Problems of Benchmarking Greenhouse Gas Emissions in Dairy Agriculture

Abstract

Purpose – To examine the suitability of free carbon calculators aimed at the agricultural industry, for use in greenhouse gas emission benchmarking, using the European dairy industry as an example.

Design/methodology/approach – Carbon calculators which were claimed to be applicable to European dairy farms were identified and tested using six production scenarios based on data from real European farms supplemented using published literature. The resulting greenhouse gas emission estimates, together with estimates apportioned using three functional units, were then compared to determine the robustness of the benchmarking results.

Findings – It was found that although there was a degree of agreement between the seven identified carbon calculators in terms of benchmarking total farm emissions, once a suitable functional unit was applied little agreement remained. Tools often ranked farms in different orders, thereby calling into question the robustness of benchmarking in the studied sector.

Research limitations – The scenario based approach taken has identified issues liable to result in a lack of benchmarking robustness within this sector; however, there remains considerable scope to evaluate these findings in the field, both within this sector and others in the agricultural industry.

Practical implications – The results suggest that there are significant hurdles to overcome if GHG emission benchmarking is to aid in driving forward the environmental performance of the dairy industry. In addition, eco-labelling foods based on GHG benchmarking may be of questionable value.

Originality/value – At a time when environmental benchmarking is of increasing importance, this paper seeks to evaluate its applicability to sectors in which there is considerable scope for variation in the results obtained.

Keywords Benchmarking, Carbon Calculators, Livestock Agriculture, Dairy Farming, Greenhouse Gas Emissions.

1. Introduction

The pioneering work on benchmarking in industry was undertaken by the Xerox Corporation in the 1970s, in order to help them meet the growing economic challenges being posed by Japanese producers (Elmuti and Kathawala, 1997; Jónsdóttir *et al.*, 2005; Wu *et al.*, 2015). Since then however, it has gone on to encompass a much broader spectrum of objectives, including those that are economic, physical (related to the production process) and environmental, and has been adopted by a significant number of businesses (Bhutta and Huq, 1999). Whatever the specific goal however, the overall aim of benchmarking (except internal benchmarking) remains the same, namely to improve the performance of one's own business (in any number of fields) by examining what others are doing and learning from it (Jónsdóttir *et al.*, 2005). Consequently, the underlying principle is that of providing businesses with a structured system for identifying the highest standards of performance within their sector and then making the changes necessary to achieve, or even surpass, those standards (Elmuti and Kathawala, 1997; Bhutta and Huq, 1999; Presley and Meade, 2010).

In environmental terms, benchmarking is a tool used to drive performance forwards through a process of "gap analysis", in which a business compares its environmental performance with similar businesses in the same sector (Matthews, 2003; Jónsdóttir *et al.*, 2005), and subsequently implements a programme of actions intended to bridge the gap between them (Jónsdóttir *et al.*, 2005). The scope for doing this has increased considerably in recent years, as the availability of data against which to benchmark has improved (Matthews, 2003), some of which is in the public domain (e.g. EBLEX, 2014; CO_2Benchmark[1]), whilst other data may only be available through securely maintained databases built up through the benchmarking activities of a number of businesses (e.g. DairyCo., 2013; CO_2Benchmark[1]). Nevertheless, there are still significant gaps in many sectors (Jónsdóttir *et al.*, 2005), and where these exist, contributory factors may include concerns over the commercial sensitivity of some information (i.e. some businesses not wishing to aid their competitors - Jónsdóttir *et al.*, 2005), and worries that data released on performance may be used to regulate and/or penalise businesses.

However, if benchmarking is to act as a driver for improvement, the identification of both "leaders" and "laggers" (Matthews, 2003) within an industry is not sufficient, instead it is essential that there is some business benefit to be achieved through that improvement. In relation to economic benchmarking, or indeed benchmarking of the physical characteristics of a production process, it is clear that precisely such benefits exists, and are therefore likely to act as stimuli for improved performance. Environmentally however, the evidence for this is less clear, since to act as a driver, a reduction in greenhouse gas (GHG) emissions for example, must present a commercial advantage through increased sales and/or higher product prices, reduced production costs (e.g. through reduced inputs), or the avoidance of penalties. Within the agricultural sector (as in others), one area in which a future for benchmarking has been envisaged, and where an impetus for improvement might be achieved, is through the use of eco-labels in general and carbon labels in particular, on food products (Jónsdóttir *et al.*, 2005;

Tzilivakis *et al.*, 2011; Tzilivakis *et al.*, 2012). To date, these have made only limited progress in the sector (with the industry preferring to go for practice based labelling), despite a number of well publicised attempts to introduce them. In 2007, for example, the UK supermarket Tesco announced that carbon labels would appear on all their products (Boardman, 2008), only to drop the idea in 2012, after limited progress had been made in labelling their 70,000 products, due to the time required to work out a suitable value for each one (several months – Vaughan, 2012). Nevertheless, the idea has not gone away, despite the benefits of eco-labels (including carbon labels), being questioned by a number of authors (e.g. D'Souza *et al.*, 2006), who have found that although many consumers say they would like carbon labels on products, many also find them confusing, and do not feel that they empower them to make informed purchasing decisions (Röös and Tjärnemo, 2011; Gadema and Oglethorpe, 2011; Upham *et al.*, 2011). One suggested solution to this however, has been the use of benchmarking to improve the popularity of carbon labelling systems, since drawing on the experience of other sectors (e.g. where Energy Performance Certificates have been used on buildings in the UK), where it has been done it has shown to be successful (Wu *et al.*, 2015).

Although a number of techniques exist for establishing benchmarks within academic studies for example (e.g. data envelopment analysis (DEA) - Gadanakis *et al.*, 2015; Kanellopoulos *et al.*, 2014), it is unclear whether the tools available to businesses, particularly smaller businesses like most farms, are capable of supporting a robust benchmarking system. Farms, like many SMEs (small and medium-sized enterprises), often have limited resources (time and money) to put towards environmental management activities such as benchmarking (Jónsdóttir *et al.*, 2005), and consequently the tools they use must be both inexpensive and simple. These are precisely the sort of systems being promoted within the agricultural industry, and this paper takes the example of greenhouse gas emissions within European dairy farming, in order to consider whether the results of the various tools available for estimating emissions, are sufficiently robust as to warrant inclusion in benchmarking activities. First however, the context in which such systems operate is explored.

1.1. The livestock industry and climate change

The key role played by anthropogenic greenhouse gas (GHG) emissions in driving climate change is a cause for concern around the world (Hagemann *et al.*, 2011; Franks and Hadingham, 2012), as is agriculture's considerable contribution to them (Smith *et al.*, 2008; Hillier *et al.*, 2011). The IPCC (Intergovernmental Panel on Climate Change – Smith *et al.*, 2007) estimates that the agricultural sector as a whole is responsible for between 10 and 12% of all such emissions, including 50% of methane (CH_4) and 60% of nitrous oxide (N_2O), gasses with global warming potentials 25 and 298 times that of carbon dioxide (CO_2 – over 100 years) respectively. These figures however, exclude many secondary emissions (e.g. those from the manufacture of inputs), and work carried out by the Food and Agriculture Organization of the United Nations (FAO – O'Mara, 2011) using life cycle assessment (LCA), has suggested that the livestock sector alone is in fact responsible for around 18% of global GHG emissions (Steinfeld *et al.*, 2006), with 4% being down to the dairy sector (FAO, 2010), which was estimated to produce 195 Mt CO_2-eq yr^{-1} in the (then) EU27 (Lesschen *et al.*, 2011). However, estimates vary considerably depending on the precise methodology used in their calculation (Herrero *et al.*, 2011).

Livestock agriculture produces GHGs in the form of CH_4 from enteric fermentation in ruminant livestock and the breakdown of stored manures, N_2O from the application of nitrogen-based fertilisers and manures, and CO_2 as a result of direct energy use (Hillier *et al.*, 2011; O'Mara, 2011; Crosson *et al.*, 2011; Schils *et al.*, 2007). Ruminant animals in particular, are central in determining emission levels (Olesen *et al.*, 2006), with the total magnitude of emissions having been shown to be closely related to the number of such animals present, particularly cattle (O'Mara, 2011). Indeed it was a reduction in the number of ruminant livestock in Europe in the decade to 2008, which was the main cause of the 7.5% decrease in GHG emissions from the sector over that period (Bolla and Pendolovska, 2011). This in turn is dependent on demand for food in general, and livestock products in particular, and with the world's population expected to exceed 8.5 billion by 2030 and 9.7 billion by 2050 (United Nations, 2015; Crosson *et al.*, 2011; O'Mara 2011; McAllister *et al.*, 2011), such demand can be expected to increase. Indeed the FAO predicts that global food supply will need to increase by nearly 40% by 2030 and 60% by 2050, although rates will need to exceed this in the developing world (Alexandratos and Bruinsma, 2012). In addition however, per capita meat consumption tends to be related to living standards (Foresight, 2011), so as these improve (particularly in Asia) demand for meat is expected to rise at a rate in excess of that for food as a whole, so that by 2050, demand for livestock derived products of all types could be at twice its current level (McAllister *et al.*, 2011), and have potentially serious implications for the future of GHG emissions from the industry (Garnett, 2009). Given the magnitude of the potentially deleterious effects of climate change (EEA, 2012), it is therefore little wonder that the livestock industry is under considerable pressure to reduce its impact (Herrero *et al.*, 2011; McAllister *et al.*, 2011).

The Kyoto Protocol of 1997 (an agreement under the United Nations Framework Convention on Climate Change - UNFCCC) established the legally binding target (for 37 developed nations) of reducing GHG emissions by at least 5% below 1990 levels over the 2008-2012 period (European Commission, 2002; Lewis *et al.*, 2013), which resulted in a target for the first 15 EU nations of an 8% reduction. Varying national targets were then set in order to result in the overall 8% reduction, with similar targets being set for nations joining the EU subsequently. Progress towards these targets was good, with an overall reduction in GHG emissions of 11.8% being achieved, without counting carbon sinks or international credits[2], and the target setting process has now been developed further. The second period of Kyoto (2013-2020), known as the Doha Amendment to Kyoto, is intended to cover the period up to the start of a new global agreement (expected to be adopted and the Paris Climate Change Conference in December 2015) in 2020, and established targets which as far as the EU is concerned are covered by its

2020 Climate and Energy Package (European Commission, 2007; European Commission, 2008), which amongst other things established the goal of reducing GHG emissions by 20% by 2020. So far it is looking reasonably good that this target will also be met, with 23 countries forecast to achieve their national targets, and only 5 requiring more to be done. However, looking further into the future the challenge is likely to become increasingly tough, with the 2030 Climate and Energy Framework (European Commission, 2014) aiming for a 40% reduction by to 2030, and the 2050 Low-Carbon Economy Roadmap (European Commission, 2011) going for 60% by 2040 and 80% by 2050 (all compared to 1990 levels). If such stringent targets are to be met, all sectors will clearly have a role to play, and there can be little doubt that pressure to improve the performance of the livestock industry will continue to mount.

Fortunately however, options for climate change mitigation within the livestock sector, particularly in developed nations, are often fairly good (Hillier *et al.*, 2011), with a number of options being identified as being applicable to the industry (Smith *et al.*, 2007; Smith *et al.*, 2008), indeed many mitigation techniques make use of current technologies and could be implemented reasonably quickly (Crosson *et al.*, 2011). It is known, for example, that the type and size of animal and their diet, all effect enteric CH_4 production, the extent to which livestock are grazed as opposed to housed impacts N_2O emissions, and the approach to handling and storing manures and slurries will have an effect on both gasses (O'Mara, 2011). However, if individual businesses are to take up the challenge, tools for facilitating this need to be readily available.

1.2. GHG accounting in livestock agriculture

Carbon footprinting has been an option for some time, albeit that its adoption by the agricultural industry has, to date, been piecemeal, not least because the need to invest in the services of a consultant continues to be seen as a barrier (Dodd, 2012). Nevertheless, such techniques potentially allow businesses to identify efficiencies which, as well as reducing GHG emissions, make sound financial sense (e.g. by reducing input costs), and there are now a number of freely available tools which purport to allow land managers to develop their own carbon footprints at minimal cost, and (except in academic studies) it is likely to be just this sort of tool which most farms will adopt. Nevertheless, the use of such systems in livestock agriculture is fraught with difficulties.

Firstly, the livestock industry differs from many others, in that the major GHGs of relevance are non-CO_2, and are the result of complex biogenic processes as opposed to the direct consumption of energy. They are therefore dependent on site and business-specific conditions (e.g. soil, weather, livestock type, etc.), leading to a higher degree of uncertainty in estimated emissions (Flysjö *et al.*, 2011) and difficulties in comparing businesses. In addition, agriculture, like many other industries, has seen a proliferation of carbon calculators, which use a series of emission factors to convert activities into emission estimates (Kim and Neff, 2009; Little and Smith, 2010). This leads to concern that variations in the scope of different tools, and a lack of transparency in the precise methodologies used, could lead to misleading, or even erroneous results (Kim and Neff, 2009).

Despite these issues however, benchmarking has already made inroads into the agricultural sector (and the livestock sector in particular), and is likely to continue to do so, since it is clear that the concept of benchmarking in general is already well established in the consciousness of both policy makers and the agricultural industry itself, and benchmarking of GHG emissions is increasing. It has become a familiar part of the analysis of business performance through such systems as 'Milkbench^{+}'[3] from DairyCo in the Dairy sector, the related 'CropBench^{+}'[4] from the Agriculture and Horticulture Development Board (AHDB) for use in the arable sector, and 'Stocktake' from AHDB Beef and Lamb (paper based benchmarking statistics – EBLEX, 2014), all of which allow benchmarking of financial and physical performance metrics, as well as the draft 'Irrigation Benchmarking' system produced by Cranfield University (Knox *et al.*, 2013). Equally however, the wider dairy industry is making increasing use of benchmarking in the implementation of its environmental policies, with the 'Dairy Roadmap' (DairyCo, 2011; DairyCo, 2013) in the UK for example, using it to both track temporal changes in resource use, and make comparisons with equivalent sectors in other parts of the world. At a governmental level, benchmarking of GHG emissions is already a factor in the EU's Emission Trading System (EU ETS) for example (Foucherot and Bellassen, 2013), where it is utilised in order to establish efficiency values from which free emission allowances can be calculated (i.e. they are not limits or targets in themselves - EU, 2013). Few agricultural businesses currently fall within the scope of this particular system, but benchmarking continues to be seen as an effective motivator for change (Policy Commission on the Future of Farming and Food, 2002; Ashworth, 2002), with the established wisdom being that consumers will seek out products with good 'green credentials', and that retailers will therefore preferentially obtain products from better performing suppliers. In fact, retailers are already demanding efficiencies within the supply chain (in terms of GHG targets), and it can be envisaged that should eco-labelling be widely expanded into the food sector, then the role of benchmarking will also expand.

The extent to which this will happen is uncertain, although the European Commission, for example, has already taken the first steps towards the introduction of a low-carbon farming scheme (of which the European Carbon Calculator discussed later in this report formed part of the pilot) centred around a carbon accounting approach coupled with a benchmarking system (Tuomisto *et al.*, 2013; Jędrzejewska and Surján, 2010). At the time of writing it is unclear whether this will ultimately be implemented, but nevertheless, as benchmarking actively permits producers to demonstrate industry leading performance, producers may gain a commercial advantage if they are able to demonstrate they are ahead of the game. Indeed, it may become an essential requirement of some major retailers, for their suppliers to be able to do so.

2. Material and methods

The reported study was comprised of three main elements, as detailed below:

1) Identification of tools suitable for analysis in the context of European livestock agriculture.
2) Development and evaluation of a series of production system scenarios based on real European farms.
3) Examination of resulting GHG emission estimates to identify their suitability for use in benchmarking activities.

2.1. Identification of tools to be studied

In recent years, a number of carbon accounting tools have been developed for use in a wide range of sectors (agricultural, domestic, industrial, etc.) and by different end-users (e.g. policy makers, scientists, environmental managers); however, not all are suitable for on-farm use in general, or in the livestock industry in particular. Therefore, in order to identify a suite of tools suitable for further evaluation, a review of available systems was carried out, in which tools were sought which met a number of predefined criteria. Specifically, they should:

1) *Have data entry and computational capabilities appropriate for the sector:* Many tools do not include the data entry characteristics and emission factors to permit use in livestock agriculture.
2) *Be applicable to the region being considered:* Only those tools designed for, or purporting to be suitable for, European use were included in this study.
3) *Be freely available:* So as to encourage widespread adoption in an industry in which financial pressures may be acute, and ensure a greater degree of tool comparability, purchasable systems (some of which may entail significant expenditure) were excluded.
4) *Be based on data liable to be held by farm managers:* Only those tools requiring little if any additional data collection were included, so as to ensure suitability for use in businesses with limited time availability.

2.2. Scenario development and evaluation

As part of an extensive pan-European research project carried out on behalf of the European Commission (Tzilivakis *et al.*, 2010), a number of case-study farms were identified for use in model validation. Those case studies in which the principle enterprise was dairy farming, were identified and reviewed in detail in order to develop standardised scenarios. This involved isolating those elements of a farms activities which were directly related to the dairy part of the enterprise, (i.e. anything which could be wholly assigned to arable production or other forms of livestock was removed). All relevant data was then extracted from the identified scenario subset, and (where appropriate) gaps in data which might impact on the ability of some tools to be fully tested were identified. These were then filled using published literature related to land and animal management in the dairy sector (e.g. Thomas, 2007; Natural England, 2012; Natural England, 2013; Defra, 2010), and the characteristics of the dairy industry in different EU nations (e.g. European Commission and EU FADN, 2013). In addition, supporting data on the local climate and soils was identified from freely available databases. In the case of climate, these belonged either to the local meteorological service (UK: Met Office[5], France: Meteo France[6], Italy: Meteo Aeronautica[7]), or a global climate database (Poland: World Weather Online[8]). Soils data was obtained in the form of the 'soil reference group code from the World Reference Base (WRB) for soil resources' and the 'dominant surface textural class', both available from the European Soil Data Centre (ESDAC[9]). The approach of developing scenarios in this way (as opposed to using the case-studies in their existing state) was adopted, in order to overcome the different approaches to data recording (reflecting local practices) taken in the original project, allow for gaps in data resulting from the specific requirements of that study, and allow for greater comparability. Each of the identified tools was then applied to each scenario so as to determine the estimated GHG emissions, and thereby emulate processes that would be undertaken in real farm management situations.

2.3 Benchmarking assessment

This element of the study was itself comprised of two parts. Firstly, the GHG emission estimates produced by each tool for each farm scenario were apportioned in a number of different ways (as well as being considered in their un-apportioned state), namely:

a) *Total GHG emissions of the farm:* emissions not apportioned.
b) *GHG emissions per productive farm hectare:* taken to be emissions divided by the area of grassland and arable (for feed) crops.
c) *GHG emissions per livestock unit:* livestock units being based on animal age and number, as detailed in the widely adopted 'Farm Management Pocketbook' (Nix *et al.*, 2003).
d) *GHG emissions per unit of milk production:* emissions divided by milk yield on m^3.

These emission estimates were then plotted in order to provide a visual assessment of the degree of separation between scenarios (Figure 1). Subsequently, a series of multiple comparisons between scenarios using one-way analysis of variance (ANOVA) were performed for each method of emission apportionment, in order to test statistically (at the 95% confidence level) the following hypotheses:

Overall ANOVA:

H_{A1}: The mean of the GHG emissions produced for at least one farm is significantly different to the others.

H_{O1}: The means of the GHG emissions produced for all farms are equal.

Tukey pairwise comparisons:

H_{A2}: The mean GHG emission estimates associated with a pair of farms are significantly different to each other.

H_{O2}: The mean GHG emission estimates associated with a pair of farms are equal.

This was done on the basis that there is currently no requirement for agricultural enterprises to use any particular carbon accounting tool in their businesses (if indeed they use one at all), therefore if benchmarking is to become a reality, it must be possible to differentiate between farm enterprises in the absence of single tool adoption (i.e. there should be some degree of consistency between the way in which farms are rated).

3. Results

3.1. Selection and characterisation of tools to be studied

In recent years a number of new carbon accounting tools have been developed for the agricultural industry, whilst others still have been significantly amended. This review identified seven which met the established criteria, and were therefore selected for in-depth evaluation. A number of others were considered for inclusion, but rejected on the grounds that they were either considered not to be applicable to mainstream European agriculture (e.g. COMET-Farm[10]), were limited in their extent (e.g. relating only to emissions associated with direct energy use – Centre for Alternative Land Use, 2007), in the main adopted a practice based scoring system rather than quantifying emissions (FCAT[11]) or they required a fee, a characteristic likely to put off many producers (e.g. CPLANv2[12]). Those selected for in-depth evaluation were as follows:

- *CPLANv0*[12]: developed by farmers in Central Scotland for UK based farm/land managers and policy makers. It is intended to serve as a management tool for assessing and monitoring GHGs and informing policy. One bug was identified within this tool, as where numbers of “other cattle < 1 year” are entered the emissions calculated are in CO_2eq, rather than the Ceq the results are stated to be in. Adjustment was made for this in this paper, although it is unclear whether users will general be aware of this problem.
- *CALM*[13]: developed by the UK’s Country Land and Business Association (CLA), for use by UK based farm/land managers, with the objective of identifying options to cut emissions and increase efficiency.
- *CCaLC*[14]: developed by the University of Manchester for use in all forms of production (not just agriculture), but encompassing primary production. It is intended for use by supply chain managers, policy makers and environmental officers, particularly for supply chain optimisation and monitoring. Its supply chain emphasis means that it may be less intuitive to use within the context of a farm business, although much of the data required is likely to be readily available.
- *COOL* (Hillier *et al.*, 2011)[15]: developed by Unilever for use in global agriculture, and intended for use by farmers and supply chain managers/companies around the world, in the identification of options to cut emissions and increase efficiency. Although much of the

required data is likely to be readily available, the international audience of the tool means that some may not be in the form required, and therefore require conversion.

- *IMPACCT*[16] (Tzilivakis *et al.*, 2010; Tzilivakis *et al.*, 2014): a prototype developed by the University of Hertfordshire to assess GHG emissions and sequestration, and advise on appropriate mitigation strategies. It is intended for use by European farmers/land managers and policy makers.
- *Farm Carbon Calculator (FCC)*[17]: developed by a non-profit making organisation to promote low carbon practice amongst UK farmers and growers, and forming part of the wider Farm Carbon Cutting Toolkit[18]. Although heavily influenced by the needs of organic producers, it is nevertheless equally applicable to the wider industry.
- *European Carbon Calculator (ECC)*[19]: developed by Solagro in France for the European Commission's Joint Research Center (JRC), with the aim of promoting "low carbon farming practices which can be implemented on (almost) every farm in the European Union".

Further details of these tools can be found in Table I.

Table I. Characteristics of assessed carbon accounting tools.

3.2. Scenario development

Of the case-study farms assessed, six in four different European countries (Table II) were found to be comprised of businesses describing themselves as predominantly dairy based, and therefore selected as the basis for scenario development. Data on production types and levels, feed inputs and basic land and manure management practices was extracted from each in as consistent a form as differences in data collection would allow, and supported with data from published literature, so as to produce standardised scenarios containing all the data required by the various tools, although not all data was used by each tool. The studied scenarios possessed a number of consistent characteristics, including the use of a static pile with forced aeration for manure storage (where livestock were housed for part of the year), and a plough depth of 20cm and the incorporation of residues on cropped areas. Other properties however, varied considerably, including the livestock mix on the farm and their diet (Table III), and the cropping, milk yield and direct energy use associated with the dairy system (Table IV). Although these scenarios vary in precise form, they may be considered typical of many European dairy businesses.

Table II. Site characteristics of studied farm scenarios.
Table III. Livestock production characteristics of studied farm scenarios.
Table IV. Cropping, milk yield and energy use characteristics of studied farm scenarios (numbers in brackets = number of applications used to achieve total).

3.3. Benchmarking assessment

When the GHG emission estimates produced for the six farm scenarios using the seven assessed carbon accounting tools were plotted (Figure 1), a number of key patterns (or in some cases their absence) were noted. Firstly, in relation to the un-apportioned emission estimates (Figure 1a), there was a good deal of agreement between tools in terms of the way in which the scenarios were ordered (benchmarked against each other). Scenario IT1 for example, always produced higher emission estimates than any other, no matter which tool was used; whilst scenarios PL1, FR3, and FR1 always produced the lowest, second lowest and third lowest estimates respectively. Only for scenarios FR2 and UK1 was there any variation in outcome between the various tools.

When emissions per unit of productive area (Figure 1b – note, as the estimates for each farm are divided by different areas, the resulting pattern will not necessarily be the same as the above) were examined, a similar, although less pronounced pattern was observed. In this case only scenario FR1 was consistently ranked (lowest emissions per unit area) in the benchmarking exercise, whilst others were ordered differently by different tools, albeit only by one or two places. In contrast, when emissions per livestock unit (Figure 1c) and per unit of produced milk (Figure 1d) were considered, marked inconsistencies in the way in which scenarios were benchmarked against each other were clear. In terms of per milk yield emissions for example, farm UK1 was ranked as one of the best performing by COOL (0.99 t CO_2e m^{-3}) and the worst preforming by CPLAN (1.94 t CO_2e m^{-3}).

Figure 1. Calculated GHG emissions for six farm scenarios from seven carbon accounting tools.

The analysis of variance (ANOVA) between farms (Table V) reveals that the overall ANOVA results produce P-values of 0.007 or less, suggesting that H_{O1} could be rejected in all cases, and that at least some significant variation between farms could be identified (i.e. at least one farm differed significantly from the others in terms of its GHG emission estimates). Again this was most pronounced in the case of the un-apportioned emission estimates and emissions per unit of productive area (P-value <0.001 in both cases). However, when looking at the Tukey pairwise comparisons in detail, it is clear that the ANOVA results support the graphical findings above, in that clear distinctions between farms (i.e. where H_{O2} can be rejected) can generally only be made in relation to total GHG emissions and emissions per productive hectare. In the former case, there was a clear distinction between many scenario farms, with significant (at the 95% confidence level – all adjusted P-values <0.001) differences between all farms except FR2 and UK1 (adjusted P-value = 0.941) and FR1, FR3 and PL1 (adjusted P-values of: FR3-FR1 = 0.943, PL1-FR1 = 0.276 and PL1-FR3 = 0.800). As far as the results for the GHG emissions per productive hectare are concerned, there was a little less distinction between scenarios with UK1 and IT1 being significantly different to all other farm scenarios (adjusted P-values <0.019 in all cases and most <0.001), whilst there was considerably less distinction between the other scenarios with only FR1 and PL1 being significantly different to each other (adjusted P-value = 0.014). For the other two methods of GHG emission apportionment, there was little statistically valid differentiation between scenarios, with per livestock unit apportionment resulting in only PL1 being significantly different to most other farms (adjusted P-values of 0.005 to 0.019) except UK1 (adjusted P-value = 0.056), whilst for per m^3 milk yield apportionment, only two significantly different pairs of means were identified (PL1-FR2 = 0.008 and PL1-UK1 = 0.027).

Table V. Overall one-way ANOVA P-value and Tukey pairwise comparisons.

4. Discussion

The above results indicate that there is broad agreement between tools when it comes to overall emission estimates, and even emissions per unit area (particularly in relation to the way the individual tools benchmark scenarios); however, there is still a considerable amount of disagreement between them in all other respects, which may hinder their usefulness within a benchmarking environment. That agreement which was observed, was no doubt a reflection of the dominant role played in determining emissions, by the number of animals (in this case cattle) present (O'Mara, 2011). In addition however, although the various tools use somewhat different methodologies, they are in the main based on those recommended nationally (e.g. PAS 2050:2011 - BSI, 2011) or internationally (e.g. Eggleston *et al.*, 2006), and therefore share many similarities. Nevertheless, there are inevitably some differences in the emission factors used, and more importantly, the scope and precise methodology (e.g. tier) adopted varies (Table I). For example, although all the tools cover scope 1 (those arising directly from sources that are owned or controlled by the farm) and scope 2 (generated as a result of purchased electricity) emissions, the extent to which scope 3 (which are a result of a farms activities but occurring from sources not owned or controlled by it) emissions are covered, varies from not at all (CPLANv0), through those which include some scope 3 emissions (CALM, COOL, FCC), to those which try to encompass this to a considerable degree (CCaLC, IMPACCT, ECC). Similarly, tools such as CPLANv0 and CALM restrict themselves to a tier 1 (general emission factor) approach, whilst others adopt tier 2 (more specific emission factors - e.g. Cool, ECC) or even partial tier 3 (meta-modelling in this case - IMPACCT) approaches, and inevitably this introduces some of the variability identified by Kim and Neff (2009) as a problem in the sector.

Where this really comes to the fore is when emissions are considered on the basis of some useful functional unit. It is now widely recognised that GHG emissions must be presented in terms of some practical functional unit (e.g. per ha, per LU, per unit of production, etc.) in order to allow meaningful comparisons between businesses to be made (Franks and Hadingham, 2012), as to do otherwise runs the risk of drawing erroneous conclusions as to performance. The above results however, highlight significant problems in doing so using the sort of carbon accounting tools currently available to the livestock sector. Within this study three functional units have been assessed (in addition to the whole farm), one area based, one animal based (taking into account their life stage – i.e. livestock units) and one based on output. Of these only the area based assessment produced a significant level of agreement between the outputs of the different tools, no doubt reflecting the relationship that exists between approaches taken to land and livestock management (e.g. the intensity of production, etc.) and the resulting GHG emissions. In policy terms, GHG emissions per unit area may be an important metric, since governments attempting to meet stringent, internationally agreed GHG emission targets, may (in the short term at least) be most interested in reducing the emissions associated with a given spatial area (country and/or region), and therefore find an area based form of apportionment attractive. However, if no account is taken of production, then emission assessments may fail to take into account the GHG emissions inherent in the imports which may be required to make up any shortfall in supply in relation to demand. This carbon leakage (the relocation of emissions to parts of the world subject to weaker regulation) through production displacement, can seriously reduce the overall effectiveness of emission reduction programmes, even if national performance appears improved (e.g. Böhringer *et al.*, 2012).

In contrast, there was far less agreement between the tools obtained when using livestock units or milk output as the functional unit for apportioning GHG emissions. This is a significant problem in as far as the benchmarking of performance is concerned, and is probably a reflection of the fact that in the dairy industry, a wide range of approaches can be taken so as to result in the same milk output (e.g. from highly intensive 100% housed systems to less intensive fully grazed systems), and each will have a very different GHG profile. In the UK for example, work by the supermarket Morrisons has suggested that there is an inverse relationship between GHG emissions per litre and the litres of milk produced per cow, such that more intensive production may actually be more efficient (Morrisons, 2011). This ties in with the concepts of 'sustainable intensification' and 'climate smart agriculture'' (Campbell *et al.*, 2014), both of which stress the importance of maximising productive output whilst minimising environmental impact, and are likely to be at the core of future agri-environment and food security policy in Europe as elsewhere (e.g. Buckwell *et al.*, 2014). In this sense, some measure of emissions per unit of output (milk) is likely to be the most valuable functional unit in relation to benchmarking activities aimed at minimising overall climate change impact. Farming after all, has to produce enough food to support the world's growing population, and as some authors have pointed out, if it comes down to a straight choice between food shortages and GHG emissions, food will always win out (e.g. McAllister *et al.*, 2011). Therefore, notwithstanding the fact that changes could (and probably should) be made to diets to reduce our requirement for some foods (reduce demand), it is essential that those businesses able to supply the remaining market demand with the minimum GHG impact should be favoured in preference to those which are less efficient.

Clearly however, this ultimate conclusion of a benchmarking approach to GHG emission minimisation, brings with it a wide range of knock on economic, social and environmental effects, not least because farmers in some geographical locations may not have the option of using the most GHG efficient production methods. In practice of course, benchmarking is generally done against businesses in a similar area, so as to ensure true comparability of results, but the extent to which this is necessary may be a function of factors that go beyond on-farm GHG emission minimisation. For example, it may be desirable to compare dairy enterprises, but if the only goal were to minimise the resulting GHG emissions per unit of output, it may be less necessary to restrict the exercise to farms in the same geographical location or facing the same environmental challenges, as concentrating production in a few areas particularly suited to it, may be desirable. Equally however, it may be undesirable for a number of reasons, including the need to maintain production over a broad area to reduce the risk posed to food security by (for example) disease, to minimise subsequent food miles or to maintain local rural economies.

These are however, factors which can only be determined in light of broader policy objectives. This study however, suggests that benchmarking on the basis of production efficiency (in GHG emission terms) should it be deemed desirable, is fraught with difficulty within dairy farming, with little agreement between tools as to the relative performance of farm scenarios, and only farms at the extremes of performance being differentiated from each other. It may be of course, that it is the farms at the extremes of performance, particularly those performing least efficiently, which it is important to identify and address if the industry is to be pushed forwards. However, there is little evidence in this study that the carbon calculators presently available to the industry are likely to be suitable tools for detailed benchmarking studies, unless evidence is found to support one methodology over others. To some extent this was something which it was hoped the European Carbon Calculator (ECC) would address, but to date at least, it has failed to take a leading role in the industry (possibly due to its heavy data entry demands), and remains only one of a range of options out there. Consequently, there is no clear guidance as to which tool producers should be using, or any clear indication of which may be the most accurate. The assumption is often made that more data hungry tools (e.g. COOL, IMPACCT and the ECC), which allow site and/or practice specific factors to be accounted for, will produce more accurate results, but the extent to which this is true over wide spatial areas with significantly different circumstances, is unclear. All are to some degree based on the use of standardised emission factors, and although in theory this ought to result in them producing comparable results (at least when the same tool is used), it brings with it no guarantee of accuracy.

Equally, if benchmarking were to be used to evaluate enterprise performance against pre-determined thresholds, which might control some element of commercial activity, for example meeting the requirements of a retailer, or allowing membership of an carbon labelling scheme, then it is likely that the variation in the results between tools might make such judgements prone to error, as where any line is drawn through the data, it is quite possible (and indeed probable) for different carbon calculators to place farms on different sides of that line; highlighting the difficulties inherent in setting such thresholds identified by some authors (e.g. Bozowsky and Mizuno, 2004). Clearly then, if such a system were to be adopted, the use of a consistent calculator, with sufficient transparency in the way in which it works for producers to know how they are being assessed, may be essential. Fortunately, although this may be a long way off in terms of the EU as a whole (see above), there is no reason that a given labelling scheme could not stipulate the use of a specific carbon accounting tool, thereby ensuring that all farms assessed were at least being evaluated on the same basis.

Finally, it is worth bearing in mind that the benchmarking of enterprises is only the first stage in driving forward the performance of any sector, as providing a basis for (in this case) on-farm GHG emission reduction, is essential if improvements are to be made. Benchmarking should be considered as an environmental management tool, and for it to act in this role, not only does the benchmarking status of an enterprise need to be identified, but there also needs to be some mechanism for accessing information on how to improve the situation (Jónsdóttir *et al.*, 2005). Some tools (e.g. IMPACCT and to some extent the ECC) attempt to make specific recommendations for improvement, and therefore take the user a significant way along the road to identifying a solution, whereas others are supported by specific downloadable guidance (e.g. FCC) and/or links to external online resources (e.g. CALM, COOL), and others still (CPLANv0) provide very little additional support. Clearly then there would be more to consider when selecting a tool for use in benchmarking activities, than simply the requirements of obtaining a quantitative benchmarking 'score'.

5. Conclusions

The results of this study indicate that there are still significant hurdles to overcome if benchmarking of GHG emissions is to play a useful role in driving forward the environmental performance of the dairy industry. This is particularly on account of the lack of any agreement between tools when suitable functional units are applied (something which is essential if meaningful assessments are to be made), or advice as to the best or most accurate tool to use, something which may itself vary from region to region and enterprise to enterprise. This severely reduces the power of benchmarking in the dairy sector, and means that should widespread carbon labelling become a reality, then scheme administrators would be required to take a view as to the most appropriate tool to use. Although it is recognised that the basis for doing this is likely to be weak, and indeed the decision is likely to be as influenced by the perceived need for mitigation advice and/or simplicity as accuracy, it would at least provide for consistent benchmarking and transparency as to the business characteristics leading to a favourable assessment. In addition however, it is important that GHG emission benchmarking is not viewed in isolation, as livestock agriculture plays a wide variety of roles in food production, rural economies and society as a whole, and these various roles must be reflected in the way in which the results of any benchmarking activities are applied on the ground. Finally, the extent to which the findings of this paper are applicable to other agricultural sectors and/or industries is unclear. However, it is quite possible that other businesses which operate in an environment in which they are subject to site or enterprise specific conditions with the potential to impact on emission factors, may be subject to similar restrictions on the usefulness of current benchmarking tools.

Notes

1. http://www.co2benchmark.com
2. http://ec.europa.eu/clima/policies/strategies/progress/kyoto_1/index_en.htm
3. http://milkbenchplus.org.uk/Public/Content.aspx?id=1
4. http://www.cropbenchplus.org.uk/Public/Content.aspx?id=1
5. http://www.metoffice.gov.uk
6. http://www.meteofrance.com
7. http://www.meteoam.it
8. http://www.worldweatheronline.com
9. http://esdac.jrc.ec.europa.eu
10. http://www.comet2.colostate.edu
11. http://www.soilassociation.org/innovativefarming/lowcarbonfarming/fcatfarmcarbonassessmenttool
12. http://www.see360.org.uk
13. http://www.calm.cla.org.uk
14. http://www.ccalc.org.uk/ccalctool.php
15. http://www.coolfarmtool.org
16. http://sitem.herts.ac.uk/aeru/impacct/software.htm
17. http://www.cffcarboncalculator.org.uk
18. http://farmcarbontoolkit.org.uk
19. http://www.solagro.org/site/476.html

References

Alexandratos, N. and Bruinsma, J. (2012). "World Agriculture Towards 2030/2050: The 2012 Revision", Working Paper No. 12-03, Food and Agriculture Organization, Rome, June 2012.

Ashworth, S. (2002). *Should we be benchmarking? Sheep and Beef Notes, November 2002.* The Scottish Agricultural College, Aberdeen, UK.

Bhutta, K.S. and Huq, F. (1999). "Benchmarking – best practices: an integrated approach", *Benchmarking: An International Journal*, Vol. 6 No. 3, pp. 254-268.

Boardman, B. (2008). "Carbon labelling: too complex or will it transform our buying?", *Significance*, Vol. 5 No. 4, pp. 168-171.

Böhringer, C., Carbone, J.C. and Rutherford, T.F. (2012). "Unilateral climate policy design: Efficiency and equity implications of alternative instruments to reduce carbon leakage", *Energy Economics*, Vol. 34 Supplement 2, pp. S208-S217.

Bolla, V. and Pendolovska, V. (2011). “Driving forces behind EU-27 greenhouse gas emissions over the decade 1999-2008”, *Statistics in Focus*, Vol. 10/2011, pp. 1-12

Bozowsky, E. and Mizuno, H. (2004). “Introduction to Ecolabelling”, available at: http://www.globalecolabelling.net/docs/documents/intro_to_ecolabelling.pdf (accessed 18 October 2015).

BSI. (2011). PAS 2050:2011 Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services. British Standards Institute, London.

Buckwell, A., Heissenhuber, A. and Blum, W. (2014). *The Sustainable Intensification of European Agriculture: A Review Sponsored by the RISE Foundation*, The RISE Foundation, Brussels.

Campbell, B.M., Thornton, P., Zougmoré, R., van Asten, P. and Lipper, L. (2014). “Sustainable intensification: What is its role in climate smart agriculture?”, *Current Opinion in Environmental Sustainability*, Vol. 8, pp. 39-43.

Centre for Alternative Land Use. (2007). “Managing Energy and Carbon - The Farmer's Guide to Energy Audits”, available at: http://www.calu.bangor.ac.uk/Technical%20leaflets/Energyauditmanual.pdf (accessed 16 September 2015).

Crosson, P., Shalloo, L., O’Brien, D., Lanigan, G.J., Foley, P.A., Boland, T.M. and Kenny, D.A. (2011). “A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems”, *Anim Feed Sci Technol*, Vol. 166-167, pp. 29-45.

DairyCo. (2011). *“Dairy Roadmap - Our Route Towards Environmental Success”*, Agriculture and Horticulture Development Board, Kenilworth, UK.

DairyCo. (2013). *“Dairy Roadmap 2013 - Environmental Sustainability Report”*, Agriculture and Horticulture Development Board, Kenilworth, UK.

Defra. (2010). *“Fertiliser Manual (RB209) - 8th Edition”*, TSO (The Stationery Office), Norwich, UK.

Dodd, B. (2012). “Carbon footprint - a vital measure for efficiency”, *Farmers Weekly*, 2 November 2012.

D'Souza, C., Taghian, M. and Lamb, P. (2006). “An empirical study on the influence of environmental labels on consumers”, *Corporate Communications: An International Journal*, Vol. 11 No. 2, pp. 162-173.

EBLEX. (2014). *“Stocktake Report 2014”,* AHDB Beef and Lamb, Kenilworth, UK.

Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (Eds.). (2006). *“IPCC Guidelines for National Greenhouse Gas Inventories”*, IGES, Hayama Kanagawa, Japan.

Elmuti, D. and Kathawala, Y. (1997). “An overview of benchmarking process: a tool for continuous improvement and competitive advantage”, *Benchmarking for Quality Management and Technology*, Vol. 4 No. 4, pp. 229-243.

European Commission. (2002). “Council Decision 2002/358/CE of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United

Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder", *Official Journal of the European Communities*, Vol. L130, pp. 1-20.

European Commission. (2007). *"Combating Climate Change - The EU Leads The Way"*, Office for Official Publications of the European Communities, Luxembourg.

European Commission. (2008). *"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: 20 20 by 2020 Europe's Climate Change Opportunity - COM(2008) 30 final"*, European Commission, Brussels.

European Commission. (2011). *"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Roadmap for Moving to a Competitive Low Carbon Economy in 2050 - COM(2011) 112 final"*, European Commission, Brussels.

European Commission. (2014). *"Green Paper: A 2030 Framework for Climate and Energy Policies - COM(2013) 169 final"*, European Commission, Brussels.

European Commission and EU FADN. (2013). *"EU Dairy Farms Report 2012: Based on FADN Data"*, European Union, Brussels.

European Environment Agency. (2012). *"EEA Report No 12 - Climate Change, Impacts and Vulnerability in Europe 2012: An Indicator-Based Report"*, Office for Official Publications of the European Union, Luxembourg.

European Union. (2013). *"The EU Emission Trading System (EU ETS)"*, Publications Office of the European Union, Luxembourg.

FAO. (2010). *"Greenhouse Gas Emissions from the Dairy Sector - A Life Cycle Assessment"*, Food and Agriculture Organization, Rome.

Flysjö, A., Henriksson, M., Cederberg, C., Ledgard, S. and Englund, J.-E. (2011). "The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden", *Agr Syst*, Vol. 104 No. 6, pp. 459-69.

Foresight. (2011). *"The Future of Food and Farming Final Project Report"*, The Government Office for Science, London.

Foucherot, C. and Bellassen, V. (2013). "Climate Report, No. 39: More than 800 agricultural and agri-food sites affected by the EU ETS", available at: http://prodinra.inra.fr/?locale=en#!Result:collectionId:59223%7Csort=%7BDATE_DESC%7D (accessed 19 October 2015).

Franks, J.R. and Hadingham, B. (2012). "Reducing greenhouse gas emissions from agriculture - Avoiding trivial solutions to a global problem", *Land Use Policy*, Vol. 29 No. 4, pp. 727-36.

Gadanakis, Y., Bennett, R., Park, J. and Areal, F.A. (2015). "Improving productivity and water use efficiency: A case study of farms in England", *Agricultural Water Management*, Vol. 160, pp. 22-32.

Gadema, Z. and Oglethorpe, D. (2011). “The use and usefulness of carbon labelling food: A policy perspective from a survey of UK supermarket shoppers”, *Food Policy*, Vol. 36 No. 6, pp. 815-822.

Garnett T. (2009). “Livestock-related greenhouse gas emissions: impacts and options for policy makers”, *Environ Sci Policy*, Vol. 12 No. 4, pp. 491-503.

Hagemann, M., Hemme, T., Ndambi, A., Alqaisi, O. and Sultana, M.N. (2011). “Benchmarking of greenhouse gas emissions of bovine milk production systems for 38 countries”, *Anim Feed Sci Tech*, Vol. 166-167, pp. 46-58.

Herrero, M., Gerber, P., Vellinga, T., Garnett, T., Leip, A., Opio, C., Westhoek, H.J., Thornton, P.K., Olesen, J., Hutchings, N., Montgomery, H., Soussana, J.-F., Steinfeld, H. and McAllister, T.A. (2011). “Livestock and greenhouse gas emissions: The importance of getting the numbers right”, *Anim Feed Sci Tech*, Vol. 166-167, pp. 779-782.

Hillier, J., Walter, C., Malin, D., Garcia-Suarez, T., Mila-i-Canals, L. and Smith, P. (2011). “A farm-focused calculator for emissions from crop and livestock production”, *Environ Modell Softw*, Vol. 26 No. 9, pp. 1070-8.

Jędrzejewska, S. and Surján, L. (2010). “Working document on pilot projects and preparatory actions in budget 2011”, working paper, European Parliament Committee on Budgets, Brussels, 3 February 2011.

Jónsdóttir, H., Sparf, A.M. and Hanssen, O.J. (2005). “*Environmental Benchmarking: A Tool for Continuous Environmental Improvements in the SME Sector”*, Nordic Innovation Centre, Oslo.

Kanellopoulos, A., Reidsma, P., Wolf, J. and vanIttersum, M.K. (2014). “Assessing climate change and associated socio-economic scenarios for arable farming in the Netherlands: An application of benchmarking and bio-economic farm modelling”, *Europ. J. Agronomy*, Vol. 52 Part A, pp. 69-80.

Kim, B. and Neff, R. (2009). “Measurement and communication of greenhouse gas emissions from U.S. food consumption via carbon calculators”, *Ecol Econ*, Vol. 69 No. 1, pp. 186-96.

Knox, J.W., Daccache, A., Kay, M.G., Hess, T.M., Else, M., Burton, M., Thelwall, D., and Malano, H. (2013). “*Irrigation Benchmarking - Comparing Performance to Improve Water Efficiency, Value and Productivity: An Information Booklet Produced for Defra”*, Cranfield University, Cranfield, UK.

Lesschen, J.P., van den Berg, M., Westhoek, H.J., Witzke, H.P. and Oenema, O. (2011). “Greenhouse gas emission profiles of European livestock sectors”, *Anim Feed Sci Tech*, Vol. 166-167, pp. 16-28.

Lewis, K.A., Green, A., Warner, D.J., Tzilivakis, J. (2013). “Carbon accounting tools: are they fit for purpose in the context of arable cropping?”, *Int J Agr Sustain*, Vol. 11 No. 2, pp. 159-75.

Little, T. and Smith, L. (2010). *"Carbon Footprinting for Farm Businesses"*, Better Organic Business Links, Aberystwyth, UK.

Matthews, D.H. (2003). "Environmental management systems for internal corporate environmental benchmarking", *Benchmarking: An International Journal*, Vol. 10 No. 2, pp. 95-106.

McAllister, T.A., Beauchemin, K.A., McGinn, S.M., Hao, X. and Robinson, P.H. (2011). "Greenhouse gases in animal agriculture - Finding a balance between food production and emissions", *Anim Feed Sci Tech*, Vol. 166-167, pp. 1-6.

Morrisons. (2011). *"UK Dairy Industry Carbon Footprint"*, Morrisons, Bradford, UK.

Natural England. (2012). *"Entry Level Stewardship: Environmental Stewardship Handbook - Fourth Edition, January 2013"*, Natural England, Peterborough, UK.

Natural England. (2013). *"Tried and Tested: Feed Planning for Cattle and Sheep"*, Natural England, Peterborough, UK.

Nix, J., Hill, P. and Edwards, A. (2003). *"Farm Management Pocketbook – 34th Edition, 2004"*, The Andersons Centre, Melton Mowbray, UK.

Olesen, J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A.H. and Djurhuus, J. (2006). "Modelling greenhouse gas emissions from European conventional and organic dairy farms", *Agriculture, Ecosystems and Environment*, Vol. 112 No. 2-3, pp. 207-220.

O'Mara, F.P. (2011). "The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future", *Anim Feed Sci Tech*, Vol. 166-167, pp. 7-15.

Policy Commission on the Future of Farming and Food. (2002). *"Farming and Food: A Sustainable Future"*, Cabinet Office, London.

Presley, A. and Meade, L. (2010). "Benchmarking for sustainability: an application to the sustainable construction industry", *Benchmarking: An International Journal*, Vol. 17 No. 3, pp. 435-451.

Röös, E. and Tjärnemo, H. (2011). "Challenges of carbon labelling of food products: a consumer research perspective", *British Food Journal*,Vol. 113 No. 8, pp. 982-996.

Schils, R.L.M., Olesen, J.E., del Prado, A. and Soussana, J.F. (2007). "A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems", *Livestock Science*, Vol. 112 No. 3, pp. 240-251.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. and Sirotenko, O. (2007). "Agriculture", in Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), *Climate Change 2007: Mitigation - Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge United Kingdom and New York, pp. 497-540.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P. McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008). "Greenhouse gas mitigation in agriculture", *Phil Trans R Soc B*, Vol. 363 No. 1492, pp. 789-813.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and de Haan, C. (2006). *"Livestock's Long Shadow - Environmental Issues and Options"*, Food and Agriculture Organization of the United Nations, Rome.

Thomas, C. (Ed.). (2007). *"Feed into Milk: A New Applieed Feeding System for Dairy Cows"*, Nottingham University Press, Nottingham, UK.

Tuomisto, H.L., Angileri, V., De Camillis, C., Loudjani, P., Nisini, L., Pelletier, N. and Haastrup, P. (2013). "*Final Technical Report: Certification of Low Carbon Farming Practices"*, Publications Office of the European Union, Luxembourg.

Tzilivakis, J., Green, A., Lewis, K.A. and Warner, D.J. (2014). *"Identifying integrated options for agricultural climate change mitigation"*, *Int J Clim Chang Strateg Manag*, Vol. 6 No. 2, pp. 192-211.

Tzilivakis, J., Green, A., Warner, D.J., McGeevor, K., MacMillan, T. and Lewis, K.A. (2011). "*Effective Approaches to Environmental Labelling of Food Products: Final Report for Project FO0419"*, Defra, London, available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17104 (accessed 15 September 2015).

Tzilivakis, J., Green, A., Warner, D.J., McGeever, K. and Lewis, K.A. (2012). "A framework for practical and effective eco-labelling of food products", *Sustainability Accounting, Management and Policy Journal*, Vol. 3 No. 1, pp. 50-73.

Tzilivakis, J., Lewis, K.A., Green, A. and Warner, D.J. (2010). *"The Climate Change Mitigation Potential of an EU Farm: Towards a Farm-Based Integrated Assessment - Final Report for EC Project ENV.B.1/ETU/2009/0052"*, European Commission, Brussels.

United Nations. (2015). *"World Population Prospects - The 2015 Revision"*, United Nations, New York.

Upham, P., Dendler, L.and Bleda, M. (2011). "Carbon labelling of grocery products: public perceptions and potential emissions reductions", *Journal of Cleaner Production*, Vol. 19 No. 4, pp. 348-355.

Vaughan, A. (2012). "*Tesco drops carbon-label pledge"*, available at: http://www.theguardian.com/environment/2012/jan/30/tesco-drops-carbon-labelling (accessed 29 June 2015).

Wu, P., Feng, Y., Pienaar, J. and Xia, B. (2015). "A review of benchmarking in carbon labelling schemes for building materials", *Journal of Cleaner Production*, doi:10.1016/j.jclepro.2015.07.067

Figure 1. Calculated GHG emissions for six farm scenarios from seven carbon accounting tools.

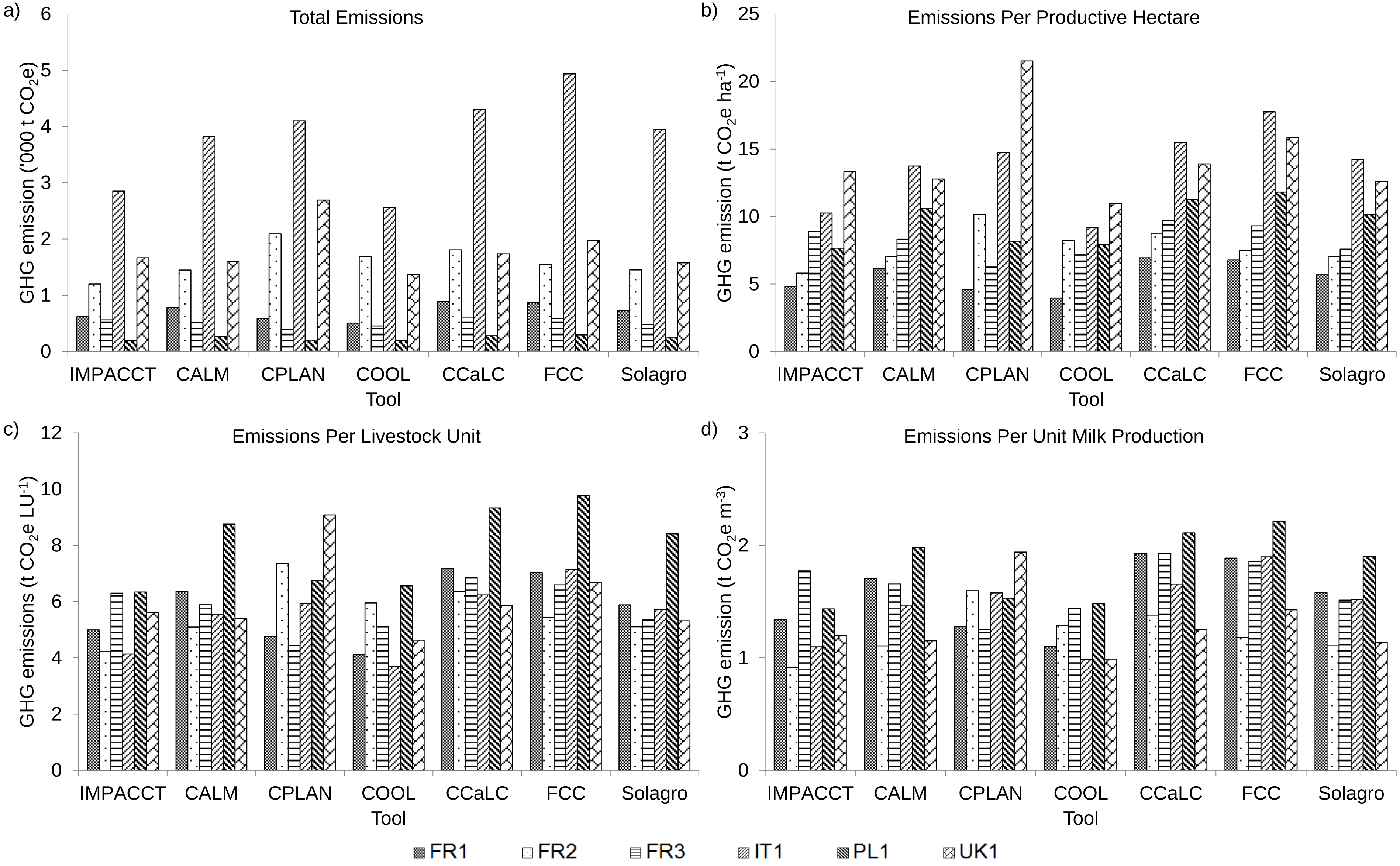

Table I. Characteristics of assessed carbon accounting tools.

Tool	Source of emission factors/ methodology	Type	Scope	Data requirements	Cattle data type	% grazed/fed assessed?	% housed assessed?	Assesses manure/ slurry N content?	Assesses fertiliser N content?	GHG emission categorised by	Assessments can be saved?
CPLANv0	IPCC tier 1 & national inventory	Online	1 & 2	Light	Type & number	No	No	No	No	Source	No
CALM	IPCC tier 1 & national inventory	Online	1, 2 & some 3	Modest	Number & productivity or age	No	No	Yes	Yes	Source & gas	Online
CCaLC	ISO 14044 & PAS 2050	Excel	1, 2 3	High	Liveweight	No	No	No	Yes	Source	Off-line
COOL	IPPC tier 2	Online (ex. Excel)	1, 2 & some 3	High	Number, type & age	Yes	Yes	Yes	Yes	Source & gas	Online (limited number in free version)
IMPACCT	IPCC tier 2 (some 3) & PAS2050	Application	1, 2 & 3	High	Number only	Yes	Yes	Limited	Yes	Source & gas	Off-line
Farm Carbon Calculator	Own	Online	1, 2 & some 3	Moderate	Type & number	Yes	Yes	Partial	Yes	Source	Online (limited number)
European Carbon Calculator	IPCC tier 2	Excel	1, 2 & 3	Very high	Type, age & number	Yes	Yes	Partial	Yes	Source & gas	Off line

Table II. Site characteristics of studied farm scenarios.

		Climate		Soil		
	Country	Climatic zone	Precipitation (mm yr^{-1})	Reference group	Dominant surface texture	pH
FR1	France	Warm temperate moist	694	Cambisol	Medium fine silty clay loam	5
FR2	France	Warm temperate dry	618	Luvisol	Medium clay loam	6
FR3	France	Warm temperate moist	694	Cambisol	Medium silt loam	5
IT1	Italy	Warm temperate moist	809	Cambisol	Coarse sandy loam	7
PL1	Poland	Cool temperate dry	566	Luvisol	Medium clay loam	5
UK1	UK	Cool temperate moist	1,053	Gleysol	Medium silty clay loam	4.5

Table III. Livestock production characteristics of studied farm scenarios.

	Livestock (number)								Animals housed (% year)
	Cows					Heifers			
	Dairy	Pregnant	Suckler	Dry	Bulls	Calves / <1 year	1-2 year	>2 year	
FR1	100	-	-	-	-	-	36	-	0
FR2	198	-	20	-	1	51	30	41	100
FR3	50	-	-	-	-	-	60	-	25
IT1	340	150	-	50	-	60	200	-	25
PL1	25	-	-	-	-	-	8	-	33
UK1	150	-	-	-	-	93	72	85	50

	Diet (kg DM dairy cow^{-1})									
			Silage			Rolled	Concentrate			
	Grass	Hay	Grass	Maize	Lucerne	wheat	Triticale	Wheat	Barley	Rapeseed
FR1	4,406	-	-	680	-	-	474	-	-	-
FR2	-	2,193	793	2,878	-	-	306	-	-	-
FR3	1,617	-	1,551	1,320	-	-	694	207	138	-
IT1	3,123	-	-	215	142	570	-	1,206	402	402
PL1	3,673	-	1,411	-	-	-	-	-	-	-
UK1	1,990	-	2,351	611	-	-	-	1,135.8	378.6	378.6

Table IV. Cropping, milk yield and energy use characteristics of studied farm scenarios (numbers in brackets = number of applications used to achieve total).

	Product	Area (ha)	Yield (t ha^{-1} / L milk)	Fertiliser[a] (kg-N ha^{-1})	FYM[b] (t ha^{-1})	H/F/GR[c] (kg-AI ha^{-1})[d]	Energy use
FR1	Triticale: feed	12.7	4.5	90 (1)	-	1/0.32/0.6	-
	Maize: silage	11	12	50 (1)	-	0.88/0/0	-
	Grass: grazed	104	10	190 (3)	-	0/0/0	-
	Milk	-	460,000	-	-	-	-
	Red diesel (L)	-	-	-	-	-	2,986
	Grid electricity (kWh)	-	-	-	-	-	11,635
FR2	Maize: silage	49	16	35 (1)	25 (1)	0.88/0/0	-
	Triticale: feed	13.5	4.5	72 (1)	30 (1)	1/0.32/0.6	-
	Grass: silage	31.4	11	188 (4)	20 (1)	0/0/0	-
	Grass: hay	112.3	5	58 (1)	20 (1)	0/0/0	-
	Milk	-	1,311,000	-	-	-	-
	Red diesel	-	-	-	-	-	10,088
	Grid electricity	-	-	-	-	-	16,619
FR3	Triticale: feed	10	4.5	90 (1)	-	1/0.32/0.6	-
	Grass: 1 cut/ grazed	35	10	294 (3)	50	0.88/0/0	-
	Cereal mix: 60% wheat, 40% barley)	4	6.6	120 (2)	-	1.23/1/1	-
	Maize	14	12	32 (1)	30	0.88/0/0	-
	Milk	-	316,000	-	-	-	-
	Red diesel	-	-	-	-	-	1,347
	Grid electricity	-	-	-	-	-	4,410
IT1	Wheat: feed	35	8.6	183 (2)	12 (1)	1.23/1/1	-
	Lucerne: feed	15	5	-	-	1.2/0/0	-
	Maize: silage	8	16	32 (1)	30 (1)	0.88/0/0	-
	Grass: grazed	220	10	334 (1)	10 (1)	0/0/0	-
	Milk	-	2,600,000	-	-	-	-
	Red diesel	-	-	-	-	-	20,943
	Grid electricity	-	-	-	-	-	28,963
PL1	Grass: grazed	15	10	187 (2)	5 (1)	0/0/0	-
	Grass: 2 cut	10	7	194 (2)	10 (1)	0/0/0	-
	Milk	-	133,500	-	-	-	-
	Red diesel	-	-	-	-	-	23,159
	Grid electricity	-	-	-	-	-	12,024
UK1	Grass: grazed	50	11	194 (4)	10 (1)	0/0/0	-
	Grass: 3 cut	58	12	258 (4)	20 (1)	0/0/0	-
	Maize: silage	17	12	258 (1)	30 (1)	0.88/0/0	-
	Milk	-	1,387,500	-	-	-	-
	Red diesel	-	-	-	-	-	9,547
	Grid electricity	-	-	-	-	-	21,652

[a] Fertiliser = NH_4NO_3, [b] FYM = farmyard manure,

[c] H/F/GR = herbicide/fungicide/growth regulator, [d] AI = active ingredient.

Table V. Overall one-way ANOVA P-value and Tukey pairwise comparisons.

Farm scenario	Total GHG emissions		GHG emissions per productive hectare		GHG emissions peR livestock unit		GHG emissions per m^3 milk yield	
P-value for overall ANOVA	<0.001		<0.001		0.004		0.007	
Pairwise comparisons	IT1	A	UK1	A	PL1	A	PL1	A
	UK1	B	IT1	A	UK1	AB	FR3	AB
	FR2	B	PL1	B	FR3	B	FR1	AB
	FR1	C	FR3	BC	FR1	B	IT1	AB
	FR3	C	FR2	BC	FR2	B	UK1	B
	PL1	C	FR1	C	IT1	B	FR2	B