the quality of the GHG emission results from farmers, when used and interpreted by FMCG companies.

Four case studies are assessed based on the application of one specific GHG calculator, the Cool Farm Tool (CFT), in four different contexts. As part of the broad research question posed above, the following specific research questions will be addressed:

I. How can GHG calculators be used to identify on-farm management practices and GHG performance?

II. To what extent can a GHG calculator be used to assess the GHG impacts of certification*?

*specifically the Rainforest Alliance certification.

The chapter is structured as follows: Section 5.2 frames the research agenda of the chapter by defining the key terms being explored and also briefly outlines why a case study research approach is suitable. Section 5.3 presents the four case studies of use of the CFT that form the focus of the chapter and sections 5.4 – 5.6 explore the two research questions I and II posed above, respectively. The findings and insights are then discussed in section 5.7 and the conclusions and recommendations are presented in the final section (5.8).

5.2 Research frame: key definitions and rationale for a case study approach

5.2.1 Key definitions in this research

To answer the research questions requires the key research terms to be defined relevant for this study. These are described in the following sub-sections.

5.2.1.1 Implementation

An important challenge for management lies in the implementation of strategy rather than the formulation of it (Dobni & Luffman, 2003; Epstein & Roy, 2001) and so without successful implementation the intended outcomes of even the most well defined strategy will not be realised. In this chapter, implementation relates to the processes put in place in the deployment of the CFT in the supply chains to the farm level. The different modes of implementation are described for each case study and summarised schematically.
5.2.1.2 Quality of results

The quality of the results is assessed from the perspective of both the recipient of the results (i.e. FMCG Company) and the user (i.e. farmer). It is frequently suggested that assessment of quality should include both qualitative and quantitative criteria/methods (Chen et al., 2014; Pipino et al., 2002). Chapter 2 (section 2.4.2) provided an overview of data quality and a sample of the criteria that might be used to assess it. In this specific research context, the ‘results’ pertain to the ‘GHG emission results’ generated from the use of the GHG calculator. Assessment of the quality of the results, relevant to the FMCG company, is largely subjective but includes quantitative and qualitative criteria based upon:

- Comparison to published GHG emission values and Life Cycle Inventory databases.
- Expert opinion to ascertain if the GHG results look sensible and realistic of the agricultural production system.

For the farmer an assessment is made of the usefulness (or quality) of the results for informing farm management practices and also the user-friendliness. The CFT was designed to increase farmers’ awareness of GHG emissions, inform them about the GHG emissions from their system and provide decision-support in relation to the management practices that can contribute to emission reductions. It is therefore important to understand the value that farmers get from using the CFT and this is based on responses to surveys and interviews conducted during the research period.

5.2.2 Case study research approach

Case studies provide an approach to analyse empirical, qualitative and/or quantitative evidence of real life events. This chapter centres around four case studies in order to explore and learn from the real-life application of the CFT in business contexts. In particular, case studies:

- Permit the exploration of the more explanatory ‘how’ and ‘why’ questions pertaining to some social phenomenon (Yin, 2009).
- Are a recommended research approach when the research area is complex, when theory and experience is limited, and when it is important to consider the ‘context’ of the situation (Cavaye, 1996; Larsson, 1993).
- Can provide insights that are generalizable to ‘theoretical propositions’ to expand and generalise theories but cannot be used to determine facts or statistical frequencies (Yin, 2009). Appropriate use of case studies can therefore allow for certain amount of generalisations from the ‘case’ to be asserted (Abma & Stake, 2001; Ruddin, 2006).

These factors render case studies the most appropriate research approach to answer the questions posed.
5.3 Overview of the four case studies

Table 25 summarises the four case studies in terms of the mode of implementation, the farming systems assessed and the support provided by the FMCG Company to assist in completion of the CFT and validation of the results. The GHG emission results are presented either with respect to yield (kgCO₂e/t fresh product) or on a land area basis (per ha). GHG emissions from production of co-products are excluded. Table 25 also indicates the key emission sources assessed in each case study where known.
Table 25: Overview of the four case studies assessed in this research project.

<table>
<thead>
<tr>
<th>ID</th>
<th>Case Study 1</th>
<th>Case Study 2</th>
<th>Case Study 3</th>
<th>Case Study 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unilever fruit and vegetable supply chain</td>
<td>Unilever supplier specific partnership</td>
<td>Smallholder cocoa farmers</td>
<td>PepsiCo potato supply chain</td>
</tr>
<tr>
<td><strong>Context of CFT use</strong></td>
<td>The CFT constitutes a criterion in the UL SAC as one of the 11 sustainable agriculture metrics required for certification. It aims to help Unilever to demonstrate continuous improvement of the GHG emissions associated with the production of raw agricultural materials. Requirement of the CFT is embedded within Unilever’s Quickfire self-assessment software. It was phased in from a ‘must’ criterion to a ‘mandatory’ criterion and from ‘supplier’ level to ‘farmer’ level between 2010 and 2013. No validation of CFT results performed.</td>
<td>Supplier A is compliant with the UL SAC and thus completed CFT assessments. Supplier A sources from between 230-280 farms each year and a sample of approximately 30 farms are assessed as part of the UL SAC. Expert resource was used to validate results and to analyse yearly trends. Some farms were sampled in multiple years.</td>
<td>A project was established with two Masters students from Chalmers University to explore cocoa supply chains and in particular to assess the GHG emissions of certified smallholder cocoa farmers compared to non-certified smallholder farmers, within a similar geographic area. This provides example of applying CFT in situation where the farmer has limited or no knowledge and capability.</td>
<td>The CFT was used as part of PepsiCo’s carbon reduction commitment ‘50 in 5’. The CFT was amended and developed to be specific to potato production and was used with UK potato farmers to assess the GHG impacts of their production, to set a baseline emission footprint to measure progress, and to inform farmer specific carbon management plans. Expert support for farmers in completion of CFT and in analysis of the results was provided.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Data collection aims</strong></th>
<th>Supplier specific GHG data</th>
<th>Supplier specific GHG data for tomatoes and compared to literature data</th>
<th>Improve understanding of GHG impacts from cocoa smallholders</th>
<th>Supply chain specific GHG data for potatoes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SAC self-assessment compliance</td>
<td>Evidence of continuous improvement</td>
<td>Compare GHG emissions of Rainforest Alliance (RFA) certified farms compared to non-RFA certified farms</td>
<td>Evidence of GHG improvements for PepsiCo’s ‘50 in 5’ commitment</td>
</tr>
<tr>
<td><strong>Crop(s)</strong></td>
<td>Fruit and vegetables (and herbs) including but not limited to, tomatoes, potatoes, onions, carrots, strawberries and basil</td>
<td>Tomatoes (for processing into tomato paste, powder and tomato fibres)</td>
<td>Cocoa beans (for processing into cocoa powder)</td>
<td>Potatoes (for crisp production)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Geographical scope</strong></td>
<td>Global</td>
<td>Spain and Portugal (Extremadura production region)</td>
<td>Ghana, focused on one growing region</td>
<td>Primarily UK focused but some continental European farmers sampled</td>
</tr>
<tr>
<td><strong>Farm type</strong></td>
<td>Mixed range of farmers; large and small, well and poorly managed farms</td>
<td>Well managed farms, high level of mechanisation</td>
<td>Smallholder farmers (&lt;5 ha), typically poorly managed, no energy use/mechanisation</td>
<td>Well managed farms, high level of mechanisation (some very advanced industrial farmers)</td>
</tr>
<tr>
<td><strong>Number of farmers / suppliers assessed</strong></td>
<td>Year 1: 103 suppliers Year 2: 194 suppliers</td>
<td>Year 1: 30 farmers Year 2: 38 farmers</td>
<td>Smallholder farmers: 18</td>
<td>Year 1: 23 farmers Year 2: 62 farmers Year 3: 92 farmers Year 4: 95 farmers</td>
</tr>
<tr>
<td><strong>Supply chain structure</strong></td>
<td>Multi-tiered supply chains e.g. farmer – processor – supplier – Unilever</td>
<td>Short supply chain Farmer – supplier – Unilever</td>
<td>Short supply chain Farmer – Unilever</td>
<td>Short supply chain Farmer – supplier group – PepsiCo</td>
</tr>
<tr>
<td><strong>Support and guidance</strong></td>
<td>• Guidance notes within the Quickfire software • Online live and recorded webinars • Email help requests via third party</td>
<td>• Supplier A sustainability manager for data collection • Committed scientific expertise within Unilever for data analysis • Regular phone/email conversations between Supplier A and Unilever</td>
<td>• Students received basic training on the CFT for the purpose of this study • Additional information provision from Ghanaian organisations including Ghanaian COCOBOD</td>
<td>• Committed expertise from a third party for data collection, auditing and data analysis • Organised supplier meetings and workshops, facilitated discussions and opportunities for training/support for using the CFT</td>
</tr>
</tbody>
</table>

33 The difference between suppliers and farmers is relevant for case study 1 in particular and is distinguished in section 5.4.1.
### Cool Farm Tool version used

<table>
<thead>
<tr>
<th>Cool Farm Tool version used</th>
<th>General CFT: Microsoft Excel CFT V.2 beta</th>
<th>General CFT: Microsoft Excel CFT V.2 beta</th>
<th>General CFT: Microsoft Excel CFT V.2 beta</th>
<th>General CFT: Microsoft Excel CFT V.1 and; Potato specific CFT developed by (Haverkort &amp; Hillier, 2011)</th>
</tr>
</thead>
</table>

### Resource (personnel)

<table>
<thead>
<tr>
<th>Resource (personnel)</th>
<th>Procurement at Unilever</th>
<th>Sustainability Manager at Supplier A</th>
<th>Chalmers University Students</th>
<th>Sustainability Manager at PepsiCo</th>
<th>Third party auditors and data collectors/assessors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Experts from Unilever</td>
<td>Supporting resource at Unilever</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Project timeline

|------------------|---------------------------------------------|---------------------------------------------|-------------|-----------------------------------------------------------------|

### References / further information

<table>
<thead>
<tr>
<th>References / further information</th>
<th>Unilever Sustainable Agriculture Code (UL SAC) (Unilever, 2010b) Implementation rules and farmer sampling strategy (Unilever, 2012b)</th>
<th>Study on UL SAC compliance undertaken in collaboration with this research project (Munoz et al., 2013)</th>
<th>The full study with the Chalmers students is available online (Borg &amp; Selmer, 2012)</th>
<th>More information can be seen online (PepsiCo, 2014)</th>
</tr>
</thead>
</table>

### Stakeholder surveys/interviews

<table>
<thead>
<tr>
<th>Stakeholder surveys/interviews</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Survey results</td>
<td>Procurement personnel at Unilever</td>
<td>Farmer interviews</td>
<td>PepsiCo stakeholder interviews</td>
</tr>
<tr>
<td></td>
<td>Supplier interviews</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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34 Some of the underlying data and algorithms in the CFT were updated and improved for later versions of the CFT after its inception in 2010. Several bug fixes were also implemented in the tool. More detail on the changes made can be seen at: [https://www.coolfarmtool.org/reports/Changes_The_Cool_Farm_Tool_April_2012.pdf](https://www.coolfarmtool.org/reports/Changes_The_Cool_Farm_Tool_April_2012.pdf). The difference in emissions results generated between different versions of the tool could be significant depending on the components of the tool involved in the GHG assessment. It is not important in this research context as there is no direct comparison between GHG emission results from different versions of the tool.
5.4 How does the mode of implementation of the CFT affect the quality of the results?

Case study 1 (Unilever global supply chain – no expert support or validation of results) and Case study 4 (PepsiCo potato supply chain – expert support and validation) involve very different modes of implementation of the CFT and in different supply chains.

5.4.1 Case study 1 CFT implementation: Unilever global supply chain (no support)

The CFT was deployed as part of the self-assessed Unilever Sustainable Agriculture Code (UL SAC). The SAC is owned and administered by the procurement function of Unilever and forms part of the contract of supply for all fruit and vegetable suppliers that are not privy to other third party certification schemes such as Fairtrade, Rainforest Alliance or others (see Chapter 3 and (Keller et al., 2013) for more detail). Tier 1\(^{35}\) suppliers and/or processors (which may be tier 1 or tier 2) and a sample of the farms that supply to them are required to demonstrate a minimum level of compliance to the code in order to achieve ‘sustainably sourced’ status (Unilever, 2010b). The range of criteria within the code required for compliance, including completion of the CFT, differs between the supplier and their farmers:

- **Supplier level** - This includes Tier 1 suppliers and/or processors who supply directly to Unilever. Unilever typically does not purchase raw agricultural materials directly; they purchase processed agricultural products such as concentrates and powders.
- **Farmer level** - This pertains to the farmers within the supply chain that grow and supply the agricultural material to Unilever’s Tier 1 supplier and/or processor. Suppliers typically have numerous farms that they source from in their supply chain, and these may change each year according to crop type, demand and other factors such as crop rotation periods.

A simplified picture of the implementation process of the CFT by Unilever is shown in Figure 34 for 2010 to 2012 (the assessment period of this case study). It summarises the CFT data entry requirements of suppliers and of farmers in the supply chain and highlights at which point in the process that support and guidance provided. It is important to note that it was at the level of the supplier in which the CFT had to be submitted to Unilever i.e. individual farmers were not required to complete and submit a CFT as part of their self-assessment. Each supplier was required to complete a number of CFT assessments per crop/ingredient supplied to Unilever. The number of farmers sampled was dependent upon the size of the supply base and the process for determining this is summarised in Figure 34. The CFT results submitted were required to be ‘representative’ of

\(^{35}\) Manufacturers or retailers often refer to different tiers of suppliers in their supply chain that are usually indicative of the commercial distance in the relationship. A tier 1 supplier in this case refers to the supplier company in which Unilever has a direct relationship with and from whom they buy agricultural products.
the farmers in their supply chain for the crop under assessment. ‘Representative’ was not defined and no further clarifying information was given for this should look like. If a supplier supplied two or more agricultural materials to Unilever e.g. tomatoes and carrots (in some processed form), then they were requested to submit separate CFT results for each crop. The supplier was required to use the CFT and enter the results into an open, single data entry field contained within the online platform that hosted the SAC assessment. The data entry field had no pre-assigned value ranges or alerts in place. Furthermore, the supplier was not required to submit the completed CFT spreadsheet as part of their SAC self-assessment and thus the input data and calculations were not available to Unilever.

Some basic guidance notes were contained within the online platform including: the scope of the farm assessment to be conducted (i.e. to exclude primary processing), the desired reporting units (kgCO₂e/t fresh product), and some basic guidance on the ‘allocation’ of emissions for only the crop under assessment. As shown in Figure 34, some training was provided through two online webinars which were made available for repeated access and aimed to provide support for using the CFT. The first was a simple walk through the tool and basic explanation of how to prepare to complete the CFT; the second provided some further ‘troubleshooting’ support particularly focusing on how to allocate the on-farm energy use in a mixed crop farm, for just the crop under assessment as well as how to represent all fertiliser use in the tool. Further to the basic webinars, guidance and support was limited. Suppliers were, however, able to contact the online platform manager, Muddy Boots if there were any particular issues they were facing but it was not always guaranteed that they would be able to help given their limited experience of the CFT.

There were no checks on the data entered online nor was any explanation on what the data represented provided. Consequently, it was not possible to confirm what the GHG number/CFT assessment provided by the supplier truly represented i.e. whether it was a ‘representative’ or ‘typical’ farmer within their supply chain, a farmer with which they had the best relationship, or a self-completed assessment based on a ‘best guess’ by the supplier. It may also have been one of the supplier’s larger most efficient farmers or conversely one of their worst performing farmers.

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36 If more than one crop was grown on a farm, then emissions allocation per crop was required. Simplistic guidance was provided to do this using an allocation based on mass e.g. division of the fuel used on the whole farm by the relative tonnes produced of the crop under assessment.

37 Muddy Boots are a provider of web-based solutions to manage quality and compliance across the operations and supply chains of food supply businesses. See: http://en.muddyboots.com/
5.4.1.1 Unilever CFT Results

The CFT results from the SAC self-assessment were made available via a download into an excel spreadsheet. Table 26 provides an overview of the results available (in Quickfire) across different crops and countries and years of assessment (for 2011 and 2012), showing that there were 115 CFT results submitted in 2011 and 194 in 2012.

Table 26: Summary of CFT results available from Unilever Supply Chain (2011 and 2012).

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of CFT entries</td>
<td>115</td>
<td>194</td>
</tr>
<tr>
<td>Number of crops represented</td>
<td>33</td>
<td>53</td>
</tr>
<tr>
<td>Countries represented</td>
<td>19</td>
<td>27</td>
</tr>
</tbody>
</table>

*If fewer than 30 farmers, all are assessed. When the number (N) of farms >30 the square root of N farms must be sampled, or 30 farms, whichever is highest.

**What constituted a ‘representative’ farmer was not defined by Unilever.
Figure 35 shows a histogram of all the raw and unedited CFT GHG emission results over both years of assessment for all crops and all countries. This data was extracted directly from the online platform, Quickfire, and had not been checked or audited by any Unilever representatives or third party. Figure 35 also, for illustrative purposes only, includes a range of GHG emission figures from the literature for a range of crops in order to show where the GHG emission values typically lie. This initial overview of the data shows the wide range of the raw GHG emission data collected from the un-audited CFT data collection process. Some of the data values fall within the comparative literature range. These values will likely consist of both valid GHG emission values but also erroneous data entries. Figure 35 also highlights that a large number of the GHG emission values received from suppliers were outside of this literature or expected range including over 90 results with no GHG emission entries, i.e. at zero (out of a total of 309 entries). Overall it indicates that the data is largely of poor-quality. The literature values are based on over 20 sources and include values from crops grown globally (the full list is included in Appendix B) (Milà i Canals et al., 2006; Williams, A. G., Audsley, E., Sanders 2006; Mouron et al., 2006; Milá i Canals et al., 2008; Brentrup et al., 2001; Tzilivakis et al., 2005 and others).

![Figure 35: Histogram of all 309 CFT entries (all crops, countries, assessment years).](image-url)
This analysis highlights the overall poor quality of many of the results and it necessitated removal/exclusion of a large number of entries prior to further analysis. Reasons for exclusion included:

1. *Blank entries* – a large proportion of the entries are entered as 0 or as non-applicable (NA) and thus constitute blank entries.

2. *Duplicated entries* – evidence of duplicated entries. In some cases a supplier has entered the same CFT value for several different crops. In other cases different but affiliated suppliers (e.g. different processing units under one umbrella supplier) have entered the same CFT value. In addition some suppliers have entered the same CFT value across the two years of the assessment.

3. *False entries* – some entries were immediately considered to be false such as those stated as 98765432.1 and 1234567.89.

Some examples of the types of poor quality of results submitted by various suppliers is shown in Table 27.

### Table 27: Examples of poor quality results for case study 1 and the data quality issues identified.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Country</th>
<th>Crop</th>
<th>Year</th>
<th>CFT result (kg CO$_2$e/t)</th>
<th>Data quality Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>Processor a</td>
<td>Belgium</td>
<td>Carrots</td>
<td>2012</td>
<td>780</td>
</tr>
<tr>
<td>Processor b</td>
<td>Belgium</td>
<td>Celeriac</td>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processor c</td>
<td>Portugal</td>
<td>Celery</td>
<td>French beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier 1</td>
<td>Processor b</td>
<td>Belgium</td>
<td>French beans</td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Supplier 1</td>
<td>Processor c</td>
<td>Portugal</td>
<td>Onions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier 2</td>
<td>France</td>
<td>Sweet pepper</td>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier 3</td>
<td>United States</td>
<td>Courgettes</td>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier 4</td>
<td>China</td>
<td>Garlic</td>
<td>2012</td>
<td>123456.79</td>
<td>False result</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>France</td>
<td>Celeriac</td>
<td>2011</td>
<td>920</td>
<td>Duplicated results for each assessment year</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>United States</td>
<td>Broccoli</td>
<td>2011</td>
<td>0</td>
<td>Results entered as zero or left as blank.</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>China</td>
<td>Tomato</td>
<td>2012</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 36 looks closer at the results for tomatoes specifically, produced globally, showing box and whisker plots of the ‘cleaned’ supplier results (18 data entries) in comparison to a number of literature values for tomato production globally (Andersson et al., 1998; Antón et al., 2014; Jones et al., 2012; Karakaya and Özilgen, 2011; Muñoz et al., 2007). The full list of literature values for tomatoes used as a comparison can be seen in Appendix C. The cleaned results set excludes duplicated entries, blank or zero entries and any values over 2,500 kgCO$_2$e/t fresh product as these were deemed to be outside of a realistic range but would still include some very high values that might be possible e.g. if LUC had occurred (King, H, personal communication, November 8, 2014). Figure 36 demonstrates two key points; firstly it shows the limited number of GHG values available for assessment for tomato production globally, from the Unilever supply chain dataset. It would of course be useful to assess results for tomato production on a per country and per year basis but there are simply not enough values to get a useful analysis. Secondly and most significantly, Figure 36 demonstrates the difference in the range of results by the supplier compared to the available published literature. It shows that within the results produced by suppliers there are some values that ‘fit’ or are closer to what is ‘expected’ based on the literature. It also shows that the median values of the Unilever supplier results are, in fact, very similar to the median of the literature values. The main difference in the two value sets is in the upper and lower extremes. Without further transparency and information from the suppliers it is not possible to analyse these any further.
A fundamental problem with Unilever’s approach in collecting GHG values from its suppliers and their farmers was the lack of transparency on the data collected and used to calculate the GHG emission values. The data collection process left no room for any supporting information to be provided and throughout the process there was no validation of the results undertaken. In case study 2, Unilever established a partnership with a supplier of tomato products who used the CFT to assess the GHG impacts of the tomato production stage. The supplier assessed 30 of their farms using the CFT and sent the results to Unilever to review. The review revealed inconsistencies in the way the supplier had modelled the amount of fertilizers applied, leading to a substantial
overestimation of the GHG emissions. Instructions were given to the supplier on how to correct the calculations to represent fertilizers more accurately and the 30 corrected CFT files were re-sent to Unilever; Figure 37 shows the GHG emission results for the 30 farmers before and after review. It illustrates the effects of an error in modelling of fertilisers on the results for tomatoes. Figure 37 demonstrates the significance of the potential error in emission estimates without both transparency on the input data used and validation (checking) of the results. It shows that the initial numbers were overestimated by a factor of up to 10 times. These errors were mainly caused by modelling phosphorus and potassium fertilizers as nitrogen-containing fertilizers, resulting in a large overestimation of nitrous oxide ($N_2O$) emissions which have a significant impact on the overall emissions footprint ($N_2O$ is 298 times as potent as $CO_2$).

![Figure 37: GHG emissions for the 2012 farmer sample from Supplier A (Case study 2)](image)

5.4.1.2 Survey of Unilever suppliers

Figure 38 shows the results for two questions from a survey conducted with 80 Unilever fruit and vegetable suppliers completing the UL SAC assessment (and responsible for collecting the data and completing the CFT assessments for farms in their supply chain). The first question asked the suppliers to state how easy they found the CFT to complete on a scale from 1 being easy to 5 being very difficult. There was also a ‘non-applicable’ option available here. The second question pertained to how useful suppliers found the CFT assessment rated 1 being very useful to 5 not useful at all.

No supplier stated that the CFT was ‘very easy’ to use and the majority, 64%, said that it was somewhat to very difficult to use (rankings 3 – 5). Approximately 40% rated it as somewhat useful to very useful (rankings 1 – 3) and just over 15% said it was not useful at all. Interestingly, despite the
requirement for suppliers to complete the tool in order to comply with the SAC, approximately a quarter of respondents answered ‘not applicable’ to both questions suggesting that they didn’t believe the CFT was relevant to them. This may also potentially explain some of the questionable results entered for the CFT (as described earlier) as some suppliers may not pay much attention to the CFT and provide a ‘blank’ or random data entry.

Figure 38: Survey results for two questions about the ease of completion of the CFT (1) and the usefulness of using the CFT (2) from 80 Unilever suppliers (2012).

The CFT is designed to be ‘farmer-friendly’, however, one of the early lessons that Unilever learnt during its implementation was the difficulty that suppliers and farmers encountered in completing the tool. For many it was the first time they were providing information of this kind and calculating their GHG emissions. Additionally, many were uncertain as to the value of the information for their farm management. Some suppliers questioned the tool:

“I don’t have time to provide all the data inputs for the Cool Farm Tool, I find the process and the software very opaque. The tool doesn’t work for my system, it seems that minor input changes can have very significant impacts on the results, I can just choose the lower impact option.”
(Unilever Supplier, 2012)

Some suppliers, however, did find the CFT useful:

“Initially it took a lot of time to understand it [the CFT] and learn about the inputs needed. Typically I would do some preparation on what I need to ask my farmers and then spend about 30-40 minutes on the phone to my farmer and then take about an hour afterwards to process this and put it into the tool. I would do an assessment typically once a year or if a major change in practice had occurred, or if I wanted to look at a different scenario. It helped me understand what my farmers were doing.”
(Unilever Supplier, 2012)
5.4.2 Case study 4: Implementation by PepsiCo with potato farmers (with support)

Agricultural raw materials are a core requirement of PepsiCo-UK’s operations constituting key ingredients for a range of their products and brands; Quaker (largely comprising cereal products), Walkers crisps (potatoes), Pepsi beverage cans, (sugar), Copella juices (apples) and Tropicana (oranges). PepsiCo launched their ‘50 in 5’ commitment to reduce the GHG emissions by 50% over 5 years from 2010 – 2015 (as described in Chapter 2) (PepsiCo, 2010). They were one of the earlier companies to assess the life cycle GHG emissions of one of their products. They selected a packet of crisps under their Walkers brand, one of the most lucrative brands for the company in the UK, and for which they source approximately 370,000 tonnes of potatoes annually. Calculation of the GHG footprint revealed that over a third of the GHG emissions, around 36%, were generated in the agricultural production stage (Walkers, 2009). This included the manufacture and on-farm impacts of fertilisers and pesticides and the energy used in farm management. To meet the 50% reduction target PepsiCo therefore realised that they would have to engage and work with their agricultural supply chain.

They opted to use the CFT with their UK potato suppliers; they adopted a very different implementation approach to that used by Unilever shown in the previous case study. PepsiCo’s supplier base for Walkers crisps is comprised of a limited number of supplier groups through which they source raw materials directly. Consequently PepsiCo does not often deal with individual farmers but instead with the head of various farmer groups. It is therefore, closer to the farmer in the supply chain than Unilever which typically works with processors of raw material ingredients.

Figure 39 provides an overview of the implementation of the CFT within PepsiCo’s UK potato supply chain for 2010 to 2013. This schematic shows some of the key implementation factors of PepsiCo’s deployment of the CFT. In particular:

- **Adaptation of the CFT** - after some trial uses of the general CFT with farmers in the first year (2010), PepsiCo identified a need to make the tool more specific to potato production to better represent their suppliers for subsequent assessments (Haverkort & Hillier, 2011).
- **Third party support** - PepsiCo commissioned the help of an agricultural specialist consultancy group to work on the ground with the farmers, providing one-on-one training and help to complete the CFT.
- **Supplier workshops** – PepsiCo identified a need to engage and motivate the farmers to use the CFT.

The above activities involved considerable resource investment in the implementation programme for engaging with farmers to help them to understand and complete the CFT. PepsiCo have a long history with many of their suppliers and in many cases have good, trusting relationships with
individual farmers and farmer families; many are considered to be heritage growers i.e. they have supplied PepsiCo over several generations.

5.4.2.1 PepsiCo CFT results

Table 28 shows the number of potato farmers submitting CFT results over a four year period, indicating the progressive increase in the number of farmers assessed. It should be noted, however,
that the scale of the programme in terms of the number of suppliers/farmers reached was much smaller than that of Unilever.

Table 28: Summary of number of farmers submitting CFT results to PepsiCo (2010 - 2013).

<table>
<thead>
<tr>
<th>Year of assessment</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of farmers submitting CFT results</td>
<td>23</td>
<td>62</td>
<td>92</td>
<td>95</td>
</tr>
</tbody>
</table>

PepsiCo source some different varieties of potato to make up their Walkers crisps range. Figure 40 shows the weighted average GHG emissions in relation to the proportion of each potato variety sourced therefore constituting a good representation of their supply chain. Figure 40 shows the GHG emission results for four years of production from 2010 to 2013 and the results show the GHG contribution from each GHG source. The results have been calculated using the potato specific CFT and are based on a standardised yield of 45 t/ha in order to remove the seasonal variability experienced each year; the storage time has also been standardised to 80 days (S. Wynn, personal communication, January 5 2015). The results in Figure 40 visually demonstrate the inter-year variability in the GHG emissions, which is likely due, in part, to the varying climatic conditions faced each year. Looking closer at the results, it is interesting to compare the mean GHG emissions from each year with a standardised yield both unweighted and weighted by the potato variety proportion sourced. These results along with the standard deviation are shown in Table 29. There was a statistically significant difference between years as determined by one-way ANOVA \((F(3,268) = 16.42, \ p = 0.0000000008)\) therefore demonstrating that there is a statistical significant different between at least two of the means. These results here, and the evidence from observing the data in Figure 40, indicate an overall downward trend in the GHG emissions from potato production over time, suggesting that there is good progress on GHG mitigation.

Table 29: PepsiCo GHG emission data over years (unweighted and weighted by potato variety) in kgCO\(_2\)e/t.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sample size</th>
<th>Unweighted arithmetic mean (kgCO(_2)e/t)</th>
<th>Weighted arithmetic mean (kgCO(_2)e/t)</th>
<th>Unweighted arithmetic standard deviation (kgCO(_2)e/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>23</td>
<td>106</td>
<td>123</td>
<td>29</td>
</tr>
<tr>
<td>2011</td>
<td>62</td>
<td>94</td>
<td>99</td>
<td>25</td>
</tr>
<tr>
<td>2012</td>
<td>92</td>
<td>128</td>
<td>111</td>
<td>23</td>
</tr>
<tr>
<td>2013</td>
<td>95</td>
<td>81</td>
<td>77</td>
<td>24</td>
</tr>
</tbody>
</table>
As well as the aggregated results like those in Figure 40, it can be useful to look at the raw data for each individual farm. In particular, it is interesting to look at the results for 2010. In this first year of implementation of the CFT, the general CFT (version 1), was deployed to assess farm GHG emissions and thus was limited by the GHG emission sources included in this version (see Chapter 4 or Keller et al., 2014 for more detail). The input data from all the farms assessed in this year were then retrospectively entered into the potato-specific CFT once it was developed in 2011. Figure 41a and b show the results from these assessments by the general and the potato-specific versions of the CFT, respectively. Fewer GHG emission sources are assessed in Figure 41a compared to Figure 41b due to the different features of the tools which results in different GHG emission results for the same farmer in the same year. The average GHG emission result from the GHG assessment using the general tool is 80 kgCO₂e/t potato compared to 111 kgCO₂e/t, a difference of around 32% (the geometric mean using the general tool is 77 kgCO₂e/t compared to 108 for the potato specific CFT). The latter result is closer to published GHG emission estimates for potato production (116 – 240 kgCO₂e/t) (Ecoinvent, 2007; Moudry, Jr. et al., 2013; Williams, A. G., Audsley, E., Sanders, 2006) including some PepsiCo commissioned studies (Table 30). The standard deviation for the results from the general CFT is 20 kgCO₂e/t compared to 29 kgCO₂e/t for the potato specific CFT, indicating that there is a greater spread of the range of emission values when using the potato specific tool; this is evident in Figure 41.
Using a paired t-test, shows that the means from the two different CFTs are significantly different \( t(22)=4.38; p=0.0002 \). This significant difference in results seen here, re-iterate the challenges of comparing results that have been generated using different GHG calculators, or in this case, different versions of the same calculator but that have different scopes and differing levels of specificity. This supports the results from the previous chapter. The results shown here demonstrate how additional specificity and greater inclusivity of more emission sources can significantly affect the GHG emission results obtained. Additionally, more information across a larger range of GHG emission sources is useful to be able to observe the variability in the GHG emission profiles between the farmers.
Figure 41: GHG emission results from CFT for PepsiCo potato farmers in 2010: a) using the General version of the CFT; b) using the adapted potato specific CFT.
Table 30 summarises the average GHG emissions from PepsiCo’s farmers in 2010-13 calculated with the CFT in comparison to the GHG emission values from two previous studies sponsored by PepsiCo. The GHG emission results calculated by the CFT, particularly when using the potato-specific version of the tool, were very similar to the results generated by the two commissioned studies which were based on a much more limited sample dataset. This provided PepsiCo with the initial confidence that the CFT could provide good quality emission estimates representative of their supply chain and would allow them to demonstrate year on year results. Unfortunately, further statistical analysis to compare the differences between these GHG emission estimates was not possible due to lack of access to the primary data.

Table 30: Comparison of GHG emission estimates calculated by the CFT and from two other studies.

<table>
<thead>
<tr>
<th>Responsible body / approach used</th>
<th>Average farm-gate GHG emission estimate (kg CO₂e/t potato)</th>
<th>No. of farms</th>
<th>Calculation methodology / tool</th>
<th>Year of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>PepsiCo-CFT general</td>
<td>80 / 111</td>
<td>23</td>
<td>CFT v.1 (General tool), subsequently entered into potato specific tool</td>
<td>2010</td>
</tr>
<tr>
<td>PepsiCo-CFTpotato</td>
<td>123</td>
<td>23</td>
<td>CFT Potato specific</td>
<td>2010</td>
</tr>
<tr>
<td>PepsiCo-CFTpotato</td>
<td>104</td>
<td>61</td>
<td>CFT Potato specific</td>
<td>2011</td>
</tr>
<tr>
<td>PepsiCo-CFTpotato</td>
<td>112</td>
<td>92</td>
<td>CFT Potato specific</td>
<td>2012</td>
</tr>
<tr>
<td>PepsiCo-CFTpotato</td>
<td>77</td>
<td>95</td>
<td>CFT Potato specific</td>
<td>2013</td>
</tr>
<tr>
<td>PepsiCo and The Carbon Trust&lt;sup&gt;a&lt;/sup&gt;</td>
<td>142</td>
<td>1</td>
<td>Carbon Trust Methodology</td>
<td>2008</td>
</tr>
<tr>
<td>PepsiCo and PE International&lt;sup&gt;b&lt;/sup&gt;</td>
<td>111</td>
<td>2</td>
<td>Gabi LCA tool&lt;sup&gt;38&lt;/sup&gt;</td>
<td>2008</td>
</tr>
</tbody>
</table>

<sup>a</sup> The Carbon Trust calculated the carbon footprint of a packet of Walkers crisps (Walkers, 2009); <sup>b</sup> PE International calculated the GHG emissions of UK potatoes using their Gabi LCA tool that utilised 2 UK farm data sets (Keller et al., 2011b).

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<sup>38</sup> Gabi is a life cycle assessment tool suitable for calculating product carbon footprints. More can be seen here: [http://www.gabi-software.com/](http://www.gabi-software.com/).
5.4.2.2 PepsiCo implementation insights

After initial conversations with some of the farmers, PepsiCo saw that several farmers failed to understand the connection between GHG emissions (carbon, as it was communicated to farmers) as a measurement indicator of becoming more sustainable. Therefore additional resources were deployed to help facilitate the adoption of the CFT by increasing their understanding of GHGs and climate change and how GHG emissions related to the management practices they employed on their farm. As described by the Head of Agricultural Sustainability at PepsiCo:

“Getting the growers to engage has been a challenge – we need to push and push and communicate the why all the time.”

For PepsiCo, the CFT helped to deepen the relationship with its already established potato suppliers. Integrating environmental concerns within the context of the commercial relationship resulted in an increase of shared information, enhanced communication and the development of a collaborative approach to farm environmental management. One PepsiCo grower noted:

“We didn’t know why PepsiCo were asking us for this information at first and thought they might forget about it after 1 year but they kept asking again and now we really see the value in it. We understand where the GHG emissions are coming from on our farm and can compare ourselves to other similar growers, which helps us to improve further. It seems to keep them [PepsiCo] happy too.”

The good quality data gathered through the use of the CFT enabled PepsiCo to create a baseline GHG impact of UK potato production, which they could use to assess the progress towards their aim of reducing their carbon emissions by 50% in 5 years. In addition to facilitating the collection of GHG data that previously had not been collected from their own supply chain, the CFT played a key role in supporting the transition towards more environmentally conscious farming practices and increasing farmers’ awareness of GHG emissions.

5.5 How can GHG calculators be used to identify on-farm management practices and their contribution to GHG performance?

This section draws on case study 2 to explore how the results collected from a number of farmers from the same geographic location and under the same management performance requirements (set by the processing company [Supplier A] and by Unilever), can be used to improve understanding of individual on-farm management practices. It builds on the findings of case study 4 (PepsiCo potato supply chain) but relates specifically to Unilever and one its processors of tomato ingredients.
5.5.1 Use of the CFT to assess annual GHG performance of tomato production in the Extremadura region

Tomatoes are one of Unilever’s top 10 agricultural materials. They use about 6% of the world’s industrially processed tomatoes (Unilever, 2014d); they are an important ingredient in several products within Unilever’s savoury product category including the Knorr and Bertolli brand product ranges for soups, stocks and sauces. Case study 2 describes a partnership that was established between Unilever and one of their key suppliers (Supplier A) of tomato based ingredients (e.g. tomato paste, powder and tomato fibres). Supplier A has tomato production operations focused in the Extremadura tomato growing region in Western Spain, with some additional farmers located across the border in Portugal as shown in Figure 42. The tomatoes were field-grown tomatoes suitable for processing into powder, paste and tomato fibres. Supplier A’s farmers typically plant their tomato crop from end of February to April. Harvesting of the crop is between September and October. Tomato cultivation typically requires warm weather conditions, well drained soils with a sufficient soil organic matter (SOM) content and requires fertiliser inputs, pesticides (if relevant) and between 2.5 and 3.5 cm of water per week, either as rainfall or via irrigation.

Supplier A is a proactive supplier with their own sustainability goals, including GHG related reduction targets. They therefore had a good understanding and capability in this area and it provided a good opportunity for engagement to assess the GHG impacts of their farmer base. Figure 43 provides a schematic of the implementation approach of the CFT under case study 2 and demonstrates the relatively short supply chain structure and relationship that was established through the partnership i.e. Unilever – Supplier – Farmers. CFT data was collected from the farmers by Supplier A and then sent to Unilever to be analysed and the results were fed back to Supplier A and their farmers. This case study required the establishment of a good relationship between Unilever and the supplier with effective and frequent engagement and support.

Supplier A has not been identified here for confidentiality reasons.

Supplier A have their own GHG reduction targets specifically focusing on reducing emissions from energy use and consumption of fertilisers and will compare GHG emission footprint figures year on year.
Figure 42: Approximate locations of the farmer sample (2013)

Figure 43: Schematic of the implementation of the CFT from Unilever to Supplier A and the Spanish tomato farmers (Case study 2).
Supplier A source from between 230 – 280 farms each year. The numbers and farmers may change each year depending on demand, changes in contracts or crop switching i.e. some farmers may grow different crops or crop varieties to meet the demand/price of the wider market place or because they are in a rotation period. As indicated in Figure 43 a random sample of farms in Supplier A’s supply chain were selected to complete a CFT assessment using the formula outlined in Unilever’s scheme rules (Unilever, 2012b). A representative from Supplier A responsible for delivering their own sustainability commitments, was tasked with data collection and farmer engagement, thereby ensuring a consistent approach to data collection from all the farmers. They engaged directly with the farmers and any associated agronomists, supported data provision for the CFT, and took the responsibility to ‘fix’ or provide defaults into the CFT where appropriate (e.g. described specific fertilisers that were used by the farmer sample for use in the CFT). The farmers were all subject to the same management performance requirements set by their buying companies, both the processor company, Supplier A, and by Unilever as part of the SAC certification requirements. They were all located in a very similar area as shown in Figure 42 and thus were subjected to similar environmental and climate/weather conditions, and although the soil properties differed between farms, the difference was not substantial across farms e.g. pH didn’t vary by more than 3 (between 5.5 – 8.5) (though this does have an impact on the GHG emissions as described in Chapter 2 and demonstrated in Chapter 4). Furthermore they all had access to very similar resources i.e. fertiliser products and production technologies. On this basis they were assumed to be a fairly homogeneous set of farms (Gomes et al., 2012).

Data collected using the CFT for each farmer included yield, area harvested, soil properties (texture, organic matter content, moisture, drainage and pH), material inputs (fertilisers, pesticides), energy carriers (fuels, electricity), and field emissions. LUC emissions were not included in the assessment because, according to Supplier A, there had been very little change in the use of land in their farming region since the 1960’s. Yield data collected represented the ‘harvested yield’ and therefore captured the crop that was removed from the field to go for processing.

Figure 44 shows the GHG results for 30 farms in 2012, representing 45% of the total tomato production processed by Supplier A for Unilever. The GHG emission results are shown by the contribution from the different farming activities assessed. The results for farm 30 are entered twice (i.e. 30 and 31) and this corresponds two different areas on the farm. In the area denoted by 31, the GHG emissions per tonne of fresh tomato are considerably higher than for the other area on the farm denoted by 30. The cause of this was a problem with the irrigation system which resulted in a lower yield (29 tonnes tomato/ha) and hence a higher GHG footprint per tonne of product for 31. Area 31 with the highest GHG emissions per tonne fresh tomato (146 kg CO₂e/t) and the lowest yield per ha (29 t/ha) can be contrasted to farmer 4 who had the lowest emissions (33 kgCO₂e/t) and the highest yield (95 t/ha). Figure 44 shows that area 31 with irrigation issues is the worst performer in
the farmer sample, whereas area 30 that didn’t suffer those issues performed very well with GHG emissions among the lowest in the sample (47 kg CO$_2$e/tonne tomato). The average of the two plots and overall value for this farmer would therefore be 97 kg CO$_2$-eq/tonne tomato, largely driven by the poor performance on area 31. This demonstrates the importance of yield when considering the GHG emissions. The farmer with areas 30 and 31 is particularly interesting as it demonstrates that a farmer who is compliant with the SAC can perform relatively poorly when one particular management practice goes wrong i.e. the technical problems experienced with the irrigation equipment.

![Figure 44: GHG emissions from 30 farmers in 2012 (CO$_2$e/tonne fresh tomato) (the mean is represented by the orange bar. Mean = 65; S.D = 18).](image)

Figure 45 shows the individual farm results for 2013 of 38 farmers. Two farms have considerably higher emissions relative to the others; farm 13 which had a particularly low yield and farm 27 where very large quantities of compost were used as a fertiliser. The compost was comprised of sheep farmyard manure modelled at 0.7% N and poultry layer manure modelled at 1.9%N. It was applied in large quantities (kg/ha by weight) and at level, 20 to 40 times higher than a comparable
synthetic fertiliser, respectively. It is estimated from the CFT that farmer 27 applied approximately 2.5 times as much N as other farmers for no apparent benefit to the yield (farmer 27 had a yield of 68 t/ha compared to an average across the farmer sample of 79 t/ha).

The mean GHG emissions for the farmer sample in 2012 (excluding the additional poor performing farm area with the irrigation issue) was 65 kg CO₂e/t in comparison to 74 kg CO₂e/t with standard deviations of 18 and 25 respectively (2 significant figures). Comparing the means of the two years in a 2-tailed T-test show that they are significantly different from each other (t(65)= -2.06; p=0.044) and therefore that 2013 was a worse performing year for GHG emissions. Without further detail at this stage it is not possible to determine why.

Figure 45: GHG emissions per tonne for fresh tomatoes for the 38 farmers in the 2013 sample (kgCO₂e/t fresh tomato) (the mean is represented by the orange bar. Mean = 74; S.D = 25).

5.5.1.1 Assessment of farm performance over time.

The sampling rules defined in the Unilever scheme rules are designed to assess a random sample of farms within the supply chain and to avoid sample bias. This makes analysis of individual farms over time difficult. 9 farms (designated 1-9), however, were common in both sampling years (2012 and 2013 and designated A and B, respectively on Figure 46). Figure 46 compares the GHG emissions of
the 9 repeated farmers across the two years. It shows that for most farmers the emissions in 2013 were higher than in 2012. The exception is farmer 8 where the emissions were over 10 kg CO$_2$e/t higher in 2012 than in 2013.

The mean\textsuperscript{41} GHG footprint of the 9 farms in 2012 was 67 kg CO$_2$e/t compared to 77 kg CO$_2$e/t in 2013 and with standard deviations of 14 kgCO$_2$e/t and 10 kgCO$_2$e/t (2 significant figures) respectively. A paired t-test showed that the GHG emissions of the 9 farmers between 2012 and 2013 were not significantly different: $t(8)=-1.55$ ; $p= 0.16$ (i.e. $p>0.05$). Despite this, there does seem to be a slight overall trend for higher GHG emissions in 2013 compared to 2012 which might be explained, at least in part, by environmental conditions.

Figure 47a shows the rainfall data collected by Supplier A and representative of the growing region being assessed compared to trend data over the period 1990 - 2009 for the same region (Figure 47b) \textit{(N.B. notice the different units on the two graphs for the comparison)}. This data shows that 2012 was representative of a ‘typical’ year whereas in 2013 farms experienced higher than average precipitation levels during the months of January to March, when transplanting of the tomato crop occurs. The heavier rain in 2013 delayed planting by several weeks (Supplier A, personal communication, October 4 2013) and also resulted in additional applications of fertilisers to help the plants reach full maturity by the scheduled harvest time. The difference in emissions over the two years was not significant, therefore indicating that the difference in precipitation across the two years did not have a significant impact on the GHG emissions. Further analysis of the GHG emission data over a longer time period is needed to better understand the effects of weather/climate on the GHG emissions.

\textsuperscript{41} The geometric mean was used in this case because it better indicates the central tendency or typical value of a set of numbers by using the product of their values rather than their sum (as is the case in the arithmetic mean). This means that it is less influenced by the presence of a few extremely small or large values.
Figure 46: Comparison of the GHG emissions for the repeated tomato farmers in 2012 and 2013 (kgCO$_2$e/t fresh tomato) (p>0.05).

Figure 47: a) monthly rainfall data for the growing area collected by supplier A, b) average monthly rainfall and temperature 1990 - 2009 (taken from: worldbank.org).
As demonstrated by Figure 45 the GHG emissions per tonne of fresh tomato are highly dependent on the yield. Of course the yield is highly dependent on the quality of the management practices but still a farmer may be unlucky and suffer from a poor yield despite their best efforts. To look closer at the results and any particular management changes that may have occurred, it is useful to look at the results on a land area basis (per hectare) which eliminates the impact of yields. Figure 48 shows the emissions for fertiliser production and N₂O emissions from soil application per hectare (ha) for 2012 and 2013. In the majority of cases, more N fertiliser was applied in 2013. However in the case of farms 4, 7 and 8, the GHG emissions from fertilisers per ha decreased slightly between 2012 and 2013 which seemed not to impact the yield significantly (there was a slight reduction in yield for farms 4 and 7, but a slight increase for farm 8). Figure 48 presents similar results for the emissions from energy use (primarily diesel but some electricity is included also) on a per ha basis for the two assessment years. This graph shows that for most farms there was an increase in the energy emissions per ha of land in 2013 compared to 2012. This may be a reflection of increased fertiliser application (more energy used in field operations to apply it) or due to greater energy expenditure in field operations due to the wetter conditions experienced in 2013. However, without further information it is not possible to ascertain this level of detail.

Figure 48: GHG emissions per ha for fertiliser production and application for the 9 farmers with 2 years of data (kgCO₂e/ha).
Figure 49: GHG emissions per ha for energy use for the 9 farmers with 2 years of data (kgCO₂e/ha).

5.6 Case study 3: Smallholder cocoa farmers (low capability with some support)

The smallholder cocoa farmer study represents an example of the implementation of the CFT in a situation where the intended user has very limited knowledge and capability with the tool. The case study was designed, primarily, to compare the GHG performance of Rainforest Alliance (RA) certified to non-certified farms in a single year study of Ghanaian cocoa farms using the CFT in collaboration with some Masters students at Chalmers University of Technology in Sweden.

5.6.1 Use of CFT to assess certified and non-certified smallholder cocoa producers in Ghana

Cocoa is another of Unilever’s top 10 raw agricultural materials (see Chapter 1); it is a key ingredient in the refreshment category for ice cream products such as Magnum, Cornetto and Ben and Jerry’s ice cream products. The Magnum brand, in particular, made a public commitment to source 100% sustainable cocoa by 2015 by partnering with the Rainforest Alliance (RA) to cover assure sustainable certification of the cocoa purchased.

Cocoa is a tree crop that grows well in tropical regions with lots of sunlight and high levels of rainfall. It is a tropical understory plant that grows well under canopy-forming native or planted trees, typically called shade trees, as these can reduce physiological stress, increase yields over the long term and reduce the risks from pests (Tscharntke et al., 2011). Shaded cocoa, combined with certain
soil conditions and rainfall patterns, may yield for 60-100 years compared to around 20 years for unshaded cocoa trees (Ruf & Zadi, 1998). The presence of shade trees plays an important role in carbon sequestration both above ground in the tree biomass but also below ground in the soil through continuous deposition of plant residues (Schroth et al., 2014) and this may be increased with shade tree species diversity (Richards & Méndez, 2014).

90% of cocoa produced globally comes from smallholder farmers, i.e. farms with up to approximately 5 ha of land (ICCO, 2011) and in Ghana the average cultivated cocoa farm is 1.24 ha (Borg & Selmer, 2012; Obiri et al., 2007). These farms are often family run, have low levels of mechanisation and thus a high dependence on manual labour; they may be poorly managed; and are usually part of more diverse agroforestry or inter-cropped systems with crops for subsistence including plantain, cassava and maize, as well as other naturally occurring tree species as well as often including the rearing of livestock (Obiri et al., 2007). The Ivory Coast is the largest cocoa producing country, followed by Ghana and Nigeria (ICCO, 2011). As indicated in Chapter 1, Unilever have a goal to engage with at least 500,000 smallholder farmers in their supply chain network, aiming to help them improve their agricultural practices and ultimately improve their livelihoods. Dominated by smallholder production, cocoa is one of the raw materials in which engagement with smallholder farmers is essential.

There have been very few studies conducted on the GHG impacts of cocoa farming. One study by Ntiamoah & Afrane (2008) performed a life cycle assessment (LCA) of cocoa production and processing in Ghana. The GHG impact was 0.365 kgCO$_2$e/kg of processed cocoa bean. Little information is provided about the practices of the farms in this study and with no mention of certification (therefore assuming that they are non-certified farms).

In case study 3, the CFT was used to assess the GHG emissions directly related to cocoa production of 18 smallholder farmers in Ghana; it did not include any GHGs associated with livestock or other crops grown on the farm. This study was undertaken in collaboration with Masters Students at Chalmers University, between 2012 and 2013 as indicated in Table 25. All farmers were located in Central Region, one of the six main growing areas of Ghana indicated in Figure 50. The farmers were not all located within the exact same growing area but were in neighbouring districts and were subject to similar environmental conditions (Borg & Selmer, 2012). They represented a mix of Unilever supply chain farms and some that do not supply to Unilever. The farms were classified into three groups depending on their prior level of experience in working on sustainability projects (e.g. awareness and training programmes; management interventions) and their RA certification status:

**Farmer group 1**: RA certified in 2010. Part of sustainability projects since 2008 (8 farms).
**Farmer group 2:** Non-certified farms with no experience in working on sustainability projects, but located near to certified farms (6 farms).

**Farmer group 3:** RA certified farms in 2010. No previous sustainability project work (denoted as newly certified) (4 farms).

A non-certified farm may represent a ‘conventional’ farm i.e. that which relies on intensive inputs of synthetic chemicals to increase yields and allow for out of season growth etc.; a poorly managed farm; or one that implements good agricultural practices but simply has not been certified against an environmental certification scheme. Where possible clarification on the characteristics of the non-certified farms being assessed is described.

Figure 51 provides a schematic representation of the implementation of the CFT with these three groups of farmers. It demonstrates the relationships involved and the way in which the CFT was completed. The two Chalmers University students were trained to use the CFT for the purpose of this study and the CFT data input requirements were transcribed into a series of interview questions for ‘offline’ use due to a lack of computers and computer illiteracy. An outline of the questionnaire is in Appendix D. CFT data inputs from farmers were compiled using a combination of farmer responses, on-farm observations and some alternative data sources where information was lacking.
Figure 50: The six main cocoa-growing regions of Ghana indicated below the red line; Brong-Ahafo, Ashanti, Western, Central, Eastern and Volta. The red circle indicates the location of the farmers assessed in this study. [Adapted from: (Borg and Selmer, 2012)]

Figure 51: Schematic representation of the implementation of the CFT within Case Study 3.
5.6.2 Results

Figure 52a show the average yields of the three farmer groups; each is higher than the national average of Ghana at around 0.4t cocoa bean/ha (Aneani & Ofori-Frimpong, 2013) but neither farmer group yield average is near the potential achievable yields of around 1 to 1.5t/ha (FAO, 2005; MOFA, 2007). The certified farmers in group 1 have the longest experience in working on sustainability projects have the highest average yield. There is very little difference in average yield between farmer groups 2 and 3.

Figure 52b shows the average GHG emissions for the three farmer groups; farmer group 1 have the lowest GHG emissions, in this case a net GHG sink through carbon sequestration. Farmer group 2, the non-certified farmers, have the next lowest GHG impact also a net sink but to a lesser extent. Farmer group 3, the newly certified farmers, have the largest average GHG impact. It is important to note the directional improvement shown between farmer group 1 and the other two groups of farmers. Looking at these results at face-value provides some very encouraging suggestions that certification might result in reduced GHG emissions, likely through a combination of yield improvements and better management.

To have confidence in these assertions, the results require further interrogation that is only possible with some understanding of the context of each farmer group. A summary of the results for each farmer group along with some the relevant context is presented in Table 31 and an explanation of the implications of this follows.

![Figure 52: a) Average yield of each farmer group (tonnes cocoa bean per hectare per year); b) Average GHG emissions for each farmer group as calculated by the CFT (kgCO₂e/t cocoa bean).](image)
Table 31: Summary of average yield and GHG emission results for the three farmer groups and the relevant supporting information.

<table>
<thead>
<tr>
<th>Farmer Group</th>
<th>Classification</th>
<th>Yield(^a)</th>
<th>GHG emissions(^b)</th>
<th>Supporting information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer group 1</td>
<td>RA certified. Experienced in sustainability projects.</td>
<td>0.77</td>
<td>-10,049</td>
<td>• High density of shade trees per ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• No previous LUC (within the last 20 years)</td>
</tr>
<tr>
<td>Farmer group 2</td>
<td>Non certified</td>
<td>0.54</td>
<td>-2,123</td>
<td>• Located near to farmer group 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• One farm in the group had undertaken land conversion (LUC)</td>
</tr>
<tr>
<td>Farmer group 3</td>
<td>Newly RA certified. Limited experience of sustainability projects</td>
<td>0.53</td>
<td>8,145</td>
<td>• Lowest density of shade trees per ha</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 2 farms in the group had undergone LUC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Delayed delivery of shade tree saplings resulted in failed plantings</td>
</tr>
</tbody>
</table>

\(^a\) Yield is represented as tonnes cocoa bean/ha/year  
\(^b\) GHG emissions are represented kgCO\(_2\)/tonne cocoa bean. These emission calculations are based on several assumptions and proxies and therefore are useful for comparative purposes only.

5.6.2.1 Impact of Shade trees

Farmer group 1, who are RA certified and had the longest experience of working with sustainability projects had the highest density of shade trees with considerable sequestration potential (as calculated in the CFT) and hence the ‘negative’ GHG footprint. Farmer group 2, also RA certified, however, had the lowest density of shade trees of the three farmer groups. As this group became certified and sought to comply with the required shade tree density they ordered some trees to be delivered to the farm. This delivery was significantly late, resulting in a delayed planting and a subsequent failure of the trees establishment which affected their tree density and thus their GHG emission footprint. Rainforest Alliance certification promotes the use of shade trees on cocoa farms and requires on average 3.24 shade trees per ha (or 8 trees per acre) as a minimum requirement for good practice (Rainforest Alliance representative, personal communication, June 2012). Given the time taken to plant and grow shade trees, RA allow five years for farms to reach the required shade tree density. The COCOBOD (The Ghana Cocoa Board) echoes the RA requirements, recommending Ghanaian farmers to have between 2.4 – 3.6 shade trees on average per ha (or between 6 – 9 shade trees per acre) (COCOBOD representative, personal communication, June 2012). In the longer term
therefore, it would be expected that certified farms would have higher densities of shade trees than their non-certified counterparts which would have considerable impacts on their GHG footprint as demonstrated here.

5.6.2.2 Impact of Land use change

Only three of the farms in the study sample assessed had records of recent land use change (within the previous 20 years) with conversion from forested land to cocoa. Two of these farms were part of the certified farmer group 3 and one was within farmer group 2. The considerable impact of LUC on the GHG footprint of crops (Flynn et al., 2012; Siangjaeo et al., 2011) has therefore had a considerable impact on the average GHG footprint of both farmer group 2 and 3, the latter in particular. The RFA does not permit the cutting of natural forest cover or burning to prepare new production areas from the date of the certification application and there are requirements to conduct some mitigation actions if forest or natural ecosystem was converted between 1999 and November 2005 (SAN, 2010).

5.6.2.3 Impact of Knowledge transfer

A key factor in the adoption of best practices is awareness raising and knowledge transfer; in particular the transfer and sharing of best practice information which may often be best placed coming from agronomists and other farmers rather than other external actors (Ingram, 2008; Vanclay & Lawrence, 1994). There are many potential and influential barriers to adoption of best practice such as conflicting information, complex messages, financial and intellectual outlay as well as other risks perceived by the farmer (Vanclay & Lawrence, 1994), however, adoption is likely to increase when farmers have a good level of environmental awareness and see the benefits of better management practices for themselves (Prokopy et al., 2008). Several of the non-certified farms among farmer group 2 were located very close by in the same growing district as the certified farms of farmer group 1 and had good relationships. Farmer group one had been part of sustainability projects for several years prior to receiving certification and it became evident that the non-certified farms had learnt from and copied some of the behaviours of the certified farmers in farmer group 1:

“My neighbour told me about not using fertilisers every year on my crop and that they should have a break, I saw his crop and decided I would do the same” (Non-certified, Ghanaian cocoa farmer in farmer group 2, via translator, 2012).

5.6.3 Implementation challenges

Using the CFT in this context proved challenging and numerous assumptions had to be made in order to fulfil the data input requirements of the CFT. Proxies based on available literature/known data or
data from other sources such as the COCOBOD who were familiar with the practices of the local farmers etc. were used. Table 32 summarises the issues encountered and any amendments or assumptions made. Many of these factors limit the validity and the overall relevance of the specific GHG results obtained but they are considered adequate for the comparative goals of the study only.

It is evident that the CFT is better suited to well managed (i.e. good record keeping and access to IT) and temperate farming systems rather than a tropical crop such as cocoa grown by Ghanaian smallholders. The students noted:

“In the end we were able to collect very little data [for the CFT] from the farmers themselves because they didn’t know it or it wasn’t relevant to them. A lot of the information we relied on was from other people from the COCOBOD and CRIG in particular”

“Sometimes we got the feeling that people gave us the answer we wanted to hear rather than the real answer and sometimes we got different answers to the same question, particularly when we asked about shade trees or pesticides used. This added to the uncertainties in the data collection process.”

(J. Borg & J. Selmer, personal communication, July 15, 2012).

Table 32: The issues, assumptions and proxies used in the completion of the CFT with Ghanaian cocoa farmers.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Description</th>
<th>Assumption/amendment made</th>
<th>Supporting information / reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (dried cocoa beans)</td>
<td>Farmers typically did not know their yield quantity in kg or tonnes. Their cocoa beans were stored in bags which were counted by the farmers.</td>
<td>One bag of cocoa beans was weighed and the yield data inputs were based on this.</td>
<td>N/A</td>
</tr>
<tr>
<td>Carbon sequestration in shade trees</td>
<td>The CFT does not include the local shade tree species present on the cocoa farms.</td>
<td>The ‘closest’ equivalent tree species/classification was modelled in the CFT using tree diameter measurements and the tree growth rate and predicted age.</td>
<td>Tree species names and average yearly growth rates were provided by advisors at CRIG</td>
</tr>
</tbody>
</table>

42 COCOBOD is the Cocoa Research Institute of Ghana.
43 CRIG is the Cocoa Research Institute of Ghana, a subsidiary of the COCOBOD (https://www.cocobod.gh/oursubsidiaries.php)
44 Shade trees were identified by the farmers using their local Ghanaian names and the scientific species names were provided by CRIG. Most farmers did not know how many shade trees were on their farm so the
<table>
<thead>
<tr>
<th>Land use change (LUC)</th>
<th>The CFT does not include land use change classifications specific or relevant to cocoa plantations (i.e. does not model perennial land use) nor does it well-represent the previous land use (secondary forest).</th>
<th>For farms with LUC (3 farms) the CFT was used to model: Forest to grassland (to represent the conversion from secondary forest to cocoa plantation. Secondary forest was modelled as ‘tropical moist deciduous forest’.</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilisers used</td>
<td>The local blends of fertilisers used on the cocoa farms are not modelled in the CFT.</td>
<td>The most similar blends of fertilisers (pertaining to N content specifically) were modelled as a proxy.</td>
<td>Information on fertiliser blends were provided by CRIG.</td>
</tr>
<tr>
<td>Fertiliser quantities used</td>
<td>The farmers did not accurately measure the quantity of fertilisers used on the farm as a whole nor per cocoa tree thus it was difficult to ascertain a reliable measure.</td>
<td>Farmers demonstrated a typical ‘handful’ or ‘bucket’ of fertiliser that was used. This quantity was measured and extrapolated from.</td>
<td>N/A</td>
</tr>
<tr>
<td>Soil properties</td>
<td>Lack of capability/resource to ascertain the soil properties required by the CFT including SOM content and soil pH.</td>
<td>Soil properties were assumed to be consistent across all the farms assessed.</td>
<td>Representative soil properties were provided by CRIG.</td>
</tr>
<tr>
<td>Local climatic conditions</td>
<td>Difficulty in distinguishing climate variability from one growing district to the next.</td>
<td>Climate conditions were assumed to be consistent across all of the farms assessed. (Tropical; annual average temperature 26°C)</td>
<td>Specified by CRIG.</td>
</tr>
<tr>
<td>System boundary</td>
<td>Other crop species and livestock were grown on the farm area. The CFT does not allow for the modelling of mixed production systems.</td>
<td>Only the impacts of cocoa and its associated system requirements (e.g. shade trees) were included in the GHG assessment.</td>
<td>N/A</td>
</tr>
<tr>
<td>Language barriers</td>
<td>There were language differences between the students conducting the research and several of the farmers in the study (some local languages and dialects were encountered).</td>
<td>An interpreter was present for the in-field CFT assessments to translate between the farmers and the students.</td>
<td>N/A</td>
</tr>
<tr>
<td>Units of measurement</td>
<td>The CFT operates in metric and imperial units only which were not always understood or used by the farmers in the study.</td>
<td>Approximate conversions/estimations were undertaken using local knowledge and real measurements where possible.</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Students counted the shade trees on a specific area of the farm and extrapolated for the whole farm area. Certified farmers had better record keeping which included some detail on their shade tree quantity.
5.7 Discussion

This discussion aims to bring together the findings and insights from the four case studies and it will focus on:

- The key insights regarding the mode of implementation, identification of management practices and detection of GHG impacts of certification.
- The agricultural GHG performance data gathered through this study.
- Challenges and limitations.
- Conclusions and chapter summary.

5.7.1 Key insights from the case studies

5.7.1.1 Mode of implementation and quality of GHG results

Four key areas of difference in the mode of implementation of the CFT have been identified in the case studies, namely:

- *The level of resource* – the amount of infrastructural, financial and personnel invested into the deployment of the CFT within the supply chain.
- *The support structures in place* – the provisions put in place to provide support and guidance for the users of the CFT (the farmers).
- *The audit/verification processes* – the level of data quality assurance in place to check either the data input parameters in the CFT and/or the final GHG result calculated from the tool.
- *CFT modifications* – i.e. the level of modification made to the CFT to make it fit the needs or capacity of the user.

Table 33 shows a comparison of the four case studies across these four implementation criteria and the quality of the GHG emission results. The quality of the results was based on a comparison to published literature sources and expert judgement (as described in section 5.2).
Table 33: Cross case comparison of the four case studies scored for four implementation criteria and the quality of the CFT GHG emission results generated.

<table>
<thead>
<tr>
<th>Case study</th>
<th>Implementation criteria Scoring: * low; ** medium; *** high</th>
<th>Results Quality: * low; ** medium; *** high</th>
<th>Quality of results</th>
<th>Use of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource commitment</td>
<td>Support structures</td>
<td>Audit / verification</td>
<td>Adaptation of CFT</td>
<td></td>
</tr>
<tr>
<td>1. UL global SC</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2. UL supplier specific</td>
<td>**</td>
<td>**</td>
<td>***</td>
<td>**</td>
</tr>
<tr>
<td>3. UL Cocoa small-holders</td>
<td>***</td>
<td>**</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>4. PepsiCo potato SC</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

PepsiCo’s use of the CFT was ranked highest, scoring 3 stars under each implementation criteria as well as for quality of results. PepsiCo invested heavily in capacity building through on-farm support and auditing. They were able to do this because they had short supply chains and direct contact with the farmers, many of which they had strong 10 year+ relationships with. Notably, PepsiCo made the decision to work with their suppliers regardless of their GHG performance after the initial assessments, i.e. no suppliers were excluded from the supply chain based on their GHG emission results. PepsiCo used the GHG emission results to benchmark their suppliers’ performance against each other by normalising against yield. In doing so they devised tailored carbon management plans specific to each farmer showing how they ranked against their peers and providing information on their GHG hotspots accompanied with advice and guidance for action plans to reduce them. Unilever’s supplier specific partnership ranked second to PepsiCo and these two case studies (2 and 4) demonstrate that to obtain good quality GHG results from farmers/suppliers requires significant
investment of resources. In contrast the deployment of the CFT in Unilever’s global fruit and vegetable supply chain (case study 1) provided poor quality overall results. This was largely due to the lack of support, weak communication (many suppliers did not know they were required to complete the CFT, see Figure 38), lack of quality assurance checks, and no requirement for upload of the CFT which meant that there was no transparency of the GHG emission estimates. Some individual results may be considered to be good quality but without transparency of the input parameters (i.e. the CFT spreadsheets) it is not possible to fully validate. In this example, Unilever sacrificed quality for quantity and unlike with PepsiCo the implementation of the CFT was part of a much broader sustainable sourcing scheme where the emphasis was placed on management practices rather than estimation of GHG emissions.

The scoring of the smallholder cocoa study reflects the difficulties in obtaining the appropriate input data for the CFT, the lack of knowledge of the smallholders and the limited suitability of the CFT for the agricultural system.

5.7.1.2 Identification of farm management practices through use of the CFT

Several of the results from different case studies demonstrated the ability of the CFT to identify differences in GHG emissions from individual management practices on the farm. However, this is only possible by analysis of the CFT input data (e.g. that highlighted the use of excess organic fertiliser in case study 2) and by having a dialogue with the supplier/farmer (e.g. an understanding of the irrigation system failures in case study 2 that led to reduced yield and hence, increased GHG emissions).

Contextual information was also important in case study 3 (Ghanaian cocoa farmers) to get a richer understanding of the differences between certified and non-certified farms in this case and to explain some of the GHG results observed e.g. the knowledge sharing between farmer groups; failed tree planting due to delayed deliveries and lack of information.

This chapter has therefore demonstrated the importance of understanding the farm context by gathering observation, interview and survey data to aid interpretation and understanding of the results from the CFT. This is possible when relationships/partnerships are established with suppliers/farmers and the farmer sample is relatively small. However, this model becomes increasingly challenging if the CFT is applied across a large number of suppliers/farmers (e.g. greater than 100).

5.7.2 Agricultural GHG performance data

The case studies have provided some useful insights into GHG data collection and reporting. These include:
• Yield has an important influence on GHG emissions i.e. GHG emissions are inversely proportional to yield and so farmers with higher yields are likely to have lower GHG emissions. Trade-offs in terms of Nitrogen fertiliser applied and potential yield gains are therefore an important management consideration.

• One or two years of GHG results for farming systems are useful but insufficient to identify trends in GHG performance and they should not be used for making claims.

• Need to collect results over a number of years and to smooth out annual variability. It is recommended that a rolling average (e.g. over three-five years) is used.

• There can be considerable variability between farms growing the same crop in the same region and under the same environmental conditions.

5.7.3 Challenges

• Correct use of the CFT is difficult even for a competent supplier with trained staff. User error can lead to results orders of magnitude higher than they should be. There is a need to perform a thorough quality check the data before analysis or communication of the results.

• Challenges using the tool in Ghanaian smallholder cocoa systems at two levels, a) insufficient modelling capability within the tool to best-represent smallholder tropical, perennial crop systems and b) social challenges of language, capacity and knowledge of core farm information such as farm size or number of shade trees.

• There is a trade-off between resource investment and the quality of the results produced.

• Scale and diversity of supply chains will make use of a GHG calculator more difficult due to the effort and investment required. This is exacerbated in supply chains where suppliers can change year on year.

5.7.4 Conclusions

The key conclusions drawn from this chapter are:

• Data collection is difficult at first but good training and perseverance can lead to good quality results and positive feedback from farmers.

• Quality of the results generated are highly dependent on the implementation process, particularly regarding the resource committed, provision for training and support, the audit/verification systems in place and the suitability of the tool being implemented.

• Challenges of implementation include:
  
  o Scale and scope of supply chain,
Resource availability,
Suitability of CFT to smallholder production systems.

- Many GHG calculators (including the CFT) provide user guidance detailing how to use the calculator and generate a result. None, however, typically include guidance for the implementation of the calculator in different contexts, the types of or level of training and support that should be offered to different user groups to ensure success, and there is not a wealth of experience to draw from.

- Considerations on the required quality of the results must be taken given the constraints on resource and investment. Depending on the use of the information it may be better to conduct a more targeted deployment of the CFT with a limited number of suppliers/farmers to achieve good quality results, compared to a larger scale deployment across a vast global supply chain. With limits on resource, the latter case may not be good if good quality results are desired, but may be sufficient if the aim is awareness raising or relationship building.

5.8 Chapter summary

This chapter has explored four diverse applications of the CFT by two multi-national companies and has demonstrated how the mode of implementation has an important influence on the quality of the GHG emission results obtained. If implemented well with appropriate investment and commitment of resource for training and support etc., then good quality GHG emission results can be acquired. Use of the CFT, or other GHG calculators, by FMCG companies provide the opportunity for supplier specific, real farm data that is representative of the supply chain sourced from. It can also begin to provide insights on the magnitude of potential variability between farms producing the same product across the same or different geographies.

Given the relative immaturity of the application of GHG calculators in agri-food supply chains, this chapter brings together some of the evidence and insights on the possible implementation approaches and how they might influence the GHG results obtained. It also provides a strong case to demonstrate that effective implementation can generate good quality, useable, supplier specific GHG emission estimates.
CHAPTER VI
DISCUSSION, CONCLUSIONS AND FURTHER WORK

*Agriculture is not crop production as popular belief holds – it’s the production of food and fibre from the world’s land and waters. Without agriculture it is not possible to have a city, stock market, banks, university, church or army. Agriculture is the foundation of civilization and any stable economy*’ (Allan Savory)

This final chapter focusses on a broader discussion of the learnings, issues and challenges that have emerged throughout the project. It includes a summary of the contribution to knowledge brought together from earlier chapters and provides recommendations for further research.
6.1 Where have we got to?

When this research was initiated in 2009/10, many companies associated with the agricultural sector were in the early stages of their sustainability journey and were just beginning to manage and quantify the GHG emissions of their own operations (scope 1 and 2). The more progressive ones, including Unilever, extended their targets to include their scope 3 emissions.

The overarching aim of this research was to improve the effectiveness of FMCG companies in managing and quantifying the GHG emissions in their agricultural supply chains and specifically up to the farm gate. This research has done a number of things towards meeting this aim. Firstly, it has identified the existing mechanisms that are being used to manage and quantify GHG emissions within agri-food supply chains. Secondly, it has evaluated some of these mechanisms in greater detail and highlighted the various levels of complexity of their use. And thirdly, it has begun to explore how evidence of GHG emissions can be gathered to demonstrate GHG performance and to highlight the methodological challenges, requirements and resources needed for implementation.

6.1.1 Summary of conclusions

Table 34 summarises research objectives 1 - 4 articulated in Chapter 1 and the key conclusions related to each one.

Table 34: Summary of conclusions from the research project.

<table>
<thead>
<tr>
<th>Objective 1: To review and summarise the approaches, standards and methodologies for GHG assessment at the farm level in the context of complete supply chains, and the company commitments being made.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objective 2: To develop a framework to assess how agri-food certification schemes address management of GHGs through to reporting of GHG emissions (outcome focused).</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>
2. Agri-food certification schemes have proliferated in the last decade and the diversity in the design, structure, language and implementation requirements render certification schemes difficult to compare.

3. Most of the certification schemes assessed are management oriented; they require farmers to adhere to a set of management practices in order to achieve certification. A few require measurement of parameters determining GHG emissions and set required GHG emission thresholds.

4. Certification does not guarantee good GHG performance.

5. Evidence that certification schemes drive GHG emission reductions is inconclusive and anecdotal.

**Objective 3:** To explore the range of agricultural GHG modelling tools available and compare three important, widely used tools in order to clarify the sources of any methodological differences between them in order to evaluate their comparability for use in GHG reporting.

1. GHG calculators vary considerably in methodology, format, structure, data sources, and nomenclature, making direct comparison difficult.

2. The three GHG calculators compared in this study were shown to be broadly similar but gave differing aggregate results with equivalent input data.

3. With no consensus or agreement on GHG emission accounting values for agricultural systems, there is considerable flexibility on the values used within a GHG calculator. Key differences between GHG calculators lie in the underlying data sources used, varying calculation methodologies employed and overarching differences in approaches.

4. There are trade-offs between flexibility and specificity of calculator functions, and user-friendliness and the expertise required.

5. For comparative assessment of a single-crop from different sources or different crops from one supply system, the same GHG calculator must be used. Full transparency and documentation is required for calculators to assist interpretation and comparison of results.

**Objective 4:** To understand how the mode of implementation of GHG calculators affects the quality of the GHG emission results from farmers, when used and interpreted by FMCG companies.
The implementation of GHG calculators requires investment in resource and training.

Data quality is improved by training and verification by experts.

There are trade-offs in resource commitments, supply chain reach and quality of the results obtained.

The fifth objective of this research was to draw upon the key insights gained throughout the whole research project in order to make some recommendations to improve FMCG or supply chain companies GHG assessment, management and reporting of farm-level data or to help guide those companies that are aiming to start the process. Table 35 presents this research objective and 6 recommendations that have come from the experiences gained throughout this research.
**Objective 5:** To use the insights gained to make recommendations for improved GHG assessment, management and reporting of farm level data for a supply chain company.

**Recommendation 1** Before embarking on farm level data collection it is necessary to decide on the required and acceptable quantity and quality of data collected that will satisfy the needs of the intended application. This will help to reduce wasting resources.

**Recommendation 2** Early engagement with data provider stakeholders i.e. suppliers, extension agents (agronomists, other third parties e.g. control union) and farmers, where possible to build awareness, buy in and increased accountability, can aid the data collection process. This should be accompanied by guidance, support and training to facilitate the data collection process and increase the quality and quantity of data collected. This should be delivered through at least one or more of the following channels:
- User-friendly guidance manuals
- Online support through webinars etc.
- Direct contact with extension agents or a dedicated company representative (in person or through a phone helpline etc.)

**Recommendation 3** Assurance and verification mechanisms are important to ensure and to increase the quality (accuracy, robustness and trustworthiness etc.) of the data collected and to help shape the data collection process. This is particularly important if data is intended to be used for reporting at some level.

**Recommendation 4** Collaboration with other stakeholders who can all provide a unique contribution to development of a single instrument or tool to capture farm level GHG relevant information can help to reduce costs, increase uptake, provide opportunity for knowledge exchange and data sharing, ultimately leading to increased data quantities and quality.

**Recommendation 5** Supply chain companies should use a GHG calculator that is suitable for the agricultural production system(s) that they wish to assess. If using a number of different calculators for reporting, they should be aware of the differences and inconsistencies between them and ensure these are well documented.

**Recommendation 6** Commit resource for data management and analysis, particularly in the early years of data collection as this will aid database development which can be designed with automated checks, specification of expected data ranges etc. which will help with cost-effectiveness over time.
6.1.2 Contributions to knowledge

This research has contributed to understanding and knowledge in four main areas:

1. A review of GHG accounting methods and standards employed in the agricultural sector, along with their associated challenges and uncertainties.
2. The development of a framework for assessing and comparing how agri-food certification schemes address GHG emissions. This work was published in Keller et al., (2013) together with a review of 10 widely used schemes.
3. An in-depth comparison of three of the key farm-level GHG calculators; this part of the work was published in Keller et al., (2014).
4. An overall improved understanding of GHG management in agri-food supply chains, some of the mechanisms available to ascertain GHG data from supply chain actors and the associated challenges in applying them.

The publications associated with this research project are described in Appendix E.

6.2 Broader discussion of the research

6.2.1 Reflections on the management of GHGs at the farm level by companies

At the farm level, the principal mechanism of GHG management is currently through environmental certification schemes. This research has shown that these schemes are primarily based on assessing management practices rather than quantifying GHG emissions. Hence there is an increasing need to demonstrate the benefits of certification in general, as well to relate management practices to quantification of GHG emissions. No longer is it accepted that certification leads to positive environmental and/or social impacts. The findings of this research have shown improvements/reduction in GHG emissions correlated with certification (Chapter 5) but they are not definitive and were limited by study design, sample size and duration.

The need to establish the benefits of certification has been recognised by a number of groups (e.g. Blackman & Rivera 2010; Barry et al., 2012) and the advocates of individual schemes. For example, for palm oil, the RSPO has outlined a 5 year research programme, the Social and Environmentally Sustainable Oil palm Research (SEnSOR) programme, to quantify the impacts of RSPO certification. SEnSOR aims to deliver a robust scientific evidence base for RSPO’s principles and criteria including GHG management and emissions (Lucey et al., 2012; SEARPP, 2012). The high costs of the SEnSOR programme, estimated at approximately £15 million, highlights a potential barrier to conducting such studies.
6.2.2 Current and future challenges

An important finding of this research is that managing and assessing GHG emission performance in agri-food supply chains is not easy. The scale, variability and diversity of farming systems, in terms of their size, capacity and readiness for GHG management and performance assessment, varies enormously across the agri-food sector. This research has highlighted the challenges in acquiring data from relatively small samples of particular supply chains, showing that achieving this at scale will be extremely difficult.

Some important challenges faced in GHG management and assessment in agri-food supply chains include:

- **Smallholder farmers** - there are estimated to be some 500 million smallholder farmers globally (IFAD, 2011) across a multitude of farming systems; they make up a significant proportion of some key commodity supply chains such as cocoa and coffee. Many of these smallholder farmers are poor, uneducated and illiterate, unorganised and face social conflicts such as land rights. These farmers typically cannot afford additional or improved farm inputs or mechanisation to improve yields and nor the costs of certification. Language barriers present further challenges.

- **Best management practices** – dissemination, uptake and achievement of best practices takes time. This needs to be taken in planning and resource allocation for monitoring performance.

- **Supply chain governance** – successful GHG management and reduction is determined by the ability to influence and work with other actors in the supply chain. Strong relationships, communication channels and trust are essential.

- **Implementation of GHG management/data collection approaches** – individual companies need to weigh the risks and benefits of different courses of action (e.g. certification schemes, GHG calculator use etc.) against their operational, strategic, financial, legislative and reputational implications for the business. Implementation is multi-dimensional and complex and a range of factors can both facilitate and stifle implementation of strategies and other activities within organisations and wider supply chains (Durlak & DuPre, 2008; Lunenburg, 2011; Noble, 1999).

- **Data provision** – Farmers may be reluctant to provide detailed farm input data to a purchasing company as there are clear links between farm inputs and economics: it could be seen as a way of obtaining financial information from a farming system. This research highlighted the need for support systems – i.e. training, communication, and resources on-hand to provide guidance on data entry - to check data-entry as well as to explain the
rationale for using the tool and to motivate and incentivise the time and effort needed to generate reliable results.

- **Traceability** – understanding the flow of materials down to the farm level remains a challenge. Many certification schemes are grappling with the challenges and costs associated with traceability and chain of custody. In some schemes, e.g. RSPO and RTRS, there are different levels of traceability. In ‘mass balance’ systems, certified material is mixed with conventionally produced material but quantities are monitored and claims can only be made on the relevant percentage certified, whereas in a ‘segregated’ supply, certified material is separated from non-certified material throughout the chain. The highest level of traceability is provided in an ‘identity preserved’ system in which the identity and integrity of a material is tracked throughout its supply chain down to the farm of origin. Mainstreaming the demand for traceability in commodity supply chains may be one way to reduce the costs of the required infrastructure and resources.

- **Incentives for behaviour change** – behaviour change takes time and so farmers need clear signals and incentives to adapt their behaviour and reduce their GHG emissions. Financial savings that can result from reduced inputs and/or increased yields are an important part of incentivising change but, as results take time to materialise, there may be a need to support the initial financial outlay either through premiums, longer-term supply contracts or other financial or reputational rewards.

- **Audit and verification** – costs associated with audit and verification can create a barrier to entry of certification. Some schemes (such as the UL SAC) rely on self-assessment data which, as demonstrated in this research, may lead to poor data quality and difficulties in data interpretation. Considerable support and effort is required to improve data quality; this needs to be balanced against the costs and benefits of tighter audit and verification procedures.

- **Comparability of approaches** - this is relevant for certification schemes and GHG calculators. There is a multiplicity of schemes and calculators and an understanding of comparability is critical if they are to be used interchangeably by FMCG companies to assess performance or by producers to claim sustainably sourced. This research has highlighted a lack of transparency and a number of key differences in the schemes and calculators studied. Guidance and consensus is, therefore, required on how to compare approaches and how to decide if the respective results are considered to be equivalent. One example of this happening is the WWF Certification Assessment Tool (WWF, 2014a) which evaluates and compares schemes requirements as well as their governance, rules and procedures in place. The ITC Standards map (ITC, 2015) also helps to compare schemes in a formalised and structured way. In the case of GHG calculators there are no co-ordinated activities to assess and align calculators although individual schemes
such as RSPO do accept submission of GHG results from either the recommended calculator (PalmGHG) or an ‘equivalent’ calculator. However, to-date no criteria have been agreed as to what is considered to be equivalent.

In particular, an understanding of equivalence is important in the certification space in order to avoid the dilution effect of the terms that classify the production of agricultural materials as ‘sustainable’ or ‘responsible’ if it is clear that some schemes deliver higher levels of sustainability/responsibility than others. A pre-competitive agreement to use common language can enable the reconciling of differences between schemes and may help to categorise them based on the level of benefit they help to deliver e.g. gold, silver and bronze level schemes that can serve as a step-wise approach for companies wishing to become/source more sustainably.

- Data quality and data use – acquisition of good quality data requires considerable effort and investment over time. Use of the data may be limited but, with systems in place for data quality assurance, it can be used in decision-making, product assessments and to inform and benchmark farm performance. There is limited information on the variability of agricultural systems in a supply chain both between system types and over time. Longer term assessments of farm performance can help to understand and thus manage variability.

Given the challenges noted above, it is important not to underestimate the efforts of addressing GHGs from agri-food supply chains. This is still a relatively immature agenda and will require the continued pursuits of leading companies such as Unilever and PepsiCo to build up experience on how to develop and implement GHG management and to define the steps for others to follow.

6.2.3 Achieving scale and impact

Over the course of this research, it became increasingly clear that no single GHG management scheme, tool or approach, nor the efforts of just one company, will achieve the scale and GHG emissions reduction necessary to mitigate global climate change. It is therefore important to consider what is needed to achieve the result. The rest of this section highlights some of the activities, tools and approaches that will play a key role.

Collaborations and partnerships need to be at the centre of the agenda to reduce emissions and tackle climate change, as well as being mission critical to help companies achieve their individual targets. Collaboration has become a “buzz-word” in this area in the last decade and continues to be

45 This is based on the assumption that not all schemes are equivalent and some are stronger or weaker than their counterparts in ensuring ‘sustainable’ production systems. For example the WWF Certification Assessment Tool (CAT) is a method to formally evaluate and compare schemes’ requirements, governance, rules and procedures (WWF, 2014a).
a focal topic, particularly in the sustainability space where individuals, organisations, NGOs and Governments have come to understand that they cannot solve the issues of climate change and other environmental and social issues by acting alone. This emphasis on collaboration, particularly pre-competitive collaboration, has been reflected in the establishment of numerous bi-lateral and multi-lateral stakeholder working groups, including many of the certification groups and roundtables researched in this project. Notably, this research agenda provided a unique opportunity to be a part of the inception, development and establishment of the Cool Farm Alliance (CFA). This saw a number of agri-food companies, including manufacturers, retailers and suppliers, coming together with agricultural consultancies and academia to develop, deploy and promote the CFT as a collaborative approach to estimation of GHG emissions and data collection from farmers in supply chains. The founding partners saw the need to collaborate on the approaches as well as the provision of funding and skills in order to develop a suitable approach that could be adopted widely. Some key co-benefits of this were reduced effort for each individual organisation, peer support and insight and reduced burdens on the farmers participating.

It is clear that emissions from land use change is a significant contributor to GHG emissions; thus it is necessary to move beyond general commitments on GHG reductions and sustainable sourcing at individual farm level to tackle this specific GHG driver. Larger commitments that aim at avoiding conversion of high carbon stock forests and other ecosystems, such as Cerrado and Savannah, are an important component of GHG mitigation as well as being fundamental to broader conservation goals. There has been a recent surge in ‘zero deforestation commitments’ that take many forms. These have resulted from several high profile and important commitments including the Consumer Goods Forum (CGF) 2010 commitment to zero net deforestation by 2020, and the many signatories of the New York Declaration on forests that aims to at least halve the rate of forest loss globally by 2020 and end natural forest loss by 2030 (UN REDD, 2015). With all these commitments being made, there is a need to map and monitor them to begin to understand the results that each is delivering as well as how they ‘add up’ to real large scale impact e.g. how the sum of individual companies’ GHG reduction commitments contribute to mitigating climate change; or how much forest zero-deforestation targets achieve. Platforms, such as Supply-change (www.supply-change.org), Forest trends (www.forest-trends.org) and the more recent NAZCA platform that documents over 2,700 commitments to climate action by companies, cities, regions and investors (www.climateaction.unfccc.int/) are beginning to facilitate this endeavour.

46 Zero deforestation commitments have arisen in many forms. Some include zero deforestation, zero net deforestation and degradation (ZNDD), zero gross deforestation, no deforestation, deforestation-free as well as commitments to no conversion on high conservation value (HCV) and high carbon stock (HCS) areas.
Technology is another important enabler of change. Developments in on-farm technology can improve farm GHG performance through reduced fuel use (e.g. fuel-efficient tractors), more efficient fertilisers (e.g. with N inhibitors), precision agriculture practices (e.g. drip irrigation), controlled traffic farming systems, and use of biological controls and integrated pest management (IPM) that can reduce chemical and energy use. Several of these technology developments can be part of the sustainable intensification of land cultivation. To achieve this, however, requires investment in agricultural production systems as well as investments in R&D to make technology more accessible; this is where national government and corporate sponsors will play a key role. There is a notable increase in the move to on-line farm management software/social media platforms in varying forms of ‘e-management’. Improved information and communication systems can facilitate good data management and the flow of this information through the supply chain, and improve traceability and transparency. Several of the GHG calculators reviewed in this study have evolved from MS excel spreadsheets to online platforms to facilitate data input, storage and version control. As farmers are one the fastest growing internet and smart technology adopter groups (Chauhan, 2010; DEFRA, 2013), this will be an interesting trend to observe and it is likely to expand into other areas such as emissions inventory reporting and alternative models of disclosure.

Policy instruments are needed to achieve widespread impact. Well enforced policy or legislative requirements that require a minimum level of performance, can help to create a level playing field, ensure costs of action are shared and fairly distributed among actors, and incentivise action to go beyond minimum legislative requirements. They also send unambiguous messages to the market of the need to act and to improve. 2015’s climate change negotiations will likely play a key role in this space and will hopefully build on examples of policy instruments that have had some success already (e.g. the UK Climate Change Act) as well as measures in other sectors and other countries (e.g. in preventing illegal timber in the EU, the EU Timber Regulation (EUTR), the EU Forest Law Enforcement, Governance and Trade (EU FLEGT) and the Australian Illegal Logging Prohibition Act).

Production and supply of low GHG or, more broadly, sustainably produced agricultural materials is demand driven. Certification schemes are one tool for market transformation and mainstreaming of these materials. Demand for and purchase of sustainably certified raw material, however, has been slow to grow across many agricultural commodities; for example, in 2014 RSPO accounted for around 16% of total market volume of palm oil and Bonsuco covered just 3% of sugarcane in around 5 years after the first certificates for sustainable materials were issued (WWF, 2014b). For many commodities, certified material may remain a niche market. There is a need for an increased demand for these more sustainable or low carbon materials. Certification is not the only way to achieve this. A comprehensive transparent system should be part of all raw material procurement requirements, just as food safety requirements are mandatory and guaranteed. It is also important
that the costs to produce sustainable raw materials are equitably distributed across the supply chain; farmers should not be expected to carry the cost of sustainable market transformation.

With so many certification schemes available some level of alignment amongst the schemes is desirable to make them manageable for farmers. One option could be the development of an overarching general standard, or what has been termed a ‘super-scheme’, that sets out the core principles and criteria to ensuring sustainable production across all crops and commodities. A second option that is currently being explored is the development of landscape or jurisdictional approaches (Bernard et al., 2013; IDH, 2015; Milne et al., 2013; Sayer et al., 2013). Such approaches may benefit smallholders and reduce the costs of certification but it remains to be established if the likely reduction in granularity and specificity of data will be acceptable to all stakeholders.

6.3 Recommendations for future work

The main recommendation for further work is to undertake long-term studies on the GHG impacts of certification schemes. One way to investigate GHG emission benefits of a certification scheme would be to compare the performance of a certified vs. non-certified farms over time, or pre and post-certification. Such a study would need to take into account the temporal variability of agricultural systems including climate as well as farming practices such as crop rotation. Consequently a comparative study would need to be conducted over a number of years or crop cycles to smooth annual variability and the result expressed as a rolling average47 (e.g. 3 year) rather than as a single year. To minimise inter-year variability it might be preferable to study a perennial crop grown in sub-tropical or tropical regions such as such as palm oil, coconut or tea rather than an annual crop from a temperate region. This would have the added benefits of reducing the time and cost of any study.

Other areas of work identified for future research are:

- Validation of the framework to compare certification schemes (developed in Chapter 3) against real empirical farm level GHG emission measurements. It would also be interesting to adapt the framework to consider other environmental and/or social impacts e.g. water, biodiversity or livelihoods, and to identify potential trade-offs.

- Analysis of GHG emissions in landscape or jurisdictional approaches. Compare a top down approach i.e. large scale GHG assessments vs. bottom-up i.e. several individual farm assessments and understand the pros and cons of each of these. In particular, it would be interesting to understand how these approaches could help to bring in and reduce the

47 A rolling average or ‘moving average’ is calculated by averaging subsets of the data over time and allows the ‘smoothing’ of fluctuations or yearly variations across data in a time series. It therefore requires several years of data to be able to perform this. E.g. See http://en.wikipedia.org/wiki/Moving_average
burden of commodity specific certification on smallholders; and the potential trade-offs between any cost-reductions and the granularity and specificity of the GHG data acquired.

- Comparing a wider range of farm level GHG calculators (further to those compared in Chapter 4) to explore the opportunities for standardisation and harmonisation across all calculators in general or within sectors.
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Appendices

Appendix A: Review of agri-food certification schemes for GHG emissions.

Assessment results as part of the work presented in (Keller et al., 2013)

This is available via memory stick (EK Thesis Stick)

Appendix B: Literature GHG data for tomato production.

<table>
<thead>
<tr>
<th>Tomato production</th>
<th>Country</th>
<th>GHG emissions (kgCO₂e/tonne)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field</td>
<td>Mainly Americas and some data from India and South Europe</td>
<td>65.6 ± 13</td>
<td>(Dutilh &amp; Koudijs, 1997)</td>
</tr>
<tr>
<td>Field</td>
<td>Spain</td>
<td>50.1 ± 10</td>
<td>(Muñoz et al., 2008)</td>
</tr>
<tr>
<td>Field</td>
<td>Brazil</td>
<td>40.2 ± 8</td>
<td>(McMaster &amp; Johnson, 2002)</td>
</tr>
<tr>
<td>Field</td>
<td>USA</td>
<td>59.6 ± 12</td>
<td>(McMaster &amp; Johnson, 2002)</td>
</tr>
<tr>
<td>Field</td>
<td>Italy</td>
<td>130 ± 26</td>
<td>(Manfredi &amp; Vignali, 2013)</td>
</tr>
<tr>
<td>Field</td>
<td>USA, Florida</td>
<td>190 ± 270</td>
<td>(Jones et al., 2012)</td>
</tr>
<tr>
<td>Field</td>
<td>Australia</td>
<td>300 ± 60*</td>
<td>(Page et al., 2012)</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>Australia</td>
<td>430 – 1860*</td>
<td>(Page et al., 2012)</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>Iran</td>
<td>50.3 ± 10</td>
<td>(Taki et al., 2013)</td>
</tr>
</tbody>
</table>

*In this study, cradle to farm-gate includes all upstream and on-farm impacts as well as packaging materials for the tomatoes on farm, thus the GHG emissions will be slightly higher.

It is important to note, that the first 4 studies in Appendix A used the 1996 IPCC Guidelines for estimating direct N₂O emissions from synthetic fertiliser applied to agricultural soils, which assumed the emission to be a fixed percentage, 1.25%, of the N applied. The more up-to-date 2006 IPCC Guidelines (IPCC, 2006) used in CFT estimations and in the last two references from 2011 (5-6), assume that only a 1 % of the N applied is released as N₂O emissions from soils. Additionally, the global warming potential of N₂O estimated over a 100yr time horizon is 310 following IPCC 1996 guidelines, corrected to 298 in IPCC 2006. Both these assumptions would result in lower GHG emissions as calculated by the CFT, as compared to literature studies. However, both CFT results and
latest studies show increased emissions as compared to earlier studies. Possible causes of this are different boundaries selection (e.g. including more on-farm processes) improved measurement or modelling capabilities etc. It is not easy to ascertain from the published studies where the specific differences lay.

Appendix C: Literature GHG data for a range of crops produced globally.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Country</th>
<th>GHG emissions* (kgCO₂e/tonne)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Switzerland</td>
<td>82</td>
<td>(Mouron et al., 2006)</td>
</tr>
<tr>
<td>Apple</td>
<td>New Zealand</td>
<td>67</td>
<td>(L. Milà i Canals et al., 2006)</td>
</tr>
<tr>
<td>Barley</td>
<td>Global (extrapolation)</td>
<td>402</td>
<td></td>
</tr>
<tr>
<td>Broccoli</td>
<td>Spain</td>
<td>350</td>
<td>(Milá i Canals et al., 2008)</td>
</tr>
<tr>
<td>Carrots</td>
<td>Sweden</td>
<td>38</td>
<td>(Mattsson et al., 1998b)</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>Sweden</td>
<td>200</td>
<td>(Davis et al., 2011)</td>
</tr>
<tr>
<td>Cucumber</td>
<td>China</td>
<td>43</td>
<td>(Yan et al., 2010)</td>
</tr>
<tr>
<td>Green beans</td>
<td>UK</td>
<td>360</td>
<td>(Milá i Canals et al., 2008)</td>
</tr>
<tr>
<td>Green beans</td>
<td>Kenya</td>
<td>30</td>
<td>(Milá i Canals et al., 2008)</td>
</tr>
<tr>
<td>Leek</td>
<td>Sweden</td>
<td>140</td>
<td>(Davis et al., 2011)</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Spain</td>
<td>120</td>
<td>(Milá i Canals et al., 2008)</td>
</tr>
<tr>
<td>Lettuce</td>
<td>UK</td>
<td>110</td>
<td>(Milá i Canals et al., 2008)</td>
</tr>
<tr>
<td>Onion</td>
<td>Europe</td>
<td>85</td>
<td>(Moudrý, Jr et al., 2013)</td>
</tr>
<tr>
<td>Onion</td>
<td>Tasmania</td>
<td>81</td>
<td>(Hay &amp; Pethybridge, 2011)</td>
</tr>
<tr>
<td>Onion</td>
<td>Sweden</td>
<td>60</td>
<td>(Davis et al., 2011)</td>
</tr>
<tr>
<td>Orange</td>
<td>Spain</td>
<td>225</td>
<td>(Sanjuan et al., 2005)</td>
</tr>
<tr>
<td>Parsnip</td>
<td>Sweden</td>
<td>120</td>
<td>(Davis et al., 2011)</td>
</tr>
<tr>
<td>Crop</td>
<td>Location</td>
<td>Emissions</td>
<td>Source</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>-----------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Potato</td>
<td>UK</td>
<td>240</td>
<td>(Williams, A. G., Audsley, E., Sanders, 2006)</td>
</tr>
<tr>
<td>Potato</td>
<td>Switzerland</td>
<td>136</td>
<td>(Ecoinvent, 2007)</td>
</tr>
<tr>
<td>Potato</td>
<td>USA</td>
<td>117</td>
<td>(Ecoinvent, 2007)</td>
</tr>
<tr>
<td>Potato</td>
<td>Global (extrapolation)</td>
<td>123</td>
<td>(Roches et al., 2010)</td>
</tr>
<tr>
<td>Rye</td>
<td>Global (extrapolation)</td>
<td>520</td>
<td>(Roches et al., 2010)</td>
</tr>
<tr>
<td>Strawberry</td>
<td>UK</td>
<td>720</td>
<td>(Williams et al., 2008)</td>
</tr>
<tr>
<td>Strawberry</td>
<td>Spain</td>
<td>590</td>
<td>(Williams et al., 2008)</td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>Germany</td>
<td>235</td>
<td>(Brentrup et al., 2001)</td>
</tr>
<tr>
<td>Sugarbeet</td>
<td>UK</td>
<td>24</td>
<td>(Tzilivakis et al., 2005)</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>Mauritius</td>
<td>233</td>
<td>(Ramjeawon, 2004)</td>
</tr>
<tr>
<td>Tomato</td>
<td>Spain</td>
<td>50</td>
<td>(Muñoz et al., 2008)</td>
</tr>
<tr>
<td>Tomato</td>
<td>USA</td>
<td>40</td>
<td>(McMaster &amp; Johnson, 2002)</td>
</tr>
<tr>
<td>Water spinach</td>
<td>China</td>
<td>105</td>
<td>(Yan et al., 2010)</td>
</tr>
<tr>
<td>Wheat</td>
<td>Global (extrapolation)</td>
<td>550</td>
<td>(Roches et al., 2010)</td>
</tr>
<tr>
<td>Wheat</td>
<td>Australia</td>
<td>269</td>
<td>(Biswas et al., 2008)</td>
</tr>
</tbody>
</table>

*GHG emissions up to the farm gate (where possible) and reported approximately as taken from the study*
Appendix D: Questionnaire used to gather data from smallholder cocoa farmers in Ghana (part of case study 3).

**Cool Farm Tool Datasheet - data from farmers**

<table>
<thead>
<tr>
<th>General Information</th>
<th>Units</th>
<th>Data entry</th>
<th>Notes (observations, relevant additional information)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Area</td>
<td>ha (or other)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Area</td>
<td>ha (or other)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield (fresh product from production area)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finished product from production area (how much do they sell)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Crop Management**

<table>
<thead>
<tr>
<th>Soil texture</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil texture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moisture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Drainage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil pH</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| Fertiliser 1 | Type | | |
|--------------|------|---|
| Fertiliser 1 | Application Rate | | |
| Fertiliser 1 | Unit | | |
| Fertiliser 1 | Application Method | | |
| Fertiliser 1 | Type | | |
| Fertiliser 1 | Application Rate | | |
| Fertiliser 1 | Unit | | |
| Fertiliser 1 | Application Method | | |
| Fertiliser 1 | Type | | |
| Fertiliser 1 | Application Rate | | |
| Fertiliser 1 | Unit | | |
| Fertiliser 1 | Application Method | | |</p>
<table>
<thead>
<tr>
<th>Pesticide applications</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue</td>
<td>Unit</td>
</tr>
<tr>
<td>Residue treatment method (if any)</td>
<td></td>
</tr>
</tbody>
</table>

**Sequestration and land use change**

<table>
<thead>
<tr>
<th>Land use changes</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>What did the land start as</td>
<td></td>
</tr>
<tr>
<td>How long ago was the change made</td>
<td>years</td>
</tr>
<tr>
<td>Percentage of farm converted</td>
<td>%</td>
</tr>
</tbody>
</table>

**Management practice changes**

<table>
<thead>
<tr>
<th>Tillage changes made</th>
<th>Y/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover cropping</td>
<td>Y/N</td>
</tr>
<tr>
<td>Compost</td>
<td>Y/N</td>
</tr>
<tr>
<td>Manure additions</td>
<td>Y/N</td>
</tr>
<tr>
<td>Residue incorporation</td>
<td>Y/N</td>
</tr>
</tbody>
</table>

**Livestock**

<table>
<thead>
<tr>
<th>Types of livestock on farm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed mix</td>
<td>% of diet from feed mix (instead of grazing)</td>
</tr>
<tr>
<td>Type of grazing</td>
<td>Quality of forage (L,M,H)</td>
</tr>
<tr>
<td>Manure management</td>
<td>Y/N</td>
</tr>
<tr>
<td>Type of management</td>
<td></td>
</tr>
</tbody>
</table>

**Field energy use**

<table>
<thead>
<tr>
<th>Fuel used on farm</th>
<th>litres/ha</th>
</tr>
</thead>
</table>

**Transport**

| On-farm transport | Distance to field |
### Background information

<table>
<thead>
<tr>
<th>Name of farm/farmer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td></td>
</tr>
<tr>
<td>Climate</td>
<td></td>
</tr>
<tr>
<td>Average annual temperature</td>
<td></td>
</tr>
<tr>
<td>People working on farm</td>
<td></td>
</tr>
<tr>
<td>Number of years been a farmer</td>
<td></td>
</tr>
</tbody>
</table>

### Management and machinery

<table>
<thead>
<tr>
<th>What machinery do you see?</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>How long have they had it?</td>
<td></td>
</tr>
</tbody>
</table>
Appendix E: Published papers

This appendix presents the papers that have been published throughout this research programme, in chronological order starting with the most recent.

1. **Footprinting Farms: a comparison of three GHG calculators** (Keller et al., 2014).

   Published in Greenhouse Gas Measurement and Management. This paper compared three internationally important GHG calculators and provided transparency on the structure and underlying data sources used. The differences were presented and the implications of their use discussed. The paper was based on the work undertaken in Chapter 4.

2. **Agri-food certification schemes: how do they address GHG emissions?** (Keller et al., 2013).

   Published in Greenhouse Gas Measurement and Management. This paper described the creation and application of a structured and transparent framework to compare ten agri-food certification schemes in their consideration of GHG emissions. This paper was based on the work conducted in Chapter 3.

3. **A product chain organisation study of certified cocoa supply** (Afrane, Arvidsson, Baumann, Borg, Keller et al., 2013).

   Published in the Proceedings of the Life Cycle Management Conference held in Gothenburg, Sweden in 2013. A comparison of the product chain organisation of conventional and certified cocoa were compared to reveal increased complexity in the certified chain due to the transparency requirements put in place by certification. This was part of the work conducted in collaboration with researchers at the Chalmers University of Technology in Gothenburg, Sweden.

4. **Quantifying global greenhouse gas emissions from land-use change for crop production** (Flynn, Milá i Canals, Keller, King, Sim et al., 2012).

   Published in Global Change Biology, this paper was the outcome of involvement in a collaboration between SEAC, Unilever and researchers at the University of Aberdeen. The paper developed a framework based on IPCC national GHG inventory methodologies to assess the impacts of LUC from crop production. Palm oil, soybean and oilseed rape were used as examples.
5. **From Ghana to Magnum ice cream: tracking down the organisation of sustainable cocoa product chains** (Borg and Selmer, 2012).

Co-supervised the project for the Master Degree Programme in Industrial Ecology for a Sustainable Society at Chalmers University of Technology, Gothenburg, Sweden. The project explored the product chain organisation of conventional cocoa in comparison to Rainforest Alliance certified cocoa from Ghana and documented the environmental and socio-economic challenges that farmers face. It included a comparison of the GHG emissions of certified and non-certified smallholder cocoa farmers using the Cool Farm Tool.

6. **Application of the Cool Farm Tool: insights from two key case studies of cotton in India and potatoes in Europe** (Keller et al., 2012).

Published in the Proceedings of the 2011 Engineering Doctorate Conference on Sustainability for Engineering and Energy systems. This paper presented two applications of the Cool Farm Tool to demonstrate how the tool could be deployed in different system types and some of the potential benefits realised.

7. **Identifying and tracking GHG emissions through the agri-food supply chain: a focus at the farm level** (Keller et al., 2011a).

Published in the Proceedings of the 2011 Engineering Doctorate Conference on Sustainability for Engineering and Energy systems. This paper described the rationale for identifying and assessing GHG emissions from agri-food supply chains and provided an overview of some of the certification schemes that could play a role in this agenda. It then highlighted the need for calculators such as the Cool Farm Tool to enable the modelling of GHG emissions at farm level.

8. **GHG management at the farm level** (Keller et al., 2011b).

Published in the Proceedings of the Life Cycle Management Conference held in Berlin, Germany in 2011. This paper provided a general overview of the need for GHG management and measurement at the farm level. It described the Cool Farm Tool and presented some of the results and early insights from some of its applications.

9. **Challenges of scale and specificity in greenhouse gas calculators** (Clift, Keller, King, Lee, Milà i Canals, 2014)
Published in the Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014) and presented at the conference in San Francisco, California, USA. This paper was a result of findings from Chapter 4; it discusses some of the implications of using different farm-level GHG calculators and some of the issues that can arise when they are used in particular contexts, specifically regarding their comparability and consistency.

10. **Limits of greenhouse gas calculators to predict soil fluxes in tropical agriculture.** (Richards Metzel, Chirinda, Nyamadzawo, Duong, de Neergaard, Oelefs, Wollenberg, Keller, Malin, Olesen, Hillier & Rosenstock 2016).

Published in Scientific Reports. This paper compared GHG fluxes and carbon stock change estimated from two commonly used GHG calculators including the Cool Farm Tool, against measured GHG fluxes for 7 cropping systems under different production conditions in tropical developing countries. It demonstrated that the GHG calculators (and the empirical models embedded within them) consistently over-estimate the GHG emission balance.