JULY 2017

GLASTIR MONITORING & EVALUATION PROGRAMME

FINAL REPORT – Annex 8

Evaluation of the Glastir Efficiency Grant

Annex 8A: Gallagher, J; Styles, D and Chadwick, D (2016) Evaluating the efficacy of Glastir Efficiency Grant Schemes from 2014 to 2016: A review of carbon and ammonia emissions across the Welsh livestock sector

Annex 8B: Taft, H; Cross, P; Weir, R; Long, E and Chadwick, D (2015) Evaluation of the potential efficacy of Glastir Efficiency Scheme for reducing carbon emissions across the Welsh livestock sector

Annex 8C: Taft, H; Cross, P and Chadwick, D (2015) Socio-economic evaluation of the Glastir Efficiency Grant Scheme

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GLASTIR MONITORING & EVALUATION PROGRAMME

FINAL REPORT – Annex 8A

Evaluating the efficacy of Glastir Efficiency Grant Schemes from 2014 to 2016:

A review of carbon and ammonia emissions across the Welsh livestock sector

John Gallagher, David Styles, and Dave Chadwick

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1 EXECUTIVE SUMMARY

Glastir Efficiency Grant (GEG) investment is provided to improve farm nutrient, water and energy efficiency, and therefore reduce the environmental footprint on farms in Wales. This report presents the carbon footprints of farms re-visited since GEG technologies have been implemented and compares the results to baseline footprints pre-installation of GEGs infrastructure. The impact of GEGs on ammonia emissions, nitrogen (N), phosphorus (P) and derived eutrophication footprints is also determined. Finally, the project assesses the feasibility on on-farm energy generation to offset net GHG emissions from farms in Wales.

A modified version of the original carbon footprint model developed at Bangor University and used by Taft *et al.* (2015) in the baseline footprinting study was used to estimate farm emissions from livestock farms. In addition, N and P footprints, ammonia (NH_3) emissions, and eutrophication and acidification burdens, were calculated based on farm nutrient balances. The carbon footprint and sequestration estimate for each farm were reported for one calendar year, using two types of functional unit comparable across enterprises: GHG emissions per unit product (e.g. per kg lamb liveweight), and GHG emissions per hectare of farmland. All emissions were converted to carbon-dioxide equivalents and reported in terms of CO_2e.

Fifteen of the original 20 farms were re-visited by project officers and interviewed face to face (two farms dropped out of the GEG scheme and three farms did not provide data prior to the report deadline). A questionnaire was used as a script for obtaining the necessary information. Farmers reported information representing one ‘typical’ business year within the period 2015 to 2016. The results were compared to baseline results between 2011 and 2013. One farm changed its farming practice from a LFA cattle and sheep farm to a dairy farm since the baseline footprint study, therefore only fourteen of the fifteen farms were used for a direct comparison of farm performance.

Farm footprint results

The average estimated PAS-compliant footprint per hectare across all farms was 9,991 kg CO_2e/ha/yr, equating to an average reduction of 4.9% compared to baseline results (however individual farm footprints presented both reductions and increases of approximately 40%). Dairy farms continued to show higher average footprints (on a hectare basis) to that of LFA cattle and sheep farms, yet the average reduction on LFA cattle and sheep farms was more notable than on dairy farms (7.3% versus 1.7%). Larger farms typically had a lower average footprint than smaller farms, however a small average increase of 2.5% was observed on large farms while small farms reduced their average footprint per ha by 9.0%.

The average footprint per kg of lamb produced was 13.1 kg CO_2e/kg LW, equating to an average reduction of 9.5% across the farms. The average footprint per kg of milk was 0.98 kg CO_2e/kg, an 18.2% reduction in the average footprint for milk. The improvements in both the footprints for lamb was due to farm intensification with an increase in cattle stock and reducing lambs economic allocation, while milk production increased as milk prices reduced with an overall improvement in the net yield.

Methane (CH_4), nitrous oxide (N_2O) and inputs (fertiliser, feed concentrates and bought-in stock) represented the majority of farm emissions per hectare of land, accounting for on average 49.6%, 23.2% and 26.5% of the overall farm footprint, respectively. Average methane emissions increased due farm intensification, while average N_2O emissions reduced by 2.6% which may be due to improved slurry/manure management on GEGs farms, and N-fertiliser use was reduced on average by 13.3% (however a 19% increase of bought-in feed was calculated).

Carbon sequestration on average offset 17.5% of the total farm footprints, ranging from 3.6% to 58.5%. On average, dairy farms sequestered more than LFA cattle and sheep farms (25.4% versus

6.9%), and larger farms offset an average 28.1% of farm emissions compared to 11.6% on smaller farms. Most sequestration occurred as carbon storage in permanent grassland soils. Factors such as a decrease in stock numbers and an increase in farm size were correlated with an increase in the percentage of emissions sequestered. The net farm carbon balance remained positive on all farms as no farm sequestered more carbon per hectare than it generated.

Nutrient footprints across the farms expressed per kg of product averaged 0.191 kg N/kg and 0.034 kg P/kg, a reduction of 18.2% and 8.1% from baseline results respectively. A broad range of variability was evident on the farms as N and P emissions ranged from an increase of up to 93% on one farm to an 83% reduction on another farm. The average N and P footprints reduced more substantially (32.0% and 33.2%) on dairy farms compared to an average 7.9% and 10.8% on the LFA cattle and sheep farms – in part reflecting reduced fertilizer application rates across seven of the farms. The reductions in N and P emissions also translates as an average 11.0% reduction in ammonia (NH_3) emissions, and similar reductions in potential eutrophication (PO_4) and acidification (SO_2) burdens. However, some nutrient burdens may have been displaced upstream to feed supply farms, owing to an increase in the use of concentrate feed across seven of the farms.

Changes in fertiliser, sulphur and lime consumption on farms, changes to stock and feed, changes in milk production and changes in farm practice were factors that influenced on-farm footprints and were taken into account in the comparison between pre- and post- GEG Scheme footprint results.

The potential uptake of renewable energy sources to offset farm footprints was also considered. Farmers identified a number of challenges to installing renewable technology on their farms: being tenant farmers; economic feasibility; unsuitable grid connection; planning permission issues; lack of trust or bad experience with renewable energy companies; and restrictions due to protected land e.g. a SSSI river. Only a small number of farmers have successfully installed renewables (solar PV), despite the majority of farmers showing interest in different sources of on-farm renewable energy generation. An assessment of rooftop solar PV was undertaken for all farms, with the potential to increase the average farm income by 3.3% and offset farm footprint by an average of 2.2%.

Impact of GEG funded technologies

A number of GEG Scheme funded technologies that were implemented on the footprinted farms were examined to determine the impact of each measure on farm footprints. These technologies fell within one of three efficiency categories: energy, slurry/manure and water.

Within the energy efficiency category, heat recovery/ heat exchanger units were installed on three dairy farms. The impact of these units were associated with a marginal 0.16% reduction in milk footprint (the majority of the milk footprint was not associated with electricity) although electricity consumption was reduced by 59% on one farm.

Support for several slurry/manure efficiency schemes were considered. Rainwater separation was provided on six farms, however evidence from the farm footprints was inconclusive as to quantifying its impact. A slurry trailing shoe or injection system was provided on five farms, which helped reduced nutrient and ammonia emissions. However, as contractors were responsible for spreading slurry on a number of farms, the most efficient methods of spreading were not always available to some GEG farmers. New slurry store were installed on eight farms, and of these four farms reduced fertiliser use, three presented no change and only one increased fertilizer use. Reductions in farm footprints were evident on all dairy farms where new stores were constructed. In addition, two farm constructed new manure stores, however due to changes in stock numbers there was inconclusive evidence regarding its impact on the farm footprint.

Lastly, one farm received a grant for rainwater collection, a measure in the water efficiency category. From the farm footprinting study, no sufficient evidence could be captured to quantify the impact of this measure on carbon or nutrient footprints. Therefore, a water footprinting study would be advised in future studies to quantify the direct or indirect impact of water efficient grants on the farm footprint.

Conclusions

The average carbon footprint per hectare across the re-visited farms reduced by 4.9% since the baseline study, and the average footprints per kg of lamb and milk reduced by 9.5% and 18.2% respectively.

Methane, nitrous oxide emissions and inputs continued to represent over 70% of farm emissions per hectare of land on the majority of farms. Differences between baseline and re-visited contributions were as a result of changes in fertiliser consumption and/or improvements in slurry/manure spreading.

Nutrient footprints were also examined, and the average N and P footprint reduced by 18.2% and 8.1% per kg of product on the farms since the baseline study. This translated to a reduction in average ammonia (NH_3) emissions of 11.0%, and similar reductions for eutrophication and acidification burdens of 8.6% and 11.7% respectively. However, the farm nutrient balance methodology for nutrient footprinting did not fully capture upstream nutrient footprints of feed production, which increased for seven farms over the period of study.

Carbon footprinting results were noted to be variable and highly farm-specific. Changes to farm size, stock numbers, fertiliser use and the quantity/sources of feed concentrates since the baseline study makes it challenging to distinguish between improvements in farm management as opposed to farm intensification.

Renewable energy generation on farms in Wales, specifically solar PV installation of farm building rooftops, has the technical potential to generate on average 59.3 MWh per farm per annum, generating an average additional income of £5,430 and offsetting an average of 208 kg of CO_2e per hectare. This can generate an average 3.3% additional income for farms and offsetting an average of 2.2% of the total farm footprint.

Several farms responded to the GEG funded technologies, e.g. the trailing shoe or injection system measure led to an average reduction in ammonia (NH_3) emissions of 11.3-16.1% per kg of milk on dairy farms and 1.5-8.2% per kg animal live weight exported on LFA cattle and sheep farms. New slurry and manure stores allowed for farms to increase stock numbers, and the results suggest that it improved slurry/manure management and led to a reduction in fertiliser use on a number of farms. This study could not capture the impacts of rainwater separation and rainwater collection measures; a water footprint would be advised in future projects.

Recommendations

On the basis of this study's findings, we recommend the following:

Further research to examine the longer term impacts of GEG scheme grants (e.g. farm intensification) as interpretation of current results are limited due to the small sample set. Due to significant changes in stock numbers and a volatile market for the dairy sector, it presents challenges in drawing substantial conclusions from this single comparison of farm footprints.

Focusing on sustainable intensification, future footprints should prioritise per unit of product as opposed per hectare.

Consider rolling out a footprinting campaign (possibly self-reporting after the first footprint) across a larger number of typical farm typologies in Wales (similar to the "Origin Green" footprinting survey in Ireland).

Consider developing a moving-average farm footprint tool to account for annual variations in stock numbers, fertiliser, sulphur and lime usage and external factors that are out of farmers' control e.g. weather impacts on home grown *vs* imported forage/feed.

Consider consequential LCA to evaluate sector changes more accurately e.g. capturing land use change if trend of increased stock numbers and more outsourcing of feed continues in coming years.

Examine the optimum solution for farmers between bought-in and home grown feed to reduce farm and product footprints (e.g. building on the C footprinting in the TSB project EFBS IUK 101097: *Sustainable Forage Protein Efficient forage-based systems for ruminant livestock production in the UK*).

A detailed examination of challenges facing farmers in Wales to implement renewable energy technologies, provide additional income for the farms and offset farm carbon footprints. Consider the feasibility of Welsh Government supporting renewable energy companies to provide farmers with impartial information on the options available on each farm.

2 ACKNOWLEDGEMENTS

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3 INTRODUCTION

3.1 Background to the Glastir Programme

Glastir was set up as part of the Wales Rural Development Plan 2007-2013, as a means of streamlining existing Welsh Axis 2 agri-environment schemes into a single whole-farm sustainable land management initiative (WG, 2014a). The Glastir Efficiency Grant (GEG) scheme is a component of a wider Welsh Government agri-environment initiative known as Glastir. Glastir is a five-year, whole farm, sustainable land management scheme available to farmers and land managers across Wales. The initiative consists five elements: Glastir Entry, Glastir Commons, Glastir Advanced, Glastir Efficiency Grants, and Glastir Woodland Creation and Management (WG, 2014a). Further details are provided in Rose (2011) and WG (2014a). The GEG scheme has provided capital grant funding for 157 farms across Wales since the baseline footprinting study was undertaken by Taft *et al.* (2015). Its primary objective is to support initiatives that improve resource use efficiency and reduce the effects of agriculture on the environment, including greenhouse gas emissions (GHGs).

3.2 Project aims and objectives

The aim of this Year 4 GMEP study in the WP on Climate Change and Diffuse Pollution was to revisit the previously carbon footprinted GEGs farms to understand if and how the GEGs investment have led to improvements in farm efficiency (e.g. more efficient fertiliser N use) and reductions in overall farm carbon footprints. We also determined the impact of the GEGs on ammonia emissions, nitrogen (N) and phosphorus (P) footprints, and derived eutrophication footprints. These footprints were not calculated in the previous carbon footprinting work, and so were calculated using original pre- GEG implementation footprint data. Finally, the project assessed how implementing a number of renewable energy generation strategies could help offset net GHG emissions from the different GEGs farms.

The overall objectives of the footprinting study included:

1. Developing a new dataset demonstrating the effect of GEGs on carbon footprints
2. Gaining an understanding of the effects of GEGs on on-farm N losses, including ammonia emissions
3. Indicating the effect of GEGs on the efficiency with which N is used to generate agricultural products, i.e. N (and P) footprint (pre- and post-installation of GEGs infrastructure)
4. Assessing the feasibility of on-farm energy generation to help offset GHG emissions

4 METHODS

The same carbon footprinting methodology described in Taft *et al.* (2015) was followed in this work. Some additional methods have been outlined for nutrient footprint calculations and the estimation of carbon offset through renewable energy installations at each farm.

The livestock enterprise footprinting model used in this study utilises farm-specific data and aims to comply with PAS 2050:2011 regulations (BSI, 2011). It is a modified version of the original model developed at Bangor University between 2007 and 2010, and described in Edwards-Jones *et al*. (2009). A description of the current Bangor University modelling approach is outlined in the following sections; further details are available in Taylor *et al*. (2010) and Jones *et al*. (2014), and in Appendix A.

4.1 Defining the system boundary

This study used the cradle-to-gate approach, and included greenhouse gas (GHG) emissions resulting from the manufacture and distribution of farm inputs (e.g. animal feed or mineral fertilisers); on-farm energy use (fuels and electricity); emissions from livestock and their excreta; and emissions from soils related to their management (e.g. mineral and manure fertiliser application, lime application, and farming on peat-based soils). Emission estimates are reported for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) – the three most important GHGs emitted as a result of agricultural activities (IPCC, 2007).

The temporal boundary used in this study is a period of one representative business year between 2015 and 2016. The spatial boundary of a farm footprint was defined by the amount of land managed by the farm business, which can vary over the course of the financial year, for example with a change in the amount of land rented, or common land utilised, in different months. This model incorporates the area of owned land, plus the area under common-land and rental agreements. Land which was rented for only a portion of the year was modelled as a proportion of its area (*N* ha multiplied by *x*/12 months), for example, if 10 ha were rented for 7 months, it was modelled as adding (10 x (7/12)) ha to the farm area.

Farms often include non-productive land, such as hedges, woodland, or wetland, which may make up large areas of the farm. These areas, and areas of productive pasture, may both emit and store carbon (Castaldi *et al*., 2007; Chapuis-Lardy *et al*., 2007). This study uses data from published scientific literature to estimate the potential range of emissions, and carbon capture and storage (sequestration), that may occur in soils and woody vegetation on different areas of the farm.

4.1.1 *Functional units and allocation*

The GHG emission footprint ('carbon footprint') in this study was reported for one calendar year, using two functional units which may be compared between enterprises: GHG emissions per unit product (e.g. per kg milk or lamb liveweight (LW) at the farm gate), and GHG emissions per hectare of farmland. Both PAS 2050:2011, and most standard LCAs recommend reporting emissions per unit product, as it is the functional unit that reaches the customer. Reporting emissions per unit land area considers the farm as an integrated production system, and allows assessment of the potential environmental impact of agricultural operations on a given area of land (Edwards-Jones *et al*., 2009).

Many farms produce more than one output, for example a dairy farm may produce milk and dairy stock (calves, barrens, etc.), and a sheep enterprise may produce lamb, breeding stock, cull stock, and wool in a given year. In this study, emissions from a farm enterprise were allocated between different outputs on an economic basis, as the percentage of total farm income earned from the relevant output.

In keeping with PAS 2050:2011 requirements, emissions of CO_2, N_2O and CH_4 are reported here in terms of global warming potential (GWP), which allows standardisation of all emissions in terms of their heating effect on the atmosphere, relative to CO_2, over a 100-year time frame (IPCC, 2007). This report uses a GWP of 296 for N_2O, and a GWP of 23 for CH_4. Standardised emissions estimates are reported in units of carbon dioxide equivalents, or CO_2e.

4.1.2 ***Data sources and data uncertainty***

Emission factor (EF) estimates used in this work were drawn from recognised standard databases and documents, such as reports by the Intergovernmental Panel on Climate Change (IPCC) and Ecoinvent (e.g. IPCC, 2006; Swiss Centre for Life Cycle Inventories, 2014). To incorporate as much of the resulting uncertainty in emissions estimates as possible, this study calculated emissions using a maximum, mid-range, and minimum value for each component of the calculation, to present readers with a worst-case, average, and best-case scenario for each emissions total.

Whilst we recognise that new country-specific (UK) agriculture N_2O EFs have just been derived and used in the recent reporting for UNFCCC submission in 2016, however the default N_2O EFs (IPCC 2006 Guidelines) are still used in the Bangor Carbon Footprinting tool, as they are in all other Carbon Footprinting tools at this time. (In brief, the new N_2O EFs for grazing excreta, manure applications and fertiliser applied to arable soils are lower than the default values, whilst the new N_2O EF for fertiliser applied to grassland is a little higher than the IPCC default. The net effect of not using the new N_2O EFs is likely to result an overestimation of the C footprint on livestock farms by the Bangor C footprinting tool. But relative differences before and after implementation of GEGs are the focus of this study. The Bangor Carbon Footprinting tool, like other tools, will need to be updated with these new country-specific EFs, once they have been published).

4.2 **Data collection**

Fifteen of the twenty farms from the baseline study were re-visited for footprinting. These fifteen farms are from the 152 farms in Wales which had been approved for Glastir Efficiency Scheme capital grants over the period 2011 to 2013. Sampling of the original 20 farms was stratified according to the number of grants received within each DEFRA robust farm type and size category (DEFRA, 2010), and farms selected randomly from within each group (LFA cattle and sheep; dairy; 50 to 199.9 ha; > 200 ha).

Relevant farmers were contacted by project officers and interviewed face to face on-farm. A questionnaire was used as a script for obtaining the necessary information. Follow-up contact with participating farmers or discussion with project officers was undertaken where details or assumptions required clarification. Questionnaires were available in both English and Welsh.

4.2.1 ***Data gaps for specific farms***

Some data were not available for some farms. In this case, national data sources, published UK reference examples, or standardised estimates were used in their place. For example, information was frequently missing on fuel use by external contractors whilst working on-farm (e.g. when hedge-flailing or harvesting crops). In this case, fuel use was estimated by combining relevant data from tables of machinery sizes, working rates and fuel efficiencies provided by a large UK-based machinery manufacturer. Where gap-filling of missing data has been used, the assumptions used are clearly stated. Further examples of using standardised data for gap-filling are included in the model descriptions in the following sections.

4.2.2 ***Economic allocations***

Variations were evident between farmer estimates for prices of outputs, therefore national annual market prices were used to determine current economic allocations based on baseline data from Taft *et al.* 2015. Annual market prices were required as baseline results ranged across two calendar years. Harmonising results to account for these changes ensured that comparisons between baseline and revisited farm footprints were fair when adopting economic allocations for separating GHG emissions for the different products. The data used to estimate current market prices from baseline data is presented in Table 1.

Table 1. Average market prices for kg of beef and lamb, milk and wool (in pence) between 2011 and 2015 (AHDB, 2016; DEFRA, 2016b; BWMB, 2016), and differences expressed over the baseline (2011-2013) to current footprinting year (2015).

Product	2011	2012	*2013*	2014	*2015*	Differences (±)		
						2011–2015	2012–2015	2013–2015
Beef	306.7	342.3	*385.8*	348.3	*346.4*	+12.9%	+1.2%	-10.2%
Lamb	423.9	401.3	*412.7*	413.2	*375.8*	-11.3%	-6.4%	-8.9%
Milk	27.36	28.08	31.64	31.52	24.46	-10.6%	-12.9%	-22.7%
Wool	124.0	77.0	103.0	110.0	87.5	-29.4%	+12.8%	-16.5%

4.2.3 ***Rooftop feasibility for solar PV***

Solar PV installations on farm building rooftops is considered as the least intrusive renewable energy source on farms. To quantify the generation potential of installing solar PV on rooftops, some assumptions were made regarding rooftop suitability. 37.5% of the rooftop area was deemed to be suitable for solar PV due to (i) one half of roofs were north facing to some degree, therefore it was assumed that solar PV panels were not viable on these rooftops and (ii) one quarter of south facing roofs may not be structurally suitable for installing solar PV panels. In addition, an average roof pitch of 30 degrees on all rooftops was considered for the calculations, yet this may vary from low pitch (5-10 degrees) to a 40 degree pitch roof. The area of farm building rooftops were determined using the Solar Calculator tool provided by the Energy Saving Trust (2016).

4.3 **Acidification and eutrophication burdens**

Data collected to calculate carbon footprints was also used to calculate acidification and eutrophication burdens and nutrient footprints based on established life cycle assessment (LCA) principles (ISO, 2006).

Acidification and eutrophication burdens were calculated from farm emissions of ammonia (NH_3), N leaching, P leaching, and embodied burdens imported in products (e.g. fertilisers and feeds) taken from Ecoinvent v.3.1 (Ecoinvent, 2014). Eutrophication and acidification burdens were expressed as kg PO_4e and kg SO_2e, respectively, based on CML (2010) methodology, and using the same suite of EFs applied in Styles *et al.* (2015), briefly elaborated below.

On-farm N and P leaching was calculated based on leaching factors of 0.1 and 0.03, respectively, applied to all manure and fertiliser applications and pasture excretions (Duffy *et al.*, 2013; Withers, 2013). On-farm NH_3 emissions arising from pasture and housing N excretion, manure storage and spreading, and fertiliser application were calculated based on EFs taken from the national emission inventory (Misselbrook *et al.*, 2012) – expressed in relation to quantities of ammonium-N excreted (60% of total N excreted). Emissions of NH_3 from housing were based on EFs of 0.315 and 0.229 for slurry-based systems and straw-based systems, respectively. Other examples of EFs applied are given in Table 2 and Table 3, for manure storage and spreading, respectively. A mass balance approach was taken, so that ammonium-N was reduced at each stage of the manure management chain according to relevant NH_3-N losses.

Table 2. Ammonia EFs applied to different storage methods, derived from Misselbrook et al. (2012).

Storage system	NH_3-N EF (fraction NH_4-N)
Solid storage	0.350
Liquid/slurry WITH natural crust cover	0.050
Liquid/slurry WITHOUT natural crust cover	0.100
Uncovered anaerobic lagoon	0.515

Table 3. Ammonia EFs applied to different spreading methods, derived from Misselbrook et al. (2012).

Spreading	Splash plate	Trailing hose	Trailing shoe	Shallow injection	Manure spread
NH_3-N EF (fraction NH_4-N)	0.37	0.26	0.15	0.11	0.25

4.3.1 ***Nutrient footprinting methodology***

Nutrient footprints were expressed as total N and P inputs in fertiliser and imported feed per kg product output. N and P embodied in imported concentrate feed, grass, maize and straw was calculated assuming dry matter N content of 2.0%, 1.8%, 0.4% and 0.6%, respectively, and dry matter P content of 0.34%, 0.26%, 0.06% and 0.05%, respectively (DEFRA, 2010b). It should be noted that current nutrient balance methodology does not capture upstream nutrient footprints from feed production. However, the comparison of baseline and revisited farm footprints presents relative percentage changes in results and therefore is acceptable in the context of this study.

4.3.2 ***Allocation to product outputs***

Footprints and burdens were allocated across farm products using the same economic methodology as for carbon footprints, after attribution of N-excretion related burdens to specific animal cohorts. Ammonia emissions were also expressed in relation to product outputs, expressed as kg NH_3-N per kg product, following the same attribution and allocation sequence.

4.4 **Renewable energy potential**

In addition to collecting data for the footprinting of each farm, a short questionnaire was presented to each farmer in relation to their opinions on different renewable energy technology. Renewable energy generation has the potential to provide additional income to farmers and offset carbon emissions on each farm.

In particular, a focus for on-farm solar PV was proposed using existing farm shed roof space, so that the technology was not intrusive to farm practices. Roof areas and specifications were collated through a combination of information provided by farmers and supported through an assessment using Google Earth (Google Earth, 2016) i.e. determining roof area where information was not provided by the farmer.

Based on roof suitability at each farm, an online Solar Energy Calculator was used to estimate the potential annual income and electricity generated for a solar PV installation on available roof space (Energy Saving Trust, 2016). In addition, the carbon offset through generating renewable electricity was also included to quantify its potential to reduce the overall farm footprints.

5 RESULTS

From the original 20 farms visited to collate data for the baseline carbon footprints, 15 farms provided data for this report. Five farms did not provide data for this report: two farms dropped out of the GEG funding programme (this would not provide valuable data to assess the impact of GEG schemes); and three farms did not respond despite several forms of communication over a two month period (an initial letter of intent to visit, several unanswered phone calls to organise a meeting, delivery of the questionnaire in person, and a final letter with attached questionnaire for return). Therefore, carbon footprints were compiled for 15 Welsh farms.

The results presented compare the baseline carbon footprints of the representative Welsh farms that used 2011-2013 farm data, from Taft *et al.* (2015) with the same farms re-visited in 2016 (baseline results included in Appendix B). The 15 farms comprised seven dairy farms and eight less-favoured area (LFA) cattle and sheep farms: six dairy farms of 50 to 199.9 ha size, and one dairy farm of > 200 ha size, four LFA cattle and sheep farms of 50 to 199.9 ha size, and four LFA cattle and sheep farms of > 200 ha size (Table 4).

Of these farms, one re-visited farm (farm 9) had changed its farming practice from a less-favoured area (LFA) cattle and sheep farm in 2014 to a dairy farm (50 – 199.9 he size) in 2016. Therefore, only the footprints from 14 farms were directly compared with baseline results to ensure a fair comparison of measures adopted on GEG farms. The data from this farm is therefore excluded from the main results and is dealt with separately in Section 5.3.4, where the performance of farm 9 is examined. It is compared to other farm, to quantify the environmental impact changes associated with changing farm practice. All farms are referenced based on the numbering provided during the baseline study.

5.1 **Carbon footprints**

5.1.1 ***Total farm emissions per hectare and per kg of product***

5.1.1.1 Total farm emissions per hectare

The average estimated footprint per hectare across all farms was 9,991 kg CO_2e/ha/yr, and showed a wide range of variability, from 2,274 kg CO_2e/ha/yr on farm 7 (LFA cattle and sheep) to 24,842 kg CO_2e/ha/yr on farm 17 (dairy; Table 4). The average footprint per hectare on dairy farms was almost three times that of LFA cattle and sheep farms (15,745 kg CO_2e/ha/yr compared to 5,676 kg CO_2e/ha/yr). Smaller farms had a higher average footprint per hectare than larger farms (12,092 kg CO_2e/ha/yr and 6,209 kg CO_2e/ha/yr respectively).

Table 4. Farm characteristics (DEFRA main farm typology, and size category), and PAS 2050-compliant carbon footprints for the farms re-visited in 2016, expressed as a footprint (kg CO_2e) per ha, and per kg product (negative percentage figures represent an increase in the footprint from the baseline study).

Farm	Farm type	Farm size	Farm footprint		Carbon footprint, kg CO_2e			
			kg CO_2e per ha	% diff from baseline	kg (LW) lamb	% diff from baseline	kg milk	% diff from baseline
1	LFA cattle & sheep	> 200 ha	2,817	<0.1%	13.3	<0.1%	-	-
4	Dairy	50-199.9 ha	16,626	0.7%	-	-	0.87	18.6%
5	LFA cattle & sheep	> 200 ha	8,761	-6.8%	12.4	-3.6%	-	-
6	Dairy	50-199.9 ha	14,873	26.7%	-	-	0.93	33.1%
7	LFA cattle & sheep	> 200 ha	2,274	4.6%	12.8	10.5%	-	-
8	LFA cattle & sheep	50-199.9 ha	5,673	38.0%	-	-	-	-
9	Dairy	50-199.9 ha	12,457	-	-	-	1.20	-
10	LFA cattle & sheep	> 200 ha	4,262	<0.1%	10.0	<0.1%	-	-
12	Dairy	50-199.9 ha	6,730	40.2%	6.0	15.7%	0.96	14.4%
13	LFA cattle & sheep	50-199.9 ha	6,817	-4.1%	18.3	-4.1%	-	-
14	LFA cattle & sheep	50-199.9 ha	5,092	7.2%	15.5	23.7%	-	-
15	Dairy	> 200 ha	12,931	-10.4%	-	-	0.90	12.6%
17	Dairy	50-199.9 ha	24,842	-44.4%	-	-	1.19	5.1%
19	LFA cattle & sheep	50-199.9 ha	9,708	19.1%	23.7	18.3%	-	-
20	Dairy	50-199.9 ha	18,466	-2.8%	6.1	25.4%	0.93	25.4%
Mean*	Dairy		15,745	1.7%	4.05	20.6%	0.98	18.2%
	LFA cattle & sheep		5,676	7.3%	6.93	6.4%	-	-
		50-199.9 ha	12,092	9.0%	13.9	15.8%	1.00	19.3%
		> 200 ha	6,209	-2.5%	12.1	1.7%	0.90	12.6%
	All farms		9,991	4.9%	13.1	9.5%	0.98	18.2%

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

Comparing the average footprint per hectare results to baseline footprint results, a reduction of 4.9% was estimated. However, the results presented a range of variability, from substantial reductions of up to 40.2% on farm 12 (dairy) to a similar increase of 44.4% on farm 17 (dairy). The changes to the farm footprint results per hectare are noted to be highly farm-specific. The average footprint per hectare reduced on the eight LFA cattle and sheep farms by 7.3% (ranging from a reduction of 38.0% to an increase of 6.8%). The farm footprint per hectare increased on only two of the eight LFA cattle and sheep farms. On the six dairy farms, the average footprint per hectare reduced by 1.7% (ranging from a reduction of 40.2% to an increase of 44.4%). These significant changes to the farm footprint per hectare on farms 12 and 17 were due to changes in farm size: a reduction in the size of farm 17 increased the footprint per hectare, and additional farmed area at farm 12 reduced the footprint per hectare. Smaller farms had an average improvement of 9.0% footprint per ha of land, while larger farms presented a small increase in their footprint per hectare of 2.5%.

5.1.1.2 Total farm emissions per kg of lamb

A similar degree of variation was seen per kg of lamb outputs. The lowest footprint per kg of lamb produced was from farm 12 (6.0 kg CO_2e/kg LW), while the highest was from farm 19 (23.7 kg CO_2e/kg LW), with an overall mean emissions of 13.1 kg CO_2e per kg of lamb across all farms. The two dairy farms that also produced lamb (farms 12 and 20) had a much lower-than-average footprint than LFA cattle and sheep farms. This was due to the high economic allocation of milk production on these dairy farms, as opposed to the high economic contribution of lamb of LFA cattle and sheep farms. The effect of farm size on product footprints followed the same pattern as emissions per hectare, with smaller farms having a larger emission than larger farms per kg lamb (13.9 versus 12.1 kg CO_2e/kg LW lamb).

The results for lamb when compared with baseline values presented a level of variability, but overall the average footprint reduced by 9.5%. The footprint per kg of lamb produced ranged from a notable reduction of 25.4% (farm 20) to a small increase of 4.1% (farm 13). A larger reduction in the average footprint for a kg of lamb was evident on dairy farms (20.6%) compared to LFA cattle and sheep farms (6.4%). Smaller farms had a greater reduction in their emissions per kg of lamb (15.8% versus 1.7%) compared to larger farms. Similar to the results for the total farm emissions per hectare, increases for the LW lamb footprint occurred on the same two of the eight LFA cattle and sheep farms.

5.1.1.3 Total farm emissions per kg of milk

The variability in emissions from milk production per kg product was low, with footprints from all six dairy farms falling within the range of 0.87 to 1.19 kg CO_2e/kg and an average of 0.98 kg CO_2e/kg. Farm size influenced milk footprint, with a larger footprint found on smaller farms of 50 to 199.9 ha in size (1.00 kg CO_2e/kg compared with 0.90 kg CO_2e/kg on farms of > 200 ha in size). The average footprint per kg of milk reduced by 18.2% (as a result of increased stock numbers and improved yield of milk per cow on most dairy farms), with the reduction of footprints across all farms ranging from 5.1% to 33.1%. A 12.6% reduction in the average footprint per kg of milk was observed on farms > 200 ha in size, with a more substantial average reduction of 19.3% on smaller farms of 50 to 199.9 ha in size.

5.1.2 ***Contribution of different farm emissions sources***

Table B.2 illustrates the relative importance of different components of farm emissions to the overall footprint per hectare of farmland; all percentage values described in the following section refer to the percentage of emissions per hectare. The largest proportion of total emissions from all farms came from methane (CH_4), accounting for 38.5 to 64.2% of emissions per ha (mean 49.6%). Nitrous oxide (N_2O) also accounted for a sizeable proportion of the footprint per ha, of between 13.2% and 32.2% (mean 23.2%). Emissions from inputs were important, averaging 26.5% of emissions per ha, but this varied quite widely, from between 6.5% to 42.2% of annual emissions per ha. The CO_2 footprint resulting from lime was applicable to nine farms and was small on all farms, from 0.5 kg CO_2e/ha (farm 1) to 2.0 kg CO_2e/ha (farm 8). On average the contribution of methane emissions on the farms increased by 6.8%, while N_2O and input emissions dropped by an average 5.5% and 3.1%, respectively.

These differences were as a result of changes in fertiliser consumption and/or improvements in slurry/manure spreading on farms using trailing shoe or injector systems (supported by GEG funding).

5.1.2.1 Methane emissions

Methane emission rates correspond to the number of ruminant livestock (sheep, cattle and horses) in each age (size) class on each farm. The majority of methane was emitted as a result of enteric fermentation and from livestock excreta, averaging 92.3% of the total CH_4 emissions. Methane emissions were, on average, a more important component of the farm footprint on LFA cattle and sheep farms (52.3% of the footprint per hectare) than dairy farms (46.0% of the footprint per hectare), and more important on larger farms > 200 ha in size than on farms with 50 to 199.9 ha in size (51.5% versus 48.5% of the footprint per hectare). The results present an average increase of 6.8% for methane emissions per hectare when compared to baseline figures: increasing by 2.5% on LFA cattle and sheep farms and a more substantial 11.0% on dairy farms. However, an average reduction of 1.3% was observed on larger farms as opposed to an average increase of 11.3% on small farms.

The increases in stock numbers on both LFA cattle and sheep farms and dairy farms required new infrastructure to be constructed on most farms, for example additional manure/slurry storage which was supported by GEG funding.

5.1.2.2 Nitrous oxide emissions

Nitrous oxide (N_2O) soil emissions can be disaggregated into direct emissions (from soil management, proportion of organic soils, and manure management) and indirect emissions (from atmospheric N deposition, leaching and runoff on soils, and ammonia volatilisation from manures). Between 71.7% and 78.3% of total N_2O emissions were direct emissions. Direct soil management related N_2O emissions accounted for more than half of N_2O emissions per ha on all farms, and are related to the amount of nitrogen applied to the land as mineral or manure fertiliser and/or excreta deposited by grazing livestock. Manure management emissions relate to the total quantity of manure stored, the manure source (e.g. beef cattle, dairy cattle), and the type of storage system (e.g. manure heap, slurry lagoon).

Organic soil emissions formed only a small percentage of total farm N_2O emissions per ha, although there was quite wide variability within this category (from less than 0.1% to 1.1% of the footprint per ha), which relates to the total area of peaty soils on each farm (varying from 0 ha to 78 ha). Most indirect emissions resulted from leaching, runoff or volatilisation of N from soils after mineral or manure application (65.0 to 94.6% of indirect N_2O emissions per ha), with the remainder volatilised from manure deposited in livestock housing and from stored manure.

The average N_2O emissions were a more important component of LFA cattle and sheep farms (25.4% of emissions per ha) than on dairy farms (20.3% of emissions per ha).

Farm size had a lesser effect on N_2O emissions (22.0% of emissions per ha on farms with 50 to 199.9 ha land, and 25.3% of emissions per ha on farms with > 200 ha land).

The change between baseline and recalculated results for average direct N_2O emissions is only marginal across almost all farms surveyed. For indirect N_2O emissions, an average reduction of 2.6% has been observed, yet the range of results varied from a reduction of up to 16.8% (farm 14) to an increase of 10.3% (farm 8). Half of the farms observed virtually no change (less than 1%) in N_2O farm emissions.

5.1.2.3 Farm input emissions

Emissions from inputs were dominated by feed concentrates (31.0% of total inputs), bought-in stock (28.0% of total inputs), and mineral N fertiliser (15.4% of total inputs), with the relative importance of these categories differing on each farm. Mineral N, feed concentrate and bought-in stock collectively accounted for more than 70% of total input emissions per ha on all but two farms (farms 4 and 10), where no bought-in stock inputs were accounted for on either farm. The importance of inputs as a percentage of the footprint per ha was much greater on dairy farms (averaging 33.2% of the farm footprint per ha, and comprising a greater use of electricity use and feed concentrates) than on LFA cattle and sheep farms (averaging 21.4%, with a relatively greater importance of bought-in stock and mineral fertiliser use). Farm size had a smaller, but notable effect on footprint per ha: smaller farms (50 to 199.9 ha in size) averaged 28.6% of the footprint per ha from inputs, while larger farms (> 200 ha in size) averaged 22.7% of the footprint per ha from inputs.

Comparing baseline and current emissions from inputs, significant differences ranging from a 100% decrease (mineral N fertiliser) to an increase of 231% (bought-in stock), were observed for individual input contributors on each farm. An average reduction of 13.3% for mineral N fertiliser was calculated, but averages increases of 19.0% and 18.3% were estimated for feed concentrates and bought-in stock respectively. On average, a small reduction of 1.7% was estimated across all farms for these three input categories, with a marginally better improvement on LFA cattle and sheep farms (average reduction of 2.1%) to that on dairy farms (average reduction of 1.2%). Considering these combined inputs as a percentage of the footprint per ha, the 9.4% reduction on dairy farms was positive compared to a small increase of 0.1% on LFA cattle and sheep farms. An average reduction of 6.5% was observed on the smaller farms for the footprint per ha from inputs, while larger farms presented an average increase of 3.1% of the footprint per ha.

5.1.3 ***Carbon sequestration and carbon balance***

5.1.3.1 Carbon sequestration

Total carbon sequestration varied considerably between farms. Sequestration accounted for an average 17.5% of the total footprint for the re-visited farms, and ranged from 3.6% on farm 17 (dairy farm, 50 – 199.9 ha in size) to 58.5% on farm 1 (LFA cattle and sheep farm, > 200 ha in size). Very few notable changes occurred between the baseline study results presented by Taft *et al.* (2015) and re-visited farms (sequestration data from the baseline study is presented in Table B3 in Appendix B). Dairy farms sequestered a larger percentage of farm emissions than on LFA cattle and sheep farms (6.9% and 25.4%, respectively). In addition, larger farms (200 ha in size) sequestered a larger average percentage of carbon offset of 28.1% compared to 11.6% on smaller farms (50 – 199.9 ha in size). Most sequestration occurred as carbon storage in permanent grassland soils, with woodlands contributing to some carbon uptake and marginal sequestration occurring in peat wetlands.

Farm 8 and farm 12 presented the most notable changes to carbon sequestration figures on any of the farms. An increase of 8.3% on farm 8 was due to a large decrease in store cattle numbers on the farm, thus lowering the total farm carbon footprint by reducing emissions from manure/slurry. A 5.3% increase in sequestration of emissions on farm 12 was due to an increase in the size of the farm. In addition, farm 17 was the only farm to reduce in size, and this farm demonstrated the largest reduction in the percentage of carbon sequestration on the farm.

5.1.3.2 Carbon balance

The net farm carbon balance (total footprint minus sequestration) remained positive on all farms, that is no farms sequestered more carbon per hectare than their total farm footprint per hectare. A similar magnitude of difference was observed between farm size categories: smaller farms yielding a higher average carbon balance than that of larger farms; and dairy farms continuing to have a substantially higher carbon balance, more than double, than that of LCA cattle and sheep farms.

5.2 **Nutrient footprints**

In addition to carbon footprints for each farm, the average footprint per hectare for nitrogen and phosphorus was calculated (expressed as kg of N or P per kg of product). The nutrient footprints for N and P indicate the performance of GEG schemes to help improve nutrient use efficiency. This included reviewing baseline data in addition to current data as nutrient footprints had not previously been considered in the original report by Taft *et al.* (2015). The results are presented in Table 5 and baseline data is included in Appendix B.

Table 5. Farm nutrient footprints for the farms re-visited in 2016, expressed as kg nitrogen (N) or phosphorus (P) per kg of total product, and as percentage increases or reductions to baseline results which are included in Appendix B.

Farm	Farm type	Farm size	Nutrient footprints per kg of product			
			Nitrogen		Phosphorus	
			kg N	±%	kg P	±%
1	LFA cattle & sheep	> 200 ha	0.154	0.0%	0.068	0.0%
4	Dairy	50-199.9 ha	0.147	-18.0%	0.009	-18.0%
5	LFA cattle & sheep	> 200 ha	0.061	83.4%	0.016	86.6%
6	Dairy	50-199.9 ha	0.002	-98.7%	0.000	-93.0%
7	LFA cattle & sheep	> 200 ha	0.326	-5.9%	0.094	-5.9%
8	LFA cattle & sheep	50-199.9 ha	0.316	11.9%	0.063	12.5%
9	Dairy	50-199.9 ha	<u>0.432</u>		<u>0.075</u>	
10	LFA cattle & sheep	> 200 ha	0.012	-39.0%	0.002	-43.9%
12	Dairy	50-199.9 ha	0.039	0.0%	0.008	0.0%
13	LFA cattle & sheep	50-199.9 ha	0.375	-19.3%	0.079	4.1%
14	LFA cattle & sheep	50-199.9 ha	0.185	-26.5%	0.054	-23.5%
15	Dairy	> 200 ha	0.035	-14.7%	0.007	-15.0%
17	Dairy	50-199.9 ha	0.187	12.9%	0.033	18.8%
19	LFA cattle & sheep	50-199.9 ha	0.489	-68.0%	0.042	56.9%
20	Dairy	50-199.9 ha	0.104	-73.7%	0.004	-92.3%
Mean*	Dairy		0.085	-32.0%	0.010	-33.2%
	LFA cattle & sheep		0.240	-7.9%	0.052	10.8%
		50-199.9 ha	0.205	-31.0%	0.032	-14.9%
		> 200 ha	0.118	4.8%	0.038	4.4%
	All farms		0.174	-18.2%	0.034	-8.1%

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

The average estimated nutrient footprints for nitrogen and phosphorus per kg of product across all the farms post GEG infrastructure implementation was 0.191 kg N/kg (range 0.002 to 0.489 kg N/kg) and 0.034 kg P/kg (range < 0.001 to 0.094 kg P/kg). A higher average nutrient footprint per kg of product was observed on small farms 50 – 199.9 ha in size (0.205 kg N/kg) than on larger farms > 200 ha in size (0.118 kg N/kg), while average phosphorus footprints were marginally higher on larger farms, 0.038 kg P/kg compared to 0.0.2 kg P/kg on the small farms. The average footprint on dairy farms was more than half that of LFA cattle and sheep farms (0.240 to 0.086 kg N/kg, and 0.052 to 0.010 kg P/kg).

The average nutrient footprint per kg of product on the farms reduced by 18.2% and 8.1% for N and P, respectively. These reductions were due to the improved yield of producing a kg of lamb and milk, while simultaneously reducing fertiliser inputs and/or reducing bought-in feed concentrates. A number of these farms constructed new slurry/manure stores through the GEG scheme which aids in improving slurry/manure management. However, the results showed a wide range of variability in nutrient emissions, from substantial N and P reductions exceeding 83% on farm 5, to equally large increases of in excess of 93% on farm 6. Therefore, in combination with stock changes on the majority of farms, it is inconclusive as to the impact of additional storage of slurry/manure in reducing fertiliser usage on all farms. The average nutrient footprints per kg of product reduced on the six dairy farms by 32.0% to 33.2% for N and P (an increase only occurred on one of these dairy farms (farm 17) due to a reduction in the farm size). On LFA cattle and sheep farms, the average nitrogen footprint per kg of product reduced by 7.9%, compared with a 10.8% average increase in the phosphorus footprint per kg of product. The range of results on LFA cattle and sheep farms presented a significant increase of over 83% (farm 5) for N and P due to increasing fertiliser use, cattle stock and feed, while a reduction in fertiliser and feed demonstrated the greatest reductions for N and P of 68.0% and 43.9% respectively. Smaller farms showed average reductions of 31.0% and 14.9% for N and P footprints per kg of product, while larger farms presented small increases of 4.7% and 4.1% in their footprints for N and P, respectively.

5.2.1 *Impacts for on-farm ammonia emissions*

On-farm ammonia (NH_3) emissions per kg of product reduced by an average of 11.0% across the farms between the baseline survey and the latest footprinting (Table 6). Results ranged from an 11.6% increase to a 49.9% reduction. Increases in NH_3 emission occurred on three of the fourteen farms. Average reductions were observed on both small and large farms, with a more notable 13.6% reduction on farms of 50 to 199.9 ha in size compared with the 6.2% reduction on farms >200 ha in size. An average reduction of 16.0% was estimated for dairy farms and 7.1% for LFA cattle and sheep farms. Stock numbers increased on all of these farms which reduced the ammonia emissions per kg of product, however some of these farms also increased bought-in fertiliser to increase the yield of grown feed.

5.2.2 *Eutrophication and acidification impacts of farms*

Trends in potential eutrophication and acidification burdens (Table 6) were examined by calculating and comparing kg PO_4e and kg SO_2e per kg of product on the farms between the baseline survey and most recent survey.

Table 6. Ammonia footprints expressed as kg of NH_3, eutrophication (PO_4) and acidification (SO_2) burdens per kg of main product output for the farms re-visited in 2016. Results are presented per kg main product and as percentage increases or reductions relative to baseline results which are included in Appendix B.

Farm	Farm type	Ammonia (NH_3)		Eutrophication (PO_4)		Acidification (SO_2)	
		kg NH_3	±%	kg PO_4	±%	kg SO_2	±%
1	LFA cattle & sheep	0.13	0.0%	0.71	0.0%	0.25	0.0%
4	Dairy	0.01	-25.4%	0.07	-17.2%	0.03	-24.8%
5	LFA cattle & sheep	0.07	-3.4%	0.46	-4.7%	0.14	-2.8%
6	Dairy	0.01	-23.8%	0.08	-8.8%	0.03	-31.2%
7	LFA cattle & sheep	0.07	-15.6%	0.58	-12.9%	0.14	-15.1%
8	LFA cattle & sheep	0.05	-49.9%	0.73	-29.4%	0.11	-47.3%
9	Dairy		-		-		-
10	LFA cattle & sheep	0.08	1.6%	0.47	-8.0%	0.15	1.6%
12	Dairy	0.05	-10.4%	0.33	-0.8%	0.10	-10.4%
13	LFA cattle & sheep	0.13	11.6%	0.80	9.9%	0.27	10.1%
14	LFA cattle & sheep	0.08	2.7%	0.61	-12.3%	0.07	1.4%
15	Dairy	0.01	-13.5%	0.02	-13.1%	0.02	-13.8%
17	Dairy	0.01	2.3%	0.05	8.1%	0.02	1.9%
19	LFA cattle & sheep	0.25	-4.1%	1.27	-3.2%	0.50	-8.3%
20	Dairy	0.05	-25.4%	0.40	-27.4%	0.09	-25.3%
Mean*	Dairy	0.023	-16.0%	0.157	-9.9%	0.046	-17.3%
	LFA cattle & sheep	0.108	-7.1%	0.702	-7.6%	0.217	-7.5%
	50-199.9 ha	0.072	-13.6%	0.481	-9.0%	0.145	-14.9%
	> 200 ha	0.071	-6.2%	0.446	-7.7%	0.141	-6.0%
	All farms	0.072	-11.0%	0.469	-8.6%	0.144	-11.7%

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

The results for eutrophication and acidification impacts reflect similar patterns to those seen for nutrient loadings and emissions. Focusing on the changes between baseline and re-visited footprint data, average eutrophication and acidification burdens reduced by 8.6% and 11.7% respectively. These results range from reductions of 29.4% for PO_4 and 47.3% for SO_2 to maximum increases of 9.9% and 10.1%, respectively.

The majority of farms reduced their eutrophication (PO_4) and acidification (SO_2) burdens per kg of product, with an increase for PO_4 occurring on two farms and an increase in SO_2 on four farms. Two farms (farms 13 and 17) presented the most substantial increases for eutrophication and acidification, and is likely due to increasing their cattle stock, and in addition farm 17 reducing in size. An average reduction was observed on both small and larger farms, with a greater mean reduction of 14.9% occurring on farms 50 – 199.9 ha in size compared to a mean reduction of 7.7% on farms > 200 ha is size. Dairy farms reduced their average eutrophication and acidification intensities by 9.9% and 17.3% respectively, while LFA cattle and sheep farms reduced their eutrophication and acidification intensities by 7.6% and 7.5%, respectively.

5.3 Effects of on-farm changes to footprints

To determine the impact of GEG schemes on carbon and nutrient footprints, the key changes that have occurred on each farm between the baseline study and the collection of re-visited footprints for each farm are presented in Table 7.

This section provides an overview of the overall changes that have occurred on the farms which may impact the footprinting results. In summary, two of the farms changed in size. Three farms presented changes in fuel consumption (one increased and two reduced usage), while electricity demands were reduced on two dairy farms. Increases in dairy stock numbers were observed on all six dairy farms and milk production also increased on each of these. Significant variation in the use of N fertiliser was observed, reductions or no change in fertiliser consumption was observed on all but three farms. Eight farms altered beef stock numbers (six farms increased stock numbers, while two farms reduced stock numbers) and changes in sheep stock numbers were evident on seven farms (increasing on three farms and reducing on the remaining four farms). Bedding and feed were impacted on the majority of farms, the tonnage of bedding increased on seven farms and decreased on only three farms, while feed requirements increased on six farms but was reduced on five farms.

Table 7. Key changes that have occurred on the GEG Scheme farms footprinted since 2014 (expressed as percentage increase or decrease to baseline results). This includes changes to farm size, fuel and electricity consumption, fertiliser-N inputs, liveweight of dairy, beef and sheep stock numbers, bedding, feed (bought-in and home) and milk production.

Farm	Farm Type	Size	Fuel	Electricity	Fertiliser-N	Dairy	Beef	Sheep	Bedding	Feed	Milk
1	LFA cattle & sheep	-	-	-	<1%	-	-	-	-	-	-
4	Dairy	-	-	-59%	7%	8%	-	-	39%	3%	25%
5	LFA cattle & sheep	-	-	-	74%	-	7%	-	16%	20%	-
6	Dairy	-	-	-	-97%	27%	3%	-	3%	12%	8%
7	LFA cattle & sheep	-	-	-	-	-	-17%	-2%	-	-	-
8	LFA cattle & sheep	-	-	-	37%	-	-69%	-43%	-43%	-18%	
9*	Dairy	-	100%	>100%	44%	>100%	-100%	-100%	>100%	17%	-
10	LFA cattle & sheep	-	-	-	-	-	30%	-	-	-5%	-
12	Dairy	50%	-	-	-100%	2%	1%	11%	-6%	-	2%
13	LFA cattle & sheep	-	-25%	-	4%	-	24%	-1%	-	-16%	-
14	LFA cattle & sheep	-	-	-	-14%	-	19%	13%	9%	1%	-
15	Dairy	-	5%	-	-11%	13%	-	-	15%	15%	20%
17	Dairy	-17%	-10%	-40%[1]	-7%	17%	-	-	90%	-68%	27%
19	LFA cattle & sheep	-	-	-	-46%	-	-	3%	-50%	-9%	-
20	Dairy	-	-	-	-19%	38%	-	-10%	36%	12%	42%
Mean*	Dairy	16.5%	-17.5%	-49.5%		17.5%	1.6%	0.3%	29.7%	-5.2%	20.7%
	LFA cattle & sheep	-	-25.0%	-		-	-0.8%	-6.1%	-16.9%	-4.4%	-
	50-199.9 ha	16.5%	-17.5%	-49.5%		18.4%	-4.5%	-4.7%	9.9%	-10.3%	18.4%
	> 200 ha	-	5.0%	-		13.0%	7.0%	-1.8%	15.5%	9.9%	13.0%
	All farms	16.5%	-10.0%	-49.5%		17.5%	-0.2%	-4.3%	11.0%	-4.8%	20.7%

* Farm 9 results (underlined) are discussed separately (Section 5.3.4) as a change in farming practice occurred between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016.

[1] Estimation of 40% based on information provided by farm 17. Insufficient data for electricity use in baseline study, an estimate of savings of £100 per month was provided during revisit due to the installation of a heat recovery/heat exchange unit on the farm.

5.3.1 *Fertiliser, sulphur and lime*

Changes occurred on a number of re-visited farms: two dairy farms dramatically reduced N-fertiliser use (farms 6 and 12 by 97% and 100% respectively). Five LFA cattle and sheep farms increased N-fertiliser consumption, however it equated as less than 10% on three of these farms. Of the remaining two farms, one farm's increase in N usage led to an increase in production of home-grown feed, however it was not clear why the other farm increased its fertiliser use. Two LFA cattle and sheep farms and one dairy farm reduced sulphur use. Of the six dairy farms, three observed changes in lime use: two farms did not apply lime while one farm doubled their lime use in the footprinted year. Also, one LFA cattle and sheep farm used no lime. The same two dairy farms that reduced fertiliser use by 99% also reduced their lime use in the re-visited footprint data. The provision of lime and sulphur is influenced by regular soil testing and is not an annual practice on farms, therefore its inclusion or omission from the results may not be representative of general practice on each farm, and cannot be directly seen as being affected by GEGs investment

5.3.2 *Farm stock and feed*

Farm stock numbers changed on eleven of the farms: six dairy farms altered stock numbers, eleven presented changes in beef and cattle stock, and two farms changed their sheep stock numbers. All dairy farms increased their stock numbers and accordingly increased calf numbers in stores for replacement dairy cows. Similarly, the two farms that increased their sheep numbers had a similar increase in lamb stocks for replacements of older ewes.

The quantity, type or source of feed for animal stock has changed on the majority of farms; four farms altered feed stock for sheep, nine farms changed beef feed figures and five altered the contribution of home feed (of which one farm represented a farm that changed in size). This is in response to a number of factors: changes in stock numbers, changes to type of stock, or changes to farm size and land use.

5.3.3 *Milk production*

In relation to the production of milk, increased stock numbers coincided with an improved yield on all dairy farms. However of the six farms, only one farm (farm 6) increased milk yield by a lower percentage than the percentage increase in dairy stock numbers on the farm. Interestingly, this farm achieved the largest reduction in nutrient footprint i.e. reducing fertiliser use by 99%, however despite a 27% increase in dairy stock numbers this only translated to an 8% increase in milk production, suggesting proportionally less feed per animal. Increasing feed inputs or increasing farm size enabled four farms to increase stock numbers and subsequently increase milk production. The remaining dairy farm (farm 17) reduced in size and reduced the tonnage of feed inputs, yet displayed a higher milk yield per cow (farm 17 produced 66% less home-grown feed of silage with same quantity of barley and maize, increased bought-in concentrate feed by 50% but had a net reduction).

5.3.4 *Changing farm practice*

Farm 9 completely changed its farming practice between the baseline and re-visited farm footprints, from a LFA cattle and sheep farm to a dairy farm. This reduced beef-cattle and sheep numbers by 100%, and led to a new stock of dairy cows. For the dairy stock, an increase in bedding and home-grown feed was noted, as well as significant increases in fertiliser (40%), sulphur (100%) and a 10-fold increase in lime use for the current footprinted year. This was due to the need for improved grazing for the dairy cows. In addition, electricity consumption on the farm increased by several orders of magnitude due to the electricity requirements of milking operations.

Comparing farm emissions per kg of milk, farm 9 produces milk at 1.21 kg CO_2e/kg, which is higher than the range of values from the other six dairy farms in the study. The high value can be attributed to the high quantity of fertiliser used on the farm, with the footprint associated with lime almost four times higher than any other farm. However, this may not be the typical demand per year, thus the contribution of lime to the carbon footprint in 2015 may be higher than the average over a longer time period. This was due to the farmland requiring additional nutrients with the change of stock. The contribution of methane, N_2O and input emissions was 47.1%, 22.1% and 22.8% respectively, all within 4% of the average emissions on the other farms. Methane emissions are lower on farm 9 than the average CH_4 emissions measured on the other farms. The change in farming practice reduced N_2O emissions per hectare by 22.8%.

Overall, the farm is not yet performing as well as other established dairy farms when considering carbon emissions per kg of milk. However, there is scope for this farm to improve and reduce its footprint in future years as higher demands for lime in this sample year is likely to exceed average annual contributions. The farm has the scope to further increase its stock numbers and improves its milk yield per cow. The construction of slurry stores through the GEG scheme allows for further expansion of the farm.

5.4 **Carbon offset**

The potential of renewable energy generation on farms in Wales to offset GHG emissions from food production was explored (farm 9 is accounted for in this assessment despite a change in farm practice). The 15 farms re-visited were asked a number of questions regarding their opinions on different renewable energy technologies. The following points summarise the responses from the farmers. The majority of the farmers were interested in some form of renewable energy generation. The main barriers to installation of renewable energy reported by farmers included:

- being tenant farmers
- economic feasibility
- unsuitable grid connection i.e. single phase
- planning permission issues
- lack of trust or bad experience with renewable energy companies
- protected land e.g. a SSSI river.

Two farms already have 50 kW solar PV installations, other farmers have looked into similar installations and wind turbines, micro-hydropower, wood pellet and biomass boilers. The majority of farmers have neighbours and friends who have invested in renewable energy technologies. However, most of the farmers interviewed do not have information on all available options.

In addition, solar PV was considered the least imposing of all renewable technologies on farms, occupying building roof space and not occupying productive farm land, and so was selected for further investigation. An assessment of the potential for solar PV generation using available roof space on farm building was undertaken. The results are presented in Table 8.

Firstly, 50% of the rooftop areas were excluded from the assessment as one half of roofs were north facing to some degree, therefore it was assumed that solar PV panels were not viable on these rooftops. The calculations considered an average roof pitch of 30 degrees on all rooftops. The installation size was determined and the annual generation potential (MWh), income (£) and carbon offset (T CO_2e) were calculated using the Solar Energy Calculator adopted from the Energy Saving Trust (2016) online tool. A generation tariff of 4.25 pence per kWh was used, and an export tariff of 4.91 pence per kWh. An electricity price of 7.21 pence per kWh was used for farms that used the electricity and saved money through on-site generation. The GHG intensity assumed for avoided grid electricity was 0.496 g CO_2e/kWh based on the energy Solar Energy Calculator (Energy Saving Trust, 2016).

Table 8. Electricity generation potential on the 15 farms re-visited as part of the GEGs footprinting study (based on assumptions made for feasible roof space (50% were partially or fully south-facing), roof pitch and feed in tariffs.

Farm	Feasible roof size (m2)	Size Installation (kW)	Annual Energy Output (MWh)	Annual income (£)	Carbon offset ($T\ CO_2$/yr)	Percentage of farm footprint offset
1	394	75	46.8	£4,287	23.2	2.6%
4	394	75	46.8	£4,287	23.2	2.3%
5	531	100	62.4	£5,716	31.0	0.8%
6	104	20	12.5	£1,143	6.2	0.3%
7	525	100	62.4	£5,716	31.0	3.7%
8	113	20	12.5	£1,143	6.2	0.9%
9	524	100	62.4	£5,716	31.0	4.9%
10	255	50	31.2	£2,858	15.5	1.4%
12	557	110	68.6	£6,287	34.0	1.9%
13	261	50	31.2	£2,858	15.5	1.9%
14	243	50	31.2	£2,858	15.5	2.8%
15	1,763	350	218.4	£20,005	108.3	1.7%
17	518	100	62.4	£5,716	31.0	1.9%
19	875	160	99.8	£9,145	49.5	4.1%
20	341	65	40.6	£3,715	20.1	2.2%
Mean	370	95	59.3	£5,430	22.1	2.3%

The farms presented a technical potential solar PV installations of an average of 95 kW capacity, with a range of 20 to 350 kW. This was estimated based upon an assumption that approximately 25% of south-facing farm building rooftops may be unsuitable for solar PV panels on each farm due to the additional structural loading of solar PV panels, which would incur additional costs and make such an installation economically unviable. This would halve all figures for electricity and carbon offsets on farms in Table 6 unless funding support could be provided to strengthen all feasible rooftops for solar PV installations. Farms 9 and 15 already have 50 kW installations; both are dairy farms that consume the electricity on their farm (although farm 9 also used the electricity for their adjacent caravan park).

Surveyed farms have the technical potential to generate between 12.5 and 218 MWh per annum, providing an average income of £5,430 (ranging from £1,143 to £20,005), and potentially offsetting an average 208 kg CO_2e per hectare at the farm level. This translates to an average 3.3% increase in farm income each year, ranging from 0.3% to 14.4%. There is very little difference between the average increases to farm income on small or large farms, but it there was a more substantial average increase of 4.7% of income achievable for LFA cattle and sheep farms compared to an average 1.9% on dairy farms. However, dairy farms can use this electricity directly and thus reduce electricity costs as well-as receive feed-in-tariffs. This would increase the overall contribution to farm income by an average 2.2%, ranging from 0.5% to 3.3%.

Electricity generation represents a comparatively small share of overall farm GHG emissions, although does contribute notably to dairy farm GHG emissions. Therefore, in relation to reducing the carbon footprint per kg of product from each farm through renewable energy generation, solar PV could contribute primarily by indirectly offsetting farm emissions via substitution of grid electricity substitution. Based on the results for generation on each farm, the average carbon footprint per farm or per hectare could be offset by 2.2%, with a significant range of results from 0.3% to 4.9%. The footprint was reduced by a similar percentage on smaller farms (average 2.3%) than on larger farms (average of 2.0%). On-farm solar PV electricity generation could offset the farm carbon footprint of LFA cattle and sheep farms to a greater extent than on dairy farms with average reductions of 2.6% versus 1.7% respectively.

Based on the total 152 farms that are supported through different GEG scheme grants between 2011-2013, and based on an extrapolation of the average generation potential of each of the 15 farms examined in this study, this could offset 9.0 TWh of electricity and 3,352 T CO_2e per year from the agriculture sector in Wales. However, for this to be achieved there would be a need to reintroduce support for renewable energy generation outcomes into the Glastir Efficiency Grants, which was removed due to high feed-in-tariffs at the beginning of the GEGs programme.

6 DISCUSSION

This project aimed to provide comprehensive farm footprints (carbon and nutrient) for a representative sample of farms receiving GEG Scheme funding, and to examine the impact of implementing these technologies. Furthermore, the potential to offset carbon emissions on Welsh farms via on-farm renewable energy generation, specifically solar PV installations, was evaluated. In fulfilment of these criteria, the following sections discuss the impact of GEG Scheme funded technologies on farm carbon and nutrient footprints in Wales, and considers further opportunities for abatement across the Welsh agricultural sector.

6.1 Influence of GEG Scheme funded technologies on farm footprints

The GEG Scheme provided opportunities to reduce emissions through three technology categories: on-farm energy use efficiency (Energy Efficiency, coded EE), efficiency of animal excreta collection, storage and application (Slurry/ Manure Efficiency, SME), and water use efficiency and recycling (Water Efficiency, WE) (WG, 2013). This section will examine the farms that implemented these different technologies and quantify their impact on carbon and nutrient footprints on each farm.

Taft *et al.* (2014) determined the level of uptake of these technologies, showing that the majority of approved grants fell within a small number of technologies: rainwater separation' (13% of grants); 'slurry store' (12%); 'new manure store' (9%); 'trailing shoe or injector system' (9%); and 'new slurry store' (8%). The farms visited in this study capture examples of each of these technologies. In addition, a heat recovery/heat exchange unit was installed on one dairy farm in the energy efficient category.

6.1.1 *Influence of energy efficiency grants*

Within the category of energy efficiency, GEG support for heat recovery/heat exchanger units were examined as a noteworthy method of reducing farm emissions.

6.1.1.1 Heat recovery/heat exchanger unit

In terms of energy efficiency technologies, the installation of a heat recovery/ heat exchanger unit through GEG Schemes was noted on three of the farms re-visited in 2016. In terms of GHG reduction, Energy Efficiency (EE) grants act through direct savings in electricity use only (WG, 2014b). As Taft *et al.* (2015) observed, for most farms, only a small percentage (less than 4.4%) of GHG emissions were attributable to electricity use in the baseline study, and the findings were similar for re-visited farms. The report did identify higher emissions from electricity use on dairy farms as opposed to LFA cattle and sheep farms, owing to significant electricity use for milking operations on dairy farms. Therefore, it is understandable that all three farms who received GEG Scheme funding for this technology were dairy farms. Nonetheless, DairyCo (2012) do state that only 3% of dairy farm milk footprints are attributable to electricity use. In two of the farms, insufficient data were available to quantify the impact of this technology on the carbon footprint per kg of product (milk). However, on one of these two farms, the impact of this technology had reduced the annual electricity bill by £1,200 (farm 17).

On farm 4, annual electricity consumption was reduced by 59% following the implementation of the heat recovery/heat exchanger unit. The system was considered to have a payback of 4-5 years. In terms of the carbon footprint of milk on the farm, and taking into account changes in stock numbers on the farm, the initial contribution of electricity on farm 6 in this study was 4.3% to the overall footprint. This was higher than previous literature suggested, but this farm is much smaller than other dairy farms in this study. The installation of the heat recovery/heat exchanger unit on farm 4 reduced the farm operational costs by approximately £1,800 per year and the farm footprint by 0.16%. The overall footprint did not reduce because other factors outweighed benefit of reduced electricity consumption. This technology reduces on-farm costs for electricity and aids in the carbon footprint of milk. Similar to the findings of the baseline report, EE grants are best suited to the dairy sector and targeting other agricultural type farms and will not make any notable difference to Welsh agricultural emissions.

No previous estimation for the abatement potential of this energy efficiency strategy has been provided in literature. In this study, the footprint abatement potential for installing a heat recovery/heat exchanger unit on a dairy farm, in this case farm 4, was estimated as 0.44 T CO_2e per hectare. It should be noted that this farm represented one of the smallest farms in the study and therefore savings on larger farms would be likely to have a smaller impact per hectare.

6.1.2 *Influence of slurry/manure efficiency grants*

Four different GEG Schemes support changes in the slurry/manure efficiency category: rainwater separation, trailing shoe or injector system, new slurry store; new manure store (WG, 2014b). This category aims at improvements in the general management of slurry/manure to reduce N losses, improve manure management emission and maximise its effectiveness as a source of nutrients on the farms.

6.1.2.1 Rainwater separation

Rainwater separation was implemented on six of the fifteen farms through GEGs. This prevents rainwater from entering the slurry store ensures that overflows and leaching of effluent does not occur from the slurry tanks. From the footprinting study, it was not possible to quantify the impact of rainwater harvesting on the farms that have installed this technology, but it could result in a significant reduction in the “blue” (abstracted) water footprint of milk production.

6.1.2.2 Trailing shoe or injection system

The use of a trailing shoe or injection systems has the potential to reduce NH_3 and indirect N_2O emissions through more efficient application of N into the soil. These systems can also can improve the uptake of nutrients in the soil, and help reduce fertiliser consumption on farms, compared with traditional splash-plate application methods. Five farms received GEG Scheme grants to employ improved methods of slurry spreading using a trailing show or injection system. Due to changes in stock numbers on each farm, it was challenging to determine the direct impact of changes to manure management on C footprints on farms.

Taking the five farms that received funding for this technology, three farms were dairy farms and two were LFA cattle and sheep farms. Examining the footprints of the re-visited footprints, the impact of improving the method of slurry/manure spreading was examined in relation to the overall nutrient footprints per kg of product. For the three dairy farms, the average ammonia (NH_3) emission was reduced by 11.3-16.1% per kg of milk. This translated into a 1.0-1.6% reduction in the eutrophication burden and a more substantial reduction of 10.0-16.1% in the acidification burden of milk production. Lamb production was also found to be associated with lower ammonia emissions, of between 1.5-8.2%, on three of the farms (two LFA cattle and sheep, and one dairy farm) implementing more efficient manure application methods. Marginal reductions of up to 0.8% were observed for potential eutrophication burdens, and between 1.4-8.2% for acidification burdens.

A number of farmers use contractors for slurry/manure spreading. This GEG scheme supported technology has been shown to reduce the farm footprint, however in the case of farmers using contractors for slurry/manure spreading, options may not be available to select alternative, more efficient slurry-spreading technologies. Therefore, a better understanding of the percentage of farmers across Wales that use contractors for slurry spreading is required, and promoting these alternative technologies with contractors is key to improving options available to farmers.

In addition, the mix of straw bedding presents a challenge in the spreading of slurry/manure using this technology, despite modern mascerators, as the viscosity or consistency of the slurry/manure in some cases may limit options available.

6.1.2.3 New slurry store

Eight farms, five LFA cattle and sheep farms and three dairy farms received GEG Scheme funding to construct new slurry stores or modification of existing stores. In is not possible to quantify the benefits of improved slurry management in the footprinting study due to the small sample size. However, the following suggests that the slurry stores may have had a positive impact on some farms. Of the eight farms, four reduced their consumption of fertiliser, three presented no change and only one increased fertiliser use (but in doing so made more significant reductions for bedding and animal feed).

Four of the five LFA cattle and sheep farms increased their use of fertiliser between the baseline report and this study. Two farms increased their stock numbers, one farm had no change in stock numbers (but reduced bought in feed) and one farm reduced stock numbers (and reduced bough in feed). The fifth LFA cattle and sheep farm reduced fertiliser use but this led to a similar reduction in home feed yield. The three dairy farms have all reduced their fertiliser use.

The results suggest that the new slurry stores are already having a positive impact to reduce the amount of fertiliser used by dairy farms, with mixed results on LFA cattle and sheep farms.

6.1.2.4 New solid manure store

Two LFA cattle and sheep farms received GEG Scheme grants for solid manure stores. Similar to the slurry stores the data cannot directly provide evidence of the impact of these stores on the carbon and nutrient footprints on the farms. The small dataset of two farms did not provide enough information to make any definite conclusions. However, it is considered that long term improvements will occur on the farms and further examination in the future may provide supporting evidence of the benefits of these new solid manure stores.

6.1.3 ***Water efficiency***

A single grant was examined under the water efficiency category: rainwater collection. This measure aimed to indirectly reduce GHG emissions by reducing water use or recycle water on the farm (WG, 2013).

6.1.3.1 Rainwater collection

One farm received a grant to implement a rainwater collection system. No information was available with regards the impact of rainwater collection on water consumption on the farm. Therefore further studies should consider how Glastir support could impact on water footprinting.

6.2 **Potential of Renewable Energy for Carbon Offsetting**

Renewable energy technologies have only been installed on a small fraction of the farms re-visited in this footprinting study, yet a number of farmers indicated an interest and/or previous consideration for installing different renewable energy technologies on their farms. As an exercise, the potential for solar PV was examined on all farms based on available roof space on each farm (least intrusive technology to the farms, where no change to land use is required). The findings presented the potential for additional income for all farmers, reducing the carbon footprint of farming practices and providing on-site electricity where required (of particular benefit to dairy farms). However, a number of barriers exist for farms that have previously been outlined, in particular grid connection restrictions, tenancy rights to install the technology and no guarantees of longevity of some renewable energy companies. Furthermore, as feed-in-tariff rates have reduced significantly since 2015, the payback of solar PV and other renewable energy technologies is less appealing to farmers. Therefore, there could be an important role for future GEG Scheme grant programmes to support farmers in the installation of these technologies to reduce their energy demands and carbon footprint.

7 CONCLUSIONS AND RECOMMENDATIONS

This report presents the footprints of farms re-visited since GEG technologies have been implemented and compares the results to baseline footprints pre-installation of GEGs infrastructure. The impact of GEGs on ammonia emissions, nitrogen (N) and phosphorus (P) footprints were also determined, and from these eutrophication footprints were derived. Finally, the project assesses the feasibility on on-farm energy generation to offset net GHG emissions from farms in Wales.

Whilst the limited dataset restricts any robust conclusions from being drawn, it is possible to provide an indication of key outcomes:

We should be able to provide some key indications of the impact of changes in management practices (related to GEGs) have had on C footprints, NH_3 emissions and eutrophication and acidification burdens – in bullet form.

On the basis of this study's findings, we recommend the following:

Further research to examine the longer term impacts of GEG scheme grants (e.g. farm intensification) as current results are inconclusive due to the small sample set. Due to significant changes in stock numbers and a volatile market for the dairy sector, it presents challenges in drawing substantial conclusions from this single comparison of farm footprints.

Focusing on sustainable intensification, future footprints should prioritise per unit of product as opposed per hectare.

Consider rolling out a footprinting campaign (possibly self-reporting after the first footprint) across a larger number of typical farm typologies in Wales (similar to the "Origin Green" footprinting survey in Ireland).

Consider developing a moving-average farm footprint tool to account for annual variations in stock numbers, fertiliser, sulphur and lime usage and external factors that are out of control of the farmer e.g. weather impacts on home grown feed.

Consider consequential LCA to evaluate sector changes more accurately e.g. capturing land use change if trend of increased stock numbers and more outsourcing of feed continues in coming years.

Examine the optimum solution for farmers between bought-in and home grown feed to reduce farm and produce footprints (e.g. building on the Carbon footprinting in the TSB project EFBS IUK 101097: *Sustainable Forage Protein Efficient forage-based systems for ruminant livestock production in the UK*).

A detailed examination of challenges facing farmers in Wales to implement renewable energy technologies, provide additional income for the farms and offset farm carbon footprints. Consider the feasibility of Welsh Government supporting renewable energy companies to provide farmers with impartial information on the options available on each farm.

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9 APPENDIX A - BANGOR UNIVERSITY LIVESTOCK ENTERPRISE CARBON-FOOTPRINT MODEL

A-1.1 Compliance with PAS 2050:2011

Bangor University carbon footprints comply with the PAS 2050:2011 cradle-to-gate approach (BSI, 2011). This includes accounting for all emissions arising from transforming raw materials (e.g. from fertiliser production); energy use; and manufacturing and service provision (i.e. from consumables, operation of premises, transport, and storage). Agriculture-specific emissions include those following fertiliser application, direct land-use change (from non-agricultural to agricultural land), and CH_4 from cattle. Excluded from the footprints are emissions from the production of capital goods (e.g. machinery manufacture), emissions associated with visits from veterinary and other advisors (due to lack of reliable emissions data), and minor emissions sources (those which are typically less than 1% of system emissions, for example from infrequently-used consumables).

The carbon footprints produced using the Bangor University model follow the requirements of the PAS 2050:2011 regulations directly relating to agricultural emissions reporting, in the following way:

Regulation	Compliance
Non-CO_2 emissions from livestock and soils should be calculated using the highest Tier IPCC approach, or the highest approach used by [our] country.	This study uses IPCC model equations and ECOSSE model EFs to estimate emissions of N_2O from managed peat and peat-derived soils.
Soil carbon content changes, except for those resulting from direct land-use change, shall be excluded from the assessment.	This study excludes changes such as sequestration rates in peatlands.
CO_2 emissions from biogenic (non-fossil fuel, biomass-derived) material should be excluded (except those arising from land use change). Non – CO_2 emissions from both fossil and biogenic material carbon sources should be included.	The system boundary for this study does not include any emissions from these categories.
Where atmospheric CO_2 is taken up by a product which is not a living organism, the impact of carbon storage is determined from the weighted average of the biogenic carbon in a product, or atmospheric CO_2 taken up and not re-emitted to the atmosphere over the 100 year assessment period.	This system boundary for this study does not include any emissions from these categories.
Biogenic carbon storage shall be included if: (1) the product is not for human or animal consumption; (2) more than 50% of the mass of C of biogenic origin in the product remains removed from the atmosphere for one year or more; and (3) the material containing the biogenic C is obtained from an input that is the result of human actions, or a recycled or re-used input (i.e. ensuring the C stored is in addition to that which would have occurred without human intervention). (C storage through forest management activities in a managed forest is not included in the scope of PAS).	This study does not include carbon storage in woodland and other woody biomass, as it is uncertain whether more than half of the biogenic carbon remains removed from the atmosphere for more than one year.
GHG emissions from direct land use change shall be assessed for any input originating from agricultural activities. In accordance with IPCC methods, this includes all direct land use change after 1st January 1990. 5% of the total emissions from land use change shall be included in each year over the 20 years following the land use change.	This study includes land where land-use change from non-agricultural (e.g. woodland) to agricultural land use has occurred since 1990.

To comply with PAS 2050:2011, all footprint results are reported to 2 significant figures and per unit of produce (kg).

A-1.2 Direct and indirect inputs

For the purposes of carbon footprinting, emissions derived from the use of inputs on-farm, (e.g. from *use* of fuels and electricity) are termed *direct inputs*, while *indirect inputs* are emissions that happen elsewhere, but can be attributed to on-farm use of inputs (e.g. from the *manufacture* and distribution of farm inputs such as fertilisers). Standard databases (IPCC; ETH EF) were consulted for emissions factors. Agrochemicals include field applications and externally applied pharmaceuticals (e.g. dips and parasite treatments), and are modelled using minimum, mid-range and maximum emission factor (EF) values from the published scientific literature sourced by Edwards-Jones *et al*. (2009).

A-1.3 Stock data and organic nitrogen

The Bangor University model estimates direct and indirect emissions from livestock on a monthly basis, to account for the effect on the carbon footprint of changes in animal numbers and emissions categories as livestock enter, grow, and leave the defined farm boundary during the course of the business year. This also allows the investigation of differences in management efficiency (expressed as fattening times) between enterprises.

Where a farm houses its livestock for part of the farming year, the model calculates the emissions from, and nutrient content of, manure and bedding materials from housed stock. Nitrogen excretion rates are based on the relevant IPCC EFs for farmers' stated manure-handling methods.

A-1.4 Nitrous oxide emissions

Nitrous oxide (N_2O) has a powerful heating effect on the atmosphere, and is produced when microbes break down certain nitrogen compounds under suitable conditions. On-farm sources of N_2O include direct emissions from manure management, soils receiving N, and managed organic soils, and indirect emissions; they are calculated in this report using the standard IPCC method (IPCC, 2006).

Direct N_2O emissions from manure management are calculated from total N entering the system using IPCC Tier 1 EFs (IPCC, 2006). This section takes account of the proportion of nitrogen in stored waste materials (animal manure and bedding material) that are emitted directly as N_2O.

Direct N_2O emissions from soil are calculated from total N added to soils in the form of mineral or manure fertilisers, crop residues, and deposited urine and faeces, and broken down by soil microbes. This section uses IPCC Tier 1 EFs specific to each N source and stock type (IPCC, 2006), and includes the range of uncertainty stated by the IPCC.

Direct N_2O emissions from managed organic soils are calculated from the total area of grazed organic soils on each farm (which for the purposes of the footprinting method are classified as 'managed'). Peaty and peat-derived soils emit 'background' levels of N_2O, due to their high levels of biological activity, particularly when managed. An EF of 0.25 kg N_2O-N/ha/yr is used here, representing a UK-specific value derived from modelling of peat soils emissions in the Welsh and Scottish uplands (SEERAD, 2007).

Indirect N_2O emissions are calculated from the amount of nitrogen which may be volatilised as ammonia (e.g. from applied mineral N fertilisers and applied and stored manures), or lost via leaching or runoff to the wider environment when applied to soil. Standard IPCC Tier 1 EFs and equations for the loss from each type of nitrogen application are used to calculate emissions.

A-1.5 Methane emissions

Methane (CH_4) is emitted from ruminant animals directly from their gut during food digestion (enteric fermentation), or indirectly from their excreta. Livestock CH_4 emissions in the field and from stored manures are computed using IPCC equations, and emissions factors given in IPCC (2006) and Baggott *et al*. (2007).

A-1.6 Emissions from liming

When lime is applied to soils, some CO_2 is released. This model calculates the carbonate-content of lime and lime-containing applications to soil and converts it to CO_2-equivalents, reporting a 50 % uncertainty range, as required by IPCC and PAS 2050:2011.

A-2 Beyond PAS 2050: carbon sequestration estimates

Using the footprinting questionnaires, participating farmers were asked to indicate the extent, type and management of tree cover, soil, and relevant habitats on their holdings. The resulting information was used to calculate carbon sequestration (i.e. addition to long-term stocks in woody biomass or soils) in units of metric tonnes of C sequestered per hectare per year (t C/ha/yr), then converted to an offset against the farm GHG footprint, given in tonnes CO_2-equivalent (t CO_2e/ha/yr).

To calculate carbon sequestration levels, it is first necessary to estimate growth rates for different species of trees on the farm. The Forestry Commission yield class tool, "Ecological Site Classification" (Forestry Commission, 2001) was used to estimate tree growth, based on soil types, altitude and climate. This report includes modelled carbon sequestration for trees (woodland, plantation, parkland and isolated trees), hedges and soils, as described by the farmer.

There is some scientific uncertainty surrounding both published tree growth rates (especially for mixed-species woodlands and plantations), and IPCC expansion factors used to calculate total biomass. Uncertainty is included throughout the sequestration calculations in the same way as for the footprint calculations, by presenting minimum, mid-range, and maximum estimates of sequestration.

A-2.1 Woodland and tree plantations

Carbon may be sequestered in woodland and plantations within living trees (above- and below-ground biomass), deadwood, litter, and soil. Following IPCC (2006), this method calculates the biomass increment in trees according to their species or species mix, age, and planting density for each separate woodland parcel, growing at the average yield class estimated for the farm. Annual increases in deadwood and litter are calculated for newly-planted woodlands, but are considered by IPCC (2006; Tier 1 calculations) to be in equilibrium in older woodlands (i.e. no net gain of deadwood or litter). Soil carbon is also considered to be in equilibrium using Tier 1 calculations. The carbon content and any associated changes in below-ground biomass are calculated for any wood harvested (e.g. firewood). Finally, the net balance between these woodland components is calculated to give an estimate of annual woodland carbon sequestration.

A-2.2 Isolated trees

'Isolated' trees are defined as trees in parkland, emergent trees in hedgerows, and any other trees not found in woodland. Free-grown trees grow more quickly than densely-planted trees, so each tree is modelled individually. Isolated broadleaves are modelled as oaks (Jobling and Pearce, 1977), following IPCC (2006) equations for above- and below-ground biomass. The carbon content of any harvested wood is subtracted from the carbon storage total.

A-2.3 Hedges

Estimates of growth or biomass for hedgerows are currently unavailable. This report calculates the total area and height of hedges, using farmers' mapping of length and width. Where hedges are flailed in the sample year, they are considered to be flailed to a standard height and width, therefore their carbon increment is considered to be in equilibrium for that year. Hedges not flailed within the sample year are modelled as an equivalent area of established short-rotation poplar coppice, including below-ground biomass (Laureysens *et al*., 2003), giving an estimated mid-range sequestration rate of 6.37 t C/ha/yr (minimum to maximum range of 2.20 to 11.40 t C/ha/yr).

A-2.4 Ungrazed peat wetlands

Areas of ungrazed peat wetland are modelled using sequestration rates from Watson *et al*. (2000), giving an estimated mid-range sequestration rate of 0.04 t C/ha/yr (minimum to maximum range of 0.02 to 0.05 t C/ha/yr). Ungrazed peat wetlands are excluded from managed organic soils N_2O calculations; grazed peat wetlands are included in calculations for permanent grassland (below).

A-2.5 Grassland and soils under grassland

Modelling carbon exchanges in grasslands is complex, and involves either measuring very small and spatially variable soil C stock changes over decades (Hungate *et al*., 1996; Conant *et al*., 2001), or full carbon accounting by measuring the considerable C fluxes in and out of the grass and soil system, which also vary over space and time (Jones and Donnelly, 2004).

To determine the likely range of sequestration that might be possible in Welsh farmed grasslands, a review of grassland carbon sequestration studies was undertaken by Taylor *et al*. (2010). The report concluded that many studies were not relevant to Welsh grasslands, largely due to differences in experimental design, cropping and management scenarios, geography and climate, or system boundaries of the study; further details are given in Taylor *et al*. (2010). Five studies were considered suitable for referencing in Welsh carbon sequestration calculations (Fitter *et al*., 1997; Vleeshouwers and Verhagen, 2002; Soussana *et al*., 2004; Janssens *et al*., 2005; Dawson and Smith, 2007). Studies of sequestration in peat soils under permanent grassland are uncommon, and available studies considered grassland that had been drained more recently (i.e. since 1990; Freibauer *et al*., 2004; DEFRA, 2009) than the sample farms in this report. Light grazing may not affect carbon sequestration in blanket peat habitats (Garnett *et al*., 2000). Given the lack of concrete evidence on the effect of organic (peat and peat-derived) soils under different grassland conditions on emissions, these soils are incorporated into the following summary of study findings across a range of soil types.

Average carbon sequestration across the five selected studies gave a mid-range of 0.45 t C/ha/yr; published estimates varies from a net loss of 2.31 t C/ha/yr (from drained organic soils; Soussana *et al*., 2004) to a net carbon gain of 2.9 t C/ha/yr (in species-poor peaty gley grassland; Fitter *et al*., 1997). High variation in estimated carbon balance was observed within these five studies, for example due to different methods, grassland types, management regimes, and period of observation, and there is still considerable uncertainty surrounding carbon sequestration rates under grasslands. Additionally, the scientific literature is unclear whether sequestration rates change over time to reach equilibrium after a period as short as ten years (Janzen *et al*., 1998), or whether sequestration may be unlimited (Six *et al*., 2002). The carbon sequestration calculation method used in this report drew values from UK permanent grazed grassland, grazed peatland and cropland in Janssens *et al*. (2005), giving a mid-range estimate of 0.24 t C/ha/yr (minimum to maximum range, 0.04 to 0.44 t C/ha/yr), and representing a conservative estimate of typical Welsh sequestration rates. These rates are lower than those quoted in the other four studies, but given the current level of uncertainty in sequestration rates across different situations and over time, a conservative approach is advisable.

10 APPENDIX B – ADJUSTED BASELINE DATA FROM TAFT ET AL. (2015) REPORT

Table B1. Farm characteristics (DEFRA main farm typology, and size category), and PAS 2050-compliant carbon footprints adjusted from baseline report by Taft *et al.* (2015) for the farms, expressed as a footprint (kg CO_2e) per ha, and per kg product.

Farm	Farm type	Farm size	Carbon footprint, kg CO_2e		
			ha	kg (LW) lamb	kg milk
1	LFA cattle & sheep	> 200 ha	2,817.1	13.34	-
4	Dairy	50-199.9 ha	16,749.9	-	1.07
5	LFA cattle & sheep	> 200 ha	8,206.2	11.97	-
6	Dairy	50-199.9 ha	20,283.9	-	1.40
7	LFA cattle & sheep	> 200 ha	2,385.1	14.29	-
8	LFA cattle & sheep	50-199.9 ha	9,154.7	-	-
9	LFA cattle & sheep	50-199.9 ha	7,841.1	15.28	-
10	LFA cattle & sheep	> 200 ha	4,262.4	10.01	-
12	Dairy	50-199.9 ha	11,247.3	7.13	1.23
13	LFA cattle & sheep	50-199.9 ha	6,551.3	17.59	-
14	LFA cattle & sheep	50-199.9 ha	5,487.8	20.30	-
15	Dairy	> 200 ha	11,711.3	-	1.03
17	Dairy	50-199.9 ha	17,208.1	-	1.25
19	LFA cattle & sheep	50-199.9 ha	12,002.5	28.98	-
20	Dairy	50-199.9 ha	17,963.7	8.15	1.24
Mean*	Dairy		15,860.7	7.64	1.20
	LFA cattle & sheep		6,523.1	16.47	-
		50-199.9 ha	12,449.0	16.24	1.24
		> 200 ha	5.876.4	12.40	1.03
	All farms		10,258.2	14.70	1.20

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

Table B2. Contribution of emissions' sources to farm footprints (per ha) and adjusted from baseline report by Taft *et al.* (2015) for the farms. Emissions shown are key examples from farm inputs (fuel and transport, energy use, agrochemicals (fertilisers and pesticides), feed concentrates, and bought in stock), direct N_2O emissions (from soil management, peaty soils, and manure handling systems), indirect N_2O emissions (from soils and manure management), methane (CH_4) emissions (from livestock enteric gut fermentation and manure sources), and CO_2 emission as a result of lime application.

Farm		Footprint per ha (kg CO_2e)	Percentage contribution to the farm C-footprint per ha												
									N_2O						
			All inputs	(fuel and transport)	(electricity)	(agrochem. incl. fert. N)	(feed concs)	(bought-in stock)	soil mgt.	organic soil	manure mgt.	Indirect (soils)	Indirect (manure)	CH_4	Lime
1		2,817	15.3	2.0	0.01	3.8	0.9	8.4	19.3	-	1.1	7.2	1.0	55.2	0.5
4		16,750	36.2	8.9	4.36	8.7	13.8	-	13.8	0.02	1.1	3.4	0.9	43.0	1.2
5		8,206	31.8	1.1	0.05	0.8	0.7	24.5	15.2	0.03	0.8	6.0	0.4	45.6	-
6		20,284	45.4	3.8	1.08	7.8	10.7	21.8	12.2	-	1.4	3.1	1.0	35.7	0.9
7		2,385	14.7	2.1	0.01	7.2	4.4	0.6	19.9	0.34	2.7	6.9	0.8	53.4	1.1
8		9,155	25.8	3.9	0.11	5.0	6.6	9.8	15.9	0.08	1.0	5.2	0.9	51.0	-
9		7,841	24.7	1.7	0.00	12.0	6.0	4.8	19.6	-	2.1	5.9	1.2	45.3	1.3
10		4,262	6.5	1.8	0.00	2.7	1.7	-	18.8	-	1.3	6.9	1.1	64.2	0.6
12		11,247	25.1	1.6	1.61	8.6	10.9	1.9	15.6	-	2.1	4.4	1.0	49.9	1.4
13		6,551	20.1	2.8	0.01	8.4	0.8	7.8	17.9	-	1.4	5.5	0.3	53.3	0.8
14		5,488	30.2	2.2	0.00	5.0	1.4	21.4	15.7	1.06	1.6	5.6	0.8	44.1	0.6
15		11,711	41.3	6.7	0.00	5.0	28.6	-	10.4	-	2.0	2.8	1.3	42.1	-
17		17,208	41.1	5.7	0.02	5.2	13.3	16.5	14.1	0.02	2.4	4.6	1.5	36.2	-
19		12,002	25.1	2.2	0.04	13.4	7.6	1.5	22.9	-	3.5	7.4	1.3	40.4	-
20		17,964	30.0	3.1	0.02	7.3	10.7	8.5	15.6	0.19	2.9	4.9	1.3	44.1	1.0
Mean*	Dairy		36.5	5.0	1.18	7.1	14.7	12.2	13.6	0.08	2.0	3.9	1.2	41.8	1.1
	LFA		21.2	2.3	0.03	5.8	3.0	10.6	18.2	0.38	1.7	6.3	0.8	50.9	0.7
	50-199.9 ha		31.0	3.8	0.81	7.7	8.4	11.2	16.0	0.27	1.9	4.9	1.0	44.2	1.0
	> 200 ha		21.9	2.8	0.01	3.9	7.3	11.2	16.7	0.18	1.6	6.0	0.9	52.1	0.7
	All farms		27.7	3.4	0.52	6.4	8.0	11.2	16.2	0.25	1.8	5.3	1.0	47.0	0.9

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

Table B3. Estimated annual carbon sequestration (t CO_2e/yr) in different elements of the farm ecosystem taken from baseline report by Taft *et al.* (2015) for the farms. Negative values indicate carbon loss from that source, e.g. through felling of trees.

Farm	Sequestration per ha (kg CO_2e)	Percentage contribution to carbon sequestration per ha				
		woodland (net)	isolated trees	hedges	grassland (soils)	peat wetlands
1	1,648	25.3	21.1	2.2	51.4	-
4	1,517	34.4	3.1	15.7	46.6	0.3
5	1,029	10.6	0.8	3.8	84.8	-
6	1,074	-	17.4	-	82.6	-
7	920	-	2.6	7.4	89.0	1.0
8	1,275	23.1	10.9	2.8	62.5	0.6
9	853	-	0.5	-	99.5	-
10	1,090	14.2	1.9	4.9	79.0	0.0
12	866	0.9	7.8	6.6	84.7	-
13	1,150	-	0.8	25.6	73.6	0.1
14	923	12.2	2.4	6.0	77.3	2.2
15	521	-	7.7	-	92.3	-
17	907	1.3	1.6	2.5	94.1	0.5
19	867	-4.7	1.3	1.9	101.5	-
20	875	5.4	5.0	0.8	86.8	2.0
Mean*						
Dairy	945	10.5	6.2	6.4	83.8	0.9
LFA	1,113	13.4	5.2	6.8	77.4	0.8
50–199.9 ha	1,031	10.4	5.1	7.7	80.9	0.9
> 200 ha	1,042	16.7	6.8	4.6	79.3	0.5
All farms	1,034	12.3	5.7	6.7	80.4	0.8

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

Table B4. Farm nutrient footprints for the baseline results of the farms used in the report by Taft *et al.* (2015), expressed as footprints (kg N or P per ha per year).

Farm	Farm type	Farm size	Nutrient Footprints	
			Nitrogen	Phosphorus
			kg N/ha/yr	Kg P/ha/yr
1	LFA cattle & sheep	> 200 ha	0.154	0.068
4	Dairy	50-199.9 ha	0.179	0.012
5	LFA cattle & sheep	> 200 ha	0.033	0.009
6	Dairy	50-199.9 ha	0.155	0.005
7	LFA cattle & sheep	> 200 ha	0.347	0.100
8	LFA cattle & sheep	50-199.9 ha	0.282	0.056
9	LFA cattle & sheep	50-199.9 ha	0.486	0.144
10	LFA cattle & sheep	> 200 ha	0.020	0.003
12	Dairy	50-199.9 ha	0.039	0.008
13	LFA cattle & sheep	50-199.9 ha	0.464	0.076
14	LFA cattle & sheep	50-199.9 ha	0.252	0.071
15	Dairy	> 200 ha	0.041	0.009
17	Dairy	50-199.9 ha	0.166	0.028
19	LFA cattle & sheep	50-199.9 ha	1.525	0.026
20	Dairy	50-199.9 ha	0.393	0.058
Mean*	Dairy		0.208	0.038
	LFA cattle & sheep		0.385	0.051
		50-199.9 ha	0.394	0.048
		> 200 ha	0.119	0.038
	All farms		0.302	0.045

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

Table B5. Ammonia footprints expressed as kg of NH_3, and eutrophication (PO_4) and acidification (SO_2) impacts for the baseline results of the farms used in the report by Taft *et al.* (2015).

Farm	Farm type	Ammonia ($kg\ NH_3$)	Eutrophication ($kg\ PO_4$)	Acidification ($kg\ SO_2$)
1	LFA cattle & sheep	0.13	0.71	0.25
4	Dairy	0.02	0.09	0.04
5	LFA cattle & sheep	0.07	0.48	0.14
6	Dairy	0.02	0.08	0.04
7	LFA cattle & sheep	0.08	0.66	0.17
8	LFA cattle & sheep	0.10	1.03	0.20
8	LFA cattle & sheep	0.11	0.55	0.23
9	Dairy	0.08	0.51	0.15
10	LFA cattle & sheep	0.06	0.33	0.11
12	Dairy	0.12	0.73	0.24
13	LFA cattle & sheep	0.08	0.70	0.17
14	LFA cattle & sheep	0.01	0.03	0.01
15	Dairy	0.01	0.05	0.02
17	Dairy	0.26	1.32	0.54
19	LFA cattle & sheep	0.06	0.54	0.13
20	Dairy	0.13	0.71	0.25
Mean*	Dairy	0.041	0.239	0.082
	LFA cattle & sheep	0.116	0.766	0.234
	50-199.9 ha	0.084	0.542	0.172
	> 200 ha	0.074	0.477	0.147
	All farms	0.081	0.520	0.163

* The results from farm 9 (underlined) are excluded from the mean carbon footprint results for the farms as it changed farming practice between baseline results (LFA cattle and sheep) in 2014 and re-visited results (dairy) in 2016. Farm 9 results are discussed separately in Section 5.3.4.

JULY 2015

GLASTIR MONITORING & EVALUATION PROGRAMME

FINAL REPORT – Annex 8B

Evaluation of the potential efficacy of Glastir Efficiency Scheme for reducing carbon emissions across the Welsh livestock sector

Helen Taft, Paul Cross and Dave Chadwick

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Further copies of this report are available from: GMEP Office, Centre for Ecology & Hydrology, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW.

Table of contents

1 EXECUTIVE SUMMARY

Introduction

This project evaluated the role of the Glastir Efficiency Scheme (GES) in reducing greenhouse gas (GHG, or 'carbon') emissions in the Welsh agricultural sector. The primary aims of the project were to:

1. Provide an average baseline carbon footprint for a representative cross-section of GES-participating farms;
2. Evaluate the potential within the Welsh agricultural sector for reducing GHG emissions through application of GES-funded technologies; and
3. Identify key aspects of farm footprints which may facilitate or inhibit the success of the Glastir Efficiency Scheme.

Of the 157 farms approved for GES grant funding, twenty farms were selected for carbon footprinting. In proportion to the number of Welsh farms in each farm type and size category, farms were randomly selected from the dairy and LFA cattle and sheep sectors, within the size categories 50 to 199.9 ha, and > 200 ha of land.

Methods

A modified version of the original carbon footprint model developed at Bangor University was used to estimate farm emissions from livestock farms. The model used farm-specific data and aimed to comply with PAS 2050:2011 regulations. In addition to calculating PAS-compliant emissions footprints, the model was used to estimate the potential offset of emissions by carbon sequestration in soils, woodlands, individual trees and hedgerows. The GHG emissions footprint and sequestration estimate for each farm was reported for one calendar year, using two types of functional unit comparable across enterprises: GHG emissions per unit product (e.g. per kg lamb liveweight), and GHG emissions per hectare of farmland. All emissions have been converted to carbon-dioxide equivalents and reported in terms of CO_2e.

The twenty farms were contacted by project officers and interviewed face to face. A questionnaire was used as a script for obtaining the necessary information. Farmers reported information representing one 'typical' business year within the period 2011 to 2013.

The model used in this study follows the methods described in IPCC and PAS 2050:2011 guidelines, requiring the use of standard, internationally-accepted emission factors (EFs) and values for calculating a carbon footprint. Many of these EFs and values are averaged over large geographic areas (Tier 1 method) and may not reflect emissions at a more local scale. The modelling work uses some locally specific (Tier 2 method) values, where this is permitted.

Estimation of potential carbon offset required data on sequestration rates in soils under managed grassland, peatlands, woodlands, isolated trees and hedgerows. Obtaining reliable measures of C sequestration for these elements is problematic, as the values reported in the scientific literature are incomplete, and in some cases, inconsistent. Uncertainty can be represented by modelling a range of sequestration rates. This report drew on values from UK permanent grazed grassland, grazed peatland and cropland from Janssens *et al*. (2005), giving a mid-range estimate of 0.24 t C/ha/yr (minimum to maximum range, 0.04 to 0.44 t C/ha/yr). Carbon sequestered in woodlands and isolated trees was estimated following standard IPCC (2006) methods, which calculate the biomass increment in trees. Estimates of hedgerow biomass and growth are lacking in the literature; instead, farmers' estimates of hedgerow volume, and an average growth rate for short-rotation poplar, were combined to model hedgerow biomass.

Attempts have been made to represent the range of possible emissions from each element of the farm footprint, using minimum and maximum values from the scientific literature. Despite this, all values provided in this report are estimates and are subject to sometimes significant levels of uncertainty.

Results

The average estimated PAS-compliant footprint per hectare across all farms was 10,236.0 kg CO_2/ha/yr, and ranged from 2,385.1 kg CO_2/ha/yr to 18,987.2 kg CO_2e/ha/yr. The average footprint per hectare on dairy farms (14,032.9 kg CO_2e/ha/yr) was almost double that of LFA cattle and sheep farms (7,704.8 kg CO_2/ha/yr). Smaller farms (11,654.3 kg CO_2e/ha/yr) averaged a higher footprint per ha of land than larger farms (7,602.0 kg CO_2/ha/yr).

The footprint of lamb for slaughter varied from 7.1 kg CO_2e/kg LW to 29.0 kg CO_2e/kg LW, and those for wool ranged from 2.8 kg CO_2e/kg to 21.3 kg CO_2e/kg. Dairy farms had a lower average footprint per kg lamb and wool than LFA cattle and sheep farms. Footprints for milk production per kg product ranged from 1.0 kg CO_2e/kg for farms 50 to 199.9 ha in size to 2.2 kg CO_2e/kg for farms > 200 ha in size.

The largest proportion of total emissions from all farms came from methane (CH_4) accounting for, on average 46.7% of emissions per ha. Methane emission rates correspond to the number of ruminant livestock, and were primarily a function of ruminant livestock enteric (gut) fermentation. Nitrous oxide (N_2O) accounted for, on average 24.5% of emissions. This was largely from direct emissions (from soil management, peaty soils, and manure handling) with the remainder coming from indirect emissions (N deposition, leaching and runoff on soils, and volatilisation from stored manure). Emissions from inputs averaged 27.6% of emissions per ha and were dominated by mineral N fertiliser, feed concentrates, and bought-in stock. The CO_2 footprint from liming was small on all farms, ranging from 0.5 kg CO_2/ha/yr to 3.9 kg CO_2/ha/yr.

Very few statistically significant associations were found between footprints of livestock and farm size, stock numbers in winter and summer, or peat soils. Farm types could not be compared statistically due to small farm sample sizes within each typology.

Carbon sequestration ranged from 520.7 to 1,648.4 kg CO_2/ha/yr (averaging 1,026.2 kg CO_2/ha/yr). Most sequestration (average 80.2%, range 46.6-100%) was in the form of carbon storage in grassland soils. Woodland contributed on average 13.2% (ranging from a net carbon loss of 4.7% to a net carbon gain of 34.4% of whole farm sequestration). Isolated trees sequestered on average 4.8% (range, 0.5% to 21.1%), and hedges 6.6% (range, 0.4 to 25.6%). Farm type and size had a negligible effect on total sequestration per hectare.

The average carbon balance (total footprint minus sequestration) of the twenty farms was 9,209.7 kg CO_2e/ha/yr, varying from 1,102.6 to 17,913.2 kg CO_2e/ha/yr. Sequestration accounted for an average of 15.1% of the emissions footprint, but this varied widely between 4.4% and 59.9% of farm emissions. None of the farms sequestered more carbon per hectare than their total footprint.

Recommendations

On the basis of this study's findings, we recommend the following:

- Carbon footprinting to be repeated on the current sample of farms, at an appropriate point in time after construction and use of GES-funded capital items. This will allow a comparison between baseline emissions and emissions post-implementation, acting as an impact indicator of the scheme.
- Prioritisation of further grant allocation to the dairy sector, subject to feasibility.
- Prioritisation of further grant allocation in the SME category.
- Avoid allocating soil aeration grants to farms where aeration would be conducted on peat soils.
- Assessment of the impact of GES on ammonia volatilisation, as this is likely to be an important environmental and human health benefit of implementing some SME technologies.
- The statistical trends in data illustrated in this report should be interpreted with caution, as the number of farms sampled within each category were too small to draw any robust conclusions from.

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1 INTRODUCTION

1.1 Background to Glastir Efficiency Scheme

1.1.1 *Background to the Glastir scheme*

Glastir Efficiency Scheme (GES, formerly known as ACRES, the Agricultural Carbon Reduction and Efficiency Scheme) is a component of a wider Welsh Government agri-environment initiative known as Glastir. The Glastir scheme was set up as part of the Wales Rural Development Plan 2007-2013, as a means of streamlining the four existing Welsh Axis 2 agri-environment schemes (Tir Cynnal, Tir Gofal, Tir Mynydd, and the Organic Farming Scheme), into a single whole-farm sustainable land management initiative (WG, 2014a). The development of a single scheme followed adoption of the European CAP Health Check reforms (Rose, 2011), with a resulting shift in emphasis from agri-environment schemes driven by production, to one driven by the need to address wider environmental and social issues (climate change mitigation and adaptation; management of water quality and quantity; soil quality enhancement; facilitating recreational access; and strengthening social capital; Reed *et al*., 2014). Under the Glastir scheme, these wider issues are addressed by treating environmental benefits contributed by farmers as provision of environmental and social goods and services (known as Ecosystem Services), which are not supplied through ordinary market mechanisms. Such goods and services are paid for through the scheme by the Welsh Government, on behalf of society (Wynne-Jones *et al*., 2013). This integrative, market-based approach aims to deliver a wider range of environmental goods and services to society, in the most efficient way possible (Reed *et al*., 2014), whilst simultaneously improving farmers' connections to markets and strengthening rural development measures under the Welsh Rural Development Plan (WG, 2014a) and Axis 2 of the Common Agriculture Policy (CAP) Rural Development Pillar (Rose, 2011).

1.1.1.1 Objectives of the Glastir scheme

The stated objectives of Glastir are (Rose, 2011):

- To provide balance between the need to produce food and protect the environment;
- To be accessible to all;
- To support biodiversity, climate change and water outputs; and
- To spread money for implementing agri-environment work more widely among farmers.

1.1.1.2 Glastir scheme structure

Glastir is a five-year, whole farm, sustainable land management scheme available to farmers and land managers across Wales. The initiative consists of five elements: Glastir Entry, Glastir Commons, Glastir Advanced, Glastir Efficiency Grants, and Glastir Woodland Creation and Management (WG, 2014a). A summary of each component is given here; further details are provided in Rose (2011) and WG (2014a).

<u>Glastir Entry (All-Wales Element, AWE)</u>

Glastir Entry is the foundation level agri-environment scheme, open to all farmers in Wales, who have full management control of more than three hectares of land for the full term of the five-year contract. Participation in the Entry level is required for eligibility to participate in all other scheme elements, with the exception of the Common Land and Woodland Creation elements. It comprises three main components: cross-compliance, the Whole Farm Code (WFC), and management options.

Cross-compliance constitutes a set of compulsory requirements that apply to all agricultural land on the farm holding. Land managers must meet standards of Good

Agricultural and Environmental Condition (GAEC), relating to the protection of soil, habitats and landscape features. Cross-compliance also requires farmers to meet a range of Statutory Management Requirements (SMRs) concerning the environment, public and plant health, animal health and welfare, and livestock identification and tracing.
Adherence to the WFC on all land included in the contract, is a further compulsory element of Glastir Entry. The WFC consists of a set of standards of good environmental practice, relating to slurry spreading, manure and silage storage, rock extraction and vegetation burning.
Regarding management options, farmers are required to select individual options from a list or choose from a package of options which deliver the greatest environmental benefits within a particular region. The whole farm entry-level component is based on a points systems, where a combination of compliance with compulsory requirements, and customised choices of optional management activities, allow farmers to build up enough points to exceed the minimum eligibility threshold.

Further to Glastir Entry, four higher level elements of the scheme are currently available:

Glastir Advanced

Glastir Advanced (previously known as the Targeted Element) was designed as an attempt to overcome reported shortcomings of previous higher-level agri-environment schemes, which were thought to have been too disparate and poorly focused to deliver significant environmental benefits (WG, 2014a). The current Advanced scheme allows farms to participate according to their potential ability to deliver environmental benefits in the key areas of soil carbon management, water quality, water quantity management, biodiversity, the historic environment, and improved access. Priority is given to applicants with the highest resulting score, based on the potential to deliver the greatest environmental benefit from their land.

Glastir Commons

The Glastir Commons scheme (previously named the Common Land element), was designed for farmers with Common Land rights, who are also members of a Grazing/Commoners' Association. Payments are made for adhering to either a closed grazing period over three months of the winter period (1st November to 31st March), or managing sward height throughout the year by varying stocking densities. The Glastir Commons element aims to encourage stewardship of peatland carbon and water storage, important functions of Welsh Common Land.

Glastir Efficiency Scheme

Previously known as the Agricultural Carbon Reduction and Efficiency Scheme (ACRES), the Glastir Efficiency Scheme (GES) provides one-off capital grants to farmers and land managers to improve resource use efficiency and reduce the effects of agriculture on the environment, including greenhouse gas emissions. Originally, the scheme prioritised renewable energy generation outcomes, but this aspect was removed after being superseded by the UK-wide Feed in Tariffs (April 2010) and Renewable Heat Incentives (July 2013). At present, grants contributing to 40-50% of costs are available for a specific range of capital works relating to reducing on-farm energy use (Energy Efficiency), management of animal excreta and associated waste (Slurry/ Manure Efficiency), and minimising waste water generation (Water Efficiency). In particular, this aspect of Glastir is aimed at encouraging dairy farmers to engage with agri-environment schemes for the first time.

Glastir Woodland Creation and Management

Originally functioning as a stand-alone initiative, the Glastir Woodland Creation and Management Scheme was integrated into the Glastir Scheme in January 2013. It was developed in response to the Climate Change and Land Use Report (Glastir Independent Review Group, 2011). This element of Glastir provides financial support to both farmers and non-farmers for managing existing continuous woodlands larger than 0.5 ha in size. Capital and multi-annual payments are provided in support of managing existing woodland and creation of new woodland, including income foregone as a result of change in land use. Priority objectives are: managing soils to help conserve carbon stocks and reduce soil erosion; improving water quality; managing flood risks; conserving and enhancing wildlife and biodiversity; managing and protecting landscapes and the historic environment; and providing new opportunities to improve access and understanding of the countryside.

1.2 Background to carbon footprinting

The carbon footprint (CF) concept originated from the idea that a certain area of land is required to assimilate the CO_2 produced during the lifetime of a person, or total global population (known as the global 'ecological footprint' concept; after Wackernagel and Rees, 1996). The CF idea has further developed, independently of ecological footprinting, and has become known as a smaller-scale quantitative indicator of climate change (Pandey and Agrawal, 2014). Present-day use of carbon footprinting is designed for the calculation of total greenhouse gas (GHG) emissions from a system, using a standardised unit (CO_2e, or carbon dioxide equivalents) to report the relative heating effect of different GHGs and system components on the Earth's atmosphere. A carbon footprint may be defined as: *'The quantity of GHGs expressed in terms of CO_2e, emitted into the atmosphere by an individual, organisation, process, product or event from within a specified boundary'* (Pandey *et al*., 2011).

The scope of CF calculation includes a wide range of products, services, activities and processes, in both natural and semi-natural systems. This allows comparison of the potential of different systems for increasing GHGs emissions to, or absorbing emissions from, the atmosphere, including comparison of natural versus anthropogenic impacts on the environment. Additionally, it can facilitate management of emissions sources, and evaluate the potential of a range of mitigation options for reducing or offsetting emissions. To calculate a CF, estimates of GHGs emitted or embodied at each step of a product's, activity's, or individual's life cycle are determined, a process known as 'GHG accounting' (Pandey and Agrawal, 2014). While carbon footprinting has gained in popularity, no single standard methodology exists at present. Most calculation methods are based on guidelines provided under the GHG protocol of World Resource Institute (WRI), or the World Business Council on Sustainable Development (WBCSD) (WRI/WBCSD, 2004), including the international ISO 14064 guidelines (ISO 2006a; 2006b), and the recently revised UK PAS 2050 guidelines (BSI, 2011). Such methods are still evolving, with modified versions informed by developments in scientific understanding of emissions from different system components (Edwards-Jones *et al*., 2009). Due to differences in definition within each of the methods, footprints may not be directly comparable (Taylor *et al*., 2010). This work uses the PAS 2050 2011 guidelines, a known UK standard methodology, following the work of Edwards-Jones *et al*. (2009) and Taylor *et al*. (2010).

1.3 Carbon footprinting in food and agriculture

To calculate a CF, the following structured framework is typically suggested (WIR/WBCSD, 2004; Carbon Trust, 2007; BSI, 2011):

1. Selection of GHGs
2. Setting of boundaries

3. Collection of GHG emission data
4. Footprint calculation

1.3.1 *Selection of GHGs*

The selection of GHGs to be evaluated in a CF is contingent upon the particular guidelines associated with the product or system to be assessed. For example, when calculating the CF of beef cattle, methane (CH_4) emissions have to be considered because substantial quantities are generated via the process of enteric fermentation, the microbial decomposition of feed in the rumen (Desjardins *et al*., 2012). Additional important emissions result from manure storage and application to land (resulting in CH_4 and nitrous oxide (N_2O) emissions), and from the production of feed crops for the cattle (resulting in N_2O and CO_2 emissions; Desjardins *et al*., 2012). The PAS 2050 (2011) guidelines require reporting of all emissions that make a 'material difference' (i.e., more than 1%) of the footprint, and material emissions will differ between agricultural systems and products.

1.3.2 *Setting of boundaries*

The setting of system boundaries determines which activities will be included and which will be excluded from the assessment, and is dependent upon the objectives of the footprinting exercise, and the characteristics of the system being assessed. Footprinting requires definition of the systematic or economic boundary, the temporal boundary, and the spatial boundary of the entity under assessment. For a farming system, the system definition can include a number of levels of different complexities within the food chain (Edwards-Jones *et al*., 2009). System definition may include all activities from manufacture of inputs, through on-farm activities, as well as processing, retail, consumption and disposal of the product (the 'cradle-to-grave' approach); or it may only include activities to the point where the product leaves the farm (the 'cradle-to-gate' approach). The Carbon Trust (2007) has designed a three-tiered approach which defines what should be included in the boundary: Tier 1 includes direct (on-site) emissions; Tier 2 includes emissions embroiled in purchased energy and Tier 3 includes all indirect emissions not included in Tier 2, for example those produced by transport associated with the relevant activity. It is crucial to define the boundary to produce a reliable and accurate footprint (Matthews *et al*., 2008; Wiedmann and Minx, 2008; Pandey *et al*., 2011). It also determines whether a footprint is directly comparable to others, and which aspects of the food chain can be examined to identify potential mitigation of emissions.

1.3.3 *Collection of GHG emission data*

Collection of GHG emission data is usually performed by direct measurement, or by estimation using models, or emission factors (EFs, which combine information on the extent to which a particular activity takes place, with coefficients quantifying the emissions or removal per unit activity; IPCC, 2006). The PAS 2050 regulations recommend the use of the highest quality available data. In the UK, this largely follows methods used in the UK Greenhouse Gas Inventory, following IPCC guidelines (e.g. Webb, 2014). At the carbon footprinting level, this usually means using the 'empirical' approach, by collecting data directly from the farmer (and if relevant, other actors in the food chain) via a questionnaire. Details of inputs into the farm system, and of on-farm processes are acquired, for example electricity and fuel use, fertiliser type and quantities used, and agronomic management practices (Taylor *et al*., 2010). These details are combined with the relevant EFs and the resulting values aggregated to form the farm carbon footprint.

1.3.4 *Footprint calculation*

Owing to the quantity and complexity of data required to calculate a CF, it is common to use a modelling approach to incorporate data into the footprint. Two standard modelling approaches may be used. The first is based on the use of empirical data collected from individual farms, as described above. This method provides a footprint specific to that particular, identifiable farm system or supply chain, but may not be representative of the wider industry (Taylor *et al*., 2010). A representation of the wider industry (e.g. the agricultural sector) may be constructed by averaging empirically-derived footprints from a large enough sample of individual farms, which then may be used to provide a baseline estimate of emissions (including expected variability of emissions) across that industry (e.g. Jones *et al*., 2014). A second, less labour-intensive method of estimating multi-farm emissions involves modelling based on theoretical considerations of farming systems, rather than real-world data. Although this second approach may yield a reasonably accurate estimate of average emissions, often it does not provide information on the within-system variability (e.g. those created by different farm management practices, or different soil types, within a region; Del Prado *et al*., 2013). Consequently, general conclusions on best management or mitigation measures drawn from theoretical system-based models, may not be suitable for application to the individual farms within the averaged system. Instead, its strength lies in providing a framework for efficiently repeating and extending analysis of the system's behaviour, including the impact of any changes applied to the system.

1.4 Uncertainty, subjectivity and variability in carbon footprints

The CF of a product is usually reported as a single figure e.g. 1.7 kg CO_2e/kg product. Provision of a single precise value can be misleading, because of issues of variability, uncertainty, and subjectivity related to carbon footprinting methods. These issues can reduce the accuracy and precision of the final estimated figure (Taylor *et al*., 2010).

In an agricultural context, there may be significant biophysical differences between farms producing the same products, resulting in marked differences in the CF of the farm and product. For example, sheep farms can be divided into different categories of lowland, upland and hill farm systems, differentiated by harsher climates, poorer quality grazing and lower productivity with increasing altitude. Lowland sheep farms have been found to have significantly lower CFs than hill sheep farms, reflecting a number of contributing factors including more rapid mean lamb growth rates, a lower percentage of unmated ewes, a lower percentage of peat soils, and lower use of lime application to soils at lower altitudes (Jones *et al*., 2014). In addition to altitude, the underlying soil type can affect the CF, and may create significant regional differences, principally related to the increase in GHG emissions often observed from managed organic (peat-derived) soils when compared to managed mineral soils (Edwards-Jones *et al*., 2009).

Differences in farmers' management choices can also influence emissions, even under very similar farm biophysical conditions. Variability in farm footprints across the agricultural sector has been attributed to management approaches, for example on dairy farms by Yan *et al*. (2013), and on cattle farms by Desjardins *et al*. (2012). Careful management may even overcome disadvantages created by biophysical factors, for example, Jones *et al*. (2014) found that despite being disadvantaged by local conditions, the most productive Welsh hill farms had lower CFs than the mean CFs of both lowland and upland sheep farms. Management practices are a difficult feature to factor into CF calculation, but they provide a good baseline for which mitigation measures can be improved through better management.

Other uncertainties inherent in CFs relate to a lack of understanding over land-use changes. Direct and indirect land use changes can affect the CF of food products, for example, a smaller footprint may be observed from soybean grown on existing agricultural land in Europe, than from soybean grown on land cleared of forest in South America, depending whether or not the effects of land use change is taken into consideration (Dalgaard *et al*., 2014).

There are large uncertainties in the emission factors used in carbon footprinting (Colomb *et al*., 2013). Emission factors are reported in standard databases such as Ecoinvent and FAOSTAT (Swiss Centre for Life Cycle Inventories, 2014; FAO, 2014), and represent the average amount of GHGs emitted during a specific process, e.g. the amount of methane emitted from ruminants of different sizes. Different databases provide different emission factors, derived from studies using different system boundaries, data collection techniques, data definitions and processing methodologies. The choice of emissions factor database is a subjective process which can introduce variability into the process of carbon footprinting. Emission factors are derived from extensive literature, but such estimates still require refining and updating because they are the product of averages. For example, the widely used IPCC National GHG inventory guidelines provide default emission factors relating to a range of agricultural sources, such as from fertiliser production, soils, and ruminant livestock. Because IPCC EFs are typically averages across a climatic zone or for a particular situation, region-specific emission factors are necessary for reducing uncertainties in the carbon footprint calculation (Pandey and Agrawal, 2014). It should be noted that without these region-specific EFs, the applicability of IPCC default EFs to Welsh farms is uncertain, and it is likely that they are a further source of inaccuracy in farm footprint estimates.

Finally, it is important to recognise that in representing real-world data in the simplified form required for modelling, researchers conducting this analysis are required to make a number of assumptions. Clearly this is a subjective process, and should be borne in mind when examining any carbon footprint.

2 PROJECT AIMS AND OBJECTIVES

This work aimed to produce a detailed carbon footprint of 20 farms participating in the Glastir Efficiency Scheme. The resulting analysis should aid in assessing the potential effectiveness of the GES element of the Glastir scheme for reducing on-farm GHG emissions, and provide a baseline emissions scenario from participating farms prior to implementation of capital works showing a measurable effect. It should also help farmers to understand which aspects of farm management might be adjusted in order to reduce their overall farm carbon footprint.

2.1 Objectives

The key objectives of this project were:

1. Provision of a baseline estimate of whole-farm GHG emissions (‘carbon footprint’), for twenty farms participating in the Glastir Efficiency Scheme. The carbon footprint should include a comprehensive account of farm emissions from ‘cradle-to-gate’, including the following:
    a. Existing land-use GHG balance, addressing variation in vegetation and soils;
    b. Emissions from agricultural management, including soils, soil management, land use change, livestock, and fertiliser and manure management;
    c. Emissions from agricultural and processing operations (fuel and energy use);
    d. Indirect emissions from all inputs, including bought-in feeds and fertilisers;
    e. Carbon sequestered in soils and plant biomass.
2. Based on the carbon footprints, evaluation of the potential within the Welsh agricultural sector for reducing GHG emissions through application of GES-funded technologies.

3. Identification of key aspects of the farm footprints influencing potential opportunities for, and barriers to, success of the Efficiency Scheme.

3 METHODS

The livestock enterprise footprinting model used in this study utilises farm-specific data and aims to comply with PAS 2050:2011 regulations (BSI, 2011). It is a modified version of the original model developed at Bangor University between 2007 and 2010, and described in Edwards-Jones *et al*. (2009b). A description of the current Bangor modelling approach is outlined in the following sections; further details are available in Taylor *et al*. (2010) and Jones *et al*. (2014), and in Appendix A.

3.1 Defining the system boundary

This study uses the cradle-to-gate approach, and includes greenhouse gas (GHG) emissions resulting from the manufacture and distribution of farm inputs (e.g. animal feed or mineral fertilisers); on-farm energy use (fuels and electricity); emissions from livestock and their excreta; and emissions from soils related to their management (e.g. mineral and manure fertiliser application, lime application, and farming on peat-based soils). Emission estimates are reported for carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) – the three most important GHGs emitted as a result of agricultural activities (IPCC, 2007).
The temporal boundary used in this study is a period of one representative business year between 2011 and 2013. The spatial boundary of a farm footprint is defined by the amount of land managed by the farm business, which can vary over the course of the financial year, for example with a change in the amount of land rented, or common land utilised, in different months. This model incorporates the area of owned land, plus the area under common-land and rental agreements. Land which was rented for only a portion of the year is modelled as a proportion of its area (*N* ha multiplied by *x*/12 months), for example, if 10 ha were rented for 7 months, it has been modelled as adding (10 x (7/12)) ha to the farm area.
Farms often include non-productive land, such as hedges, woodland, or wetland, which may make up large areas of the farm. These areas, and areas of productive pasture, may both emit and store carbon (Castaldi *et al*., 2007; Chapuis-Lardy *et al*., 2007). This study uses data from published scientific literature to estimate the potential range of emissions, and carbon capture and storage (sequestration), that may occur in soils and woody vegetation on different areas of the farm.

3.1.1 *Functional units and allocation*

The GHG emission footprint ('carbon footprint') in this study is reported for one calendar year, using two functional units which may be compared between enterprises: GHG emissions per unit product (e.g. per litre milk or kg lamb liveweight (LW) at the farm gate), and GHG emissions per hectare of farmland. Both PAS 2050:2011, and most standard LCAs recommend reporting emissions per unit product, as it is the functional unit that reaches the customer. Reporting emissions per unit land area considers the farm as an integrated production system, and allows assessment of the potential environmental impact of agricultural operations on a given area of land (Edwards-Jones *et al*., 2009).
Many farms produce more than one output, for example a dairy farm may produce milk and dairy stock (calves, barrens, etc.), and a sheep enterprise may produce lamb, breeding stock, cull stock, and wool in a given year. In this study, emissions from a farm

enterprise are allocated between different outputs on an economic basis, as the percentage of total farm income earned from the relevant output.

In keeping with PAS 2050:2011 requirements, emissions of CO_2, N_2O and CH_4 are reported here in terms of global warming potential (GWP), which allows standardisation of all emissions in terms of their heating effect on the atmosphere, relative to CO_2, over a 100-year time frame (IPCC, 2007). This report uses a GWP of 296 for N_2O, and a GWP of 23 for CH_4. Standardised emissions estimates are reported in units of carbon dioxide equivalents, or CO_2e.

3.1.2 *Data sources and data uncertainty*

Emission factor estimates used in this work are drawn from recognised standard databases and documents, such as reports by the Intergovernmental Panel on Climate Change (IPCC) and Ecoinvent (e.g. IPCC, 2006; Swiss Centre for Life Cycle Inventories, 2014). To incorporate as much of the resulting uncertainty in emissions estimates as possible, this study calculated emissions using a maximum, mid-range, and minimum value for each component of the calculation, to present readers with a worst-case, average, and best-case scenario for each emissions total.

3.2 Data collection

Twenty farms were selected for footprinting, from the 152 farms in Wales which had been approved for Glastir Efficiency Scheme capital grants over the period 2012 to 2013. Sampling was stratified according to the number of grants received within each DEFRA robust farm type and size category (DEFRA, 2010), and farms selected randomly from within each group. This resulted in the selection of six dairy farms of 50 to 199.9 ha size, two dairy farms of > 200 ha size, seven less-favoured area (LFA) cattle and sheep farms of 50 to 199.9 ha size, and five LFA cattle and sheep farms of > 200 ha size.

Relevant farmers were contacted by project officers and interviewed face to face on-farm. A questionnaire was used as a script for obtaining the necessary information. Follow-up contact with participating farmers or discussion with project officers was undertaken where details or assumptions required clarification. Questionnaires were available in both English and Welsh.

3.2.1 *Data gaps for specific farms*

Some data were not available for some farms. In this case, national data sources, published UK reference examples, or standardised estimates were used in their place. For example, information was frequently missing on fuel use by external contractors whilst working on-farm (e.g. when hedge-flailing or harvesting crops). In this case, fuel use was estimated by combining relevant data from tables of machinery sizes, working rates and fuel efficiencies provided by a large UK-based machinery manufacturer. Where gap-filling of missing data has been used, the assumptions used are clearly stated in individual farm reports. Further examples of using standardised data for gap-filling are included in the model descriptions in the following sections.

4 RESULTS

Carbon footprints were compiled for 20 representative Welsh farms, comprising six dairy farms of 50 to 199.9 ha size, two dairy farms of > 200 ha size, seven less-favoured area (LFA) cattle and sheep farms of 50 to 199.9 ha size, and five LFA cattle and sheep farms of > 200 ha size (Table 1).

4.1 Basic patterns in PAS2050 compliant farm footprints

4.1.1 *Total farm emissions per hectare and per kilogramme of product*

The average estimated footprint per hectare across all farms was 10,236.0 kg CO_2e/ha/yr, and showed a wide range of variability, from 2,385.1 kg CO_2e/ha/yr on farm 7 (LFA cattle and sheep) to 18,987.2 kg CO_2e/ha/yr on farm 6 (dairy; Table 1). The average footprint per hectare on dairy farms was almost double that of LFA cattle and sheep farms (14,032.9 kg CO_2e/ha/yr compared to 7,704.8 kg CO_2e/ha/yr). Smaller farms had a higher average footprint per ha of land than larger farms (11,654.3 kg CO_2e/ha/yr and 7,602.0 kg CO_2e/ha/yr respectively).

A similar degree of variation was seen per kg of lamb and wool outputs. The lowest footprint per kg of lamb produced was from farm 12 (7.1 kg CO_2e/kg LW; dairy), while the highest was from farm 19 (29.0 kg CO_2e/kg LW; LFA cattle and sheep). Farm 5 produced the lowest wool footprint (2.8 kg CO_2e/kg), and farm 19 the highest (21.3 kg CO_2e/kg). Compared to the overall mean emission per kg lamb (14.9 kg CO_2e/kg LW) and wool (7.8 kg CO_2e/kg), dairy farms had a lower-than-average footprint (10.1 kg CO_2e/kg LW lamb, and 5.7 kg CO_2e/kg wool), and LFA cattle and sheep farms had a higher-than-average footprint (16.3 kg CO_2e/kg LW lamb, and 8.3 kg CO_2e/kg wool). The effect of farm size on product footprints followed the same pattern as emissions per hectare, with smaller farms having a larger emission than larger farms per kg lamb (16.1 and 13.4 kg CO_2e/kg LW lamb respectively), and per kg wool (9.0 and 6.1 kg CO_2e/kg respectively).

The variability in emissions from milk production per kg product was low, with footprints from all farms falling within the range of 1.0 to 2.2 kg CO_2e/kg milk. No dairy cattle were kept on LFA cattle and sheep farms, but farm size influenced milk footprint, with a larger footprint found on farms > 200 ha in size (1.6 kg CO_2e/kg compared with 1.3 kg CO_2e/kg on farms of 50 to 199.9 ha in size).

Table 1. Farm characteristics (DEFRA main farm typology, and size category), and PAS 2050-compliant carbon footprints for each farm, expressed as a footprint (kg CO_2e) per ha, and per kg product.

FARM	ROBUST FARM TYPE	FARM SIZE	Carbon footprint, kg CO_2e			
			ha	kg (LW) lamb	kg wool	kg milk
1	LFA cattle & sheep	> 200 ha	2,751.0	13.0	9.8	-
2	LFA cattle & sheep	> 200 ha	18,525.3	15.1	6.0	-
3	LFA cattle & sheep	50-199.9 ha	11,276.1	-	-	-
4	Dairy	50-199.9 ha	16,749.9	-	-	1.1
5	LFA cattle & sheep	> 200 ha	7,791.6	11.4	2.8	-
6	Dairy	50-199.9 ha	18,987.2	-	-	1.3
7	LFA cattle & sheep	> 200 ha	2,385.1	14.3	6.0	-
8	LFA cattle & sheep	50-199.9 ha	8,892.7	-	7.2	-
9	LFA cattle & sheep	50-199.9 ha	7,841.1	15.3	12.2	-
10	LFA cattle & sheep	> 200 ha	4,035.4	11.6	4.8	-
11	Dairy	50-199.9 ha	13,665.6	-	-	1.6
12	Dairy	50-199.9 ha	11,247.3	7.1	5.9	1.2
13	LFA cattle & sheep	50-199.9 ha	6,401.7	17.2	7.4	-
14	LFA cattle & sheep	50-199.9 ha	5,221.1	19.3	3.3	-
15	Dairy	> 200 ha	11,711.3	-	-	1.0
16	LFA cattle & sheep	50-199.9 ha	5,333.7	16.8	10.9	-
17	Dairy	50-199.9 ha	16,373.2	-	-	1.2
18	Dairy	> 200 ha	6,014.5	15.3	7.2	2.2
19	LFA cattle & sheep	50-199.9 ha	12,002.5	29.0	21.3	-
20	Dairy	50-199.9 ha	17,514.7	7.9	4.1	1.2
Mean	Dairy		14,032.9	10.1	5.7	1.4
	LFA cattle & sheep		7,704.8	16.3	8.3	-
		50-199.9 ha	11,654.3	16.1	9.0	1.3
		> 200 ha	7,602.0	13.4	6.1	1.6
	All farms		10,236.0	14.9	7.8	1.4

4.1.2 *Contribution of different farm emissions sources to the overall footprint per hectare*

Table 2 illustrates the relative importance of different components of farm emissions to the overall footprint per hectare of farmland; all percentage values described in the following section refer to the percentage of emissions per hectare. The largest proportion of total emissions from all farms came from methane (CH_4), accounting for 35.5 to 60.9% of emissions per ha (mean 46.7%). Nitrous oxide (N_2O) also accounted for a sizeable proportion of the footprint per ha, of between 16.6% and 34.4% (mean 24.5%). Emissions from inputs were important, averaging 27.6% of emissions per ha and making up more than one quarter of the total footprint on 13 of the farms, but this varied quite widely, from between 9.0% to 46.5% of annual emissions per ha. The CO_2 footprint resulting from lime application to land was small on all farms, from 0.5 kg CO_2e/ha (farm 1) to 3.9 kg CO_2e/ha (farm 3).

Methane emission rates correspond to the number of ruminant livestock (sheep, cattle and horses) in each age (size) class on each farm. The majority of methane on these 20 farms (averaging 92.5% of CH_4 emission per hectare) were emitted as a result of enteric (gut) fermentation, and the remainder from livestock excreta. Methane emissions were, on average, a more important component of the farm footprint on LFA cattle and sheep farms (48.6% of the footprint per hectare) than dairy farms (43.8% of the footprint per hectare), and more important on farms of 50 to 199.9 ha in size (49.9% of the footprint per hectare) than on farms with > 200 ha land (44.9% of the footprint per hectare).

Nitrous oxide soil emissions can be disaggregated into direct emissions (from soil management, proportion of organic soils, and manure management) and indirect emissions (from atmospheric N deposition, leaching and runoff on soils, and ammonia volatilisation from manures). Most emissions (71.7% to 81.8% of total N_2O per ha) were direct emissions. Direct soil management related N_2O emissions accounted for more than half of N_2O emissions per ha on all farms, and are related to the amount of nitrogen applied to the land as mineral or manure fertiliser. Manure management emissions relate to the total quantity of manure stored, the manure source (e.g. beef cattle, dairy cattle), and the type of storage system (e.g. manure heap, slurry lagoon). Organic soil N_2O emissions formed only a small percentage of total farm N_2O emissions per ha, although there was quite wide variability within this category (from 0% to 1.11% of the footprint per ha), which relates to the total area of peaty soils on each farm (varying from 0 ha to 78 ha). Most indirect emissions resulted from leaching, runoff or volatilisation of N from soils after mineral or manure application (68.4 to 94.3% of indirect N_2O emissions per ha), with the remainder volatilised from manure deposited in livestock housing and from stored manure. On average, N_2O emissions were a more important component of LFA cattle and sheep farms (26.9% of emissions per ha) than on dairy farms (21.2% of emissions per ha), but farm size category had only a very small effect on the importance of N_2O emissions (25.2% of emissions per ha on farms with 50 to 199.9 ha land, and 23.6% of emissions per ha on farms with > 200 ha land).

Emissions from inputs were dominated by mineral N fertiliser (21.2% of total inputs), feed concentrates (28.0% of total inputs), and bought-in stock (26.8% of total inputs), with the relative importance of these categories differing on each farm. Mineral N, feed concentrate and bought-in stock collectively accounted for more than three quarters of total input emissions per ha on all but one farm, where no mineral N or bought-in stock inputs were used (farm 10; LFA cattle and sheep). The importance of inputs as a percentage of the footprint per ha was much greater on dairy farms (averaging 33.8% of the farm footprint per ha, and comprising a greater use of electricity use and feed concentrates) than on LFA cattle and sheep farms (averaging 23.5%, with a relatively greater importance of bought-in stock and mineral fertiliser use). Farm size had a smaller effect on footprint per ha: smaller farms (50 to 199.9 ha in size) averaged 28.7% of the footprint per ha from inputs, while larger farms (> 200 ha in size) averaged 25.4% of the footprint per ha from inputs.

Table 2. Contribution of emissions' sources to farm footprints (per ha). Emissions shown are key examples from farm inputs (fuel and transport, energy use, agrochemicals (fertilisers and pesticides), feed concentrates, and bought in stock), direct N_2O emissions (from soil management, peaty soils, and manure handling systems), indirect N_2O emissions (from soils and manure management), methane (CH_4) emissions (from livestock enteric gut fermentation and manure sources), and CO_2 emission as a result of lime application.

Farm	Footprint per ha (kg CO_2e)	Percentage contribution to the farm C-footprint per ha												
								N_2O						
		All inputs	*(fuel and transport)*	*(electricity)*	*(agrochem. incl. fert. N)*	*(feed concs)*	*(bought-in stock)*	soil mgt.	organic soil	manure mgt.	Indirect (soils)	Indirect (manure)	CH_4	Lime
1	2,751.0	13.2	2.0	0.01	3.9	0.9	6.2	19.8	-	1.1	7.4	1.0	56.5	0.5
2	18,525.3	46.5	1.5	0.00	1.8	2.1	41.0	8.2	0.07	1.3	2.5	0.6	35.5	0.8
3	11,276.1	37.4	3.2	0.04	11.7	16.3	5.8	15.1	-	2.1	4.6	0.9	35.5	3.9
4	16,749.9	36.2	8.9	4.36	8.7	13.8	-	13.8	0.02	1.1	3.4	0.9	43.0	1.2
5	7,791.6	28.2	1.2	0.05	0.9	0.7	20.5	16.0	0.03	0.9	6.4	0.4	48.0	-
6	18,987.2	41.6	4.1	1.16	8.4	11.4	16.5	13.8	-	1.5	3.3	1.1	38.1	0.9
7	2,385.1	14.7	2.1	0.01	7.2	4.4	0.6	19.9	0.34	2.7	6.9	0.8	53.4	1.1
8	8,892.7	23.6	4.1	0.11	5.1	6.8	7.2	16.4	0.08	1.0	5.3	0.9	52.5	-
9	7,841.1	24.7	1.7	0.00	12.0	6.0	4.8	19.6	-	2.1	5.9	1.2	45.3	1.3
10	4,035.4	9.0	1.9	0.00	3.5	3.3	-	18.5	-	1.0	6.9	0.8	60.9	2.2
11	13,665.6	34.6	1.6	0.00	9.6	12.2	10.8	14.4	-	2.0	3.8	1.7	41.1	2.0
12	11,247.3	25.1	1.6	1.61	8.6	10.9	1.9	15.6	-	2.1	4.4	1.0	49.9	1.4
13	6,401.7	18.3	2.9	0.01	8.6	0.8	5.6	18.3	-	1.5	5.6	0.3	54.5	0.9
14	5,221.1	26.6	2.3	0.00	5.3	1.4	17.4	16.6	1.11	1.7	5.8	0.9	46.3	0.7
15	11,711.3	41.3	6.7	0.00	5.0	28.6	-	10.4	-	2.0	2.8	1.3	42.1	-
16	5,333.7	14.1	2.5	0.00	6.6	4.6	-	17.9	1.09	2.0	6.4	1.3	54.4	2.2
17	16,373.2	38.1	6.0	0.02	5.5	14.0	12.3	14.8	0.02	2.5	4.8	1.6	38.0	-
18	6,014.5	25.2	5.0	0.02	8.2	5.1	6.2	13.7	-	1.0	3.4	0.8	53.1	2.6
19	12,002.5	25.1	2.2	0.04	13.4	7.6	1.5	22.9	-	3.5	7.4	1.3	40.4	-
20	17,514.7	28.2	3.1	0.02	7.5	11.0	6.2	16.0	0.20	3.0	5.0	1.4	45.2	1.0
Mean	Dairy	33.8	4.6	0.89	7.7	13.4	6.7	13.9	0.08	1.9	3.9	1.2	43.8	1.1
	LFA	23.5	2.3	0.02	6.7	4.6	9.2	17.4	0.45	1.7	5.9	0.9	48.6	1.1
	50-199.9 ha	28.7	3.4	0.56	8.5	9.0	6.9	16.5	0.42	2.0	5.1	1.1	44.9	1.2
	> 200 ha	25.4	2.9	0.01	4.3	6.4	10.6	15.2	0.15	1.8	5.2	0.8	49.9	1.0
	All farms	27.6	3.2	0.37	7.1	8.1	8.2	16.0	0.33	1.8	5.1	1.0	46.7	1.1

4.2 Understanding variation

4.2.1 *Effect of farm type and size on emissions per kg product*

Individual comparisons were made between farm size (ha), and emissions per kg of product leaving the farm (lamb, wool, and milk) or kg of livestock remaining on-farm (sheep, beef cattle and dairy cattle). Comparisons with on-farm stock have been used here because they represent potential future product sales, so may be used as an indicator of potential future emissions per kg product, where no sales have been made in that year (e.g. only one farm sold beef in the sample year, but 14 farms had beef cattle stock on-farm). When all data were examined together, no relationships between farm size and emissions per kg were observed. Further comparisons were made by examining the two farm types (dairy, and LFA cattle and sheep) separately. Again, no relationships were revealed, except for a strong linear relationship between increasing farm size and decreasing lamb footprint (LFA cattle and sheep farms only; R^2 = 0.68, p < 0.01; Figure 1). However, it should be noted that the small sample sizes used in this study mean that any conclusions drawn from statistical analyses should be interpreted with caution (this is discussed in more detail in section 5.1.3.).

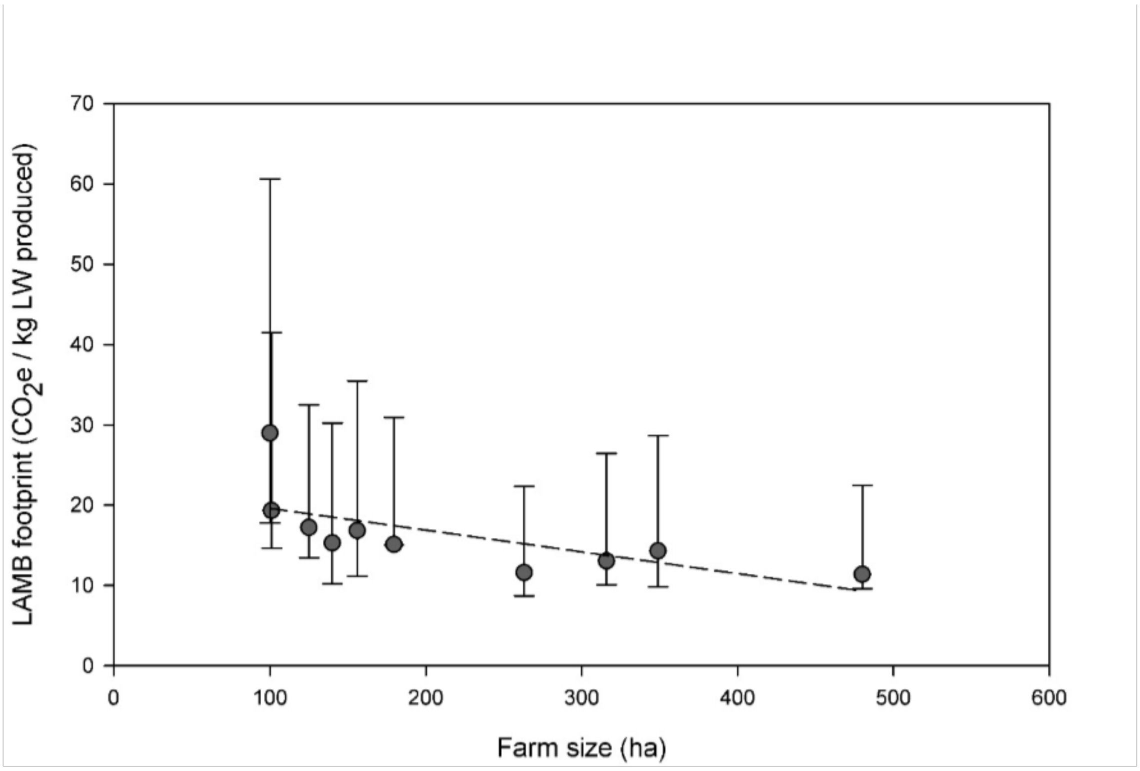

Figure 1. Carbon footprint of lamb (kg CO_2e/kg LW) against farm size (ha), on individual LFA cattle and sheep farms only (circles). Vertical bars show maximum and minimum values, representing the full range of uncertainty in GHG emissions estimates. Linear trend R^2 value = 0.68 (dashed line).

4.2.2 *Effect of stock numbers on emissions per kg product*

Individual comparisons were made between stocking numbers, and emissions per kg of product leaving the farm (lamb, wool, and milk) or kg of livestock remaining on-farm (sheep, beef cattle and dairy cattle). The effect of stocking numbers (sheep, beef cattle, dairy cattle, and all livestock) on emissions during summer (June) and winter (December) were examined separately.

When all farms were grouped together for analysis, summer and winter stocking numbers did not show a relationship with emissions per kg product or on-farm stock, except for a strong relationship between dairy cattle numbers, and the footprint per kg of beef cattle kept on-farm during the year (summer and winter stock, R^2 = 0.38, p < 0.01; Figure 2).

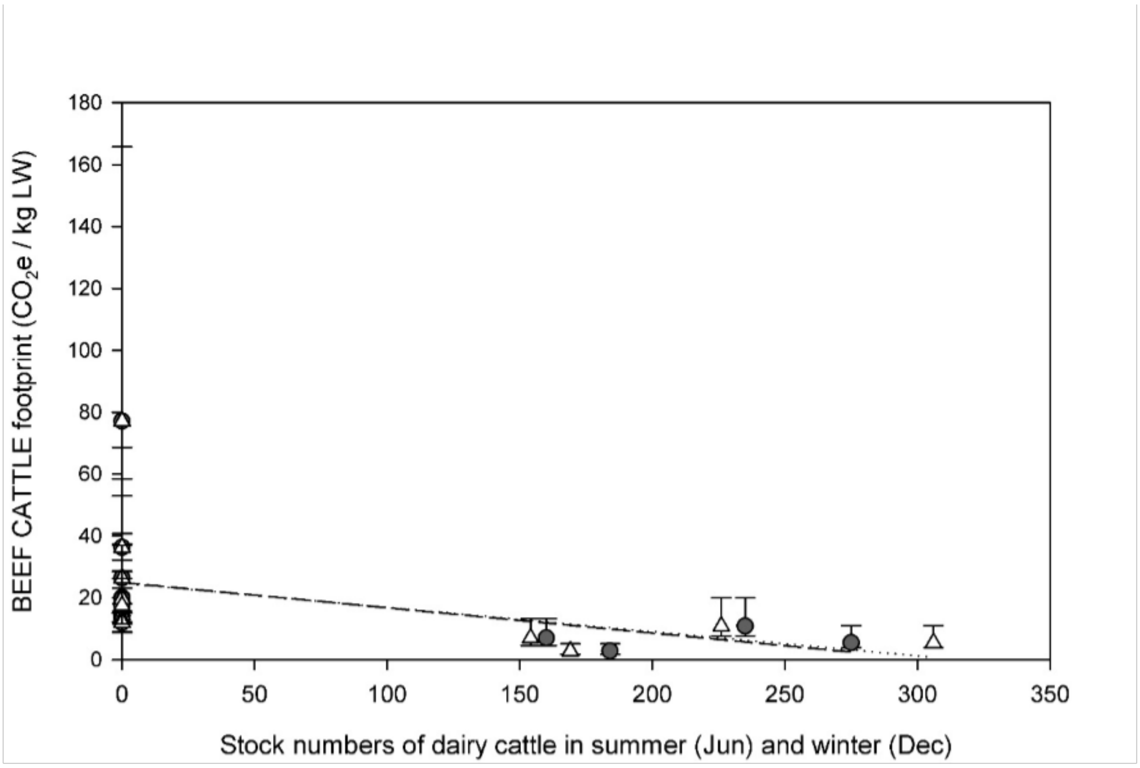

Figure 2. Carbon footprint of beef cattle (kg CO_2e/kg LW) against dairy cattle stock numbers, for individual farms in summer (circles) and winter (triangles). Vertical bars show maximum and minimum values, representing the full range of uncertainty in GHG emissions estimates. Linear trend R^2 values = 0.38 (summer, dashed line) and 0.38 (winter, dotted line).

When stock numbers on dairy and LFA cattle and sheep farms were compared with emissions per kg separately, no linear relationships were found for dairy farms, but a number of correlations were found on LFA cattle and sheep farms. Emissions per kg lamb on LFA cattle and sheep farms showed linear relationships with sheep stock numbers, although this was more pronounced in summer than winter (summer: R^2 = 0.41, p < 0.01; winter: R^2 = 0.31, p < 0.05; Figure 3). Additionally, emissions per kg lamb were correlated with total stock numbers (sheep, beef cattle and dairy cattle), again more strongly in summer than winter (summer: R^2 = 0.54, p < 0.01; winter: R^2 = 0.31, p < 0.05; data not shown). Emissions per kg on-farm beef cattle stock was related to beef cattle stock numbers, but only in winter (R^2 = 0.31, p < 0.05; Figure 4).

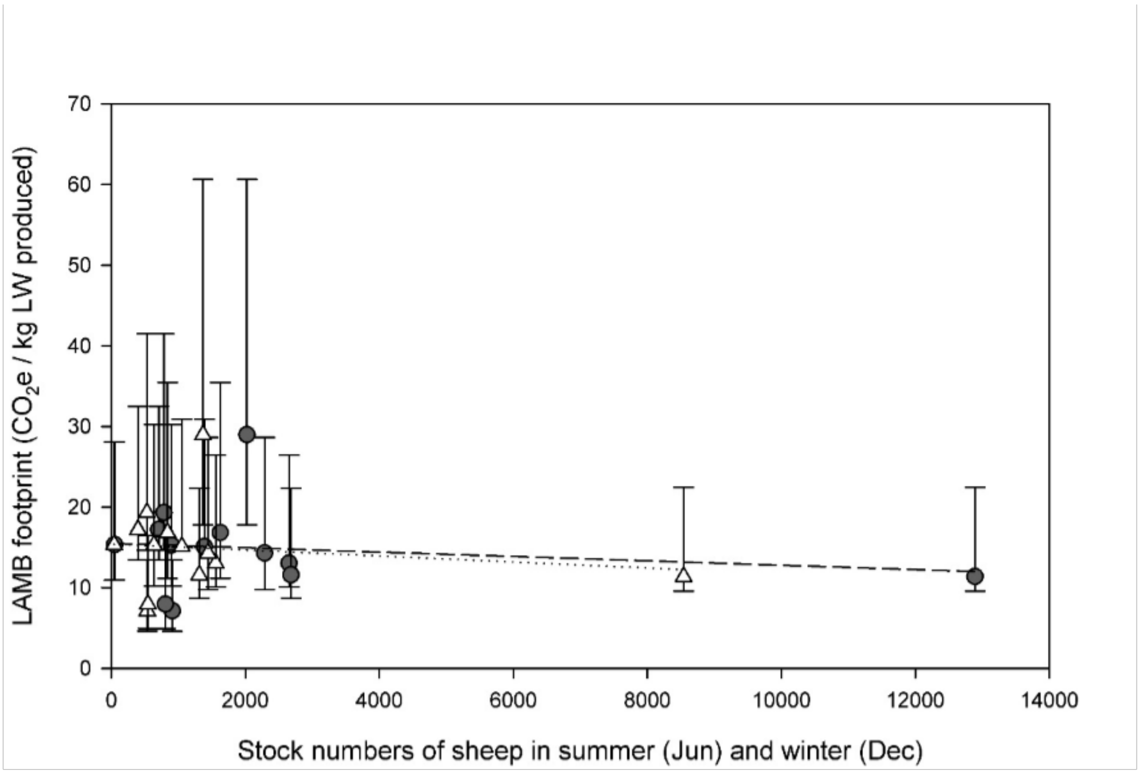

Figure 3. Carbon footprint of lamb (kg CO_2e/kg LW) against sheep stock numbers, for individual farms in summer (circles) and winter (triangles), on LFA cattle and sheep farms only. Vertical bars show maximum and minimum values, representing the full range of uncertainty in GHG emissions estimates. Linear trend R^2 values = 0.41 (summer, dashed line) and 0.31 (winter, dotted line).

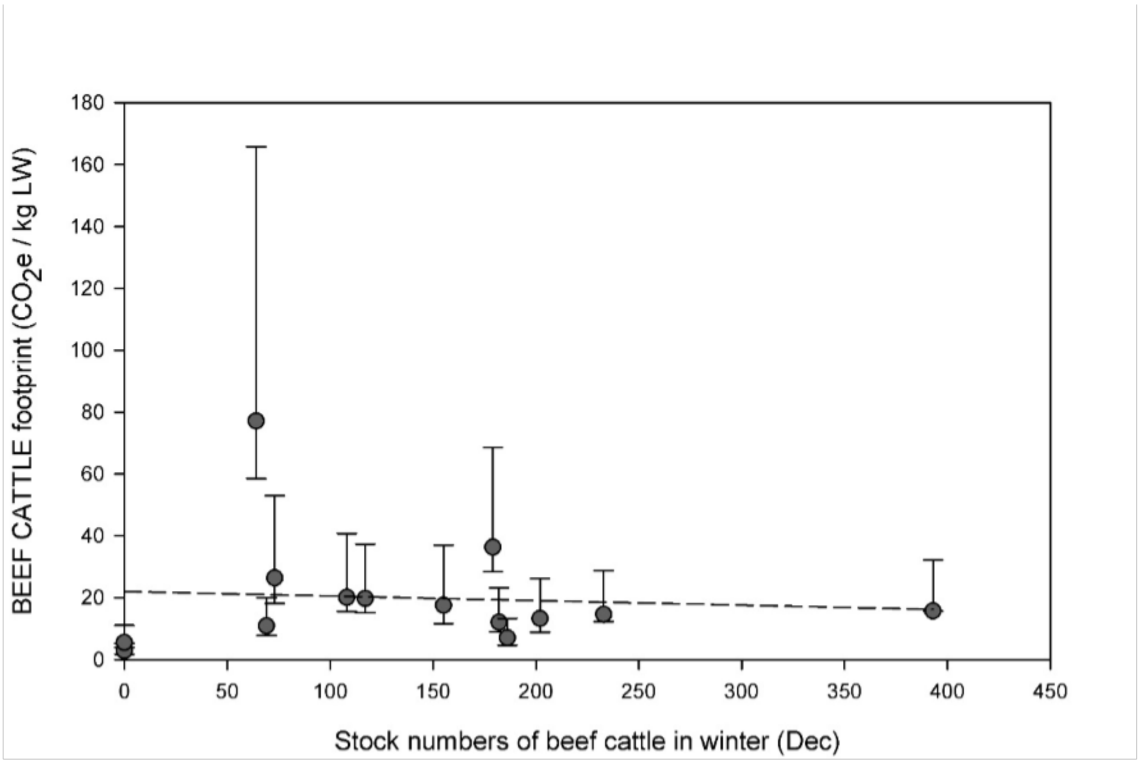

Figure 4. Carbon footprint of beef cattle (kg CO_2e/kg LW) against beef cattle stock numbers, for individual farms in winter, on LFA cattle and sheep farms only (circles). Vertical bars show maximum and minimum values, representing the full range of uncertainty in GHG emissions estimates. Linear trend R^2 value = 0.31 (dashed line).

4.2.3 *Comparison of emissions for different types of livestock*

Emissions per kg of product leaving the farm (lamb, wool, milk) or per kg of livestock retained on-farm (sheep, beef cattle, dairy cattle) were compared in different combinations on the same farm, to identify potential underlying sources of variation.

When all farms were analysed together, the only relationships found were between footprint per kg LW lamb and per kg wool (R^2 = 0.19, p < 0.05), and between footprint per kg LW sheep and per kg wool (R^2 = 0.29, p < 0.05; Figure 5). No relationships were found when the same comparisons were made for dairy and LFA cattle and sheep farms separately. Comparing emissions per kg on smaller farms (50 to 199.9 ha) and larger farms (> 200 ha) separately revealed only one relationship, between wool and sheep footprints on farms of 50 to 199.9 ha in size (R^2 = 0.33, p < 0.05; Figure 6).

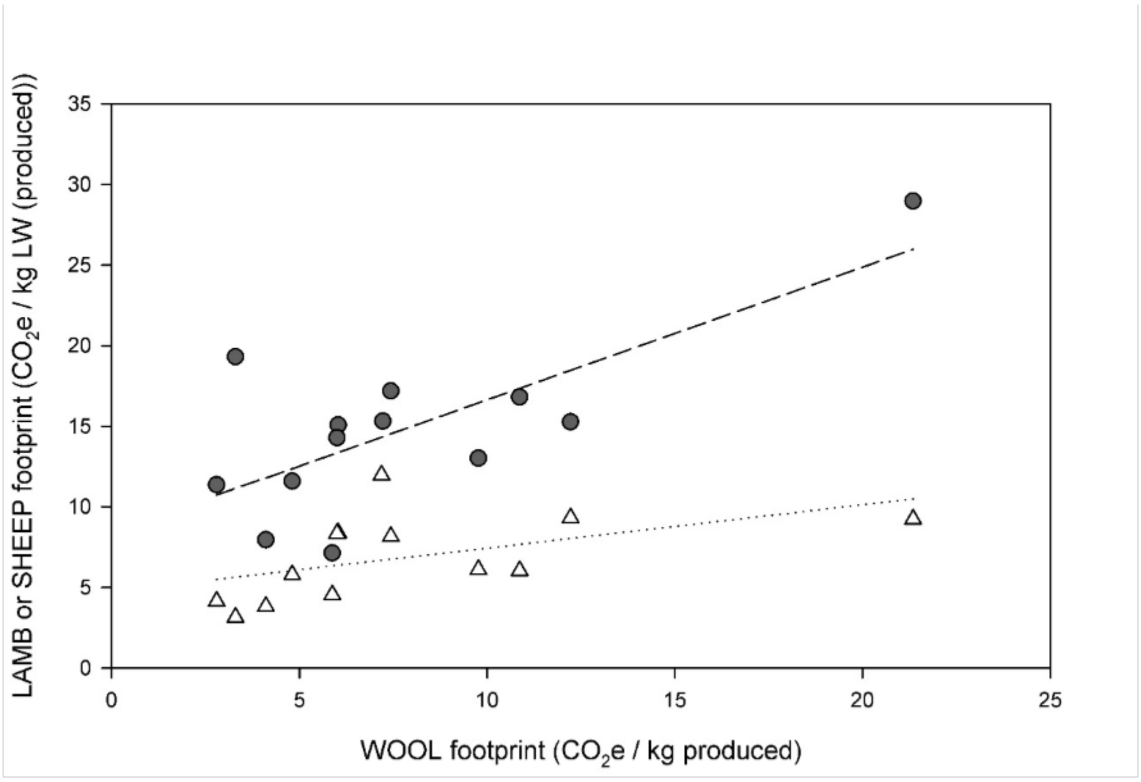

Figure 5. Carbon footprint of wool (kg CO_2e/kg), against carbon footprint of lamb (circles) and sheep (triangles) (kg CO_2e/kg LW), for individual farms. Vertical bars omitted for clarity. Linear trend R^2 values = 0.19 (lamb, dashed line) and 0.29 (sheep, dotted line).

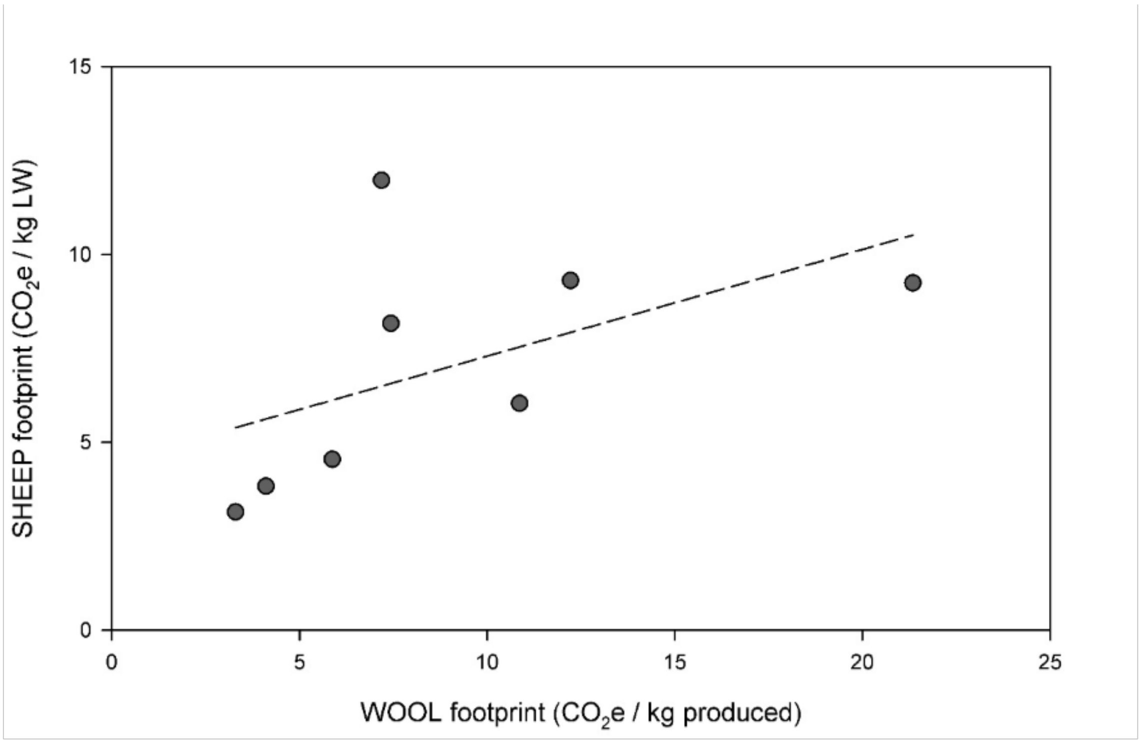

Figure 6. Carbon footprint of wool (kg CO_2e/kg) against carbon footprint of sheep (kg CO_2e/kg LW), for individual farms of 50 to 199.9 ha in size only. Vertical bars omitted for clarity. Linear trend R^2 value = 0.33 (dashed line).

4.3 Carbon sequestration

Total carbon sequestration varied considerably between the 20 farms, from 520.7 to 1,648.4 kg CO_2e/ha/yr (averaging 1,026.2 kg CO_2e/ha/yr), with more than three quarters of the farms sequestering at the upper end of this range, at between 800 and 1,200 kg CO_2e/ha/yr (Table 3). On all sampled farms, most sequestration (46.6-100%, averaging 80.2%) occurred as carbon storage in permanent grassland soils. In contrast, very little sequestration occurred in peat wetlands (0.04 to 2.2% of total sequestration, averaging 0.8%). Woodland contributed the most to sequestration in terms of carbon taken up into woody biomass on half of the farms (averaging 13.2%), but its contribution varied widely, from a net carbon loss of 4.7%, to a net carbon gain of 34.4% of whole farm sequestration. Where trees had been felled during the sample year, this reduced the woodland sequestration value for that year. Tree felling was particularly important on Farm 19, where a greater volume of carbon had been removed than that which remained in the woodland, resulting in a net carbon loss of 4.7%. The percentage contribution of isolated trees to total sequestration averaged 4.8% and varied from 0.5 to 21.1%, and was dependent largely on the total number of trees and amount of tree growth. Hedges contributed an average of 6.6% (0.4 to 25.6%) of farm sequestration, and varied according to the proportion of hedges flailed during the year.

Farm type made only a small difference to average sequestration rate (Table 3). Slightly higher average sequestration was observed on LFA cattle and sheep farms (1,041.9 kg CO_2e/ha/yr, ranging from 853.3 to 1,648.4 kg CO_2e/ha/yr), than on dairy farms (1,002.6 kg CO_2e/ha/yr, ranging from 520.7 to 1,516.9 kg CO_2e/ha/yr). When comparing LFA cattle and sheep farms to dairy farms, a greater proportion of sequestration per ha was within grasslands (averaging 82.8%, compared to 76.3% on dairy farms). Sequestration within peat wetlands was virtually identical on both farm types, while dairy farms drew a greater proportion of sequestration from woodlands, isolated trees and hedgerows than LFA cattle and sheep farms, although only by 2-3%.

Similarly, differences in sequestration rates per ha between farms of 50 to 199.9 ha in size and > 200 ha in size, were also quite small (Table 3). The larger farms had a greater average rate (1,046.6 kg CO_2e/ha/yr, ranging from 520.7 to 1,648.4 kg CO_2e/ha/yr) than the smaller farms (1,015.2 kg CO_2e/ha/yr, ranging from 853.3 to 1,516.9 kg CO_2e/ha/yr). Differences in percentage carbon storage in tree biomass was more important in relation to farm size, with larger farms storing on average 18.5% of carbon in woodlands (and a further 5.7% in isolated trees), compared to 10.3% and 4.3% in woodlands and isolated trees respectively on smaller farms. Storage in grasslands was more important on smaller farms, making up 82.7% of sequestration per ha, compared to 75.5% on larger farms.

Table 3. Estimated annual carbon sequestration (t CO_2e/yr) in different elements of the farm ecosystem. Negative values indicate carbon loss from that source, e.g. through felling of trees.

FARM	Sequestration per ha (kg CO_2e)	Percentage contribution to carbon sequestration per ha				
		woodland (net)	isolated trees	hedges	grassland (soils)	peat wetlands
1	1,648.4	25.3	21.1	2.2	51.4	-
2	954.2	14.2	0.9	0.4	83.5	0.9
3	862.9	-	1.5	-	98.5	-
4	1,516.9	34.4	3.1	15.7	46.6	0.3
5	1,029.4	10.6	0.8	3.8	84.8	-
6	1,074.0	-	17.4	-	82.6	-
7	920.1	-	2.6	7.4	89.0	1.0
8	1,275.3	23.1	10.9	2.8	62.5	0.6

9	853.3	-	0.5	-	99.5	-
10	1,090.1	14.2	1.9	4.9	79.0	0.04
11	1,096.7	17.5	2.4	5.0	74.5	0.6
12	866.4	0.9	7.8	6.6	84.7	-
13	1,150.2	-	0.8	25.6	73.6	0.1
14	923.4	12.2	2.4	6.0	77.3	2.2
15	520.7	-	7.7	-	92.3	-
16	930.8	2.6	1.9	2.4	93.1	-
17	906.6	1.3	1.6	2.5	94.1	0.5
18	1,164.1	28.3	4.5	18.3	48.5	0.4
19	867.2	*-4.7*	1.3	1.9	101.5	-
20	875.3	5.4	5.0	0.8	86.8	2.0
Dairy	1,002.6	14.6	6.2	8.2	76.3	0.7
LFA	1,041.9	12.2	3.9	5.7	82.8	0.8
50–199.9 ha	1,015.2	10.3	4.3	6.9	82.7	0.9
> 200 ha	1,046.6	18.5	5.7	6.2	75.5	0.6
All farms	1,026.2	13.2	4.8	6.6	80.2	0.8

4.4 Carbon balance and carbon offset

While sequestration is not currently included in PAS 2050:2011-compliant footprints, it is included in national GHG inventory reports. It is useful to examine the contribution of sequestration to offsetting the total farm footprint here, as it indicates the extent to which farm characteristics unrelated to GES grants may affect the potential usefulness of GES funding on the sampled farms.

In terms of net farm carbon balance (total footprint minus sequestration), sampled farms participating in the Glastir Efficiency Scheme averaged a net emission per ha of 9,209.7 kg CO_2e /ha/yr, varying from 1,102.6 to 17,913.2 kg CO_2e /ha/yr (Figure 7). The carbon balance of all farms was positive, that is, none of the farms sequestered more carbon per hectare than their total farm footprint per hectare. Farm type made a substantial difference to net C balance, with dairy farms yielding a net emission of more than double that from LFA cattle and sheep farms (averaging 13,030.3 kg CO_2e /ha/yr and 6,662.6 kg CO_2e /ha/yr respectively). The variation in C balance was wide on both farm types, falling within the range 4,850.4 to 17,913.2 kg CO_2e /ha/yr on dairy farms and between 1,102.6 and 17,571.2 kg CO_2e /ha/yr on LFA cattle and sheep farms. A similar magnitude of difference was observed between farm size categories. Smaller farms had a higher mean carbon balance per hectare than larger farms, although again considerable variability was observed. Smaller farms (50 to 199.9 ha in size) yielded a C balance of between 4,297.7 and 17,913.2 kg CO_2e /ha/yr (averaging 10,638.9 kg CO_2e /ha/yr), while larger farms (>200 ha in size) yielded between 1,102.6 and 17,571.2 kg CO_2e /ha/yr (averaging 6,555.3 kg CO_2e /ha/yr).

Sequestration accounted for an average of 15.1% of the total farm footprint (GHG emissions plus carbon sequestration), but this varied very widely, from a minimum of 4.4% (farm 15, dairy farm with > 200 ha of land) to a maximum of 59.9% (farm 1, LFA cattle and sheep with > 200 ha land). Almost half of the farms sequestered more than one tonne (1,000 kg) CO_2e/ha/yr. Potential C offset through sequestration made up a much greater proportion of the farm footprint on LFA cattle and sheep farms than dairy farms (19.8% and 8.1% respectively), although the variation was considerably wider on LFA cattle and sheep farms than dairy farms (5.2% to 59.9%, and 4.4% to 19.4%, respectively). A very similar magnitude of difference was observed between farm size categories. Holdings with between 50 and 199.9 ha of land sequestered on average 10.3% (5.0% to 18.0%) of the farm footprint, while farms with > 200 ha of land sequestered on average 24.0% (4.4% to 59.9%) of the farm footprint.

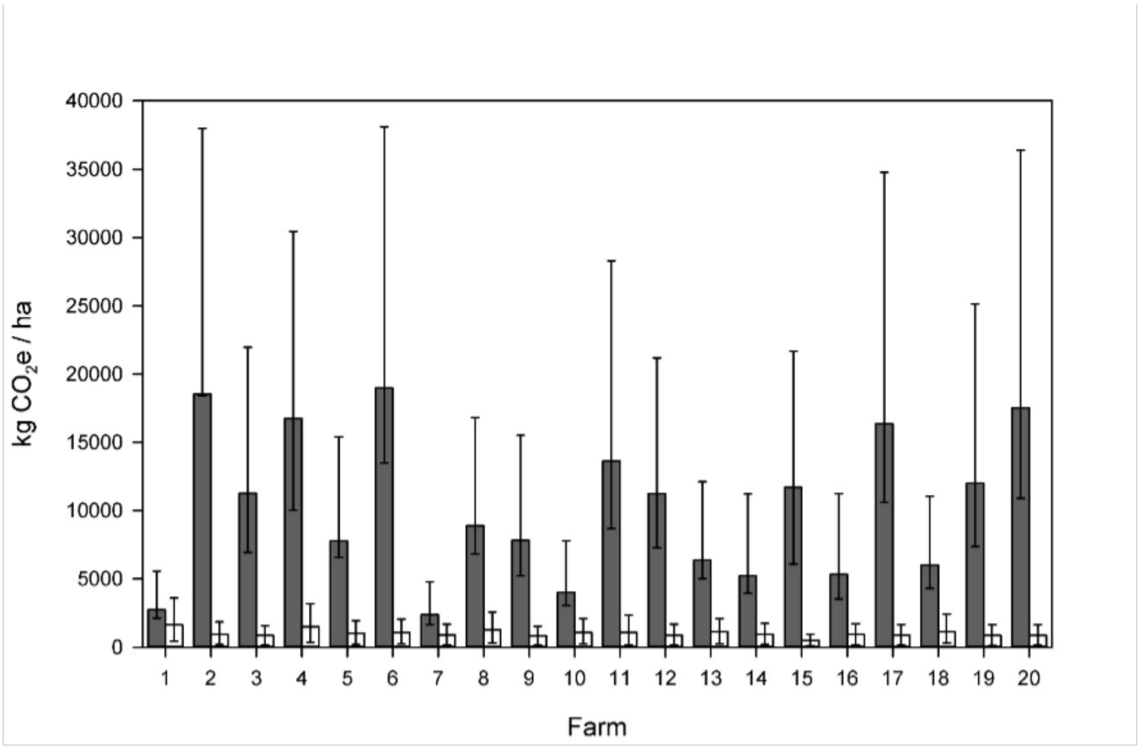

Figure 7. Footprint per ha (PAS 2050:2011 Tier 1; grey columns) compared with estimated C-sequestration (potential C-offset; white columns), both in kg CO_2e/ha, for individual farms. Vertical bars show maximum and minimum values, representing the full range of uncertainty in GHG emissions and sequestration estimates.

5 DISCUSSION

This project aimed to provide comprehensive farm footprints for a representative sample of farms receiving grant funding from the Glastir Efficiency Scheme, in order to provide a baseline estimate of emissions prior to implementing GES-funded technologies. An additional objective was to estimate the potential of GES implementation, in facilitating abatement (reduction) of emissions on Welsh farm holdings. In fulfilment of these criteria, the following sections discuss the reliability of, and sources of uncertainty from, the model; discuss the factors influencing GHG abatement potential of Glastir Efficiency Scheme; and relate the results of the baseline footprinting exercise presented in this report to the potential for emissions abatement across the Welsh agricultural sector.

5.1 Model validation and uncertainty

There are a number of inherent uncertainties introduced whenever a mathematical model is used to simulate conditions in the real world. Detailed discussions of sources of uncertainty in the Bangor University footprinting model are provided in Edwards-Jones *et al*. (2009), Taylor *et al*. (2010), and Jones *et al*. (2014), and have been discussed to some extent in the introduction to this report. The most important points are summarised here.

Mathematical models only provide simplified versions of reality. Sometimes it is possible to test how representative of reality a model is, by comparing model output data to real-world data obtained by carrying out experiments that measure the same variables of interest. This process of comparison with experimental data is known as model *validation*. For the type of modelling used here, it is difficult to validate the modelled data with experimentally derived data. This is because it is impossible to run 'farm level experiments' to collect data for model development, and because current technology is unable to directly measure the amount of GHGs emitted from a farm over any time period. Since neither experimental model input data nor validation data are available, the output data presented here should be treated with care. However, efforts were made in the development of the Bangor University footprinting model to ensure *internal model validity* (the mathematical components of the model accurately performing the desired functions), by consulting an external auditor. As the model has been used over time, it has undergone modifications, including attempting to eliminate any mathematical and processing errors, but this is an ongoing process. Further validity could be lent to the model by inputting data into other models and comparing the results with the outputs from this model.

There are a number of other sources of uncertainty introduced during the modelling process, relating to the methods used for calculating on-farm GHG emissions, the quality of available empirical data on emissions and sequestration in different parts of the farm ecosystem, and finally, the quality of data provided by interviewed farmers.

5.1.1 *Uncertainty associated with GHG calculation methods*

Uncertainty associated with GHG calculation methods originates from a number of sources. Issues relating to averaging of values over a non-uniform system, and the subjectivity of some aspects of the modelling process, are discussed in the introduction to this study. Here, we consider three further key sources of variability introduced via assumptions made in the Bangor University modelling approach.

The current PAS 2050:2011 regulations follow the IPCC recommendation that grazed organic (peat and peat-derived) soils are classified as 'managed' (IPCC, 2006), and consequently are included as a potentially substantial source of N_2O emissions on Welsh farms. Since the original release of PAS 2050 guidelines in 2008, the previously used default IPCC emission factor for managed organic soils (8 kg N_2O-N/ha/yr) has been replaced with a value thought to be more appropriate to UK upland peat soils (0.25 kg N_2O-N/ha/yr; SEERAD, 2007). While this has resulted in a substantial reduction in the modelled contribution of managed peat soil emissions to the overall farm footprint on Welsh livestock holdings (Taylor *et al*., 2010), clarification is required as to whether grazed unmodified upland soils should be classified as 'managed' at all. Reclassification as unmanaged organic soils would result in organic soils on Welsh holdings changing from a net source of emissions to a net carbon store, reducing both the overall farm footprint, and the overall carbon balance of each farm. Given the large areas of upland grazing found in Wales, particularly on LFA cattle and sheep farms, this could make a substantial difference to Welsh carbon footprints.

In accordance with IPCC and PAS 2050:2011 requirements, this study calculates N_2O emissions associated with the breakdown of N in manure and excreta, based on the total modelled N contained within these animal wastes. Potentially, this over-estimates the true N_2O emissions from manure and excreta (Taylor *et al*., 2010). Other authors (e.g. Cranfield University, 2007; EBLEX, 2009; Taylor *et al*., 2010) use an alternative, 'available N' approach, which estimates the proportion of total N that is actually available to microbes for breakdown into N_2O. The total quantity of available N may be considerably lower than the total N, resulting in sometimes substantially lower estimated N_2O emissions. This is important to bear in mind when evaluating the effects of GES technologies on GHG emissions, as both positive and negative effects will have a lower impact on the estimated farm footprint using the 'available' N approach.

In this study, emissions were allocated between different products on an economic basis. This is the most commonly used approach in CF reports, and therefore allows easy comparison between the results of different studies. Despite this advantage, it is known to act as a confounding factor in comparing emissions from different co-products. This is because economic allocation is based on market values of products relative to a particular point in time and geographical location (Jones *et al*., 2014). This variability in market prices may account for the poor correlation between footprints for farm co-products in this study.

5.1.2 ***Uncertainty associated with empirical data quality***

Although potential carbon offset through sequestration is not directly affected by the Glastir Efficiency Scheme, it may be a useful aspect of the farm carbon balance to consider, particularly when allocating GES funding resources between farms. Estimated sequestration rates are subject to considerable uncertainty. There is uncertainty regarding the ability of grassland soils to sequester carbon, especially in relation to the amount of carbon stored in grasslands of different types and ages. For example, when grassland is first converted from arable land (which tends to lose carbon), the rate of carbon sequestration is usually quite high, but tends to decline over time to eventually reach an equilibrium point, which in some cases is zero. The exact rate at which sequestration slows down, and the amount of sequestration at equilibrium, is unknown for most grasslands. In this report, the mid-range used to estimate the figures given in Table 3 was 0.24 t C/ha/yr, but Janssens *et al*. (2005) gives a minimum value of 0.04 t C /ha/yr, which is six times lower than the mid-range value. Depending on the true sequestration rate of grassland soils on the farms sampled in this study, actual on-farm sequestration may be many times lower than the values reported in Table 3.

The amount of carbon sequestered in hedgerows is also very uncertain. No known data is available on sequestration rates in hedges, or the volume of biomass contained within a 1 m length of hedge (Taylor *et al*., 2010). Although attempts have been made here to find a suitable proxy estimate, its value may be inaccurate. Further, including hedge flailing in sequestration estimates is a somewhat contentious issue, as the effect of flailing on emissions (e.g. how it affects shoot and root growth, and the fate of hedge clippings) is largely unknown (Taylor *et al*., 2010).

5.1.3 *Uncertainty associated with questionnaire data*

Inaccuracies in data provided by farmers are reflected in less accurate farm footprints. Given that farm details are anonymised in this and previous footprinting reports, it is unlikely that farmers would deliberately provide inaccurate data. However, some random errors may be introduced via questionnaires, for example through misinterpretation of questions, or inaccurate estimates where accurate farm records are not available (e.g. total hedgerow length or number of individual trees on the farm). There is no easy way to check these inaccuracies, but in the long term, repeating the questionnaires on the same sample of farms used in this study may aid identification of sources of error (Taylor *et al*., 2010).

This study used random stratified sampling to select twenty GES-participating farms from the Welsh agricultural sector. The number of farms in each of the four sampled sector categories (dairy farms 50-199.9 ha in size, dairy farms > 200 ha in size, LFA cattle and sheep 50-199.9 ha in size, and LFA cattle and sheep > 200 ha in size) closely matched the target proportions determined by the number of grants allocated to each sector, creating a successfully representative sample in this sense. Clearly, this does exclude a large number of farm categories (other farm types and sizes) from carbon footprinting analysis. Given the small number of farms having received grants in these other categories (9% of all grants), this exclusion should not negatively impact on the representativeness of the sample used here. Although twenty farms represents more than 10% of the farms approved for GES grants, one possible improvement to implement in future studies would be to increase the sample size, as this would allow for valid in-depth analysis of differences between farm categories. Examining differences between robust farm types and sizes was difficult in this work. This was because splitting data for comparison sometimes resulted in very small sample sizes; this was a particular problem when analysing dairy farm data (e.g. milk footprints). Because of the small sample sizes used in this report, any conclusions drawn from statistical analyses (section 4.2.) should be interpreted with caution. For example, the high variability within farm typologies compared to the lower variability between different farm typologies found by Taylor *et al*. (2010), obscured meaningful differences between farm types.

5.2 Mitigation potential through the Glastir Efficiency Scheme

A lower farm net carbon balance may be achieved by either reducing farm emissions or increasing on-farm C-sequestration (in this case, in trees and soil) (Taylor *et al*., 2010). The Glastir Efficiency Scheme currently provides opportunities to reduce emissions, through three technology categories: on-farm energy use efficiency (Energy Efficiency, coded EE), efficiency of animal excreta collection, storage and application (Slurry/ Manure Efficiency, SME), and water use efficiency and recycling (Water Efficiency, WE) (WG, 2013).

There are a number of factors influencing the GHG abatement potential of applying GES-funded technologies across Wales. They relate to the estimated abatement potential of individual technologies, current levels of uptake of technologies in Wales, and current levels and sources of emissions on Welsh farms, and are discussed in the following sections.

5.2.1 *Abatement potential of individual technologies*

A search of peer-reviewed and government literature was conducted to compile a range of estimates of the GHG abatement potential of GES-funded technologies (Table 4). A number of issues surrounding the estimation of abatement potential both across Wales, and on an individual farm basis, should be considered when interpreting the values drawn from the literature given in Table 4. Relevant UK-based studies were relatively scarce, and often assessed a limited range of GHG mitigation options. Technologies and the assumptions made about their application given in other literature sources may not translate directly into the technology structure and application made by farmers receiving GES grants. Abatement studies usually test a limited number of application scenarios, to give an 'average' rate for each technology when applied to one or more farm type. In reality, farm structures and modes of application (for example, slurry or manure store size, area of rainwater separation, size of housed units using energy efficiency measures, number and type of livestock units on each farm) vary between individual farms and different farm types, which introduces error into average estimated values. In an attempt to address these issues of comparability and missing information in the literature, some GES technologies have been grouped in the table, but the authors recognise that this grouping is subjective. Further, abatement rates drawn from the literature have been calculated at different scales (e.g. at the UK- or region- scale), using different base years, and are reported using different metrics. While we have converted abatement rates to a standard unit here (kg CO_2e/ha), it should be noted that this process required some assumptions to be made (described in the footnotes of Table 4).

The Glastir Efficiency Scheme aims to encourage carbon emissions reduction via energy and resource efficiency, offering grant funding for three categories of technologies: Energy Efficiency (EE), Slurry and Manure Efficiency (SME), and Water Efficiency (WE) technologies (WG, 2014a; b). Of the three components of the initiative, the greatest potential for reducing emissions on a per-hectare basis is from SME technologies, which on average carry a higher estimated abatement rate than EE or WE technologies (Table 4). Reported slurry and manure abatement rates in the scientific literature are highly variable, and depend on the individual technology, successful implementation, and the sector it was applied to. Potential abatement rates from installation SME capital works vary from 0 kg CO_2e/ha (installing covers on slurry stores, all sectors) to 25.49 kg CO_2e/ha (slurry injection, dairy sector). Inadequate information was available to evaluate the reasons for differences in abatement rates. The scientific literature yielded insufficient information to assess the potential abatement rates of EE technologies. Only one estimate of abatement potential was found for WE technologies, and this had low potential (0.34 kg CO_2e/ha, separating out rainwater from animal wastes, all sectors).

Certain technologies offer a potential abatement rate of zero under certain circumstances. For example, EE technologies primarily relate to savings in electricity use, which is close to negligible in the sheep and beef industries compared to the dairy industry (HRI, 2007). This lack of potential for emissions reduction via EE measures in the sheep and beef industries is reinforced by the fact that the majority of EE eligible technologies are specific to the dairy industry (WG, 2014b). In contrast, SME and WE technologies have the potential to be applied across the entire livestock sector.

5.2.2 *Uptake of abatement technologies across Wales*

Levels of uptake across Wales by October 2013 have been estimated in a questionnaire-based study conducted in tandem with this work (Taft *et al*., 2014). The results indicate that the majority of approved grants were for a very small number of technologies: 'rainwater separation' (13% of grants), 'slurry store' (12%), 'new manure store' (9%), 'trailing shoe or injector system' (9%), and 'new slurry store' (8%). Uptake was mainly in the dairy and LFA cattle and sheep sectors. Particularly for dairy, these correspond to the technologies with the highest potential abatement rates (Table 4).

The abatement rates given in Table 4 are based on a technology's technical potential (the potential abatement rate, if costs are ignored; DEFRA, 2012b). Future potential emission mitigation is additionally contingent on factors such as economic cost to the farmer, farmer attitude, farm structural constraints, and future legal frameworks (Barnes *et al*., 2010).

The potential barriers to uptake in each sector should be considered to optimise uptake of GES grants in the future.

Table 4. Abatement potential of GES-funded technologies, applied across Wales and to the farms footprinted in this study.

	Glastir Efficiency Scheme Technology	Mitigation practice (referenced source)	Sector	Abatement potential, kg CO_2e/ha	Source
SME	Rainwater separation	Minimise the volume of water produced (sent to slurry store)	All	0.34	DEFRA (2012a)
	Slurry separators and associated equipment	Use liquid/ solid manure separation techniques	All	0.11	DEFRA (2012a)
			Dairy	1.06	DEFRA (2012a)
	Roof/cover and floating cover over slurry stores	Install covers on slurry stores	All	0.00	DEFRA (2012a)
		Install covers to slurry stores	All	0.00	DEFRA (2012b)
	Trailing Shoe or injector system	Use slurry injection application techniques	Dairy	25.49	DEFRA (2012a)
		Use slurry band spreading techniques	All	-2.63	DEFRA (2012a)
	Manure Store (New/ Extension/ Modification)	Store solid manure heaps on an impermeable base and collect effluent	All	1.13	DEFRA (2012a)
			Dairy	1.06	DEFRA (2012a)
			LFAs	0.85	DEFRA (2012a)
		Site solid manure heaps away from watercourses/ field drains	All	0.23	DEFRA (2012a)
	Slurry Store (New/ Extension/ Modification)	Increase the capacity of slurry stores to improve timing of slurry applications	All	0.56	DEFRA (2012a)
		Increase the capacity of slurry stores to improve timing of slurry applications	Dairy	5.31	DEFRA (2012a)
	Dirty Water Store (New)	Capture of dirty water in a dirty water store	All	1.01	DEFRA (2012a)
			LFAs	7.61	DEFRA (2012a)
WE	Rainwater collection	Minimise the volume of water produced (sent to slurry store)	All	0.34	DEFRA (2012a)

The following GES technologies have been excluded from the Table, as no grants had been approved for associated capital works by October 2013: Air circulation/ ventilation fans (R), Thermal screens (N), Temperature sensors (R/N), Humidity controls for grain drying and dehumidifiers (R/N), Mixed flow driers (R), Enclosed piglet creeps (R), Flexible insulated store dividers (N), Hydraulic ram pump (R/N), and Wind pumps – mechanical only (R).
The following GES technologies were excluded due to lack of available information for comparison in the scientific and industry literature: Variable speed drive (R/N); Variable speed drive vacuum pump (R); Scroll Compressor (R); Thermostats/ controls (R/N); Cross flow driers with recirculation (R); Plant heat exchange (R/N); Heat recovery / Heat exchange unit (N); High efficiency direct expansion tank (R); Energy efficiency lighting system (R); Roof over manure stores; Soil aerator; Technical Fees; Water recycling.
For EE technologies, the suffix R = replacements only, N = new only, and R/N = replacements or new equipment eligible for funding application.

5.2.3 *Influence of current (baseline) emissions from Welsh farms*

The majority of GHG emissions from footprinted GES-participating farms in this study were associated with livestock enteric fermentation (CH_4 emissions), soil management through application of mineral or manure fertilisers (N_2O emissions), and manufacture and use of inputs (primarily mineral fertilisers, feed concentrates and bought-in livestock). These were the major emissions sources from both dairy farms and LFA cattle and sheep farms. The potential for GHG abatement depends partly on the extent to which the different Glastir Efficiency Grant technologies can influence emissions from each of these source categories.

5.2.3.1 Influence of baseline emissions on potential abatement using Energy Efficiency grants

Energy Efficiency (EE) grants act largely through direct savings in electricity use only (WG, 2014b). The results of this study indicated that only a very small proportion of baseline farm emissions per ha were attributable to electricity use (0.0 to 4.4%), although in absolute terms these values translated into sometimes substantial amounts (<0.1 to 730.6 kg CO_2e/ha/yr, or 8.7 to 43,103.5 kg CO_2e/farm/yr). In terms of percentage of farm footprint per ha, and absolute footprint per ha and per farm, dairy farms yielded a footprint several magnitudes greater than LFA cattle and sheep farms, averaging 142.5 kg CO_2e/ha/yr or 12,021.2 kg CO_2e/farm/yr on dairy farms compared to 2.1 kg CO_2e/ha/yr or 336.5 kg CO_2e/farm/yr. The results for LFA cattle and sheep farms are similar to those found on beef and sheep farms by Taylor *et al*. (2010), while Jones *et al*. (2014) also reported a small contribution of electricity to overall the overall footprint of lamb (<1% of the footprint per kg). A DairyCo report published in 2012 similarly found a low contribution of electricity to the overall footprint of milk (3% of the footprint per litre; DairyCo, 2012). Given the much larger baseline emissions from electricity use on Welsh dairy farms compared to Welsh LFA cattle and sheep farms, targeting of EE grants at dairy farms constitutes a prudent use of resources, as it offers the highest chance of success at reducing emissions from electricity use across the sector. It should be noted that other sectors not included in this study may also yield substantial emissions from electricity use (e.g. protected horticultural crops), but these are unlikely to make up a large portion of the Welsh agricultural sector, so targeting future EE grants at non-dairy sectors may not make a material difference to Welsh agricultural emissions.

5.2.3.2 Influence of baseline emissions on potential abatement using Slurry and Manure Efficiency grants

Implementation of SME technologies chiefly involves construction of new slurry, manure and dirty water stores, or modification (including extension) of old ones, as well as the use of alternative slurry spreading technologies and soil aerators (WG, 2014b).

In terms of footprinted emissions categories, construction of new stores or modification of old ones offer potential emission reductions related to reduced mineral N fertiliser inputs (manufacturing-related emissions), soil management (direct and indirect N_2O emissions), and manure handling and storage. Mineral N fertiliser use may decline if additional storage provides the opportunity for more effective use of manure nutrients (i.e. improved timing and rates of applications). Soil management emissions may decline, as increasing storage capacity allows flexibility of timing for applying manure N to the land when the risk of N_2O efflux and nitrate leaching and runoff are lower. Implementing GES slurry storage technologies also potentially impacts on CH_4 emissions. Although CH_4 emissions from livestock farms comprised a high percentage of total farm emissions for most farms in this study (table 2), most of this emission was from enteric fermentation rather than slurry storage (section 4.1.2.). It is questionable whether increasing storage capacity is likely to result in a measurable net increase or decrease in manure management emissions: evidence from other studies is inconclusive. Further investigation into the balance between changes in N_2O and CH_4 emissions when implementing slurry store grants would therefore be useful.

The results of this study indicate considerable baseline potential for abatement in the SME grants category. The total proportion of the carbon footprint per ha in this study, attributable to mineral N inputs and N_2O generated from manure application to land, varied from 11.6 to 43.4% of the footprint per ha. The actual footprint per ha varied from 769.6 to 5,204.1 kg CO_2e/ha/yr, and the footprint per farm varied from 140,087.4 to 1,125,203.4 kg CO_2e/farm/yr). If we assume that implementing SME technologies will also affect N_2O emissions from slurry and manure storage, then baseline emissions from this category (comprising direct and indirect emissions) provides a further potential of 1.3 to 4.8% of the footprint per ha, 57.5 to 717.7 kg CO_2e/ha/yr, or 11,728.0 to 207,263.1 kg CO_2e/farm/yr. As for electricity use, dairy sector emissions per ha and per farm were greater than LFA emissions, by a factor of one and a half for mineral N and manure application emissions, and by a factor of three for slurry and manure storage.

Alternative slurry-spreading technologies such as injection or trailing shoe techniques aim to reduce the quantity of NH_3 volatilised from applied slurry, and may reduce the quantity of N_2O emitted as a result of application to the soil, although the evidence supporting this in the scientific literature is inconclusive (e.g. Chadwick *et al*., 2011). These potential reductions correspond respectively to the indirect and direct soil management categories of N_2O emission. Given that these categories comprise a smaller proportion of each farm footprint than those associated with improving manure and slurry storage, then baseline conditions suggest that the scope for reducing emissions through alternative slurry application technologies is slightly lower than that from storage improvement, for N_2O emissions. The baseline footprint relating to soil emissions varied from 639.5 to 3,671.5 kg CO_2e/ha/yr, and 118,124.9 to 840,008.8 kg CO_2e/farm/yr. Although average dairy emissions were again higher than average LFA cattle and sheep emissions, this was only by a small factor. As discussed above, the balance of changes in N_2O emissions compared with CH_4 emissions should also be considered when evaluating the overall effect of alternative slurry-spreading technologies.

Soil aeration may reduce GHG emissions on grassland by creating unfavourable conditions for CH_4 and N_2O generation (e.g. Saggar *et al*., 2008; Eckard *et al*., 2010). It may be difficult to evaluate the efficacy of soil aeration techniques by comparison to baseline emissions in this study, largely because emissions categories directly relating to the effects of soil aeration are not included in this carbon footprinting method. It is possible that soil aeration (e.g. through sub-soiling) could reduce the risk of indirect N_2O loss via nutrient leaching and runoff. If this is the case, baseline emissions indicate that soil aeration offers a moderate measurable potential for emissions reduction (2.5 to 7.4% of emissions per ha, 165.2 to 883.9 kg CO_2e/ha/yr, or 30,834.0 to 237,537.6 kg CO_2e/farm/yr). Baseline emissions from the dairy and LFA sectors were of a comparable magnitude, with dairy emissions actually slightly higher than those of LFA farms, at the farm scale. It should be noted that under certain circumstances, soil aeration could actually enhance GHG emissions. For example, deeply cultivated peat soils are a notable source of CO_2 and N_2O (e.g. Kasimir-Klemedtsson *et al*., 1997). On balance, this may compromise any advantages of reducing N_2O losses from leaching and runoff.

5.2.3.3 Influence of baseline emissions on potential abatement using Water Efficiency grants

Water Efficiency (WE) grants are aimed at reducing water use or recycling water on the farm (WG, 2013), but offer opportunities to reduce GHG emissions indirectly. Of the three WE technologies listed in Table 4, this carbon footprinting method is not suitable for assessing the potential effectiveness of the 'Technical fees' or 'Recycling' options. It may be possible to gauge the potential success of applying rainwater collection technology for emissions reduction by examining the baseline farm footprint. Rainwater collection enables re-direction of water which may otherwise flow from the roofs of farm buildings onto adjacent livestock yards and hard standings, reducing both the quantity of dirty water requiring storage, and runoff of dirty water onto fields. Minimising the volume of stored dirty water allows greater storage capacity for manures in slurry stores, yielding the same advantages and disadvantages as described above for SME storage technologies (i.e. increased flexibility of manure spreading, but potentially increased emissions from stored manure). As such, baseline emissions may be assumed to be identical to those relating SME storage options.

5.2.3.4 Other baseline factors influencing potential abatement rates

Certain features of Welsh farm footprints are not directly influenced by GES grants, but are important to consider when analysing the potential impact of implementing GES technologies on baseline emissions. These include the area of organic (peat) soils on each farm, and the carbon included in tree and grassland biomass.

The area of managed organic soils on a farm as a proportion of the total farm area influences the potential impact of applying GES-funded measures on the farm. In this study, the contribution of N_2O emissions from managed organic soils to the farm footprint per hectare was small (0 to 1.1% of the footprint per hectare), and as an absolute value this was also relatively small (up to 58.1 kg CO_2e/ha/yr, or up to 9,070.3 kg CO_2e/farm/yr). The footprint from managed organic soils was on average higher from LFA cattle and sheep farms than from dairy farms, on both a per-hectare basis (12.2 kg CO_2e/ha/yr compared to 5.2 kg CO_2e/ha/yr), and a whole-farm basis (1,812.4 kg CO_2e/ha/yr compared to 284.3 kg CO_2e/ha/yr). Using equivalent units and emission factors, this is a smaller average footprint than that reported by Taylor *et al*. (2010) on Welsh cattle and sheep farms (2.1 to 99.4 kg CO_2e/ha/yr), and by Edwards-Jones *et al*. (2009) on a Welsh mixed cattle and sheep farm (87.2 kg CO_2e/ha/yr). No studies reporting footprints from managed peat soils on dairy farms could be found in the scientific literature for comparison here.

In accordance with other studies (e.g. Taylor *et al*., 2010; Jones *et al*., 2014), this study also found a trend of increasing footprints per kg of lamb sold or beef cattle retained on-farm as farm peat area increased, although this trend was not statistically significant at the 95% confidence level. Compared to these other studies, the area of peat soils on farms in this study was relatively small, and it may be that the relationship between peat area and carbon footprint becomes clearer as peat area increases, as indicated in Taylor *et al*. (2010). On this basis, applying GES grant funded capital works on farms with a large area of organic soils results in a proportionally lower impact on reducing emissions per ha of farmland. Additionally, it is important to consider that soil aeration of peats, or spreading manures on peat soils, may cause an increase in the overall farm footprint, so the efficacy of GES grants approved for such farms may be low. Again, this indicates prioritising grants to the dairy sector, which are less likely to be geographically situated on a large area of peat soils (in this study, the average area of managed peat was 2 ha on dairy farms, and 16 ha on LFA cattle and sheep farms).

Farm carbon footprinting using the Bangor University model estimates CH_4 emissions from enteric fermentation and animal excreta. On average, emissions of methane were the most important component of the sampled farms' footprints, in particular those from enteric fermentation. Likewise, emissions from inputs were an additional important emissions source. These two categories represent a considerable portion of the farm footprint which will probably not be influenced by the application of GES grants, limiting their potential for abatement across the Welsh livestock sector.

5.3 Efficacy of Glastir Efficiency Scheme in the wider context

The maximum potential of GES-funded capital works to mitigate GHG emissions in the Welsh dairy and LFA cattle and sheep sectors, based on the relevant baseline emissions calculated in this study, lies between 844.2 to 5,713.4 kg CO_2e/ha/yr, or 152,534.7 to 1,332,570.7 kg CO_2e/farm/yr. This should be considered a maximum estimate, subject to the sources of uncertainty and potential barriers to future uptake outlined in the introduction and discussion of this document. In reality, emissions abatement is likely to be considerable lower than the value of the total baseline footprint.

The main strengths of Glastir Efficiency Scheme technologies may lie in the delivery of other environmental and social benefits, which have not been considered in this work. Overall, the Glastir Scheme aims to deliver a range of benefits to society including climate change mitigation and adaptation, management of water quality and quantity, soil quality enhancement, facilitating recreational access, and strengthening social capital (Reed *et al*., 2014). A key aim of the GES was to encourage involvement of the dairy sector, which it appears to have achieved. The relatively small potential for reducing GHG emissions through application of GES grants may be complimented by potential enhancement of water and soil quality, and encouraging growth in the Welsh economy through sourcing of capital goods and labour locally.

One key knowledge gap that could be addressed in future work is an assessment of the impact of GES on ammonia (NH_3) volatilisation from manures. Welsh agriculture was responsible for 11% of the agricultural emissions in the UK in 2012, with the vast majority of these emissions arising from the livestock sector (Salisbury *et al*., 2014). As most of the grants awarded to date under GES have been within the SME category, implementation of some technologies might be expected to reduce NH_3 emissions, and consequently reduce negative impacts on the environment and human health. Attempting to quantify these impacts merits further investigation.

6 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this report was to provide baseline footprints for a representative sample of GES-participating farms across the Welsh dairy and LFA cattle and sheep sector. We aimed to evaluate the potential of GES technologies for reducing carbon emissions, and identify key components of farm footprints which could influence the success of the scheme.

On the basis of this study's findings, we recommend the following:

- Carbon footprinting to be repeated on the current sample of farms, at an appropriate point in time after construction and use of GES-funded capital items. This will allow a comparison between baseline emissions and emissions post-implementation, acting as an impact indicator of the scheme.
- Prioritisation of further grant allocation to the dairy sector, subject to feasibility.
- Prioritisation of further grant allocation in the SME category.
- Avoid allocating soil aeration grants to farms where aeration would be conducted on peat soils.
- Assessment of the impact of GES on ammonia volatilisation, as this is likely to be an important environmental and human health benefit of implementing some SME technologies.
- The statistical trends in data illustrated in this report should be interpreted with caution, as the number of farms sampled within each category were too small to draw any robust conclusions from.

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8 APPENDIX A

A-1 Bangor University livestock enterprise carbon-footprint model

A-1.1 Compliance with PAS 2050:2011

Bangor University carbon footprints comply with the PAS 2050:2011 cradle-to-gate approach (BSI, 2011). This includes accounting for all emissions arising from transforming raw materials (e.g. from fertiliser production); energy use; and manufacturing and service provision (i.e. from consumables, operation of premises, transport, and storage). Agriculture-specific emissions include those following fertiliser application, direct land-use change (from non-agricultural to agricultural land), and CH_4 from cattle. Excluded from the footprints are emissions from the production of capital goods (e.g. machinery manufacture), emissions associated with visits from veterinary and other advisors (due to lack of reliable emissions data), and minor emissions sources (those which are typically less than 1% of system emissions, for example from infrequently-used consumables).

The carbon footprints produced using the Bangor University model follow the requirements of the PAS 2050:2011 regulations directly relating to agricultural emissions reporting, in the following way:

Regulation	Compliance
Non-CO_2 emissions from livestock and soils should be calculated using the highest Tier IPCC approach, or the highest approach used by [our] country.	This study uses IPCC model equations and ECOSSE model EFs to estimate emissions of N_2O from managed peat and peat-derived soils.
Soil carbon content changes, except for those resulting from direct land-use change, shall be excluded from the assessment.	This study excludes changes such as sequestration rates in peatlands.
CO_2 emissions from biogenic (non-fossil fuel, biomass-derived) material should be excluded (except those arising from land use change). Non – CO_2 emissions from both fossil and biogenic material carbon sources should be included.	The system boundary for this study does not include any emissions from these categories.
Where atmospheric CO_2 is taken up by a product which is not a living organism, the impact of carbon storage is determined from the weighted average of the biogenic carbon in a product, or atmospheric CO_2 taken up and not re-emitted to the atmosphere over the 100 year assessment period.	This system boundary for this study does not include any emissions from these categories.
Biogenic carbon storage shall be included if: (1) the product is not for human or animal consumption; (2) more than 50% of the mass of C of biogenic origin in the product remains removed from the atmosphere for one year or more; and (3) the material containing the biogenic C is obtained from an input that is the result of human actions, or a recycled or re-used input (i.e. ensuring the C stored is in addition to that which would have occurred without human intervention). (C storage through forest management activities in a managed forest is not included in the scope of PAS).	This study does not include carbon storage in woodland and other woody biomass, as it is uncertain whether more than half of the biogenic carbon remains removed from the atmosphere for more than one year.
GHG emissions from direct land use change shall be assessed for any input originating from agricultural activities. In accordance with IPCC methods, this includes all direct land use change after 1st January 1990. 5% of the total emissions from land use change shall be included in each year over the 20 years following the land use change.	This study includes land where land-use change from non-agricultural (e.g. woodland) to agricultural land use has occurred since 1990.

To comply with PAS 2050:2011, all footprint results are reported to 2 significant figures and per unit of produce (kg).

A-1.2 Direct and indirect inputs

For the purposes of carbon footprinting, emissions derived from the use of inputs on-farm, (e.g. from *use* of fuels and electricity) are termed *direct inputs*, while *indirect inputs* are emissions that happen elsewhere, but can be attributed to on-farm use of inputs (e.g. from the *manufacture* and distribution of farm inputs such as fertilisers). Standard databases (IPCC; ETH EF) were consulted for emissions factors. Agrochemicals include field applications and externally applied pharmaceuticals (e.g. dips and parasite treatments), and are modelled using minimum, mid-range and maximum emission factor values from the published scientific literature sourced by Edwards-Jones *et al*. (2009).

A-1.3 Stock data and organic nitrogen

The Bangor University model estimates direct and indirect emissions from livestock on a monthly basis, to account for the effect on the carbon footprint of changes in animal numbers and emissions categories as livestock enter, grow, and leave the defined farm boundary during the course of the business year. This also allows the investigation of differences in management efficiency (expressed as fattening times) between enterprises. Where a farm houses its livestock for part of the farming year, the model calculates the emissions from, and nutrient content of, manure and bedding materials from housed stock. Nitrogen excretion rates are based on the relevant IPCC emission factors for farmers' stated manure-handling methods.

A-1.4 Nitrous oxide emissions

Nitrous oxide (N_2O) has a powerful heating effect on the atmosphere, and is produced when microbes break down certain nitrogen compounds under suitable conditions. On-farm sources of N_2O include direct emissions from manure management, soils receiving N, and managed organic soils, and indirect emissions; they are calculated in this report using the standard IPCC method (IPCC, 2006).

Direct N_2O emissions from manure management are calculated from total N entering the system using IPCC Tier 1 emission factors (IPCC, 2006). This section takes account of the proportion of nitrogen in stored waste materials (animal manure and bedding material) that are emitted directly as N_2O.

Direct N_2O emissions from soil are calculated from total N added to soils in the form of mineral or manure fertilisers, crop residues, and deposited urine and faeces, and broken down by soil microbes. This section uses IPCC Tier 1 emission factors specific to each N source and stock type (IPCC, 2006), and includes the range of uncertainty stated by the IPCC.

Direct N_2O emissions from managed organic soils are calculated from the total area of grazed organic soils on each farm (which for the purposes of the footprinting method are classified as 'managed'). Peaty and peat-derived soils emit 'background' levels of N_2O, due to their high levels of biological activity, particularly when managed. An emission factor of 0.25 kg N_2O-N/ha/yr is used here, representing a UK-specific value derived from modelling of peat soils emissions in the Welsh and Scottish uplands (SEERAD, 2007).

Indirect N_2O emissions are calculated from the amount of nitrogen which may be volatilised as ammonia (e.g. from applied mineral N fertilisers and applied and stored manures), or lost via leaching or runoff to the wider environment when applied to soil. Standard IPCC Tier 1 emission factors and equations for the loss from each type of nitrogen application are used to calculate emissions.

A-1.5 Methane emissions

Methane (CH_4) is emitted from ruminant animals directly from their gut during food digestion (enteric fermentation), or indirectly from their excreta. Livestock CH_4 emissions in the field and from stored manures are computed using IPCC equations, and emissions factors given in IPCC (2006) and Baggott *et al*. (2007).

A-1.6 Emissions from liming

When lime is applied to soils, some CO_2 is released. This model calculates the carbonate-content of lime and lime-containing applications to soil and converts it to CO_2-equivalents, reporting a 50 % uncertainty range, as required by IPCC and PAS 2050:2011.

A-2 Beyond PAS 2050: carbon sequestration estimates

Using the footprinting questionnaires, participating farmers were asked to indicate the extent, type and management of tree cover, soil, and relevant habitats on their holdings. The resulting information was used to calculate carbon sequestration (i.e. addition to long-term stocks in woody biomass or soils) in units of metric tonnes of C sequestered per hectare per year (t C/ha/yr), then converted to an offset against the farm GHG footprint, given in tonnes CO_2-equivalent (t CO_2e/ha/yr).

To calculate carbon sequestration levels, it is first necessary to estimate growth rates for different species of trees on the farm. The Forestry Commission yield class tool, "Ecological Site Classification" (Forestry Commission, 2001) was used to estimate tree growth, based on soil types, altitude and climate. This report includes modelled carbon sequestration for trees (woodland, plantation, parkland and isolated trees), hedges and soils, as described by the farmer.

There is some scientific uncertainty surrounding both published tree growth rates (especially for mixed-species woodlands and plantations), and IPCC expansion factors used to calculate total biomass. Uncertainty is included throughout the sequestration calculations in the same way as for the footprint calculations, by presenting minimum, mid-range, and maximum estimates of sequestration.

A-2.1 Woodland and tree plantations

Carbon may be sequestered in woodland and plantations within living trees (above- and below-ground biomass), deadwood, litter, and soil. Following IPCC (2006), this method calculates the biomass increment in trees according to their species or species mix, age, and planting density for each separate woodland parcel, growing at the average yield class estimated for the farm. Annual increases in deadwood and litter are calculated for newly-planted woodlands, but are considered by IPCC (2006; Tier 1 calculations) to be in equilibrium in older woodlands (i.e. no net gain of deadwood or litter). Soil carbon is also considered to be in equilibrium using Tier 1 calculations. The carbon content and any associated changes in below-ground biomass are calculated for any wood harvested (e.g. firewood). Finally, the net balance between these woodland components is calculated to give an estimate of annual woodland carbon sequestration.

A-2.2 Isolated trees

'Isolated' trees are defined as trees in parkland, emergent trees in hedgerows, and any other trees not found in woodland. Free-grown trees grow more quickly than densely-planted trees, so each tree is modelled individually. Isolated broadleaves are modelled as oaks (Jobling and Pearce, 1977), following IPCC (2006) equations for above- and below-ground biomass. The carbon content of any harvested wood is subtracted from the carbon storage total.

A-2.3 Hedges

Estimates of growth or biomass for hedgerows are currently unavailable. This report calculates the total area and height of hedges, using farmers' mapping of length and width. Where hedges are flailed in the sample year, they are considered to be flailed to a standard height and width, therefore their carbon increment is considered to be in equilibrium for that year. Hedges not flailed within the sample year are modelled as an equivalent area of established short-rotation poplar coppice, including below-ground biomass (Laureysens *et al*., 2003), giving an estimated mid-range sequestration rate of 6.37 t C/ha/yr (minimum to maximum range of 2.20 to 11.40 t C/ha/yr).

A-2.4 Ungrazed peat wetlands

Areas of ungrazed peat wetland are modelled using sequestration rates from Watson *et al*. (2000), giving an estimated mid-range sequestration rate of 0.04 t C/ha/yr (minimum to maximum range of 0.02 to 0.05 t C/ha/yr). Ungrazed peat wetlands are excluded from managed organic soils N_2O calculations; grazed peat wetlands are included in calculations for permanent grassland (below).

A-2.5 Grassland and soils under grassland

Modelling carbon exchanges in grasslands is complex, and involves either measuring very small and spatially variable soil C stock changes over decades (Hungate *et al*., 1996; Conant *et al*., 2001), or full carbon accounting by measuring the considerable C fluxes in and out of the grass and soil system, which also vary over space and time (Jones and Donnelly, 2004).

To determine the likely range of sequestration that might be possible in Welsh farmed grasslands, a review of grassland carbon sequestration studies was undertaken by Taylor *et al*. (2010). The report concluded that many studies were not relevant to Welsh grasslands, largely due to differences in experimental design, cropping and management scenarios, geography and climate, or system boundaries of the study; further details are given in Taylor *et al*. (2010). Five studies were considered suitable for referencing in Welsh carbon sequestration calculations (Fitter *et al*., 1997; Vleeshouwers and Verhagen, 2002; Soussana *et al*., 2004; Janssens *et al*., 2005; Dawson and Smith, 2007). Studies of sequestration in peat soils under permanent grassland are uncommon, and available studies considered grassland that had been drained more recently (i.e. since 1990; Freibauer *et al*., 2004; DEFRA, 2009) than the sample farms in this report. Light grazing may not affect carbon sequestration in blanket peat habitats (Garnett *et al*., 2000). Given the lack of concrete evidence on the effect of organic (peat and peat-derived) soils under different grassland conditions on emissions, these soils are incorporated into the following summary of study findings across a range of soil types.

Average carbon sequestration across the five selected studies gave a mid-range of 0.45 t C/ha/yr; published estimates varies from a net loss of 2.31 t C/ha/yr (from drained organic soils; Soussana *et al*., 2004) to a net carbon gain of 2.9 t C/ha/yr (in species-poor peaty gley grassland; Fitter *et al*., 1997). High variation in estimated carbon balance was observed within these five studies, for example due to different methods, grassland types, management regimes, and period of observation, and there is still considerable uncertainty surrounding carbon sequestration rates under grasslands. Additionally, the scientific literature is unclear whether sequestration rates change over time to reach equilibrium after a period as short as ten years (Janzen *et al*., 1998), or whether sequestration may be unlimited (Six *et al*., 2002). The carbon sequestration calculation method used in this report drew values from UK permanent grazed grassland, grazed peatland and cropland in Janssens *et al*. (2005), giving a mid-range estimate of 0.24 t C/ha/yr (minimum to maximum range, 0.04 to 0.44 t C/ha/yr), and representing a conservative estimate of typical Welsh sequestration rates. These rates are lower than those quoted in the other four studies, but given the current level of uncertainty in sequestration rates across different situations and over time, a conservative approach is advisable.

JULY 2015

GLASTIR MONITORING & EVALUATION PROGRAMME

FINAL REPORT – Annex 8C

Socio-economic evaluation of the Glastir Efficiency Grant Scheme

Helen Taft, Paul Cross and Dave Chadwick

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CYNGOR YMCHWIL YR AMGYLCHEDD NATURIOL

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Further copies of this report are available from: GMEP Office, Centre for Ecology & Hydrology, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW.

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

This report focuses on the Glastir Efficiency Scheme (GES), previously known as the Agricultural Carbon Reduction and Efficiency Scheme (ACRES). The GES provides grants to farmers and land managers to improve farm management, particularly to improve Slurry and Manure Efficiency (SME), Energy Efficiency (EE) and Water Efficiency measures (WE). Through these grants, GES aims to improve resource use efficiency and reduce the environmental effects of the agriculture sector, and in particular, the dairy sector. This study surveyed recipients of GES grants and evaluated the socio-economic impact of the scheme at a regional scale. We report herein on the following criteria:

- Grant allocation – the current status of approved grants, and grants in progress;
- Economic outputs and efficiency of farms;
- Labour – how employment has been impacted;
- The wider economy – farm expenditure, what money is being spent on imports and tax.

Of the 157 Glastir Efficiency Scheme participants in June 2014, 120 surveys were completed for analysis and discussion in this report. A total of 383 GES grants were approved and of these, 327 were awarded for SME, 39 for EE and 17 for WE measures.

Current status of GES grants

Of the 120 completed surveys, 59% of respondents farmed on LFA cattle and sheep farms, a further 30% on dairy farms, 7% of farms were described as 'other' consisting of various main farm types and 4% of farms did not specify. A total of 305 grants were approved for farms in the survey. EE grants accounted for 9.2% of total approved grants, 7.9% were assigned to dairy farms, 1.3% to 'other' farms and none to LFA cattle and sheep. Grants awarded to LFA cattle and sheep farms were nearly all for SME (174 of the 179 approved grants).

The total monetary value of the paid grants amounted to £1,006,490. No WE grants were in progress by July 2014. SME grants accounted for £883,000 and EE (£123,490). Lowland dairy farms received the largest grant per farm on average (£16,102), compared to £9,855 for LFA cattle and sheep farms and £8,732 for LFA dairy farms. The smallest size category of farms (0-19.9 ha) received the smallest average grant of £8,370.

Economic impacts of GES

Farm sales

As a consequence of the GES grants more than a quarter (28%) of farm businesses reported a general increase in sales with 51% reporting an increase in sales from farming specifically.

Farm expansion

The majority of members disagreed (71%) that expansion opportunities had been curtailed by GES.

Allocation of farm spending

More than 90% of respondents agreed that GES had encouraged them to undertake new capital investments. Similarly, the majority of farmers (83%) agreed that access to GES increased their scale of planned investment. Over 87% of farmers agreed that their funded project would not have happened without the grant. This suggests that GES has provided a useful tool for delivering economic development and encouraging new on-farm initiatives.

Impacts on labour

GES grants increased the annual workloads of existing employees, family members and farmers per farm per year. The workload for new employees and contractors decreased. The decrease in annual workload for contractors was greatest on LFA sheep and cattle farms. The farm type that saw the greatest increase in annual labour was lowland dairy farms.

Impacts on the wider economy

Farm expenditure

According to 77% of respondents, perceived farm viability to have increased as a consequence of receiving the grant, with 21% reporting no change. This appears to have been driven by the effect of GES grants on increased expenditure, with 52% reporting increases in expenditure. Of the 59 farms in LFA sheep and cattle, 43 reported a positive impact on changes in expenditure due to the grants.

Increased farm expenditure was spent within Welsh industries (68%), Welsh households (18%) and taxes (8%) with the remaining 6% unaccounted for due to respondent survey error.

Expenditure allocated to imports

Of the expenditure that respondents allocated to imported materials, the majority was for building materials (49%), and machinery and equipment (32%). Of these imports, 57% of spending was within the UK and Ireland; 8% reported a mixture of spending throughout the UK and European countries and 13% imported products from other European countries.

Financial effects

According to 71% of respondents, GES grants have promoted a beneficial effect on farm suppliers across all farm types. Similarly, 44% of respondents stated that farm customers and clients had experienced beneficial financial effects from the grants.

Recommendations

There were no grants in progress according to the progress report (WG, 2013). The number of WE grant types was considerably lower than for SME and EE, and it may be useful to further understand the drivers for this lack of uptake for WE grants. There were very few farms of <50 ha within the GES. There may be the potential for policy makers to consider developing grants suitable for smaller sized farms.

2 INTRODUCTION

2.1 Background to the Glastir Efficiency Scheme

The Glastir Efficiency Scheme (GES, formerly known as ACRES, the Agricultural Carbon Reduction and Efficiency Scheme) is a component of a wider Welsh Government agri-environment initiative known as Glastir. The Glastir scheme was set up as a means of merging the four existing Welsh Axis 2 agri-environment schemes (Tir Cynnal, Tir Gofal, Tir Mynydd, and the Organic Farming Scheme), into a new, single whole-farm sustainable land management initiative for farmers and land managers across Wales (WG 2014). This merger constitutes part of the Wales Rural Development Plan 2007-2013, and was made in response to the European CAP Health Check proposals (Rose 2011). The changes were driven by the need to move away from agri-environment schemes driven by paying farmers for production, to one emphasising the need for provision of environmental goods and services (known as Ecosystem Services), not usually supplied through standard market mechanisms (Wynne-Jones 2013; Reed *et al.* 2014). Under the new scheme, farmers and land managers are paid by the Welsh Government on behalf of society, for the provision of Ecosystem Services (e.g. climate change mitigation and adaptation; management of water quality and quantity; soil quality enhancement; facilitating recreational access; and strengthening social capital; (Reed *et al.* 2014). Glastir attempts to meet the need for greater integration between schemes to attain a wider and more efficient delivery of environmental services for society (Reed *et al.* 2014), whilst simultaneously improving farmers' connections to markets and strengthening rural development measures under the Welsh Rural Development Plan (WG 2014) and Axis 2 of the Common Agriculture Policy (CAP) Rural Development Pillar (Rose 2011).

2.1.1 *Glastir objectives*

The stated objectives of the Glastir scheme are (Rose 2011):

- To provide balance between the need to produce food and protect the environment;
- To be accessible to all;
- To support biodiversity, climate change and water outputs; and
- To spread money for implementing agri-environment work more widely among farmers.

2.1.2 *Glastir scheme structure*

Glastir is a five-year, whole-farm, sustainable land management scheme available to farmers and land managers across Wales. It comprises five elements: Glastir Entry, Glastir Commons, Glastir Advanced, Glastir Efficiency Grants, and Glastir Woodland Creation and Management (WG 2014). Each component is summarised below:-

Glastir Entry (All-Wales Element, AWE)

Glastir Entry is the Welsh foundation level agri-environment scheme, open to all farmers who have full management control of more than three hectares of land for the entire length of the five-year contract. Participation in the Entry level is required for eligibility to participate in all other scheme elements, with the exception of the Common Land and Woodland Creation elements. The whole-farm entry-level component is based on a points systems, where a combination of compliance with compulsory requirements, and customised choices of optional management activities, allow farmers to build up enough points to exceed the minimum eligibility threshold. It comprises three main parts: cross-compliance, the Whole Farm Code (WFC), and management options.

Cross-compliance constitutes a set of compulsory requirements that apply to all agricultural land on the farm holding. Land managers must meet standards of Good Agricultural and Environmental Condition (GAEC), concerning the protection of soil, habitats and landscape features. Additionally, cross-compliance requires farmers to meet a range of Statutory Management Requirements (SMRs) relating to the environment, public and plant health, animal health and welfare, and livestock identification and tracing. Adherence to the WFC on all land included in the contract, is a further compulsory element of Glastir Entry. The WFC comprises standards of good environmental practice, in terms of slurry spreading, manure and silage storage, rock extraction and vegetation burning. Regarding management options, farmers are required to select individual options from a list or choose from a package of options which deliver the greatest environmental benefits within a particular region.

Further to Glastir Entry, four higher level (optional) elements of the scheme are currently available:

Glastir Advanced

Glastir Advanced (previously known as the Targeted Element) was designed as an attempt to overcome reported shortcomings of previous higher-level agri-environment schemes, which were thought to have been too disparate and poorly focused to deliver significant environmental benefits (WG 2014). Candidate farms are selected for eligibility under the current Advanced scheme, on the basis of their potential for delivering environmental benefits in the key areas of soil carbon management, water quality, water quantity management, biodiversity, the historic environment, and improved access. Priority is given to applicants with the highest resulting score, based on the potential to deliver the greatest overall environmental benefit from their land.

Glastir Commons

The Glastir Commons scheme (previously named the Common Land element), was designed for farmers with Common Land rights, who are also members of a Grazing/Commoners' Association. Payments are made for adhering to either a closed grazing period over three months of the winter period (1^{st} November to 31^{st} March), or managing sward height throughout the year by varying stocking densities. The Glastir Commons component aims to deliver key environmental benefits relating to peatland carbon and water storage, which are important functions of Welsh Common Land.

Glastir Efficiency Scheme

Previously known as the Agricultural Carbon Reduction and Efficiency scheme (ACRES), the Glastir Efficiency Scheme (GES) provides capital grants to farmers and land managers to improve resource use efficiency and reduce the environmental imnpacts, including greenhouse gas emissions, from the agriculture sector. The scheme originally prioritised renewable energy generation outcomes, but this aspect was removed after being superseded by the UK-wide Feed in Tariffs (April 2010) and Renewable Heat Incentives (July 2013). At present, grants contributing to 40-50% of costs are available for a specific range of capital works relating to reducing on-farm energy use (Energy Efficiency), management of animal excreta and associated waste (Slurry/ Manure Efficiency), and minimising waste water generation (Water Efficiency). Grants currently available are particularly aimed at encouraging dairy farmers to take part in agri-environment schemes, in some cases for the first time.

Glastir Woodland Creation and Management

Originally functioning as a stand-alone initiative for both farmers and other woodland owners, the Glastir Woodland Creation and Management Scheme was integrated into the Glastir Scheme in January 2013. It was developed in response to the Climate Change and Land Use Report (Glastir Independent Review Group, 2011). This element of Glastir currently provides financial support to both farmers and non-farmers for managing existing continuous woodlands larger than 0.5 ha in size. Capital and multi-annual payments are provided in support of managing existing woodland and creation of new woodland, including income foregone as a result of change in land use. Payments are prioritised for delivering the following: managing soils to help conserve carbon stocks and reduce soil erosion; improving water quality; managing flood risks; conserving and enhancing wildlife and biodiversity; managing and protecting landscapes and the historic environment; and providing new opportunities to improve access and understanding of the countryside.

2.2 **Socio-economical trickle down impacts in rural areas**

Rural areas in Wales account for 82% of the total area and contain one third of the total population (OECD 2011). Agri-environment schemes are implicit in their support of agricultural economies, reflecting an understanding of the defining relationship between farming and the rural landscape (Davies-Jones 2011). Agriculture plays a dominant role in land-use, and in some regions it continues to play a pivotal role in the local economy (OECD 2010). Without adequate financial support, farmers may be unable to continue to farm, resulting in a loss of skills and neglected land, with subsequent environmental and socio-economic implications beyond the farm gate (e.g. less money for the local economy, movement of the young population sector to cities). Consequently, this poses a threat to the Welsh tourist industry, culture and language (Davies-Jones 2011).

Glastir seeks to move the basis of payment for farms from production-based to environmental outcome-based payments, whereby farmers are paid for providing environmental goods and services (Wynne-Jones 2013). Agricultural policies are important for those who obtain their livelihood from the agricultural sector, not only from farming but also in related upstream and downstream industries, or through activities associated with agriculture (e.g. forestry and tourism). The significance of agriculture for the rural economy can be amplified through linkages to agro-food industries and employment in these industries (OECD 2010; OECD 2011). The trickledown effect of agriculture in rural areas is important for the continuation of a sustained rural community, one which can potentially be enhanced by agricultural policies such as Glastir, by promoting 'sustainable intensification' on farms (Caballero 2011). There are many potential direct and indirect trickledown effects. A simple example offered by Glastir would be the construction of a new manure shed as a result of extra funding provided by the GES, whereby raw materials are bought locally, and local workers contracted in to construct the manure shed. On a larger scale, better land management could lead to increased biodiversity, increased tourism and increased spending in local communities. The key feature is that on-farm developments should have a beneficial trickledown effect to the wider rural community.

3 PROJECT AIMS AND OBJECTIVES

This study aimed to improve understanding of the current status of grants within GES and to evaluate the wider economic benefits to farmers and the Welsh economy.

3.1 Objectives

The key objectives of this project were:

- to summarise the current status of approved GES grants, and grants in progress;
- to assess the impact of GES grants on economic outputs and efficiency of farms;
- to determine the effect of GES grants on employment ;
- to better understand the impacts of GES grants on the wider economy.

4 METHODS

4.1 Survey structure

The survey comprised 33 questions, which aimed to assess the effect of GES grants on economic output and efficiency, farm spending, farm labour and the wider economy for each farm. To alleviate respondent burden when completing the survey, 25 Likert Scale questions were included, while the remaining eight questions were of an open-ended format. Where possible, answers to open-ended questions were grouped for the purposes of analysis. A copy of the survey is provided in Annex 1 (at the end of this report). All proportions were rounded-up to the nearest whole integer.

4.2 Data collection

All farmers from the 157 GES-participating farms were invited to complete the survey, initially by postal contact, followed by telephone calls made within a month of initial contact. Data was collected between November 2013 and July 2014.

Farms types and sizes follow the DEFRA categorisation of robust farm types (DEFRA 2010).

5 RESULTS

5.1 Participant response rate and characteristics

The survey participation rate attained 75% of the total GES member population (120 farmers agreed to complete the survey, from the original 157 Glastir Entry members invited).

5.1.1 *GES-participating farms*

Of the 157 farms awarded GES grant funding, the majority were LFA cattle and sheep farmers (93 farms), while the remainder were primarily dairy farmers (34 lowland dairy, and 14 LFA dairy farms). Only 16 farms were designated to other farm type categories, including 4 farms of unspecified type (Fig. 5.1).

Only three participating farms were smaller than 50 hectares. Most farms were 50 to 199.9 ha in size (92 farms), while the remainder were more than 200 ha in size (58 farms; Fig. 5.2). The average size of surveyed farms (189 ha) was larger than both the average farm size for the 2378 farms in the Glastir Entry level scheme (93 ha), and the average size of all Welsh agricultural holdings (41 ha; (WG 2014)).

5.1.2 *Survey-participating farms*

The distribution of survey respondents amongst both farm type and farm size categories closely matched the distribution of GES-participating farms, resulting in a robust representation of almost all classes of farms (Fig. 5.2.). In terms of farm type, LFA dairy and lowland cattle and sheep farms were slightly under-represented (approximately half of farmers from each group took part in the survey). In the farm size categories, the larger farms were slightly less well represented in percentage terms than the smallest farms (up to 19.9 ha in size).

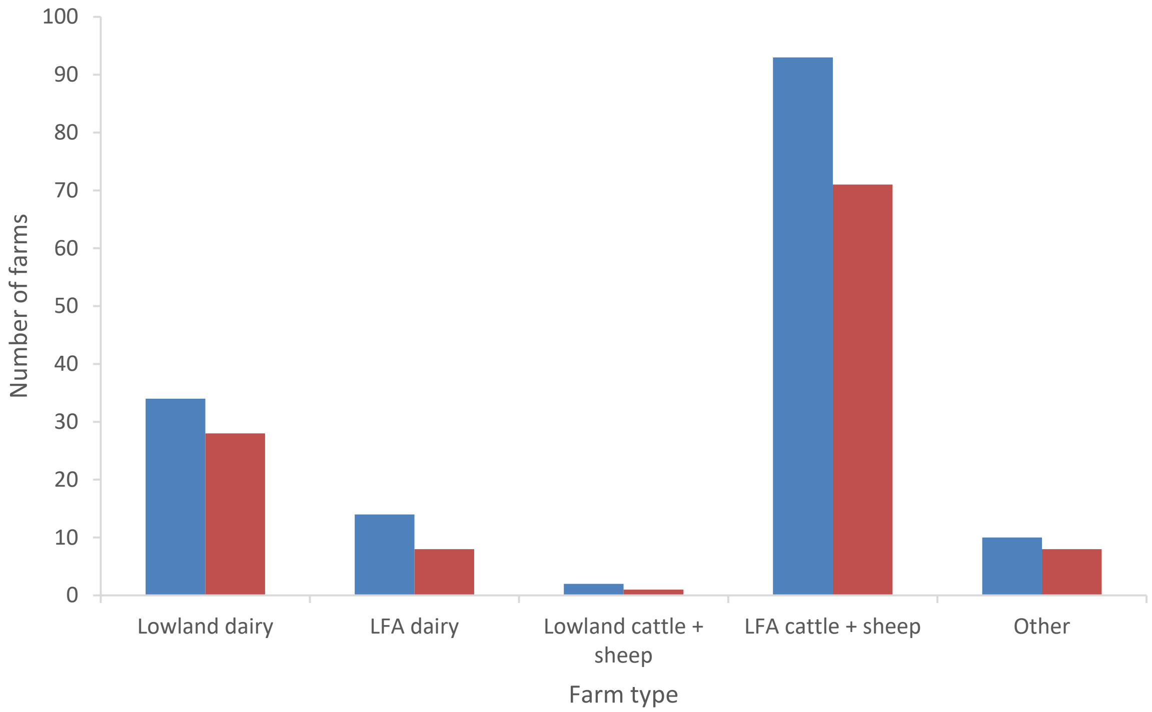

Figure 5.1. Number of participating farmers in GES (blue bars) and the survey sample (red bars), by farm type. ‘Other’ farm types include mixed livestock and cropping, and specialist poultry farms.

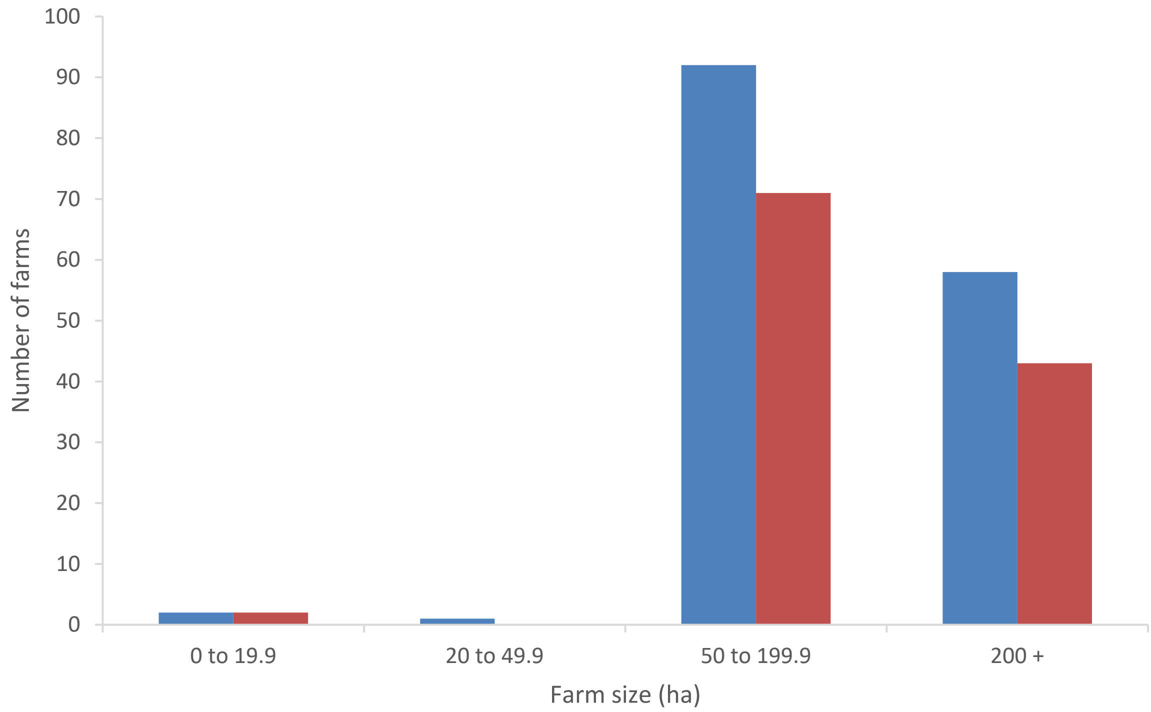

Figure 5.2. Number of participating farmers in GES (blue bars) and the survey sample (red bars), by farm size (ha).

5.2 Employment characterisation

The majority of those employed on the farms were family workers, with a strong bias towards full-time male workers (34% of all workers; Table 5.1.). Full-time male workers worked the longest average hours per week (71 hours), and were employed on the largest number of farms (113 farms). Full-time female family workers worked the second-longest hours per week (50 hours), but in lower numbers (49 workers), and on fewer farms (43 farms). In addition to family workers, many farms also employed additional (again, predominantly male) full-time and part-time workers. In contrast to family workers, female employees worked a similar number of hours per week to male employees.

Both family and non-family seasonal workers were also employed by farms, but made up a much smaller proportion of workers than full or part-time workers.

Table 5.1: Proportion of workload by employee type

Employee type	Total employees	Farms with employee type	Average hours per employee per week
Full-time male family workers	181	113	71
Full-time female family workers	49	43	50
Part-time male family workers [1]	51	37	29
Part-time female family workers [1]	46	37	19
Seasonal male family workers	30	16	-
Seasonal female family workers	10	10	-
Full-time male employees	45	25	46
Full-time female employees	4	3	43
Part-time male employees [1]	71	36	18
Part-time female employees [1]	2	2	22
Seasonal male employees	34	17	-
Seasonal female employees	5	4	-

Notes: [1] *Part-time workers are assumed to work up to 30 hours per week.*

5.3 Grant allocation

5.3.1 *Approved grants*

The grants allocated to farms were categorised into the following three types: Slurry and Manure Efficiency (SME); Energy Efficiency (EE) and Water Efficiency (WE). A total of 383 grant requests were approved across the 157 GES participants (Fig. 5.3 and 5.4). Of these, 327 were awarded for SME measures, 39 were awarded for EE measures, and 17 were awarded for WE measures. Most individual grants were awarded to LFA cattle and sheep farms (58.7%), with a further 23.0% awarded to lowland dairy farms (Fig. 5.3). Farms of 50 to 199.9 ha in size received the greatest number of grants (61.6%); the majority of remaining grants were allocated to farmers > 200 ha in size (33.4%; Fig 5.4).

A total of 305 grants were approved across the survey sample farms, of which the majority were SME grants (86%; Table 5.2). With respect to farm size, the largest portion of grants had been approved for larger farms, primarily in the 50 to 199.9 ha size category (62%). Most of the approved grants were allocated to LFA cattle and sheep farms (59%), while lowland dairy farms received 23% of grants.

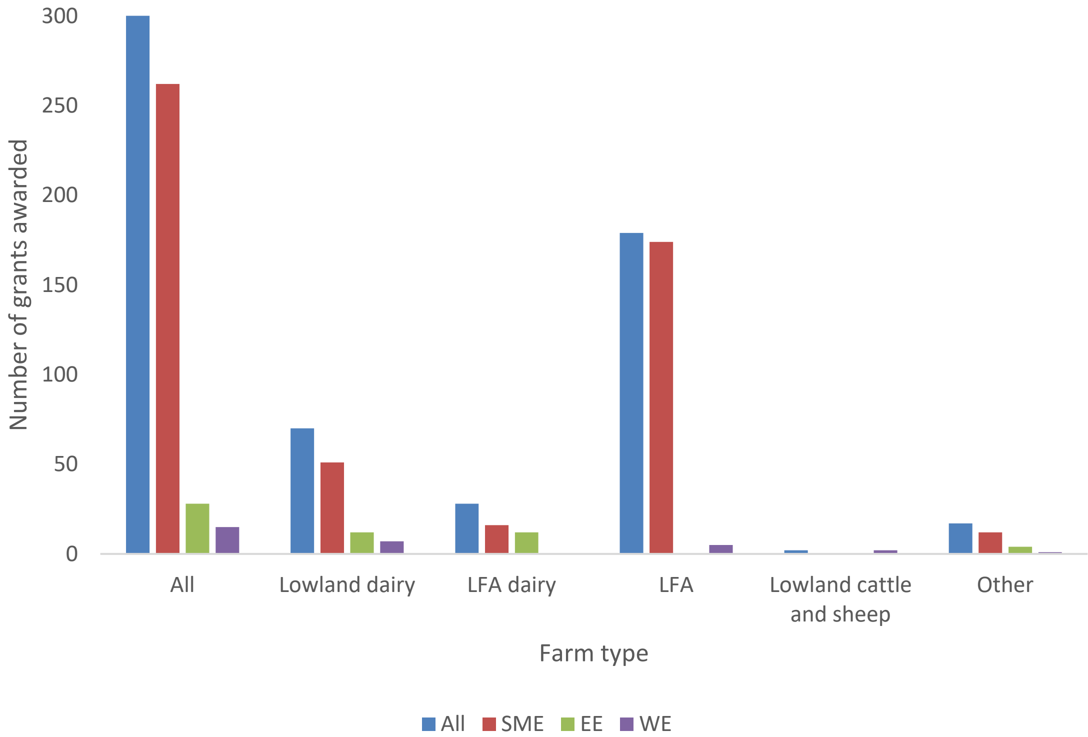

Figure 5.3. Grants approved for GES-participating farms, by farm type and grant type. Slurry and Manure Efficiency (SME); Energy Efficiency (EE) and Water Efficiency (WE)

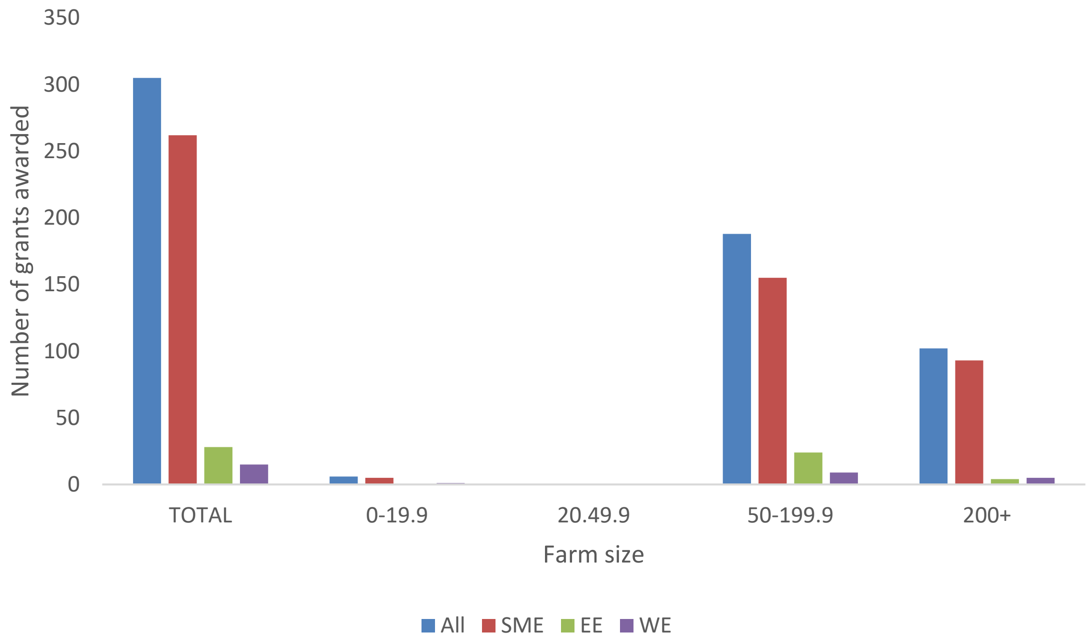

Figure 5.4. Grants approved for GES-participating farms, by farm size and grant type. Slurry and Manure Efficiency (SME); Energy Efficiency (EE) and Water Efficiency (WE)

Table 5.2. Grants approved by farm size and type (with proportion of total approved grants in parentheses)

Farm size and type	**All**	**SME**	**EE**	**WE**
TOTAL	305 *(100%)*	262 *(86%)*	28 *(9%)*	15 *(5%)*
0 to 19.9 ha	6 *(2%)*	5 *(2%)*	0 *(0%)*	1 *(0.3%)*
20 to 49.9 ha	0 *(0%)*	0 *(0%)*	0 *(0%)*	0 *(0%)*
50 to 199.9 ha	188 *(62%)*	155 *(51%)*	24 *(8%)*	9 *(3%)*
200+ ha	102 *(33%)*	93 *(30%)*	4 *(1%)*	5 *(2%)*
Unknown size	9 *(3%)*	9 *(3%)*	0 *(0%)*	0 *(0%)*
Lowland dairy	70 *(23%)*	51 *(17%)*	12 *(4%)*	7 *(2%)*
LFA dairy	28 *(9%)*	16 *(5%)*	12 *(4%)*	0 *(0%)*
LFA cattle and sheep	179 *(59%)*	174 *(57%)*	0 *(0%)*	5 *(2%)*
Lowland cattle and sheep	2 *(1%)*	0 *(0%)*	0 *(0%)*	2 *(1%)*
Other	17 *(6%)*	12 *(4%)*	4 *(1%)*	1 *(0.3%)*
Unknown type	9 *(3%)*	9 *(3%)*	0 *(0%)*	0 *(0%)*

5.3.2 *Grants in progress*

By October 2013, the overall percentage of grants in progress as a proportion of approved grants was 33% (Table 5.3; (WG 2013)). More than half (57%) of approved EE grants were in progress by the same date, but only 32% of approved SME grants. No approved WE grants were in progress. No EE grant money had been paid to LFA cattle and sheep farms. Overall, the majority of grants in progress were received by farms in less favoured areas (LFA) (70%), and by farms of 50 to 199.9 ha in size (68%).

Table 5.3. Grants in progress (as a proportion of category's approved grants in parentheses)

Farm size and type	All	SME	EE
TOTAL	100 *(33%)*	84 *(32%)*	16 *(57%)*
0 to 19.9 ha	2 *(33%)*	2 *(40%)*	0 *(0%)*
20 to 49.9 ha	0 *(0%)*	0 *(0%)*	0 *(0%)*
50 to 199.9 ha	68 *(36%)*	53 *(34%)*	15 *(63%)*
200+ ha	27 *(26%)*	26 *(28%)*	1 *(25%)*
Unknown size	3 *(33%)*	3 *(33%)*	0 *(0%)*
Lowland dairy	19 *(27%)*	13 *(25%)*	6 *(50%)*
LFA dairy	13 *(46%)*	6 *(38%)*	7 *(58%)*
LFA cattle and sheep	57 *(32%)*	57 *(33%)*	0 *(0%)*
Lowland cattle and sheep	0 *(0%)*	0 *(0%)*	0 *(0%)*
Other	8 *(47%)*	5 *(42%)*	3 *(75%)*
Unknown type	3 *(33%)*	3 *(33%)*	0 *(0%)*

5.3.3 *Grant money received*

The total monetary value of grants received by October 2013 was £1,006,490, of which £883,000 was awarded as SME grants and £123,490 as EE grants (Table 5.4.). The average grant value awarded per project was £10,988. Lowland dairy farms tended to receive larger grants, with an average of £16,103 per individual grant compared to an average grant value of £9,855 for LFA cattle and sheep farms. Farms with 50 to 199.9 ha of land received the largest average grant of £11,534, with farms of 200+ ha receiving £10,005 on average. Farms in the 0 to 19.9 ha category received the lowest average grant (£8,370).

Table 5.4. Total and average monetary values of grants by grant type, farm type and farm size

Farm size	Total (£)			Average per grant (£)		
and type	ALL	SME	EE	ALL	SME	EE
0-19.9 Ha	16, 741	16, 741	-	8, 370	8, 370	-
20.49.9 Ha	-	-	-	-	-	-
50-199.9 Ha	703, 770	583, 421	120, 348	11, 534	11, 875	8, 827
200+ Ha	258, 658	255, 515	3, 143	10, 005	10, 409	3, 143
Unknown size	27, 324	27, 324	-	10, 228	10, 228	-
Lowland dairy	257, 054	225, 848	31, 205	16, 103	19, 413	4, 775
LFA dairy	89, 759	63, 884	25, 875	8, 732	12, 942	2, 988
LFA c+s [1]	540, 459	540, 459	-	9, 855	9, 855	-
Lowland c+s [1]	-	-	-	-	-	-
Other	91, 897	25, 486	66, 411	10, 606	7, 201	20, 822
Unknown type	27, 324	27, 323	-	10, 228	10, 228	-
Total	1, 006, 493	883, 001	123, 491	10, 988	11, 298	8, 117

[1] *Less favoured area cattle and sheep.*

5.4 Economic impacts of Glastir Efficiency Scheme

By October 2013, 60 of the 120 survey farms had received approved funding for capital investments, and of the 157 farms to whom the survey was sent, a further nine farmers declined to complete the questionnaire as they had not yet received the grant. The following sections describe the impact on the Welsh economy of the Glastir Efficiency Scheme, based up on the 120 completed surveys.

5.4.1 ***Economic outputs and efficiency***

Respondents considered that the GES grants increased the value of sales for 28% of farms, while the majority of farmers (63%) suggested that the value of sales had not changed (Fig. 5.5). Only a small proportion of farmers (3%) said that the value of their sales had decreased since obtaining grants.

When considering the overall impact of GES grants on sales from farming, most farmers reported no change (48%), while a further 33% reported 'little positive impact' and almost a fifth of respondents stated an 'important positive impact' (18.3%) (Fig. 5.6.). Very few farmers said GES grants had had a negative impact on sales (< 1%).

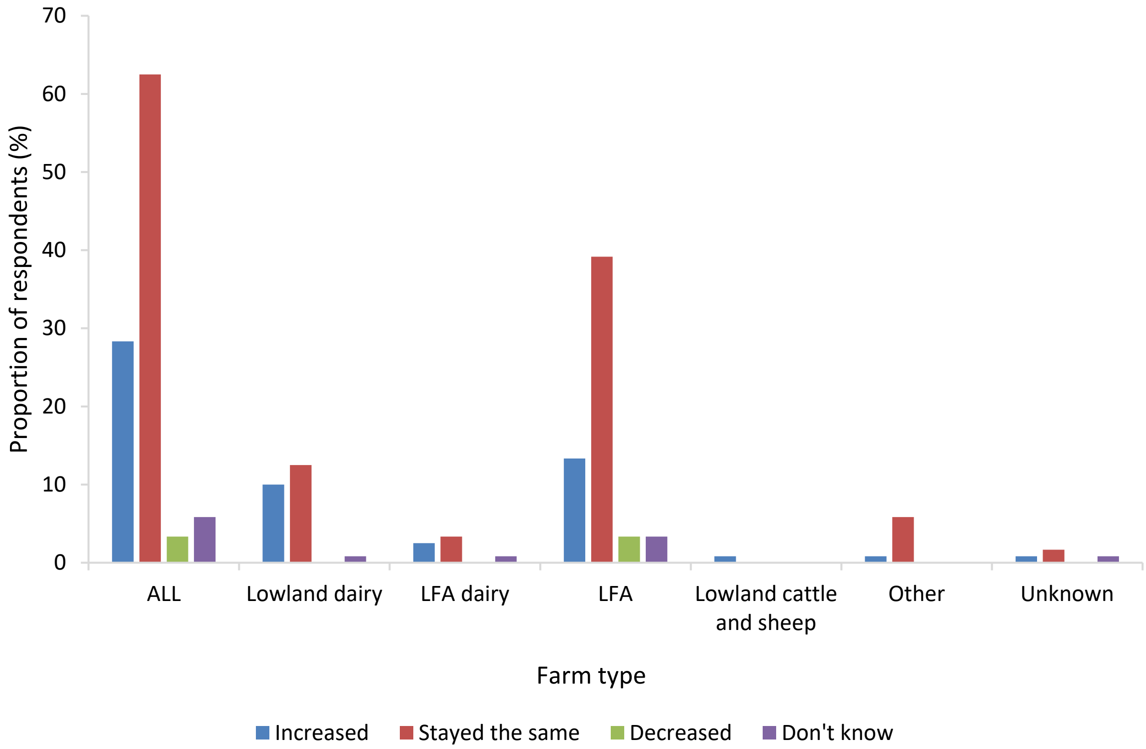

Figure 5.5. Impact of receiving GES grants on the value of sales

5.4.2 ***Allocation of spending***

Access to GES grants appears to have encouraged new capital investment by farmers in all farm type categories (Fig. 5.7). It was agreed by 65% and strongly agreed by 28% that the grant had encouraged them to undertake new capital investments, whilst only 5.9% of farmers disagreed with this statement.

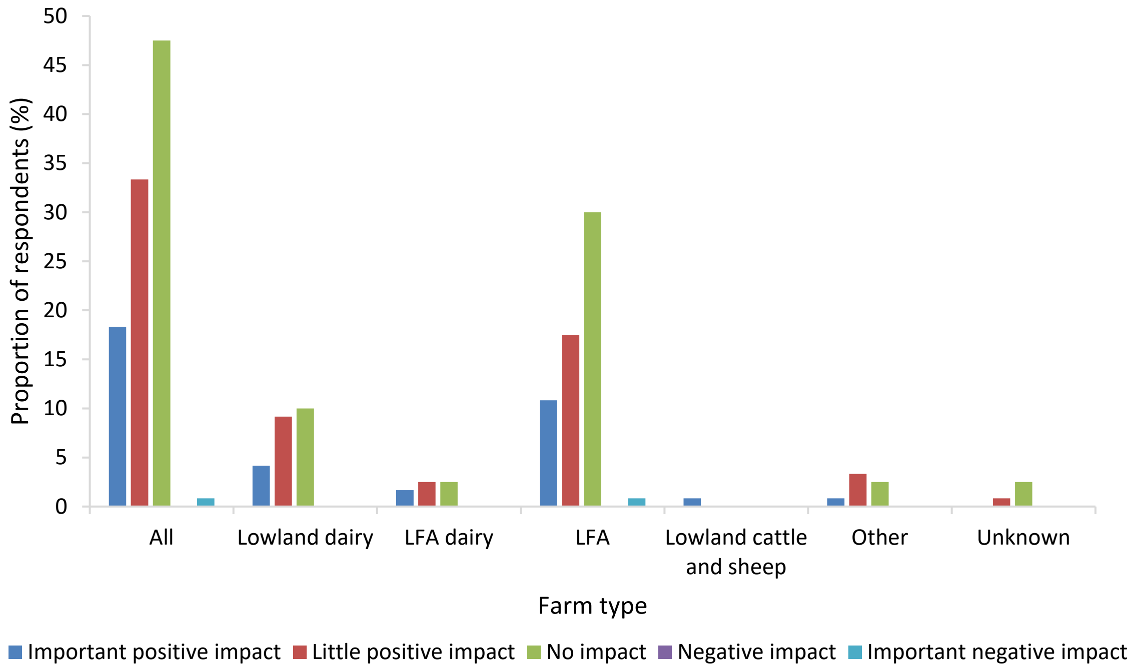

Figure 5.6. Impact of GES grants on sales from farming.

Access to GES grants appears to have helped farmers to increase the scale of their planned investments, with 16% strongly agreeing, and 67% agreeing with the statement 'Access to the Glastir Efficiency Scheme (ACRES) grants encouraged you to increase the scale of planned investments'. Only 12% of respondents disagreed or strongly disagreed with the statement (Fig. 5.8). More than half of the respondents (55%) agreed, and one third (32%) strongly agreed that the funded project would not have happened without the grant, while only 8% of farmers disagreed with that this was the case (Fig. 5.8).

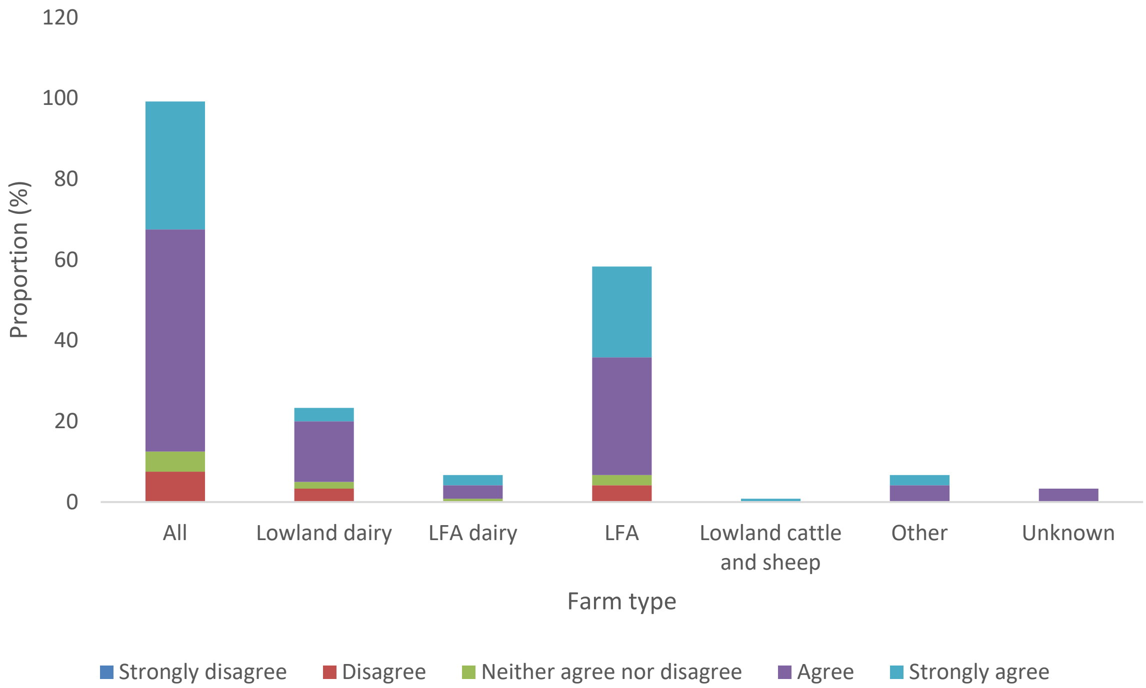

Figure 5.8. Degree of agreement that funded projects would not have happened without receiving GES grants.

More than half of respondents reported the grants having no impact on all but two sectors of farm expenditure. Fertiliser annual expenditure was positively impacted by the grants on 75% of farms (Fig. 5.9). Labour expenditure was positively impacted in 50% of cases, and 40% of contractor expenditure. Negative impacts were reported by a minority of farmers (2-7%, depending on sector), with the largest negative impacts for contractors and building materials expenditures (7% of respondents in both cases), while the least frequently reported negative impact was on veterinary fees (2%).

Only a few respondents were able to provide monetary values for reduced expenditure. Spending on fertilisers was reduced by an average of £3,291 per farm (46 farms; range from

£500-£20,000), on-farm purchases by an average of £2,375 (22 farms), and chemicals by an average of £425 per farm (4 farms).

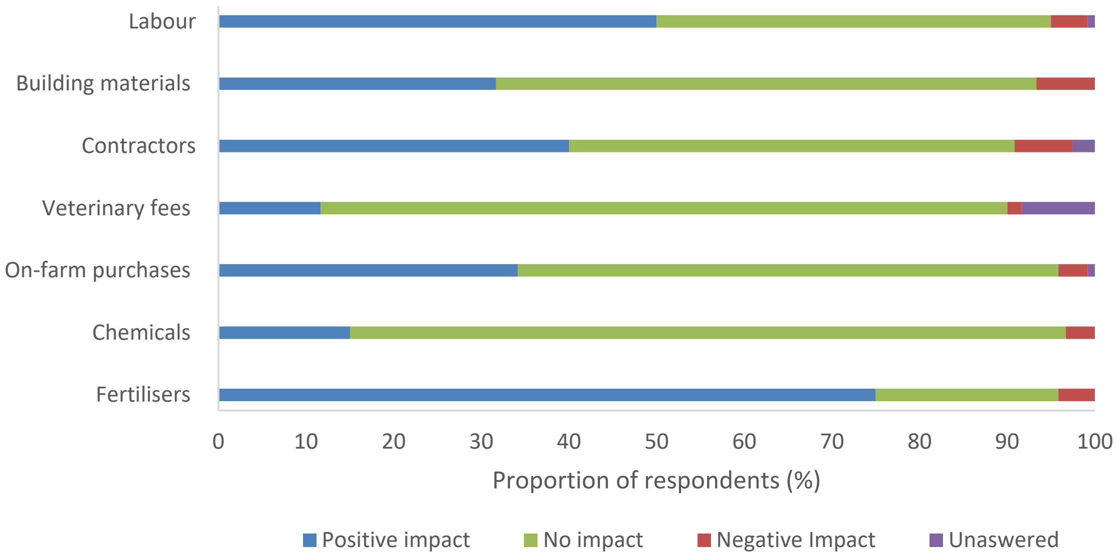

Figure 5.9. Respondents' perception of grant impact on different sectors of on-farm expenditure.

5.4.3 *Impacts on labour*

On average, existing employees, family members and farmers found their annual workloads increased as a result of receiving GES grants, when aggregated across farm types (Fig. 5.10), possibly as a result of on-farm decisions to maximise the proportion of GES funding allocated to material purchases by minimising direct labour costs. In contrast, a net decrease in annual labour-days was experienced by contractors and new employees averaged across all farm types. However, an average decrease in annual labour-days was experienced on LFA cattle and sheep farms (71 farms), for contractors (3.3 labour days per farm per year), and for new employees (0.8 days per farm per year). This appeared to be countered by an annual increase of annual labour-days on lowland dairy farms (28 farms) for both existing employees (10.7 days per farm per year), and for contractors (4.3 days per farm per year).

The impact of grants on labour varied across farm size categories. No change in annual labour-

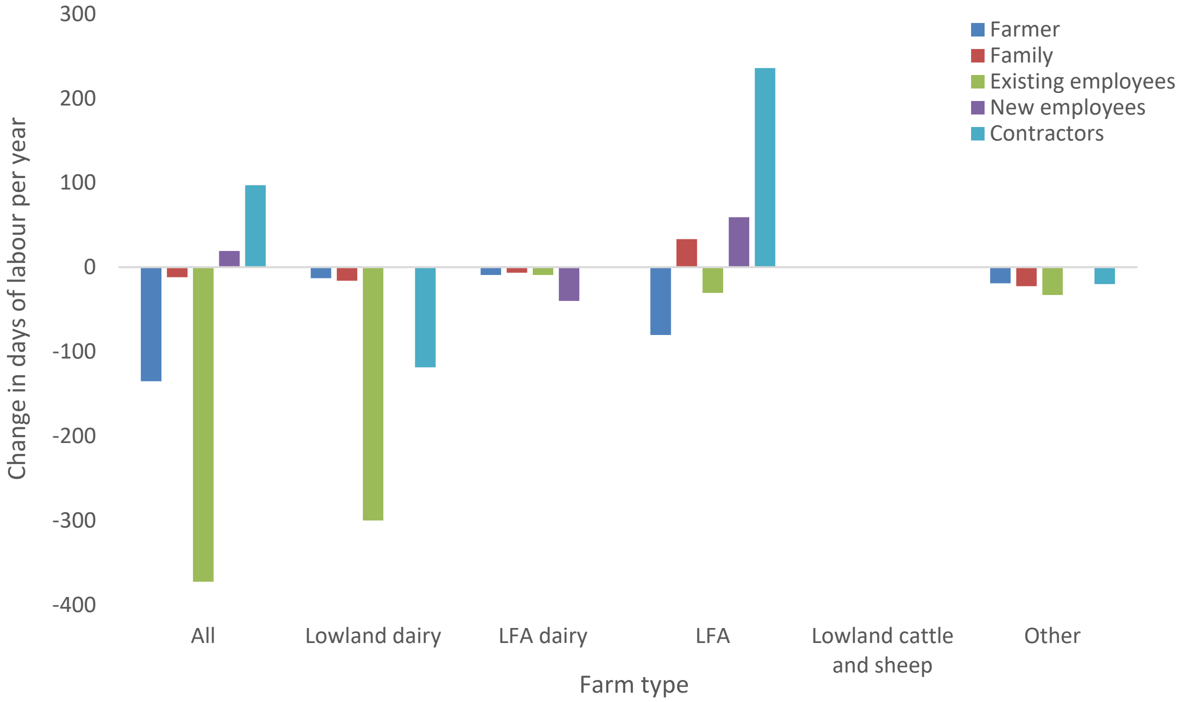

Figure 5.10. Net annual change in days of labour per year by farm type.

days worked was reported from farms of less than 50 ha in size (omitted from Fig. 5.11). Farms of 50 to 199.9 ha in size experienced an overall increase in workload, for all worker categories, and for existing employees in particular (Fig. 5.11). Conversely, farms of more than 200 ha in size showed a decrease in annual labour-days across all categories except for 'existing employees', with contractors losing the greatest number of additional days of labour (5 days per farm per year).

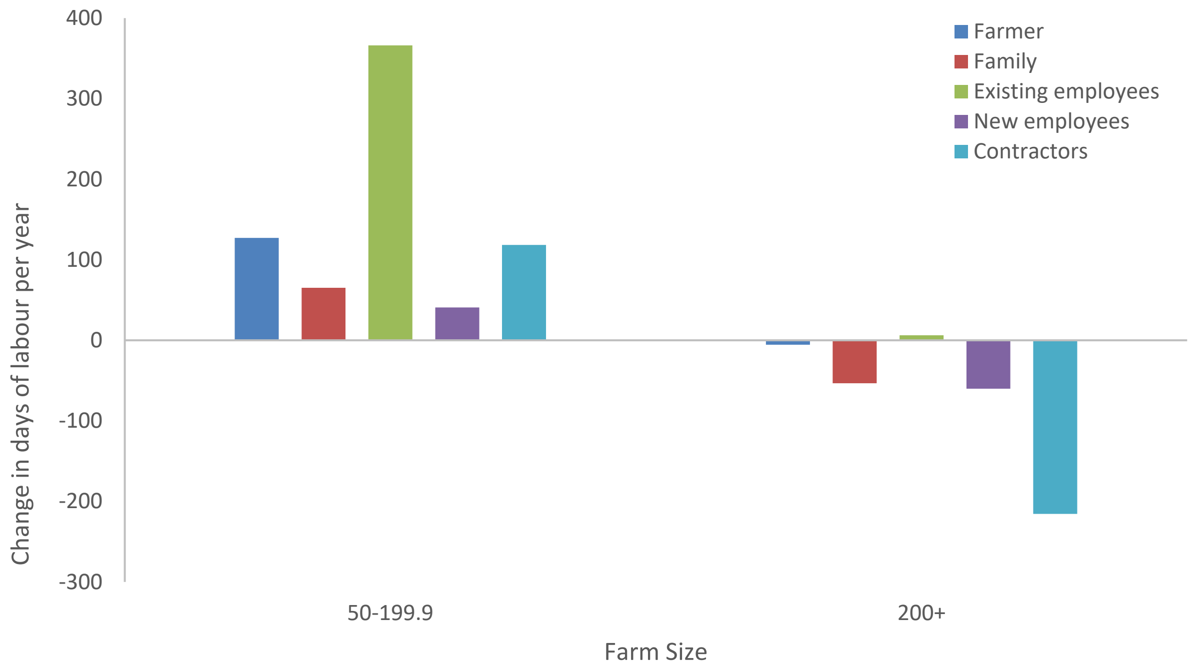

Figure 5.11. Net annual change in days of labour per year by farm size (ha).

Few respondents reported that their weekly working hours would have been different without GES grants. An increase in labour-hours worked per week on receiving grants was only experienced by 12 farmers (25.7 hours per week), while 10 farmers stated that they would have worked an additional 18.6 hours per week, had they not received GES grants.

5.4.4 ***Impacts on the wider economy***

5.4.4.1 Farm viability

Farm viability was perceived by 77% of respondents to have increased due to GES grants, while 21% stated that farm viability remained unchanged (Fig. 5.12). As a proportion of the respondents within each farm type, lowland cattle and sheep farms and lowland dairy farms most frequently reported a perceived increase in viability (100% and 88% of respondents respectively). None of the farmers in the survey reported a perceived decrease in farm business viability after receiving GES grants.

5.4.4.2 Changes in farm expenditure

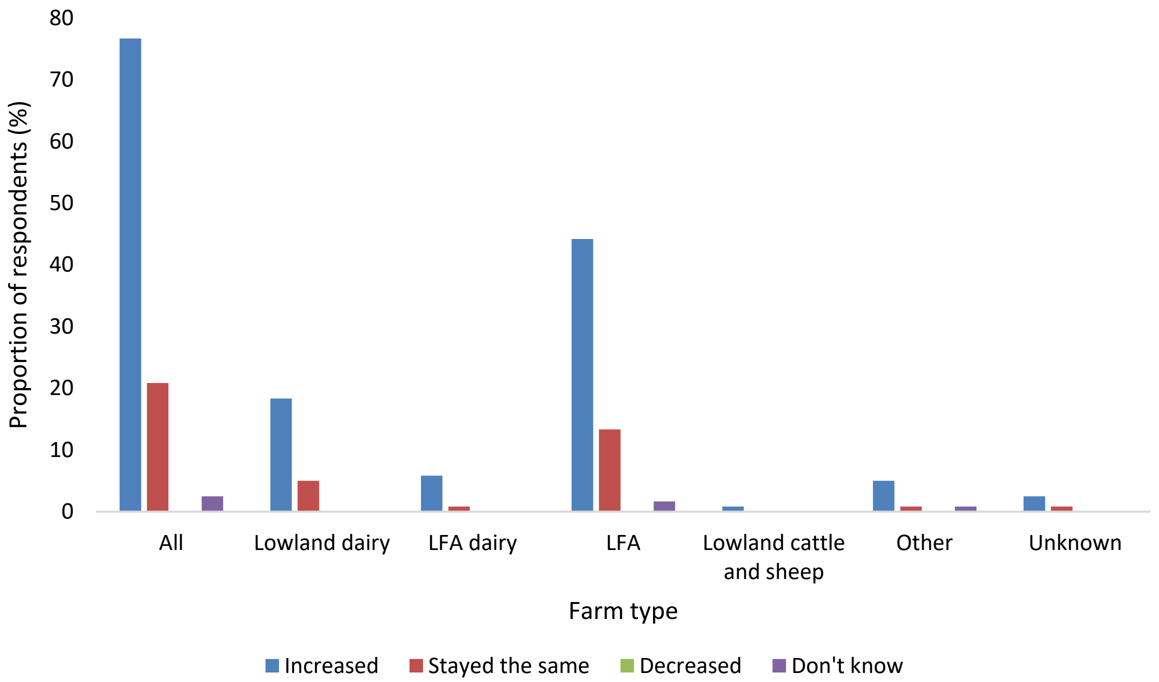

Figure 5.12. Impact of receiving GES grants on perceived farm viability

Grants appear to have had a positive impact on changes in expenditure, with 68% of respondents experiencing positive impacts (i.e. improved farm infrastructure and decreased personal expenditure), and 9% strongly positive impacts (Fig. 5.13). No impact on changes in expenditure was reported by 11% of farmers. The remaining 13% of respondents reported a negative impact, but only one farmer perceived a strongly negative impact on expenditure.

Farmers were asked whether they agreed that farm expenditure had increased after receiving GES grants. Of those who answered the question (98% of survey respondents), 42% agreed, and 11% strongly agreed, whilst 42% disagreed or strongly disagreed with this statement (Fig. 5.14).

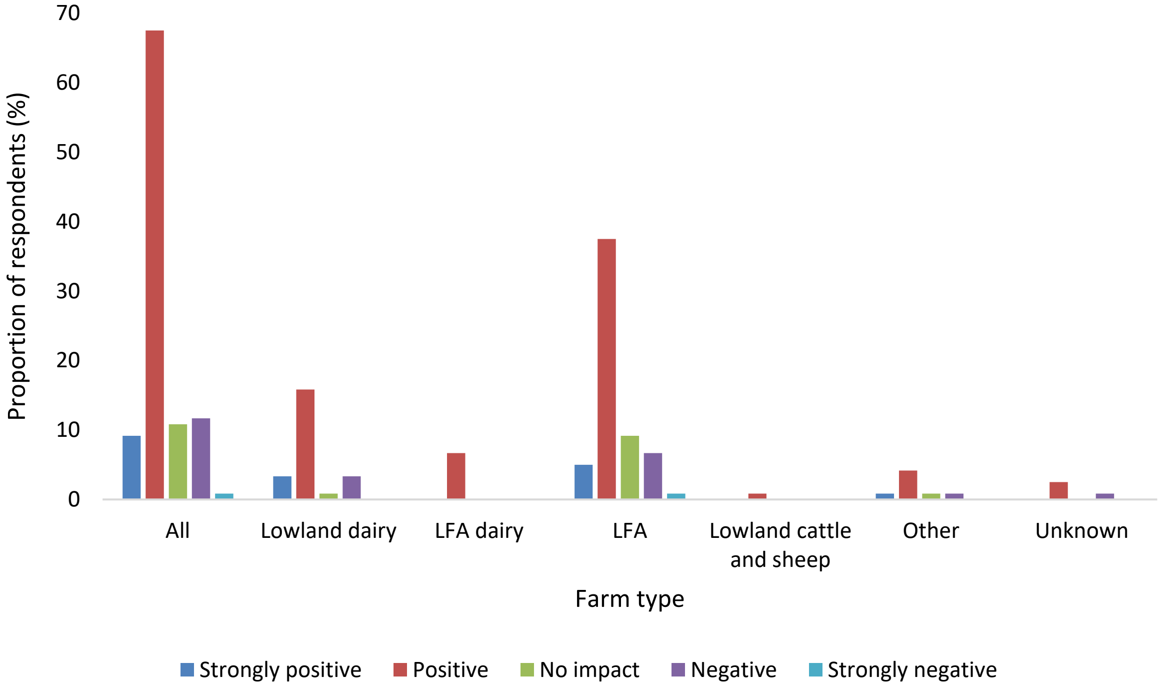

Figure 5.13. Impact of GES grants on farm expenditure.

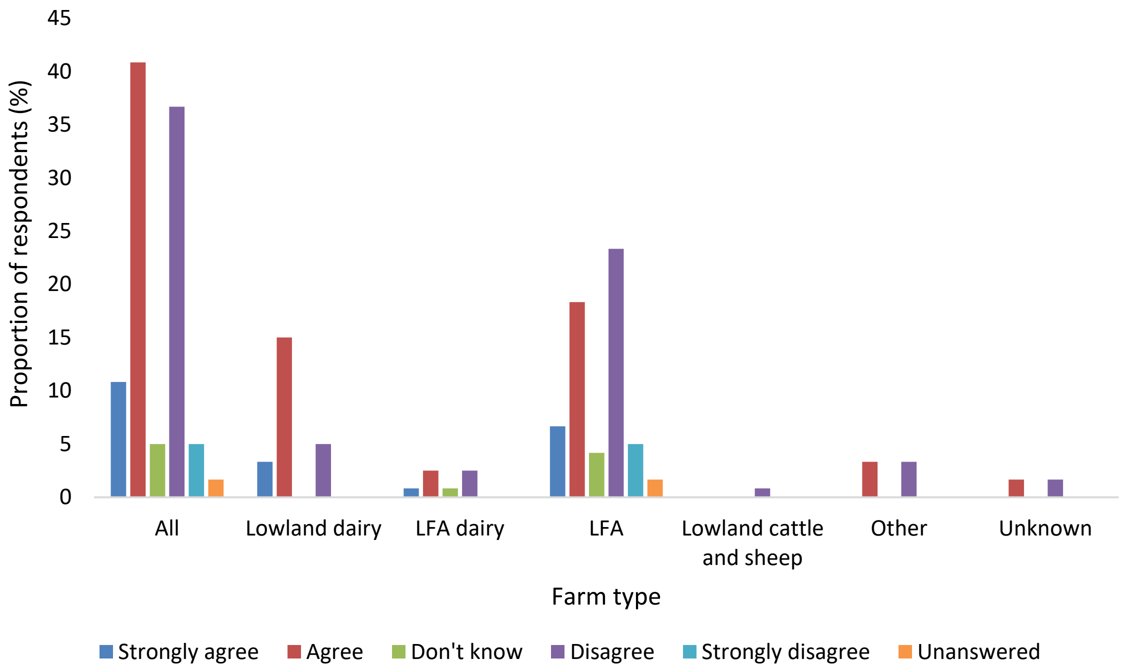

Figure 5.14. Proportion of farmers reporting an increase in expenditure after receiving GES .grants

Of the farmers reporting an increase in expenditure, 58% answered the follow-up question detailing how the additional money was spent. Increased expenditure was distributed primarily to Welsh industries (68%), Welsh households (18%) and taxes and imports (8%; Fig. 5.15). The remaining 6% of expenditure was unaccounted for[1]

Of the respondents that had grants in progress (60 farms), 87% spent money on building

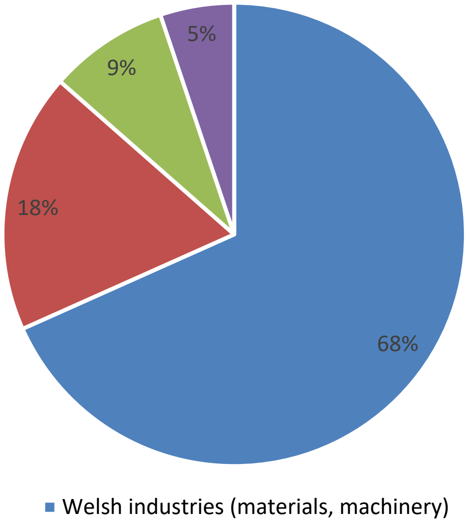

Figure 5.15. Allocation of increased expenditure following receipt of GES grants.

materials (52 farms), 65% on machinery and equipment (39 farms), and 45% on labour (27 farms; Table 5
.6). Only a small proportion of farms had spent money on rental and hire of equipment (13%) or repairs (5%). (Table 5.5).

[1] Here, 'unaccounted for' represents respondents whose answers to this question represented less than 100%, implying that some of their expenditure was allocated towards something unrepresented by the other three sectors

Table 5.5. Total and average farm expenditure (£) across sectors, for GES-participating farms.

	Building materials	Machinery or equipment	Rental and hire	Repairs	Labour
Number of farms	52	39	8	3	27
Total expenditure	561,381	309,931	92,792	4,666	136,529
Average spent per farm	10,796	7,947	11,599	1,555	£5,057

5.4.4.3 Expenditure on taxes and imports

A small number of open-ended questions were included in the survey regarding expenditure allocated to taxes and imports. When asked what proportion of the expenditure was allocated specifically to taxes, 49% of participants stated 0%, with a further 17% not knowing, and 8% declining to answer (Fig. 5.16). Of those able to give an estimate, 16% recorded allocating 20% of expenditure towards taxes, and a further 5% of respondents recorded less than 20%. Five per cent of respondents reported that more than 20% of their expenditure was allocated to tax.

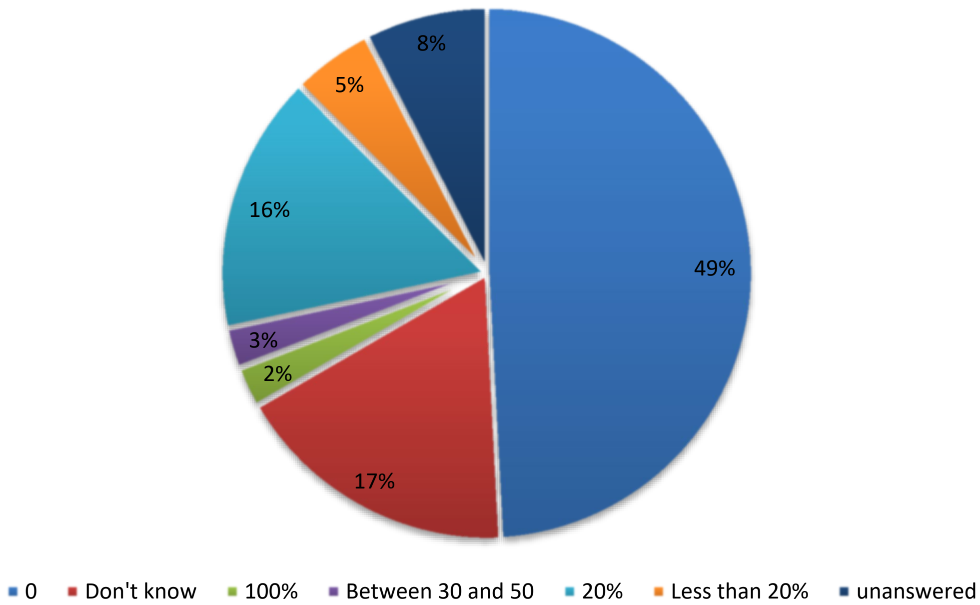

Figure 5.16. Proportion of expenditure allocated to tax per farm.

Thirty-seven respondents stated they had spent money on imports. Expenditure was primarily allocated to building materials (35% of farmers) and machinery and equipment (32% of farmers; Fig. 5.17). A small amount of expenditure was allocated to slurry equipment (14%)

or animal care (feed, veterinary care; 5%). The remaining 14% of farmers did not know which imported products they had spent money on.

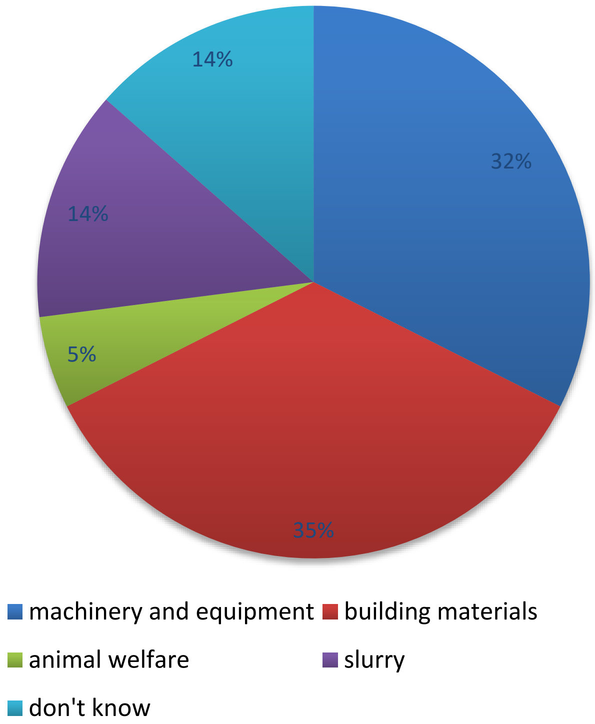

Figure 5.17. Farmer expenditure on imported products.

Of the expenditure allocated to imports, 57% of respondents purchased products from within the UK and Ireland; 14% from other European countries; and 8% from within Europe including the UK. The remaining 22% of respondents did not know the origin of their imports (Fig. 5.18).

5.4.4.4 *Upstream and downstream economic impacts*

Overall, 71% of respondents claimed that the GES grants financially benefitted their suppliers, while only 2% of respondents reporting a perceived negative financial effect on suppliers. One fifth of respondents (19%) were unable to offer an estimate (Fig. 5.19).

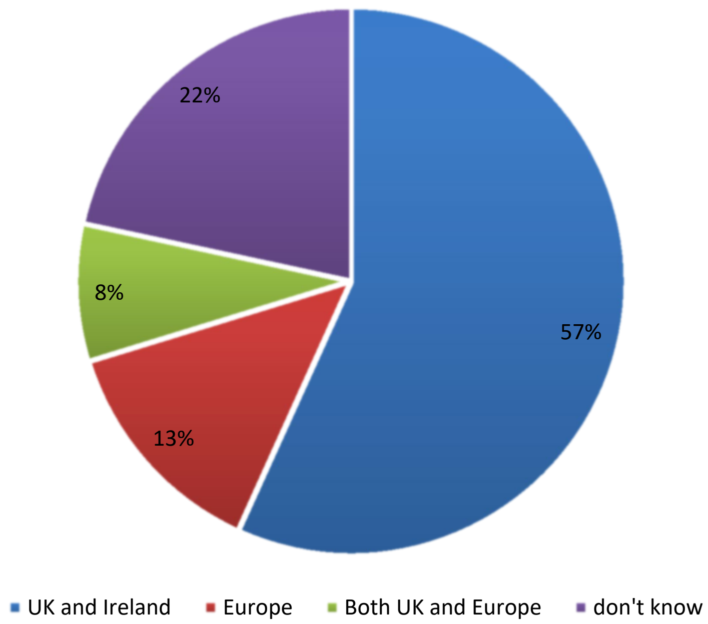

Figure 5.18. Country of origin of respondents' imported products.

Most respondents reported that the financial impact of GES grants on their customers was beneficial (44%), although an almost equal proportion of respondents estimated no effect on their customers (38%; Fig. 5.20). Thirteen per cent of respondents declined to comment.

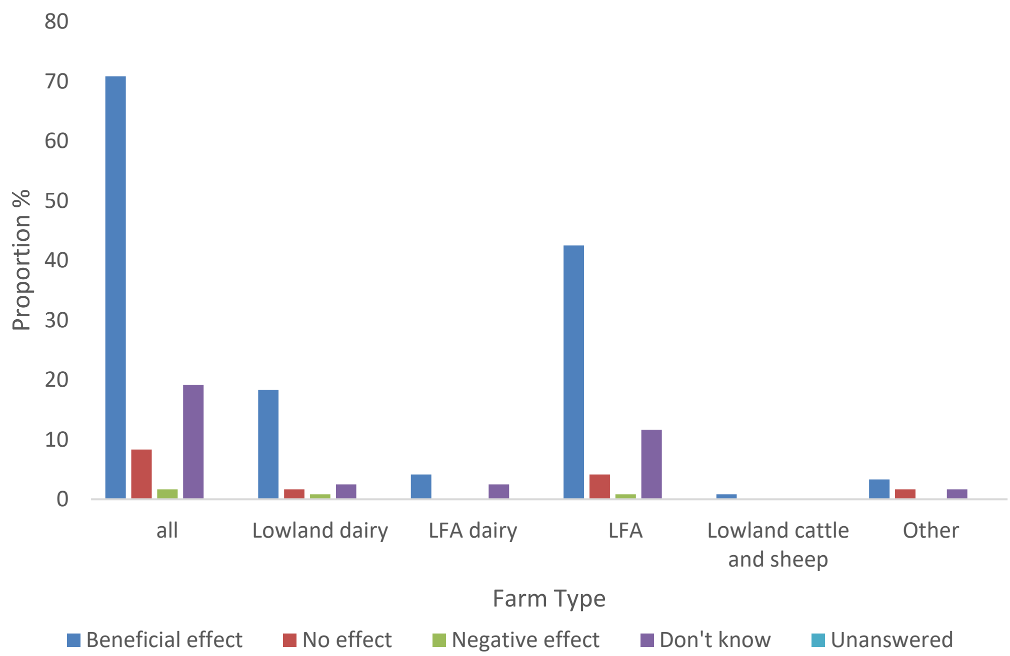

Figure 5.19. Perceived financial impact of GES grants on farm suppliers.

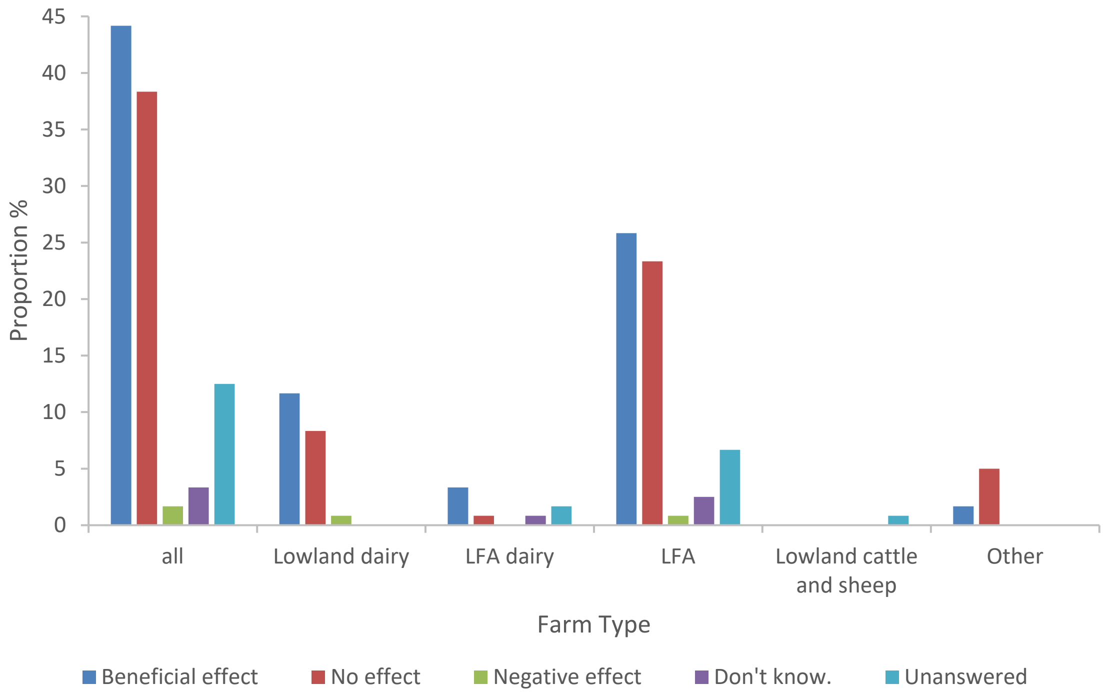

Figure 5.20. Perceived financial impact of GES grants on participating farms' customers and clients.

The perceived effect on farmers' competitors was smaller still, with only 13% of farmers claiming a beneficial effect on competitors, and the majority (54%) reporting no perceived effect (Fig. 5.21). A relatively large proportion of respondents did not answer this question (22%), while a further 8% stated they did not know the answer. Only 3% of respondents reported that GES grants had a negative effect on competitors

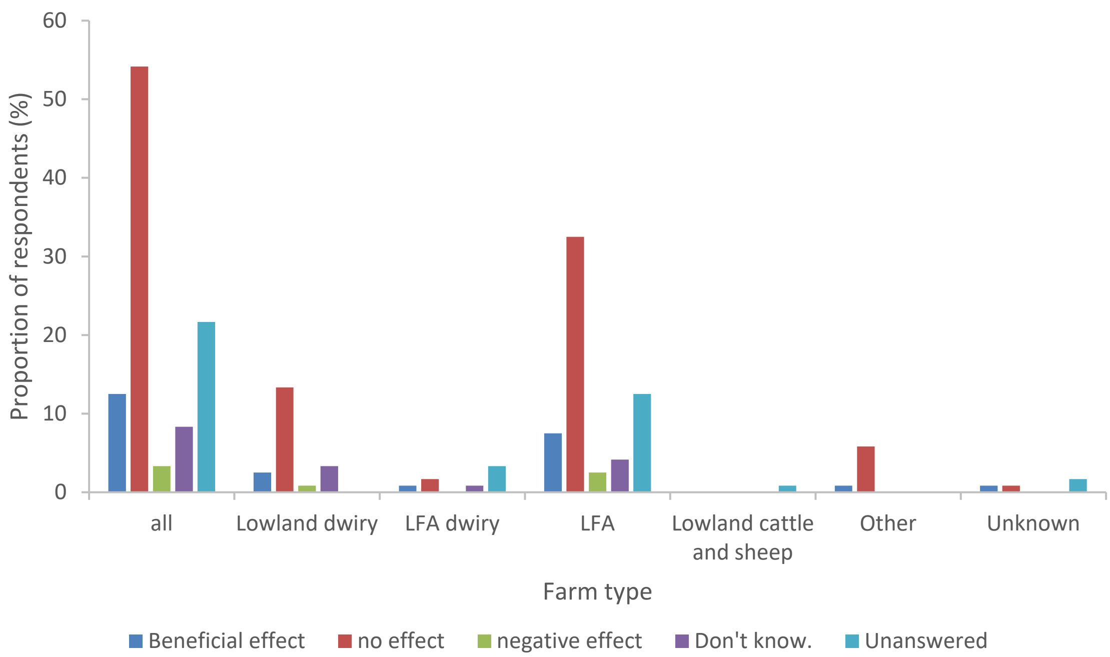

Figure 4521. Perceived financial impact of GES grants on participating farms' competitors.

5.4.5 ***Farm efficiency***

The majority of respondents (70%) stated that they could do more for themselves to increase efficiency on their farms, with almost a third of these (26% of all respondents) giving examples of how they could increase efficiency (Table. 5.6). The most popular specific suggestions for increasing efficiency, related to improvements in equipment (8% of respondents), land use or quality (8%), or energy and electricity use (4%), although it is possible there may be some cross-over between these categories implicit in farmers' responses. Less than a quarter of farmers (23%) reported that there was nothing more they could do, or that they did not know how to further improve efficiency on their farms. A small number of respondents (3%) claimed that financial constraints prevented them from doing anything further to improve efficiency, while 4.2% of farmers declined to answer.

Table 5.6. Farmers' responses to 'Is there anything more you could do to increase efficiency on your farms?'

Answer	Proportion of farms (%)
Yes / Probably	41
No / Not a lot / Don't think so / Already doing everything we can	18
Invest in buildings and expansion	7
Don't know / Possibly	5
Improve efficiency of grass, fertiliser and slurry use	5
Financial constraints / If I had a grant	3
We're always looking for ways to improve	3
Get equipment for handling and monitoring, especially Electronic ID	3
Renewable energy	3
Farmland or soil improvement	3
Recycling rainwater	2
Reduce electricity bill	1
Variable speed drive	1
Reduce dairy unit workload	1
Work even longer hours	1
Unanswered	4

Respondents (93%) commented that the Welsh Government could help them increase efficiency further, and three quarters of these (72% of farmers) provided examples of things that could be improved to increase efficiency on their farms (Table 5.7). Specific examples for government-facilitated improvements suggested by farmers most frequently related to providing additional financial support, and economic regulation. Only 7% of farmers were unsure whether the Welsh Government could help them further to increase efficiency on their farms, or thought that nothing more could be done by the government.

Table 5.7. Farmers' responses to whether Welsh Government could help them increase efficiency on their farms.

Response type	Proportion of farms (%)
Yes	21
No	6
'More grants' (often 'More GES grants')	15
Less bureaucracy or paperwork	8
Buildings, fencing, and walls	8
Electricity (and 'Green energy')	6
Don't know / Possibly	5
Pay the GES grants we've been waiting for	5
Equipment funding (e.g. Electronic ID)	5
Soil investment	3
Increase fertiliser and slurry efficiency (e.g. with a GPS grant)	3
'Get a better agricultural minister than Carwyn Jones'	2
Farming Connect is beneficial	2
Clear TB	2
Cattle keeping and comfort	2
Support farmers under 40	2
Keep the price of beef and lamb up	2
'We like to think the government respects that farming is among the most important industries Wales has to offer'	1
Capital items	1
Send more advisors out	1
Benchmarking	1
Not reduce Single Farm Payment as much / Use Euros	1
Give equal playing field against English farmers	1
Unanswered	1

Awareness of 'sustainable intensification'

More than half of respondents (55%) either did not know the meaning, or had never heard of, the term 'sustainable intensification' (Table 5.8). Of the remaining 45% of respondents, 42% offered a definition, but only 8% provided an accurate definition.

Table 5.8. Farmers' responses to the question 'Have you come across the term 'sustainable intensification' and if so what would it mean for you farm?'

Response	**Proportion of farms (%)**
Haven't heard of it	44
Don't know the meaning	11
An increase in intensity without harming the environment	8
An increase in efficiency / productivity	8
'A good thing'	7
'What they're trying to do with Glastir'	6
An increase in sustainability / environmental friendliness	4
For organic farms, it involves increasing farm efficiency while decreasing input	2
It would mean increasing profits	2
An increase in long-term viability for the whole of Wales	1
Optimum cropping / livestock numbers	1
'It means focusing investment on infrastructure instead of on efficiency'	1
'It would mean more livestock kept per hectare, and more work for the current area we farm; returns need to be better to pay for employees to cover the extra work'	1
'We're not very intensive anyway'	1
'Not plausible for organic farms'	1
Unanswered	4

6 DISCUSSION

6.1 Survey design

6.1.1 *Sampling design*

A number of caveats need to be considered before discussing the findings of the study. Both the total number of respondents, and the spread of respondents across sub-categories of farm type and size, can influence the representativeness of conclusions drawn from the resulting survey data. This socio-economic survey yielded a relatively large sample size, with 120 of the 157 (76%) farms completing the survey. Additionally, the number of surveys completed within each farm type and size category was approximately proportionate to the number of GES participants in each category. Therefore, it can be assumed that the opinions of farmers taking part in this study are representative of all farmers participating in the Glastir Efficiency Scheme.

6.1.1.1 Dissemination method

The survey data was collected through the combined use of telephone interviews and anonymous postal surveys. It is important to bear in mind that the data gathering technique can introduce potential bias into a study, such as social desirability bias and/or non-response bias (Warner 1965; Fisher 1993; Ansolabehere & Schaffner 2014).

Social desirability bias, also known as the *good subject effect* (Nichols & Maner 2008), arises when respondents wish to present a favourable image of themselves through their responses to questions, independent of the underlying validity of their responses (Furnham 1986). Such a bias tends to be more marked in face-to-face interviews where the desire to please the interviewer is at its strongest. This leads to the over-reporting of desirable behaviours and the under-reporting of undesirable items (Bowling 2005). Telephone interviews tend to minimise this effect, but the extent to which it influenced this study is difficult to determine.

By contrast, postal surveys are susceptible to non-response bias. The reliability of the survey can be undermined if the response rate becomes too low. A typically acute risk is that the non-responders may differ in some marked way from the responders. Such sample bias can invalidate attempts at population estimates (in this case, the opinions of all GES-participating farmers; (Bowling 1997; Lahaut *et al.* 2002)). All surveys that typically seek to elicit responses using data collection techniques employing postal, telephone, computer or face-to-face data collection methods are likely to suffer from non-response bias (Hill *et al.* 1997; Lahaut *et al.* 2002; Bowling 2005). Surveys that ask sensitive questions are likely to compound lower response rates as they will be further affected by social desirability bias (Tourangeau, Rips & Rasinski 2000). However, given the high response rate of this study, non-response bias is likely to be negligible.

6.1.2 *Grant implementation status*

Not every farm participating in the Glastir Efficiency Scheme had implemented the capital works funded by GES grants by the time the survey was conducted. This may be for a number of reasons, such as capital works being postponed due to delays in receiving grant money, or because of seasonal constraints to construction projects.

Implementation of many types of grants may have be constrained by seasonal conditions, for example, instalment of outdoor works such as slurry or manure stores would require suitable weather conditions in order to begin construction. Given that local weather conditions vary across Wales, this may have contributed to individual farms finishing projects at different times.

The relative progress of GES funded works on individual farms indicates that respondents would have experienced differing levels of benefits (or dis-benefits) from GES capital works, thereby influencing their survey responses. For example, building new slurry and manure stores would be expected to increase storage capacity for livestock manures. Approximately 40% of dairy slurry is usually applied in February-April, while only 10% is typically applied in May-July, and 25% each in August-October and November-January (Smith *et al.* 2001). Farmers completing the survey after the main period of application would have more evidence relating to the impact of GES-funded works, than those who completed it before this period. Since 78% of respondents completed the survey in July 2014 (after the main slurry application period), the data received regarding this particular grant type (SME grants) are probably more robust. This may not be the case with data relating to other grant works, particularly those that had not had time to take effect by the time the survey was completed.

6.2 **Socio-economic impact of GES grants**

6.2.1 ***Impact on Labour***

The impact of the GES on labour and farm workload varied between worker categories and farm characteristics. With the provision of grants for on-farm development, a net increase in annual workload might be expected, to incorporate the additional hours required to implement construction works. An average net increase of 3.3 labour-days per farm per year was indicated when all farm and worker categories were considered together (Fig. 5.10), although this average conceals important differences in workload changes, worker categories, and the influence of farm types and sizes.

Farm type affected changes in workload, by a greater margin for some farm types than others. Most notably, an average increase in annual labour-days was seen on LFA cattle and sheep farms (3.3 labour-days per farm per year for contractors and 0.8 days per farm per year for new employees), but a large decrease was observed on lowland dairy farms (10.7 days per farm per year for existing employees and 4.3 days per farm per year for contractors). In terms of farm size, contrasts were seen between farms < 50 ha in size (no overall change), 50 to 199.9 ha in size (an overall increase), and > 200 ha in size (an overall decrease). It is important to consider the response in workload of different farm types and sizes when allocating future grant funding, and when considering the up-scaled effect on the Welsh economy as a whole.

6.2.2 ***Allocation of spending***

Most farmers agreed that GES grants had a positive impact for capital investment and motivating project development. More than 90% of farms either agreed or strongly agreed that the grant encouraged new capital investment (Fig. 5.7). Additionally, 82% of respondents said that their project would not have happened without the grant (Fig. 5.8).

Clearly, GES grants are not intended to curtail opportunities for expansion, but in some cases, development in one area may limit development in another. However, over 70% disagreed that the grants curtailed expansion, with only 15% agreeing that it had done so.

Three out of four respondents reported a positive impact on reducing fertiliser consumption and labour costs, after receiving GES funding (Fig. 5.9). Forty-six respondents gave monetary figures for how much their farms had saved on fertilisers (an average of £3,291 per farm). This suggests that the GES has helped improve farm input costs, as well as providing additional benefits, such as reducing on-farm greenhouse gas emissions (GHG) associated with fertiliser use, and potentially wider reductions in GHG emissions associated with fertiliser production.

6.2.3 *Impacts on the wider economy*

Overall, 77% of respondents reported that GES grants appeared to have had a positive impact on farm viability. The majority of respondents' GES grant expenditure (68%) was allocated to Welsh industries, with a large portion of the remainder going to Welsh households (18%). This suggests that the majority of grant money is entering the local economy, although to a slightly lesser extent than that under the Tir Gofal scheme, where 73% of expenditure was directed towards Welsh industries, and 23% towards Welsh households (CEASC 2005). Imports and taxes in the present study account for approximately 8% of the increased expenditure – more than twice the proportion spent on taxes and imports under Tir Gofal (CEASC 2005). The majority of imports were sourced from the UK (57%), and all imported products were sourced from within the EU (section 5.4.4.3).

Most of the expenditure allocated to imports was spent on either building materials (87% of responding farmers) or machinery and equipment (65%; section 5.4.4.3). Less than half of the 60 farmers spent money on labour, suggesting that many farmers preferred to manage labour requirements themselves. This may explain the pronounced difference observed between the reduction in labour-days worked on smaller farms (50 to 199.9 ha in size), and the increase in labour-days worked on larger farms (> 200 ha in size) – larger may have been able to afford to subcontract work, or may have had a greater need for additional labour corresponding to larger construction projects.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This study set out to generate information on the impact GES grants have had on four key themes: grant allocation, economic outputs and farm efficiency, labour and the wider economy). Each of these are taken in turn in this conclusions section.

7.1.1 *Grant allocation*

The results highlight an information gap regarding the number of approved grants and grants in progress. This aside, the report has observed that the number of grants have been dispersed equitably across farm types and size categories. Farmers opted primarily to improve slurry and manure efficiency and energy efficiency.

7.1.2 *Economic outputs and efficiency of farms*

The Glastir Efficiency Scheme had positive impacts for farm economy indicators, such as increased farm sales and the value of those sales; wider? expenditure, and increased uptake in new capital investments.

7.1.3 *Labour*

The impacts on labour were varied across farm types and size. The previous scheme, Tir Gofal, increased demand for labour. For GES, some farms have had an increased demand for labour and others a reduced demand, but overall there was a net decrease.

7.1.4 *The wider economy*

The GES grants increased perceived farm viability and had a positive effect on farm expenditure, e.g. less money spent on fertilisers. Increased grant expenditure was spent locally on Welsh industries and households. The majority of imports came from the UK and Ireland and no imports were sourced from outside of Europe. Evidently, much of the money from GES grants is being recirculated within the local economy. In rural areas this is particularly important.

7.2 Recommendations

7.2.1 *Grants*

There were no water efficiency grants in progress according to the progress report (WG 2013). The number of these grant types was considerably lower than for SME and EE, and it may be useful to further understand the drivers for this lack of uptake for WE grants. There were very few farms of <50 ha within the GES. There may be the potential for policy makers to consider developing grants suitable for smaller sized farms.

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9 ACKNOWLEDGEMENTS

This research was made possible through WG funding via the GMEP project, and the kind participation of the farming community.

10 ANNEX 1: GLASTIR EFFICIENCY SCHEME SOCIAL-ECONOMIC SURVEY

The Glastir Efficiency Scheme, previously known as ACRES, aims to increase the efficiency of Welsh farms by granting funds towards capital investments in slurry, manure and water storage and management as well as in energy efficiency.

The following questionnaire is aimed at assessing **only the Glastir Efficiency Scheme** and its impact on the Welsh economy (and not the other schemes within Glastir).

I. Economic outputs and efficiency

1. How has the value of your sales from your farming enterprise changed since obtaining a Glastir Efficiency Scheme (ACRES) grant?

- o Increased
- o Stayed the same
- o Decreased
- o Don't know

2. What impact do you think that the Glastir Efficiency Scheme (ACRES) grant has had on your sales from farming?

- o Important positive impact
- o Little positive impact
- o No impact
- o Negative impact
- o Important negative impact

3. Your opportunities for expansion have been curtailed as a result of your Glastir Efficiency Scheme (ACRES) grant.

- o Strongly agree
- o Agree
- o Don't know
- o Disagree
- o Strongly disagree

II. Allocation of spending

4. Access to the Glastir Efficiency Scheme (ACRES) grants encouraged you to undertake new capital investment.

- o Strongly agree
- o Agree
- o Don't know
- o Disagree
- o Strongly disagree

5. Access to the Glastir Efficiency Scheme (ACRES) grants encouraged you to increase the scale of planned investments.

- o Strongly agree
- o Agree
- o Don't know
- o Disagree
- o Strongly disagree

6. How much do you agree or disagree with the following statements?

MY FUNDED PROJECT WOULD	STRONGLY AGREE	AGREE	NEITHER AGREE NOR DISAGREE	DISAGREE	STRONGLY DISAGREE

NOT HAVE HAPPENED WITHOUT THE GRANT	○	○	○	○	○
HAVE HAPPENED MORE SLOWLY WITHOUT THE GRANT	○	○	○	○	○
HAVE BEEN SMALLER WITHOUT THE GRANT	○	○	○	○	○

7. Within changes in expenditure due to Glastir Efficiency Grant (ACRES) Scheme, what were the impacts on the following sectors?

	POSITIVE IMPACT	**NEGATIVE IMPACT**	**NO IMPACT**
FERTILISERS	○	○	○
CHEMICALS	○	○	○
ON-FARM PURCHASES (FEEDSTUFF, FUEL)	○	○	○
VETERINARY FEES	○	○	○
CONTRACTORS	○	○	○
BUILDING MATERIALS	○	○	○
LABOUR	○	○	○

8. By how much were your fertiliser expenses reduced due to the Glastir Efficiency Grant (ACRES) Scheme?

=£

9. By how much were your chemical expenses reduced thanks to the Glastir Efficiency Grant (ACRES) Scheme?

=£

10. By how much were your on-farm purchases expenses reduced thanks to the Glastir Efficiency Grant (ACRES) Scheme?

=£

III.

11. By how many days of labour per year was the workload on your farm **reduced** as a result of your Glastir Efficiency Grant (ACRES)?

Number of days =

12. Or, by how many days of labour per year was the workload on your farm **increased** as a result of your Glastir Efficiency Grant (ACRES)?

Number of days =

13. (*if answered to Q.11 or Q.12)* What proportion of the increased workload was devoted to the following labour sources on an annual basis :

	Proportion of reduced workload	Proportion of increased workload
Farmer		
Family		
Existing employees		
New employees		
Contractors		

Please provide answers to the following three questions (14, 15 and 16) in the table provided below.

14. How many of each of these types of people work on your farm nowadays?
15. How many hours do the workers work per week nowadays? Please differentiate hours worked and hours paid.
16. How many hours do you think they would work per week nowadays if you had not received grants from the Glastir Efficiency Grant (ACRES) Scheme?

Please place a tick in the appropriate column for each of the following

Worker type	Number	Hours worked per week	Hours paid per week	Hours per week without Glastir grant
Full-time male family workers				
Full-time female family workers				
Part-time male family workers				
Part-time female family workers				
Seasonal male family workers				
Seasonal female family workers				
Full-time male employees				
Full-time female employees				
Part-time male employees				
Part-time female employees				
Seasonal male employees				
Seasonal female employees				

part time workers = 30 hours a week.

IV. Impacts on wider economy

17. Has the grant from the Glastir Efficiency Scheme (ACRES) changed the viability of your farm enterprise?

- Increased

- Stayed the same
- Decreased
- Don't know

18. What impact did the Glastir Efficiency Grant (ACRES) scheme have on any changes in expenditure?

- Strongly positive
- Positive
- No impact
- Negative
- Strongly negative

19. The overall annual farm expenditure has **increased** following the investment under the Glastir Efficiency Grant (ACRES) scheme.

- Strongly agree
- Agree
- Don't know
- Disagree
- Strongly disagree

20. OR **decreased** following the investment.

- Strongly agree
- Agree
- Don't know
- Disagree
- Strongly disagree

21. *(If expenditure increased)* Out of the increased spending as a result of the Glastir Efficiency Scheme grant (ACRES), what proportion was allocated to the following (answer to the best of your knowledge):

	Proportion of grant
Welsh industries (materials, machinery,…)	
Welsh households (labour, farm income,…)	
Taxes + imports	

22. If unable to answer Q19, please name purchased products and their manufacturers.

23. What proportion of the Glastir Efficiency Scheme's grants was allocated to the following sectors:

	Proportion of grant
Building materials	
Machinery/equipment	
Rental and hire	
Repairs	
Labour	

24. What proportion of the expenditure was allocated to taxes?

25. What proportion of the expenditure was allocated to wholesalers who import products from outside Wales?

26. Of the expenditure allocated to imports, for what purposes/sectors/products was the spending allocated?

27. Of the expenditure allocated to imports, towards which countries was the spending allocated?

28. What has been the financial effect of the Glastir Efficiency Grant (ACRES) scheme on your suppliers?
- Beneficial effect
- no effect negative effect
- Don't know.

29. What has been the financial effect of the Glastir Efficiency Grant (ACRES) scheme on your customers/clients/suppliers?
- Beneficial effect
- no effect
- negative effect
- Don't know.

30. What has been the financial effect of the Glastir Efficiency Grant (ACRES) scheme on your competitors?
- Beneficial effect
- no effect
- negative effect
- Don't know.

31. Is there anything more you could do to increase efficiency on your farm?

32. Is there anything more Welsh Government could do to help you increase efficiency on your farm?

33. Have you come across the term “sustainable intensification” and if so what would it mean for your farm?

Many thanks for the time and effort you have put into the completion of this survey. The information you provide is critical to our understanding and improving the scheme’s objectives.

NERC SCIENCE OF THE ENVIRONMENT

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Athena SWAN Bronze Award

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