

Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP) Sustainable Farming Scheme Evidence Review Technical Annex

Annex 7: Systems approach to GHG emissions reduction

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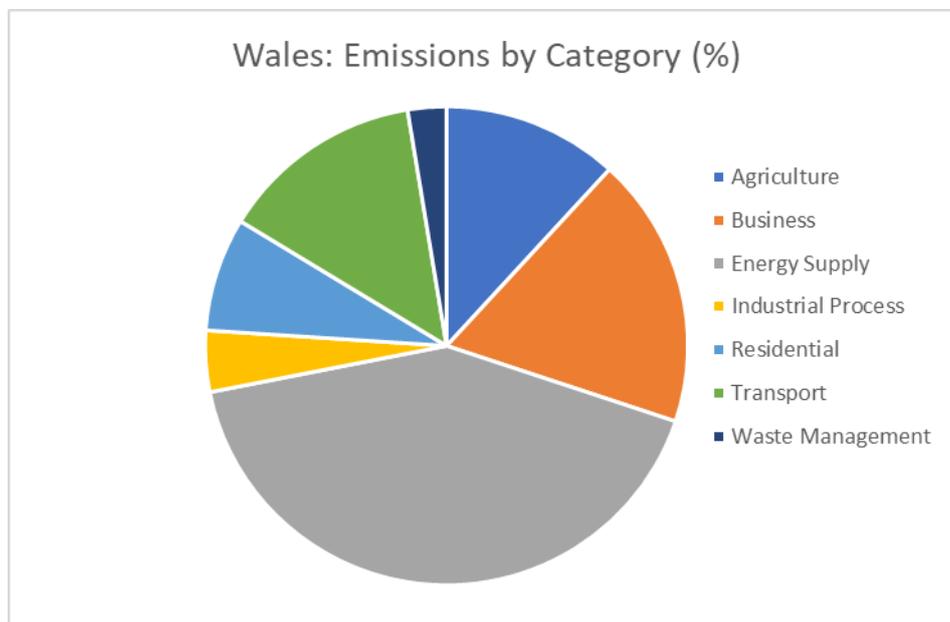
1 Introduction

GHG emissions and removals from Welsh agricultural systems include net emissions reported in the Agriculture and Land Use, Land Use Change and Forestry (LULUCF) sectors of the National Greenhouse Gas Inventory (Figure 1.1 & 1.2). However, GHG emissions arising from Welsh agricultural systems also include those resulting from the manufacture of inputs such as fertiliser and concentrate feed production. These emissions occur remotely and are not included in agriculture and LULUCF inventory reporting categories. Further to this, where production takes place abroad, they are accounted for in other countries' emissions inventories.

A systems approach (life cycle assessment (LCA)) to GHG carbon footprinting can identify options for emissions reduction across robust farm types (RFTs) in Wales. It will provide a better understanding of the accumulative impact of agricultural practices and help identify where there are synergies between GHG emissions reductions and the provision of other environmental outcomes.

In line with the Well-being of Future Generations goal, 'a globally responsible Wales', this report reviews methodologies and tools for assessing remote emissions in addition to those arising directly from farms.

Figure 1.1 below provides the details of emissions by sector in Wales (not including LULUCF). According to the 2018 inventory for 2016, agriculture represents 12% of the total emissions in Wales, with 5,729 kt/CO₂ equivalent emitted. This compares to the UK figure, where agriculture is 10% of the total, with 46,457 kt/CO₂e.



Source: NAEI 2018 (for 2016) GHG emissions Inventory

Figure 1.1. Emissions sources for Wales (not including LULUCF)

Figure 1.2 provides more insight into the source of emissions from agriculture. The majority of emissions arise from the livestock sector, with enteric fermentation accounting for 54%, and manure management 13%. The dominance of the livestock sector reflects the land capability, with grass accounting for over 90% of the total

agricultural area in Wales. In 2015, permanent grass accounted for 61%, rough grazing 25% and the arable area is 14% of agricultural land. Over 50% of the arable land was recorded as temporary grass.

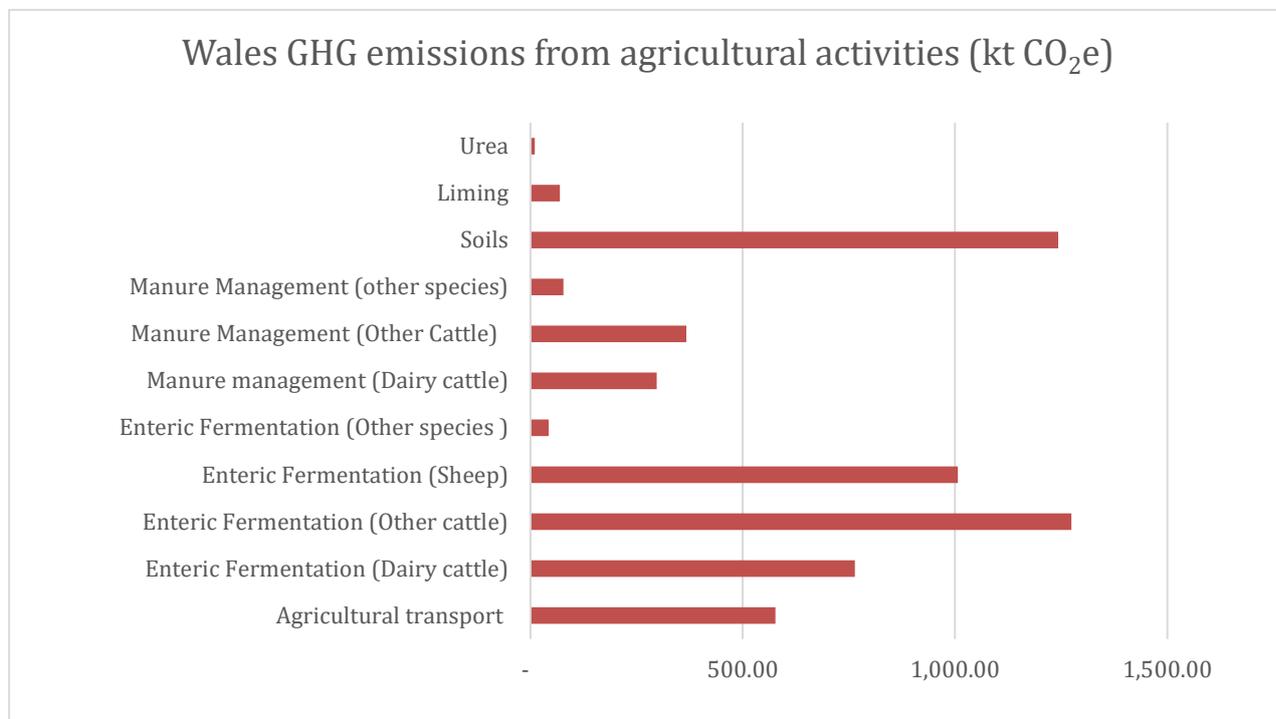
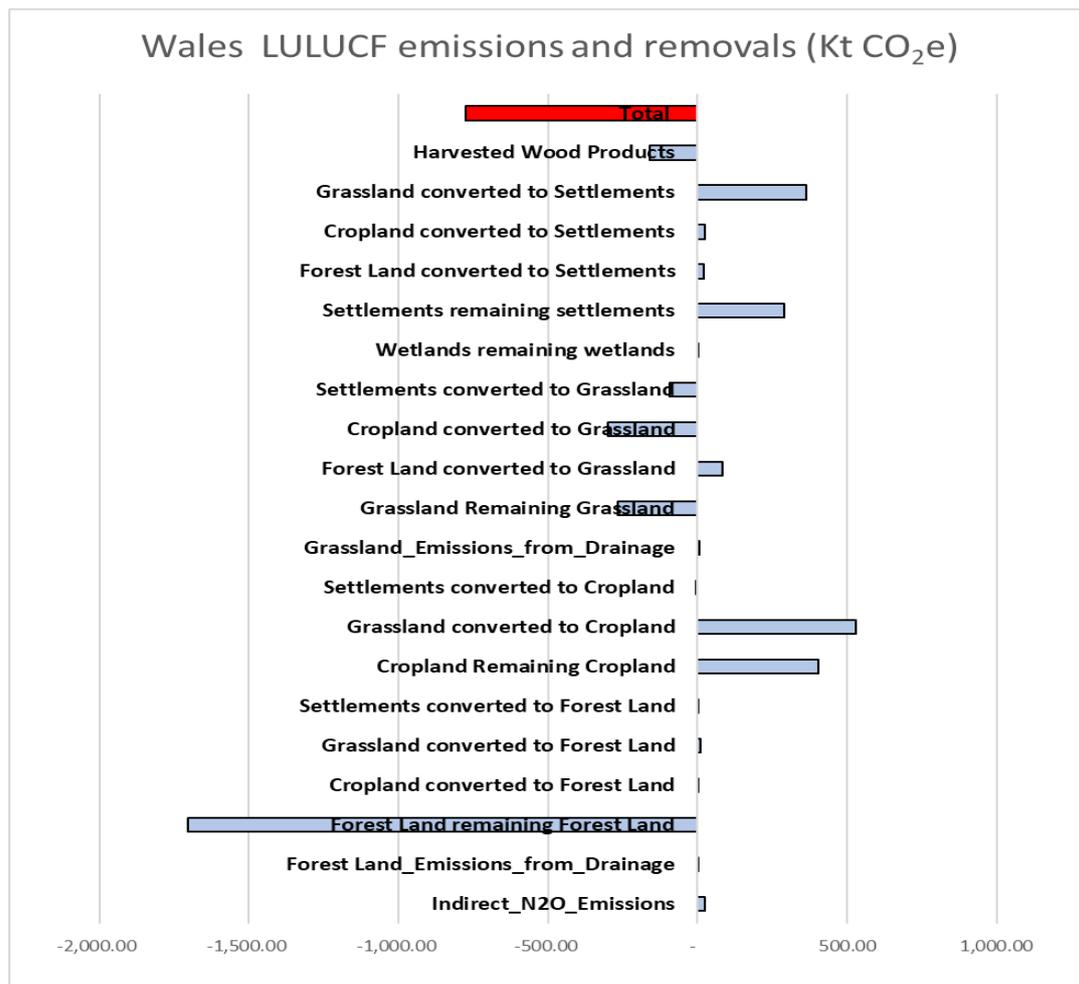


Figure 1.2: Wales Agriculture emissions by inventory sub category

Figure 1.3 provides details of LULUCF emissions and removals in Wales and shows that Wales was a net sink in 2016. However, this is mainly due to the impact of the forest area which does not disaggregate farmland trees. If we remove the forest area from calculations, land use in Wales would be a net emitter of emissions of 931 kt/CO₂. Although there are gains from grassland and land converted to grassland, these do not offset emissions from cropland or grassland converted to cropland.

Taking a farm-scale approach to emissions and removals using a life cycle assessment approach will bring together the emissions sources and sequestration potential and help inform the understanding of production efficiency in terms of GHG emissions intensity. Understanding emissions intensity or ‘carbon footprint’ is important as it provides evidence relating to the comparative advantage of agricultural products produced in Wales and the risks of possible emissions displacement (if the equivalent products are produced elsewhere and subsequently imported).



Source: NAEI 2018 (for 2016) Inventory

Figure 1.3: Land use, land use change and forestry emissions and removals by inventory sub-category

The output of this review is an assessment of the value of measuring and monitoring farm-scale greenhouse gas emissions and removals using a life cycle assessment approach. As agreed with the Welsh Government and delivery partners, this report does not look at the effectiveness of specific mitigation actions available to farmers but reviews the tools available to help assess the most appropriate actions that can be taken. Reports undertaken through the Climate-Smart Agriculture Wales project, Kipling et al (2017), the Committee on Climate Change Agriculture Marginal Abatement Cost Curve, and Eory et al (2015) provide a good basis for the effectiveness of specific actions for Wales and UK.

A lifecycle approach requires inputs and outputs to be used as a basis for calculating emissions. Strategies for reducing emissions will then focus on the greatest sources of emissions. Figure 1.2 shows that the greatest sources of emissions in Welsh agriculture are methane from enteric fermentation, methane and nitrous oxide from manure management and nitrous oxide from soils as a result of nitrogen fertiliser applications. Smaller sources should also be considered where emissions reductions are possible.

Assessing inputs in combination with outputs provides the data required for assessment of GHG emissions intensity (kg/CO₂e per kg of production output) or 'Carbon Footprint' in addition to total farm emissions which incorporate embedded emissions. Many mitigation actions improve both emissions intensity and overall production efficiency. The use of farm-scale carbon calculators will help identify measures to reduce emissions and improve efficiency, which will often have an overall positive impact on farm business profitability.

It is important to understand the whole farm GHG balance to fully appreciate the impact of agricultural production. Inventories report on agricultural production emissions and land use emissions in separate categories according to the IPCC reporting structures. However, the interactions between carbon sequestration, emissions and carbon stock changes are all linked to farm scale activities. The benefits of using systems-based approaches is that a farm baseline can be created for carbon stock, sequestration and GHG emission and the interactions between. This baseline provides a platform for action that can accelerate emissions reduction, identify opportunities for additional sequestration and understand the carbon stock that needs to be protected.

In the context of targets set for 'Net Zero' emissions as detailed in the Committee on Climate Change Report, "Net Zero, The UK's contribution to stopping global warming" (May 2019) will require agriculture and land-based industries to play a significant role. Adequate removals of CO₂ will depend on the availability of land both for large scale removal methods such as bioenergy with carbon capture and storage (BECCS) and afforestation. These demands for land will compete with food production.

The report for the Committee on Climate Change "Quantifying the impact of future land use scenarios to 2050 and beyond" (Thomson et al. 2018) modelled scenarios of agricultural land use taking account of population increase and urban expansion. This includes a breakdown of land requirements and potential emission reductions for Wales under different scenarios in Appendix 5¹ (p76). The report modelled a land requirement of 344,000ha for a high mitigation scenario.

¹ <https://www.theccc.org.uk/wp-content/uploads/2018/11/Quantifying-the-impact-of-future-land-use-scenarios-to-2050-and-beyond-Full-Report.pdf>

2 Policy Relevance and Outcomes

Greenhouse gas emissions reduction strategies and actions can meet multiple objectives both in terms of improving farm productivity and providing environmental outcomes. Actions taken by farmers to reduce GHG emissions and improve emissions intensity of production have the potential to have positive outcomes for all areas of interest to the Welsh Government namely: Productivity (reduced input costs), Air Quality, Public Health, GHG balance, Biodiversity and Water quality.

The Farm Sustainability Assessment, as detailed in the SFS policy framework, has the potential to incorporate an assessment of GHG on Farm. There are examples of how this has been incorporated in to Rural Development Programme funded schemes through CAP; Origin Green in Ireland and the Beef Efficiency Scheme in Scotland are relevant case studies.

Determining the specific policy objectives and outcomes and the boundaries of such an assessment is essential.

Possible metrics for success and policy objectives include:

- Farm-scale total emissions reductions? Target 36% reduction by 2050.
- Emissions intensity improvements? Improve efficiency of production and comparative advantage to increase profitability based on benchmarking of products.
- Improvement in GHG balance total emissions less sequestration? Contribution to the increase in Wales's carbon sink to 127% by 2030.
- Inform detailed strategies on GHG reductions – Provide and evidence-base for targeted advice activity and investment through measurement of farm-scale emissions.

Defining boundaries: One of the challenges faced might be determining what the boundaries are for measurement. Some discussion was had with contributors relating to the role of exported energy from wind, solar or biogas for example.

Concerns were also raised over the risk of double counting carbon credits in calculating farm-scale sequestration that could be sold as part of a carbon credit scheme. If a farm provides a balance sheet of emissions, it should be clear what has been traded through schemes such as the Woodland Carbon Code². Such trading of credits is currently in its infancy hence this is no major immediate concern, but it is something to be mindful of as such initiatives inevitably grow.

² <https://woodlandcarboncode.org.uk>

3 Interventions

Assessing the emissions reduction opportunities at a farm-scale has complexities, especially when considering the range of interventions available to farmers and land managers across multiple enterprises and farm systems. The approach taken in this analysis, as indicated in the initial briefing, was to review mechanisms for measurement and identification of interventions. As such, this analysis focuses on:

- *Monitoring Verification and Reporting: Farm-scale emissions measurement and benchmarking tools and approaches*

3.1 Intervention: Measuring farm GHG emissions

Using a farm-scale tool for measuring and benchmarking emissions is not in itself a GHG mitigation action, but can be an important component of developing strategies for GHG mitigation on farms and is an essential element of measurement and benchmarking.

At present, changes that GHG inventories can measure are limited, mainly due to a lack of granularity in the activity data to represent management practices on farms. Inventories vary in terms of their approaches and thus the ability to detect changes in emissions levels; even the most sophisticated inventories such as the UK agriculture GHG emissions inventory are limited by data relating to detailed, farm-scale activities. To illustrate this, the European Commission Report, 'Effective performance of tools for climate action policy' (Martineau et al. 2016) found that of 22 mitigation actions reviewed, only six could be reliably accounted for and detected within the inventory.

Generally, actions that impact on GHG emissions intensity are difficult to detect in inventories. Inventories are designed to measure progress towards total emissions reduction – they do not identify individual components of production. But undoubtedly there are GHG benefits in being more efficient and reducing GHG emissions intensity per unit of output which can be achieved through a large range of on-farm management improvements.

To identify and measure the benefits of GHG emissions reductions resulting from good management of inputs and outputs, carbon auditing and benchmarking tools have an important role. As we move towards outputs-focused policy, these tools will be an essential part of developing evidence for causality for the specific GHG emissions actions adopted.

A further limitation of inventories is the difficulty in accounting across categories. For example, agricultural fuel use sits in category 1 (transport), fertiliser production is in category 2 (industrial processes), and this only accounts for domestic production. Emissions from production of imported fertilisers are in inventories in the country of origin. Furthermore, in terms of providing an evidence base for the impact of on-farm action, inventories separate agricultural emissions from land use, land use change and forestry (LULUCF) emissions and removals. Although the 2006 IPCC guidelines did set out to combine these categories in to a single category (Agriculture, Forestry and other land use), this has not been implemented successfully. The result is that emissions and sequestration are treated independently while the opportunities for

GHG abatement and removals need to be considered in an integrated way which includes protection of carbon stock, enhancing removals and reducing emissions.

What do the tools need to do?

There are many tools and approaches available for the measurement of on-farm emissions. Taking a life cycle approach to GHG footprinting is essential to understand the emissions embedded in farm inputs such as bought in animal feed, fertiliser and fuel. This means the entire emissions effect is accounted for and not only the on-farm emissions.

Tools must be able to provide outputs which are useful to the farmer in terms of identifying actions to reduce GHG emissions. To achieve this, they must be able to cope with the complexity of farming systems while being practical and user-friendly.

The tool must be able to account for the transfer emissions between enterprises. Home grown feed and seed are good examples of this.

The outputs required of GHG calculators for farms include:

- Total farm emissions (GHG, CO₂e)
- Total farm output of products (e.g. tonnes of grain, or litres of milk)
- Emissions intensity for each product (GHG CO₂e/kg output)
- Sequestration (CO₂ removals)
- Additionally - a measurement of carbon stock would be a useful benchmark, but not to be confused with annual sequestration

3.2 Tools available and in development

Recent studies have reported that there are many tools, approaches and methodologies available to produce estimates of GHG emissions from farms but limited numbers that adequately do what is required. Taft et al. (2018), *Climate-Smart Agriculture (Wales) Report, A review of greenhouse gas calculators for use in the Welsh agricultural sector* revealed that there were 580 tools available, however only 14 were relevant for further evaluation. Leinonen et al. (2019)³ conducted by SRUC on behalf of Climate Xchange, *Comparative analysis of farm-based carbon audits*, identified 64 tools and only 9 for detailed analysis.

Following more detailed multi-criteria analysis (MCA), the Welsh Agricultural Sector Review established three tools met a minimum standard across the MCA. Table 3.2.1 is an extract from the report.

³ <https://www.climatexchange.org.uk/media/3584/farm-based-carbon-audits-final.pdf>

Criteria category	Tool										
	AgRE Calc ©	CFF Farm Carbon Calculator	Cool Farm Tool	EAgRET ¹	E-CO ₂ EA Tool Suite ¹	E-CO ₂ Swift-EA Tool Suite ¹	E-CO ₂ What If? Tool Suite	EX-ACT	FARMSCOOPER	Origin Green Carbon Footprint / Navigator Tool ¹	Average
Practical	96%	83%	75%	75%	46%	46%	58%	88%	83%	42%	69%
Usable	65%	67%	69%	40%	35%	35%	48%	58%	63%	58%	54%
Enabling	60%	38%	38%	60%	23%	23%	33%	54%	67%	63%	46%
Rigorous	62%	41%	69%	44%	10%	10%	8%	49%	62%	49%	40%
Complete	41%	48%	48%	42%	25%	25%	6%	40%	27%	36%	34%
Overall	54%	51%	54%	47%	26%	26%	21%	49%	46%	45%	42%

¹ Because these tools were not publicly available, assessment of their suitability was based on the limited information that could be collected within the time available.

Table 3.2.1 Overall performance of shortlisted tools within MCA categories (extract of the MCA from A review of greenhouse gas calculators for use in the Welsh agricultural sector report)(Taft et al. 2018).

The tools that scored over 50% across the MCA criteria were then investigated further through a comparative analysis. AgRE Calc, CFF Farm Carbon Calculator and the Cool Farm Tool were each tested by running notional farm data through the calculators, based on standardised data parameters for dairy and cattle and sheep systems.

The findings show some variability across each of the tools available relating to the emissions sources. The CFF tool only reports at a farm-scale and does not report at an enterprise level which rules out calculations of emissions intensity by enterprise and limits the ability to measure effectiveness of mitigation actions. For this reason, it is recommended that this is discounted as a viable option for effective analysis to meet the policy need for measurement of GHG emissions reduction.

AgRE Calc and Cool Farm Tool both allocate emissions to enterprise, however Taft et al. (2018) reported widely different enterprise emissions output data. Similar variations were found during testing conducted by Ricardo Energy and Environment for a project for ClimateXChange (Wiltshire et al., 2019), however, the differences identified were mainly attributed to errors in relation to livestock output calculations.

The ClimateXChange report Leinonen et al. (2019) agrees with the assessment of Taft et al. (2018) that AgRE Calc and the Cool Farm Tool are two of the most viable options for on-farm carbon assessment. In addition, the ClimateXchange report identifies the Solagro tool funded by the JRC.

In development

Following reported inconsistencies found in tools available, which varied due to the level of source inclusion and resulted in differences in the balance of emissions and due to inconsistencies with updated inventory approaches (Taft et al., 2018), it was recommended that a bespoke calculator be developed. RSK ADAS Ltd (ADAS), Bangor University (BU), the Welsh Lamb and Beef Producers (WLBP) cooperative

society, and the Institute of Biological, Environmental and Rural Sciences (IBERS) have developed a prototype tool.

The Farm Enterprise Survey Tool (FEST) has been developed to record physical farm attributes and calculate a standard set of enterprise performance indicators (EPI) based on the record of a year's activity. Like other tools, the activity data collected includes animal purchase and sales, field operations, housing management, forage production and energy consumption. However, it also collects financial performance data, the only other tool with that functionality at present is AgRE Calc.

The approach taken records labour, energy, fertiliser and forage production for the whole farm, and requires the farm manager provide a percentage allocation of the resources used to each of the enterprises present, so that detailed information on animal management need only be collected for a single enterprise of interest. The farm manager's allocation of resources between enterprises was difficult on mixed enterprise farms and introduced some uncertainty into the calculation of EPIs but was necessary to minimise the time taken to complete the survey. The pilot assumed that an enterprise did not significantly expand or contract or suffer a recent disease outbreak during the recorded year, as this would affect the herd structure and apparent replacement rates. This was found to have occurred on several enterprises. Through data collection using AgRE Calc tool for the Beef Efficiency Scheme in Scotland, similar challenges were recorded and required some qualitative input to explore and explain these situations.

The recorded activity data were enough for calculation of a product carbon footprint compliant with PAS 2050 (BSI, 2011) and calculation of the gross margin or profitability for an enterprise. The calculated EPI quantified the efficiency with which resources were translated into products that could then be used to benchmark and explain variation in enterprise profitability. The EPIs include the quantity of manufactured fertiliser nitrogen and concentrate feed used per animal, the rate of live-weight gain and age at first calving, final carcass weight or milk production, and mortality and herd replacement rate.

3.2.1 Methodologies and assessment of tools

Leinonen et al. (2019) concludes that three tools (AgRE Calc, Cool Farm Tool and Solagro) follow a similar calculation framework in quantifying the GHG emissions, in line with the IPCC guidelines and international standards for 'cradle-to-gate life cycle assessment (LCA). However, "Although all these tools can capture a variety of sources of farm level GHG emissions, none of these tools can be considered to be fully comprehensive."

Taft (2018) comments that the estimates of carbon sequestration are highly inconsistent across GHG calculators because of what they included and the method for calculating sequestration. This report did not assess Solagro which Leinonen et al. (2019) reports to be the 'most comprehensive' in terms of coverage.

What's included:

AgRE Calc	Cool Farm Tool	Solagro
GHG emissions from		
<ul style="list-style-type: none"> • synthetic and organic fertiliser use and crop residues • Embedded emissions from fertiliser production and pesticides • Carbon dioxide emissions from application of urea and lime • Indirect emissions from fertiliser application because of volatilisation, leaching and runoff. • Emissions embedded in feed • Methane from enteric fermentation • Nitrous oxide and methane from emissions from manure management. 	<ul style="list-style-type: none"> • Synthetic and organic fertiliser use and crop residues • Embedded emissions from mineral fertilisers and changes in soil carbon stock • Carbon losses and removals resulting from management and land use changes, crop residue management, biomass changes and changes in soil carbon stocks. • Emissions embedded in livestock feed, • Emission from enteric fermentation and • Emissions from manure management. • Electricity and fuel use are based on user input data. 	<ul style="list-style-type: none"> • Synthetic and organic fertiliser use feedstuffs and crop residues and associated embedded emissions • Enteric fermentation, manure management (housing and storage) and burnt crop residues • Emissions from drained and managed organic soils. • Diesel fuels, other fuels and indirect energy emissions (electricity) and other indirect, feedstuffs, machinery) • Hydrofluorocarbons, • Perfluorocarbons and sulphur hexafluoride emissions from cooling storage, machinery, • Cooling buildings and transport
Carbon Sequestration		
<ul style="list-style-type: none"> • Woodland disaggregated by broad leaved and conifer by age 	<ul style="list-style-type: none"> • Land use change over the past 20 years which includes conversion land use type • Tillage practices and cover crops using country-specific emissions factors • Sequestration in woodland although tree species options do not apply in the UK. 	<ul style="list-style-type: none"> • Carbon stock changes between crops and grasslands • Trees, hedges and permanent crops • Agroforestry
Methods		
<ul style="list-style-type: none"> • The calculations based on scientifically approved IPCC (2006) guidelines applying a Tier 2 methodology. • BSI 2011, PAS 2050 compliant 	<ul style="list-style-type: none"> • Applies a detailed method for calculation of soil GHG emissions and goes beyond the IPCC Tier 1 and Tier 2 methods, including indirect and direct nitrous oxide emissions, embedded emissions from mineral fertilisers and changes in soil carbon stock. • Applies Tier 2 approach for manure management • Livestock calculations are reported as being more simplistic • Feed emissions are calculated using Dutch FeedPrint data 	<ul style="list-style-type: none"> • Combination of IPCC (2006) guidelines tier 1 and 2
Geographic relevance		
<p>AgRE Calc covers all main agricultural production systems initially built for Scotland but will have relevance for Welsh agriculture.</p>	<p>Cool Farm Tool has been developed for an international market, when testing we found that the terminology used relating to farm systems was less relevant to UK farms and some of the forage</p>	<p>Solagro developed for the EU. Through testing conducted established relevance to the UK and terminology used consist with Farming systems.</p>

	assumptions were overly simplified. A major constraint is the fact that only one enterprise can be assessed at a time meaning that aggregation to a whole farm scale is difficult	
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Note that although taking an LCA approach, none of the tools consider the embedded emission from bought-in animals. This presents potential limitations when assessing different farm systems such as finishing farms vs store producers.

3.2.2 Ability to assess mitigation

Table 3.2.2.1 below is taken from the assessment of tools undertaken by Leinonen et al. (2019). It specifically reviews the ability of the three tools that their project assessed to report on changes in farm practices likely to affect GHG emissions. As is observed in this analysis, each of the tools can detect changes in management practices with some exceptions. For example, each of the tools look at the embedded emissions associated with livestock feed productions, but the Cool Farm Tool also factors in land use change emissions from feed.

	AgRE Calc	Cool Farm Tool	Solagro
Crops			
- Increasing yield	y	y	y
- Changing the amount of synthetic fertilisers	y	y	y
- Changing the type of synthetic fertiliser	n ¹	y	y
- Using / changing the amount of organic fertilisers	y	y	y
- Reducing fuel consumption	y	y	y
- Changing management, e.g. tillage	n	y	y
- Increasing woodland area	y	y	y
- Managing the woodland	n	y	y
Livestock			
- Changes in feeding: embedded emissions	y	y	y
- Changes in feed consumption: manure N ₂ O emissions	y/n ²	y	n
- Feed emissions: direct land use change (e.g. soya)	n	y	n
- Changes in feed composition: manure N ₂ O emissions	y/n ³	y	n

- Changes in feeding: methane emissions	y	y	y
- Changes in animal performance: manure emissions	y	y/n ⁴	y
- Changing manure management system	y	y	y
- Herd structure (embedded emissions of brought-in animals)	n	n	n
- Reducing fuel and electricity consumption in livestock housing	y	y	y

1 Only urea has different emission factors compared to other synthetic fertilisers

2 Feed consumption is estimated by the tool, not based on real data

3 Not included in the current web version

4 Very limited information on animal performance (apart from cattle) can be used as input.

Table 3.2.2.1: Extract from Climate Exchange report. Farm Practices that are expected to effect GHG emissions and the ability of tools to measure

The level of reporting on distinct areas of management offers opportunities to more easily detect management changes to reduce GHG emissions. As a simple example, identifying an over-supply of N fertiliser and reducing accordingly will have an immediate and identifiable effect on total GHG emissions. Through work conducted in Scotland with over 1,400 beef farmers, GHG emissions intensity has been the focus and key areas for improvement have been identified. One such area is improving herd fertility. Again, this can be an area where benefits can be realised within carbon accounting tools as carrying fewer unproductive breeding animals has a significant impact on emissions intensity.

Although this assessment demonstrates the ability of tools to assess changes in relation to management practices, it does not necessarily mean that individual mitigation actions can always be identified. In some instances, there may be changes in management to reduce GHG emissions that are masked by farm systems changes. An example of this is where livestock numbers are increasing or decreasing due to decisions to increase or decrease herd/flock numbers. This may mean that higher or lower numbers of breeding stock are being carried, which in the short-term impact on the GHG efficiency and have an impact on overall emissions. There can be numerous complicating factors such as this which are likely to require qualitative explanations alongside the quantitative results.

3.2.3 User Testing

Testing of the tools for the purposes of comparing functionality and user experience was undertaken by Ricardo for ClimateXChange on behalf of Scottish Government – (Wiltshire et al 2019). Using a similar approach to Taft et al. (2019), a standard set of notional farm data was used. The purpose was to test the usability of the tools, not to check the validity of the tool outputs. Information on the user experience with each of the three tools is given below in Table 3.2.3.1, Table 3.2.3.2, and Table 3.2.3.3.

Attribute	Notes
User interface	<p>The web-based platform steers the user through a series of logical data entry tables. Farm details and enterprise details are entered first before more detailed data entry. The following menu structure is used for data entry:</p> <ul style="list-style-type: none"> • Land and Crops • Land/crop areas • Fertiliser • Manure and Lime • Pesticides • Crop production • Crop use allocated to livestock • Livestock • Numbers and weights • Sales, purchases, deaths • Performance • Manure management • Bedding • Feed (multiple tabs) • Energy and Waste • Electricity and Fuel • Renewable electricity • Renewable heat • Transport, Waste and Water <p>The interface is in a simple, tabular format.</p>
Complexity for users	<p>Overall the data requested should be obtainable by a farmer with a reasonable approach to record keeping and basic knowledge of their farming system. However, there are areas that may cause some farmers difficulties, including:</p> <ul style="list-style-type: none"> • Reconciling fuel and energy usage against enterprise activities. The tool has incorporated an automated allocation to enterprise based on standard values which is useful is and likely to improve the consistency of assessments compared with farmer-estimated allocation. • Grassland crop removals by grazing might be difficult for some farmers to estimate unless they are measuring swards regularly. There are some typical values used within the guidance document, but it would be better to have these values within the tool as default values.
Data Entry	<p>Units are clear although some farmers might prefer to see options for land area in both acres and hectares. This is a minor point and generally the data input is requested in an intuitive way.</p>
Gaps in emission or removal sources	<p>Key gaps relate to sequestration potential. It is unclear from the guidance what is included in sequestration estimates, but it appears only to be the sequestration from Farm woodland⁴. AgRE Calc does not include sequestration from other woody biomass such as hedgerows. It also does not include any estimates for grassland sequestration.⁵</p>
Reporting	<p>There are many useful functions of the AgRE Calc reporting. Firstly, it offers measures of GHG in multiple ways which importantly include a GHG intensity value in kg CO₂e/kg of output, offering both a liveweight and deadweight option. It also includes whole farm or enterprise emissions. The reporting structure gives an option to view comparative data which provides benchmarking opportunities. There are other outputs provided such as environmental indicators for water, nitrogen, phosphate and potassium use, although these indicators are not contextualised to show whether they are high, medium or low. The addition of financial data is useful to monetise efficiencies that have an impact on GHG emissions.</p>

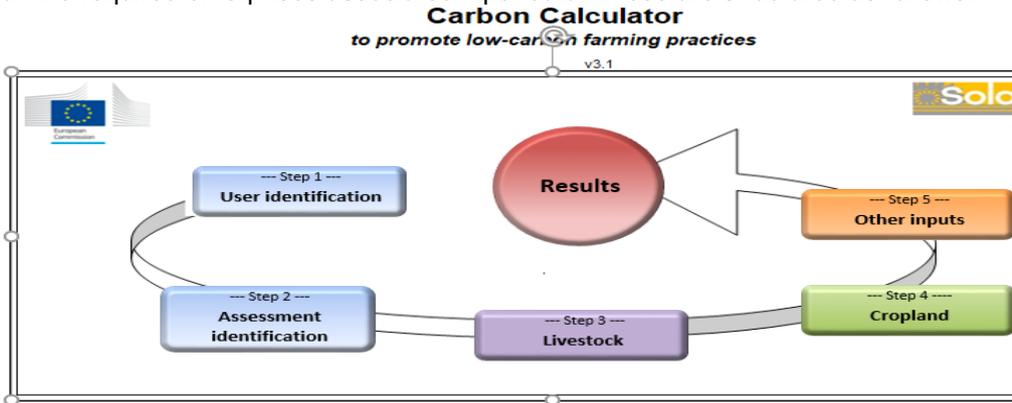
Table 3.2.3.1: AgRE Calc test results – user experience

⁴ Based on discussions with SAC Consulting.

⁵ Uncertainty for grassland sequestration is high.

Attribute	Notes																																																																																				
User interface	<p>The interface is easy to use. The visual appearance of the user interface is good but the need to separate out forage crops into a separate analysis causes confusion. The data input format is completed through a series of input data tabs. The Beef enterprise data input tabs are as follows:</p> <ul style="list-style-type: none"> • General • Production • Herd • Grazing • Feed • Manure • Energy • Transport <p>The crop input for silage production is done through a separate assessment under the following headings:</p> <ul style="list-style-type: none"> • Crop • Soil • Inputs • Fuel and Energy • Irrigation • Carbon • Transport 																																																																																				
Complexity for users	<p>The main area of complexity relates to the separation of enterprise types. For our notional farm, which is a simple beef enterprise, we needed to separate out the forage crops and beef production system. This creates problems for determining enterprise emissions as there are separate outputs for the same beef enterprise in our case. Although there is a tab labelled “aggregation”, this does not appear to be functioning at present.</p>																																																																																				
Data Entry	<p>The format is relatively clear although some of the units and terminology are designed for an international market and might not be immediately clear to farmers.</p>																																																																																				
Gaps in emission or removal sources	<p>It is unclear how or where sequestration opportunities are recorded and calculated.</p>																																																																																				
Reporting	<p>The reporting structure is clear although the separation of forage from the beef enterprise make understanding the overall emissions difficult. The report provides:</p> <ul style="list-style-type: none"> • Emissions per unit liveweight (kg CO₂e/kg) • Total Farm emissions (kg CO₂e) • A breakdown of GHG by source and gas <p>Example output:</p> <div style="background-color: #e6f2ff; padding: 10px;"> <p>Detailed data (all values in kg)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>Sources</th> <th>CO₂</th> <th>N₂O</th> <th>CH₄</th> <th>Total CO₂ eq</th> <th>Per ha</th> <th>Per tonne</th> </tr> </thead> <tbody> <tr> <td>Seed production</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>Residue management</td> <td>0</td> <td>10.39</td> <td>0</td> <td>3.10k</td> <td>143.30</td> <td>7.16</td> </tr> <tr> <td>Fertiliser production*</td> <td>11.11k</td> <td>0</td> <td>0</td> <td>11.11k</td> <td>514.26</td> <td>25.71</td> </tr> <tr> <td>Soil / fertiliser</td> <td>0</td> <td>22.33</td> <td>0</td> <td>6.65k</td> <td>308.04</td> <td>15.40</td> </tr> <tr> <td>Paddy methane</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>Crop protection</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>Carbon stock changes</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>Energy use (field)</td> <td>6.12k</td> <td>0</td> <td>0</td> <td>6.12k</td> <td>283.26</td> <td>14.16</td> </tr> <tr> <td>Energy use (processing)</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>Waste water</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>Off-farm transport</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> </tbody> </table> <p><small>* Calculated with validated default values for fertiliser production.</small></p> </div> <p>There is the function to compare results against previous activities, but it does not compare with benchmark data from other holdings.</p>	Sources	CO ₂	N ₂ O	CH ₄	Total CO ₂ eq	Per ha	Per tonne	Seed production	0	0	0	0	0	0	Residue management	0	10.39	0	3.10k	143.30	7.16	Fertiliser production*	11.11k	0	0	11.11k	514.26	25.71	Soil / fertiliser	0	22.33	0	6.65k	308.04	15.40	Paddy methane	0	0	0	0	0	0	Crop protection	0	0	0	0	0	0	Carbon stock changes	0	0	0	0	0	0	Energy use (field)	6.12k	0	0	6.12k	283.26	14.16	Energy use (processing)	0	0	0	0	0	0	Waste water	0	0	0	0	0	0	Off-farm transport	0	0	0	0	0	0
Sources	CO ₂	N ₂ O	CH ₄	Total CO ₂ eq	Per ha	Per tonne																																																																															
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Waste water	0	0	0	0	0	0																																																																															
Off-farm transport	0	0	0	0	0	0																																																																															

Table 3.2.3.2: Cool Farm Tool test results – user experience

Attribute	Notes
User interface	<p>The user interface is poor and not well designed. Non-experts in Excel were challenged with getting the settings right to run the Excel macros.</p> <p>The size of the data input windows that open from the 'Home Page' are not adjustable which is difficult when working on a small screen (such as on a laptop computer).</p>
Complexity for users	<p>Other than the general problems with the user interface, there are no significant problems with the complexity of data input requirements; in some areas there is useful prepopulated information generated from geographic data sets, such as for soil and rainfall data.</p>
Data Entry	<p>Despite the basic interface the data entry is relatively intuitive and provides fields for all the required enterprises associated input data. These are structured as follows:</p> <div style="text-align: center;">  </div> <p>User Identification: Name and organisation</p> <p>Assessment identification: Products, climate/weather and farm details</p> <p>Livestock:</p> <ul style="list-style-type: none"> • Offers a range of species • Livestock Numbers • Forage • Feed • Manure management <p>Cropland:</p> <ul style="list-style-type: none"> • Enter a range of crops • Enter details for fertilisers, pesticides, crop management, machinery operation and irrigation <p>Other inputs:</p> <ul style="list-style-type: none"> • Energy • Natural elements and land use change • Buildings • Organic matter flows • Secondary inputs • Machinery • Cooling and refrigerant
Gaps in emission or removal sources	<p>The tool appears to capture all the required input data and goes further than the other tools on sequestration relating to hedgerows and other woody biomass, however, it is not clear how this information is used.</p>
Reporting	<p>Solagro CC provides high level results as presented below which detail the emissions per ha and emissions intensity per tonne of beef (liveweight).</p>

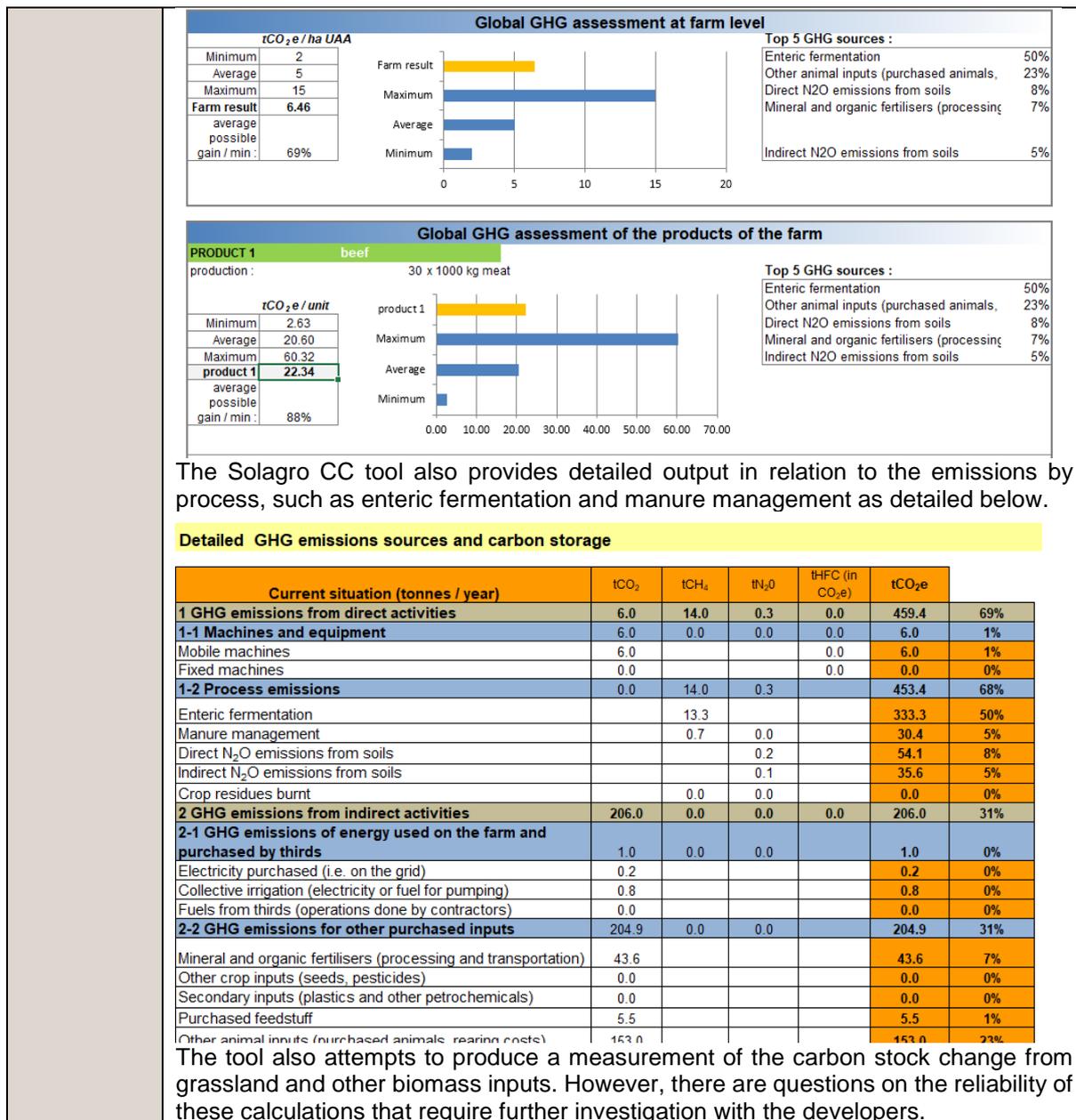


Table 3.2.3.3: Solagro Carbon Calculator test results – user experience

Ricardo tested the Tools based on a 100-cow upland spring calving beef suckler system, with progeny sold at weaning. Calculations included sales of cull cows and breeding replacements. The results given in Table 3.2.3.4 indicate that the three tools produce numerical results that are of the same order of magnitude, and that are closer on an area basis (emissions per ha) than on an emissions intensity basis (emissions/kg liveweight). This is because estimations of production vary and in the case of the Cool Farm Tool contain an error in calculations. Note that for the purpose of these calculations, sequestration was not included due to the large variability between tools in what was recorded, and the assumptions made.

	AgRE Calc	Cool Farm Tool	Solagro CC
GHG emissions (kg CO ₂ e/kg deadweight) ¹	59.67	-	-
GHG emissions (kg CO ₂ e/kg liveweight)	31.63 ²	7 ³	22.34
Total farm emissions (kg CO ₂ e)	625,712	581,830	665,380
Emissions per ha (kg CO ₂ e)	6159	5704	6460

¹Deadweight calculations are assumed in this example as animals are sold store (to be finished on another holding) Refer to 3.2.3 for farm systems explanations. ²The output from the AgRE Calc appears to underestimate output meaning GHG intensity is higher than expected. ³Due to a significant over estimation of output (kg beef) 83,085 vs 27,635, the Cool Farm Tool appears to be calculating output incorrectly by including breeding stock in output figures.

Table 3.2.3.4. Results comparisons from three carbon footprinting tools.

The results from the Taft (2019) report a larger difference between tools as shown in the table below (table 3.2.3.5) taken directly from the report.

Footprint component	Farm	Metric	Units	Tool		
				AgRE Calc ®	CFF Farm Carbon Calculator	Cool Farm Tool
Emissions	Dairy	Farm	t CO ₂ e / yr	3,045.3	1,905.3	2,022.7 ¹
		Enterprise (dairy)	t CO ₂ e / yr	3,045.3	1,905.3 ²	1,784.4
		Product (milk)	kg CO ₂ e / kg FPC milk / yr	1.82	ns	1.12
		Product (beef) ³	kg CO ₂ e / kg LW beef	6.70	ns	ns
	LFA cattle and sheep	Farm	t CO ₂ e / yr	2,832.4	3,343.1	2,437.5 ⁴
		Enterprise (beef)	t CO ₂ e / yr	414.3	ns	478.7
		Enterprise (sheep)	t CO ₂ e / yr	2,418.1	ns	1,958.8
		Product (beef) ⁵	kg CO ₂ e / kg LW beef	46.08	ns	10.23
		Product (lamb) ⁶	kg CO ₂ e / kg LW lamb	8.27	ns	6.13
		Product (wool)	kg CO ₂ e / kg / yr	7.93	ns	ns
Sequestration ⁷	Dairy	Farm	t CO ₂ e / yr	-4.4	-8.6	0.0
	LFA cattle and sheep	Farm	t CO ₂ e / yr	-87.1	-60.5	0.0
Balance (net emissions)	Dairy	Farm	t CO ₂ e / yr	3,040.9	1,896.8	1,784.4
	LFA cattle and sheep	Farm	t CO ₂ e / yr	2,745.3	3,282.7	2,437.5 ⁵

ns, not supplied. ¹ Not supplied; calculated by summing milk product and beef co-product enterprise level footprints. ² Not provided by the tool, but equivalent here. ³ Cull cows. ⁴ Not supplied; calculated by summing beef and lamb enterprise level footprints. ⁵ Cull cows and finished stores. ⁶ Cull ewes and finished lambs / hogs. ⁷ Sequestration is presented as a negative value (carbon sink).

Table 3.2.3.5 Summary emissions and sequestration metrics, estimated by the three shortlisted tools

It is difficult to make direct comparisons as the farm data used to test tools are based on different enterprises. The differences are likely to occur mostly due to the way in which data are collected and reported as emissions, although methodologies are very similar. There are some structural differences that make comparisons challenging, such as the difficulty in aggregating data between enterprises in the Cool Farm Tool.

Further 'real-world' testing of the AgRE Calc Tool has occurred with over 1,600 farmers across Scotland through the Farm Advisory Service and Beef Efficiency Scheme. The use of the tool has been carried out by advisers across Scotland, but very few audits have been done by farmers without assistance.

3.2.4 Sequestration and changes in carbon stock

The issue relating to sequestration, removals and measurements of carbon stock is the area that creates the largest disparity between the tools. Due to the different approaches taken in relation to what to include and methodological approaches, differences occur.

In relation to land use changes in carbon stock, the Cool Farm Tool has an approach that covers land use change, while AgRE Calc does not. This is likely to influence the results relating to crop production enterprises. This will not have affected any of the testing examples due to the nature of the enterprises used as examples.

The ability to calculate sequestration is the most significant challenge in tools reviewed. Due to the complexity involved and uncertainty in calculations this is likely to be an ongoing issue with carbon calculators.

The expert group discussed this at length and concluded that above ground woody biomass should be able to be incorporated as there are models such as Carbine (Forest Research) that can do this. It may add complexity to data collection and inputs due to the additional measurements and management activities that impact rates of carbon sequestration.

The group also discussed the potential to record soil carbon sequestration based on modelled activity and there was consensus that this is still an evidence gap and considerable uncertainty in relation to carbon emissions and sequestration from crop and grassland.

3.2.5 Conclusions from the analysis

This review required us to consider GHG emissions reductions for farms in Wales taking an LCA approach. Recognising the limitations of the GHG inventory, to achieve this a GHG calculation tool(s) will be required to create farm emissions assessments that provide farmers with the ability to:

- Estimate a baseline for GHG emissions to the farm-gate
- Provide enterprise emissions in units of emissions intensity to inform decisions relating to potential mitigation actions
- Measure improvements made following uptake of mitigation actions
- Measure sequestration
- Record carbon stock to determine gains and losses over longer periods (not just an annual balance)

To meet the Welsh Government requirements, the tools used must be based on robust methodological approaches that provide reliable and defensible results.

The benefits of GHG emissions measurement has the potential to deliver significant benefits to farmers. The main benefit is as a benchmarking tool. The Beef Efficiency Scheme in Scotland has conducted over 1,400 'carbon audits' which has created a baseline for improvements at an individual farm level and an inter-farm benchmarking tool. This has been used to identify mitigation opportunities and potential financial

savings. Figure 3.2.5.1 below provides example outputs from the AgRE Calc Tool which provides benchmark data from similar enterprises.

It should also be recognised that there are other benefits and risks that could be assessed through GHG emissions calculation tools. These can help inform wider sustainability assessments such as air quality, water usage and quality, biodiversity, soil health and financial performance. Tools available provide some basic assessments of these at present. Note Figure 3.2.5.1 below provides an example output from AgRE Calc showing ‘Whole Farm Sustainability Indicators’ but these are presented at a high level.

Quick glance enterprise emissions				Physical performance of enterprise		
	* kg CO ₂ e/ kg dwt	Opportunity Level	Comparison		Value	Comparison
Enteric fermentation	30.77	Medium	21.26	Area of land utilised (ha)	102	201
Manure management	10.74	Medium	8.88	Female breeding stock (no)	100	111
Fertiliser	11.80	Medium	5.13	Heifer sale weight (kg lwt/head)	235	452
Purchased feed	1.08	Low	2.20	Steer sale weight (kg lwt/head)	235	473
Purchased bedding	2.88	Medium	0.75	Young bulls sale weight (kg lwt)	-	862
Fuel	1.42	Low	1.45	Purchased feed use (kg/cow)	400	1,591
Electricity	0.02	Low	0.11	Homegrown fodder use (kg/cow)	4,320	9,667
Other	0.97	Low	1.07	Live weight gain (kg/day)	0.80	0.94
Total emissions **	59.87	Medium	40.84	Mortality (%)	-	3
<i>Other: crop residues, lime, transport and waste</i>				Calving percentage (%)	92	92
				Cow cull rate (%)	15	15
				Enterprise net output (kgs)	10,486	27,953

Whole farm sustainability indicators					
Nitrogen Use	79.54	kg/ha	Water use	876,000.00	litres
Phosphate Use	39.77	kg/ha	Stocking density	1.36	LU/ha
Potash Use	39.77	kg/ha	Sequestration	10.89	tCO ₂ e
Waste	216.00	kg	Renewable energy used	-	kWh

Figure 3.2.5.1: Example output from AgRE Calc

This assessment has provided a synthesis of recent comparative analysis that have been produced relating to the functionality and reliability of available GHG emissions calculators.

In summary, there are tools available that are actively being used for on-farm measurement of emissions. The review suggests that AgRE Calc Tool and Cool Farm Tool and Solagro are the most developed tools to meet the requirements, however they have limitations.

Solagro is currently unsupported and has been since 2016 and The Cool Farm Tool was discounted from recent analysis (Wiltshire et al 2019) due to its inability to adequately cope with the complexities in the livestock sectors.

The measurement of carbon removals is a key limitation and there is considerable inconsistency between tools. However, when considering GHG reductions in isolation, the capability to measure sequestration may be considered useful but not essential.

Given the dominance of the livestock sector in Wales, it is imperative that the full value of grazing systems in terms of **protection of carbon stock** and opportunities for **additional sequestration** are explored and understood. The areas for sequestration such as trees, hedges and grassland are integrated themes also addressed in other Evidence Review Reports (“*Review 2: Sward Management*”, “*Review 3: Soil Carbon Management (SCM)*” & “*Review 5: Building ecosystem resilience*”). However, through further development of tools, this is an area that could provide the basis for GHG/Carbon balance calculations to help determine the feasibility of carbon neutrality at a farm-scale.

The FEST prototype tool in development for the Welsh Government has not been reviewed like the other tools covered by this review. However, the main advantage to that tool is that its calculations are based on Agriculture GHG emissions Inventory updates first incorporated in the 2018 reporting year (for 2016) which will reflect regional variation and calculations more accurately. Other tools have not yet been updated to reflect Inventory updates.

3.3 Causality

The measure of causality for this intervention is less relevant than in relation to specific mitigation actions. The adoption of appropriate, farm-scale GHG calculators provides the vehicle for determining causality where there would otherwise be limited ability to do so through existing data collection structures. The use of GHG calculators provides the evidence for causality across a large range of mitigation actions that could be appropriate for any given farmer.

Determining an effective and consistent approach to identifying and measuring the impact of emissions reductions activities is essential. It is likely that this will need to be conducted on an annual or biennial basis depending on the policy structure for implementation. The use of tools should be viewed as a means of detecting inefficiencies in farming systems and improving productivity through benchmarking in addition measuring and reducing GHG emissions and understanding sequestration potential.

3.4 Co-benefits and trade-offs

The most relevant benefit to the utilising GHG emissions calculators is the ability to benchmark activities associated with production efficiency and identify actions to improve performance. Many actions taken to improve GHG emissions intensity will also have a positive impact on financial performance of the business but this is likely to be dependent on the level of capital investment required to make changes

However, we need to be aware of the risks or trade-offs which may occur because of the actions to improve production efficiency or intensify production. For example, to improve efficiency, a farm business may identify a need to improve grass leys through means that may have a detrimental impact on biodiversity or carbon stock. On the other hand, not improving grass leys will necessitate greater need for purchasing of feed, which will have environmental cost elsewhere. Such scenarios need careful consideration around prioritisation of environmental goods, and it is imperative that over-simplified messages to industry does not lead to unintended consequences.

Co-benefits and barriers to implementation of a variety of land-use mitigation options was detailed in CCC Report *Quantifying the impact of future land use scenarios to 2050 and beyond* (Thompson et al. 2018). The report considered the impacts of hedgerows and agroforestry, bio-energy and afforestation and forest management. The report states that *“the implementation of these measures has the potential to increase the resilience of the UK’s land management sector and counter-balance some of the negative impacts of climate change”*.

Wider sustainability metrics are included in GHG calculators and should be considered through an LCA approach. While collecting a wide range of data relating to inputs and outputs, other indicators can be assessed based on information provided. This could include water resources and nutrient management, habitat availability and quality, and air quality (specifically ammonia emissions).

A further trade-off is likely to be the additional administrative burden placed upon farmers if obliged to undertake a GHG assessment or ‘Carbon Audit’. Undoubtedly, there is benefit in understanding the resource utilisation within farm businesses, but farmers need to be able to use the outputs and act as a result. Simply undertaking a ‘Carbon Audit’ will not benefit the farmer or meet policy objectives if action is not taken as a result or data used to benefit the industry. There is also likely to be a requirement for support for farmers to undertake carbon auditing as has been the case with the Beef Efficiency Scheme in Scotland. The role of retailers / processors in driving such initiatives should also be considered.

3.5 Magnitude

It is difficult to estimate the magnitude of the effect of adopting farm GHG calculators. The act of completing a ‘Carbon Audit’ is not a mitigation action in itself (Martineau et al. 2016). Looking at results from existing GHG benchmarking activities such as the Beef Efficiency Scheme (Scotland) or Origin Green (Ireland) provides an indication of the potential for GHG savings on farm. However, it is important to consider that there are many farm system related factors that influence the results such as intensity of production and quality of land. Figure 3.5.1 below provides an indication of the range of GHG emissions intensity across 1,400 beef producing farms in Scotland. Although this range includes a variety of farming systems, it provides some indication of the potential for improvements and associated emissions reductions per unit of output. Repeated audits (annual or bi-annual) would of course help quantify the impacts of the implementation of measures, and would likely help engage industry much more than one-off audits with no follow-up.

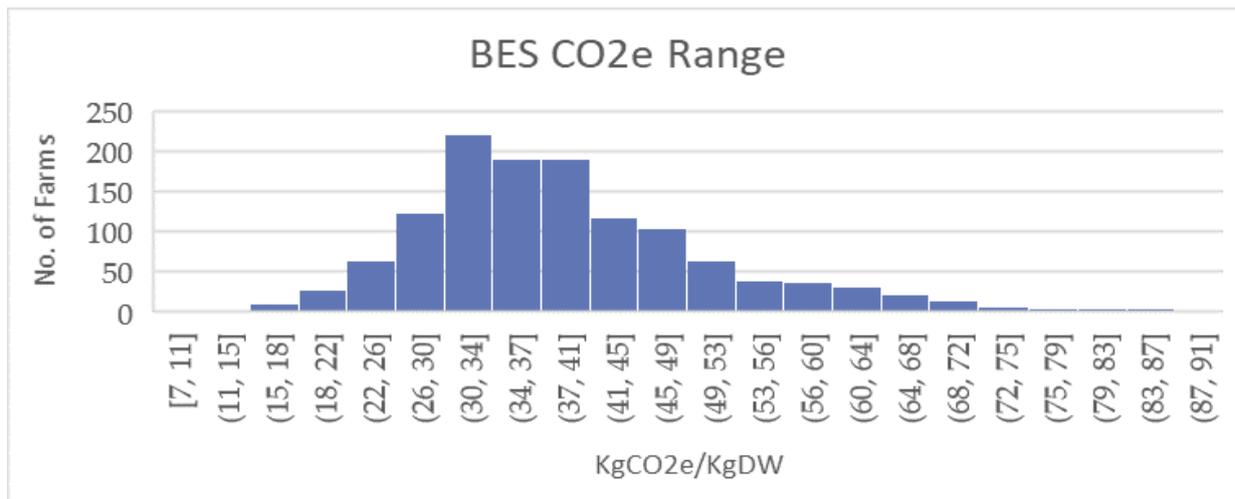


Figure 3.5.1: Beef efficiency Scheme Scotland. Aggregated data

3.6 Timescale

In relation to the timescales for deployment of tools, many GHG foot printing tools still use 'older' IPCC default emissions factors (EFs), and do not yet utilise the revised emissions factors for nitrous oxide and methane resulting from recent inventory improvements. The FEST tool currently under development does factor in the new emissions factors but is still a prototype.

Tools may also need to adapt to include new mitigation actions resulting from innovative developments in the future such as slurry acidification, use of feed additives such as 3-NOP and Nitrification inhibitors.

In terms of seeing measurable impacts of undertaking a GHG emissions analysis with an appropriate tool. The likelihood is that benefits will be seen over the short, medium and long terms. There will be a requirement to continue to measure and understand the benefits and the permanence of activities. This is particularly important when considering the impact of sequestration and protection of carbon stock.

3.7 Spatial issues

There is unlikely to be specific spatial issues or benefits, although emission reductions may be more achievable within certain enterprises which may be clustered within geographic areas.

3.8 Displacement

Displacement will be dependent on the mitigation actions taken up by farmers and the resulting effect on primary production. There are likely to be measures that increase productivity and production at a farm-scale thus reducing GHG intensity but possibly increasing total emissions. In this instance, we could see the negative impact of an increase in overall emissions but the benefit of improved productivity and emissions intensity.

In some instances, given the right incentive, farms may choose to enhance sequestration through tree planting, but may reduce production (food, fuel and fibre) output.

Alternatively, improving efficiencies may give extra scope for farmers to manage other (less productive) areas of farmland for off-setting / sequestering purposes, thereby both reducing both emissions intensity and total emissions.

If we are to assume constant demand there would be some displacement if lost production is made up elsewhere. Equally, if we see increase in production we may generate surplus for export.

3.9 Longevity

The permanence of mitigation actions will be dependent on the perception of benefits to the farmer. As many mitigation actions will also benefit farm efficiency, they are likely to generate lasting change.

Establishment and permanence of carbon stock changes may vary depending on activities; i.e. tree planting potentially offers greater permanence and certainty than grassland management actions for some farms. Permanence of certain actions may need to be part of a long-term monitoring and evaluation programme to measure outcomes – especially when linked to payments.

3.10 Climate interactions

The primary focus of this intervention is to develop appropriate, farm-specific mitigation strategies.

3.11 Social and economic barriers

Based on the evidence from Scotland and Ireland, it is unlikely that farmers will adopt the use of GHG calculators voluntarily and support through appropriate advice will be required to ensure quality of data entry.

Careful consideration should be given to the level of ongoing support and guidance on offer to farmers that require GHG assessments to be completed.

3.12 Metrics and verification

The use of GHG emissions calculators is a method for measurement. Verification could be achieved through secondary LCA or farm outputs. Additional benefits of a programme of using farm tools to measure emissions based on farm management actions is that it could provide valuable evidence and data for inventory improvement and justification for production in Wales due to comparative advantage (e.g. grass-based production systems).

3.13 Evidence gaps

Evidence gaps in measuring on-farm emissions and sequestration mainly relate to the capability of tools to accurately and appropriately measure sequestration. This is due to the highly variable nature and uncertainties relating to rates of sequestration.

The view of the working group based on evidence available is that the measurement of woody biomass and related sequestration potential can be accurately calculated. However, the ability to measure carbon stock in soils and particularly in grassland systems has considerable variation and uncertainty.

A further consideration is that GHG emission calculations are highly dependent on activity data that are dependent on consistency in approach of data entry and the user-friendly nature of tools.

4 Summary

A high-level summary of our conclusions is presented in Table 4.1.

Confidence	Key Outcome	Key Benefits	Critical concerns
Blue	Assessment of GHG emissions at a farm-scale	<ul style="list-style-type: none"> Understanding of Emissions Sources By category Measure on emissions intensity and associated production efficiency Identification of Areas for improvement Brings elements of the elements of the inventory recorded in different categories together 	<ul style="list-style-type: none"> Availability of tools and inconsistencies between them. They take a simplistic approach that does not cater for the complexities of farming systems. e.g. uplands, lowlands, store vs finisher, etc.
Blue	Recording farm-scale sequestration for woody biomass	<ul style="list-style-type: none"> Assessing carbon stock in trees and woody biomass provides details on the carbon sequestered annually to understand the carbon balance Good modelling available for tree sequestration 	<ul style="list-style-type: none"> Variability in the approach taken by different tools at present
Amber	Recording of farm-scale carbon sequestration from grass	<ul style="list-style-type: none"> Recording farm sequestration allows CO₂e balance to be recorded and thus the overall impact of the farming system 	<ul style="list-style-type: none"> Catering for uncertainties and variables is very challenging There are significant uncertainties. Grassland sequestration is highly available Measuring permanence and understanding the balance between C Stock and annual sequestration
Amber	Additional farmer administration	<ul style="list-style-type: none"> Management benefits in terms of understanding measures that affect productivity Benchmarking capability 	<ul style="list-style-type: none"> Evidence suggests that to do a full GHG calculation in a thorough way, guidance from an adviser would be required, which has costs
Blue	Aggregation of data to provide industry indicator	<ul style="list-style-type: none"> Adds supplementary data to the inventory in terms of production efficiency. Could give product based intensity figures at a farm scale. Evidence for the efficiency of the sector to show GHG comparative advantage Can give a indication of where to channel advisory activity to address common issues. Helps counter/support displacement arguments 	<ul style="list-style-type: none"> Accessing data - Tools not well set up to give this data at present.

Table 4.1 Key outcomes, benefits and critical concerns associated with Carbon audits

Colour Key:

- **Blue** = well tested at multiple sites with outcomes consistent with accepted logic chain. No reasonable dis-benefits or practical limitations relating to successful implementation.
- **Amber** = agreement in the expert community there is an intervention logic chain which can be supported but either evidence is currently limited and/or there are some trade-offs or dis-benefits which WG need to consider.
- **Pink** = either expert judgement does not support logic chain and/or whilst logic chain would suggest it should work there is evidence of one or more of the following:
 - its practical potential is limited due to a range of issues (e.g. beyond reasonable expectation of advisory support which can be supplied and/or highly variable outcome beyond current understanding or ability to target),
 - the outcome/benefit is so small in magnitude with few co-benefits that it may not be worth the administration costs,
 - there are significant trade-offs.

5 References

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