Defra Sustainable Intensification Research Platform

SIP Project 1: Integrated Farm Management for Improved Economic, Environmental and Social Performance (LM0201)

Objective 1.1: Developing improved indicators and standardised methodologies for land managers and their advisers to measure the economic, environmental and social performance of farms

Work Package 1.1A: Developing farm performance assessment methodologies

Final Report prepared by:

Stephen Ramsden University of Nottingham

John Lynch University of Nottingham

Contact:

Stephen Ramsden stephen.ramsden@nottingham.ac.uk

Start Date: 01/08/14

End Date: 31/07/16

Total Costs: £182,051.04

September 2016

Contents

ACKNOWLEDGEMENTS

The Sustainable Intensification Research Platform (SIP) is a multi-partner research programme comprising farmers, industry experts, academia, environmental organisations, policymakers and other stakeholders. The platform has explored the opportunities and risks of Sustainable Intensification (SI) from a range of perspectives and scales across England and Wales, through three linked and transdisciplinary research projects:

SIP Project 1	Integrated Farm Management for improved economic, environmental and social performance
SIP Project 2	Opportunities and risks for farming and the environment at landscape scales
SIP Project 3	A scoping study on the influence of external drivers and actors on the sustainability and productivity of English and Welsh farming

Projects 1 and 2 have investigated ways to increase farm productivity while reducing environmental impacts and enhancing the ecosystem services that agricultural land provides to society.

Project 1 partners are: NIAB (lead), IBERS (Aberystwyth University), ADAS, Agri-Food and Biosciences Institute (AFBI), Bangor University, Biomathematics and Statistics Scotland (BioSS), University of Bristol, University of Cambridge, Carbon Trust, Centre for Ecology and Hydrology (CEH), Duchy College, University of Exeter, Fera, Game and Wildlife Conservation Trust (GWCT), Glasgow Caledonian University, Harper Adams University, University of Hertfordshire, Linking Environment And Farming (LEAF), University of Leeds, Newcastle University, NIAB EMR, University of Nottingham, Organic Research Centre, University of Reading, Rothamsted Research, Royal Society for the Protection of Birds (RSPB), Scotland's Rural College (SRUC), Soil Association and Velcourt.

Funding for the SIP from Defra and The Welsh Government is gratefully acknowledged.

The data used for this publication was created as part of the SIP, and is freely available (subject to data embargo) at the Agricultural and Environmental Data Archive (AEDA) owned by the Freshwater Biological Association (FBA). All data is owned by Defra.

ABBREVIATIONS

AFI	Agri-Environment Footprint Index
AHDB	Agriculture and Horticulture Development Board
DEA	Data Envelopment Analysis
Defra	Department for Environment, Food and Rural Affairs
DSS	Decision Support System
DTC	Demonstration Test Catchment
EAgRET	Environmental and Agricultural Resource Use Efficiency Tool
ESA	Environmentally Sensitive Area
FADN	Farm Accountancy Data Network
FBS	Farm Business Survey
GHG	Greenhouse Gas
Ha	Hectares
IFM	Integrated Farm Management
ISIM	Integrated sustainable intensification methodology
KE	Knowledge Exchange
LCA	Life-Cycle Assessment (or Analysis)
LEAF	Linking Environment And Farming
N	Nitrogen
ORC	Organic Research Centre
PG (Tool)	Public Goods (Tool)
P	Phosphorus
SI	Sustainable Intensification
SIP	Sustainable Intensification Research Platform

EXECUTIVE SUMMARY

An integrated sustainable intensification (SI) methodology was developed for use with the Farm Business Survey (FBS) for England and Wales; as data from the Survey are part of the European Farm Accountancy Data Network (FADN), the approach can also be extended to other countries. The methodology has two integrated, complementary 'strands'. Strand 1 provides practitioners with a methodology and associated indicators that can be used to benchmark performance across the three SI pillars. These will be used as part of the benchmarking tools that are being developed as part of SIP Project 2 (LM0302). Strand 2 provides the industry with indicators that show the position of farms relative to the frontier of what is technically and economically achievable, including nutrient balance and biodiversity objectives, with current knowledge, under current technological conditions. Changes over time can be captured for both the Strand 1 and 2 indicators, as the FBS is part of a long-running and ongoing resource, standardised across different times and years.

Following a literature review, two workshops and discussions across both SIP Project teams, an initial candidate set of indicators was refined to produce indicators for seven economic, seven environmental and 28 social categories. Economic indicators include both the Strand 1 farm indicators and the farm efficiency scores generated through Strand 2. Social indicators are largely drawn from existing information available in the FBS. Environmental indicators were derived using an augmentation protocol, developed for the project, which is described in detail in this report; in summary, sample FBS data-sets for dairy farms in the south west and cereal farms in the east of England were used with a suite of mechanistic models and other methodologies to generate indicators of air and water quality, energy and water use efficiency, climate change regulation and biodiversity. To capture biodiversity, an index was developed in collaboration with Work Package 1.2A of SIP Project 1, and using an industry backed methodology.

Results showed considerable variation across the different indicators, with dairy farms generally showing greater environmental impact than cereal farms on a per hectare basis. Results for both air and water quality and climate change regulation were comparable to the literature. Linking the environmental metrics to food output, as measured by energy content, suggested that there was considerable variation in environmental impact for a given level of energy output, particularly on cereal farms: relatively low levels of environmental loss can be associated with high food energy content; an assessment of the robustness of this finding should be the subject of further research, as would the degree to which food energy content per hectare correlates with the Strand 2 efficiency scores.

Tests were conducted to establish whether proxy variables – data already existing within the FBS – could be used as indicators. Some variables performed better than others, *e.g.* value or physical amount of nitrogen applied is a better predictor of water quality than value of physical amount of phosphorous applied; ruminant stocking rate is a good predictor of methane-based greenhouse gases. However, these proxies are limited as indicators for farmers as they cannot capture the effect of management interventions.

Results are indicative of what could be achieved with the fuller FBS dataset: farms could track their environmental and economic performance over time, characteristics of 'top performing' farms could be identified and benchmarking frameworks routinely used to determine economic success could be extended to include environmental performance. The effect of improvement in overall farm efficiency (as measured by Strand 2 methodologies) on environmental and social performance could be monitored over time; alternatively, the implications for productivity and efficiency of a social policy (*e.g.* limit farm support to farms below a certain size) could be evaluated.

1. INTRODUCTION

1.1 Overview of Objective 1.1

In Objective 1.1 we sought to review current methodologies for assessing the environmental and social performance of farm businesses and to identify suitable indicators for further development into an integrated sustainable intensification methodology (ISIM) that was 'rooted in standard economic theories of production and the environment'. This would be replicable and open to refinement as new data became available. From an initial literature review, which was reported in the SIP Project 1 Scoping Study (Knight *et al.* 2014), we identified a range of suitable indicators for use with a core dataset provided by Farm Business Survey (FBS) for England and Wales. The FBS is part of the European Farm Accountancy Data Network (FADN) and thus the methods that we employ can be extended to other European countries and projects. The ISIM has two integrated 'Strands' that both use FBS data; by using two approaches, we overcome some of the limitations of each individual approach.

1.1.1 Strand 1 (Work Package 1.1A)

Strand 1 (described in this report) used a sub-set of FBS data for 2012, together with a suite of mechanistic environmental models and other techniques to generate economic, social and environmental indicators for individual FBS farms. These indicators are detailed in this report and cover a wider range of environmental and social outcomes than those covered in Strand 2. Our primary objective in Strand 1 is to provide farmers and other interested parties with a range of metrics that can be used to benchmark performance across the three pillars of Sustainable Intensification (SI). As a practical demonstration of the approach, the FBS benchmarking tools that are being developed as part of SIP Project 2 (LM0302, reported separately) are using the Strand 1 methodology across three core indicators: nutrient balance, greenhouse gas (GHG) emissions and biodiversity, together with other economic and social indicators identified under Objective 1.1.

1.1.2 Strand 2 (Work Package 1.1B)

Strand 2 (described in full in the Work Package 1.1B final report) used the full FBS data-set for 2012 and 2013 (including the methodology 1 sub-set data) to generate composite SI metrics for individual farms within the FBS. Collectively, these indicators show the position of each farm relative to a 'frontier' of what is technically achievable with current knowledge, under current technological conditions (for example, on cereal farms, with current varieties of cereals). As the FBS contains value data, it is possible to calculate efficiency of farms in relation to all inputs (land, labour and capital) and not just land (for example, yield per hectare); further, the approach allows both technical efficiency to be calculated (for a given combination of inputs, are farms producing what is currently technically feasible?) and economic efficiency (are farms using the right combination of inputs, given input and output prices?). Sustainability is captured through metrics for nutrient balance and biodiversity – as noted; it is not possible to capture the range of metrics captured in Strand 1. However, Strand 2 ensures that the work is embedded within recent economic theory relating to production and the environment. In particular, in relation to the objectives of the SIP, it allows us to identify farms that are falling short of the agri-environmental production possibility frontier and to explore sustainable farming practices that can help farmers move towards what is attainable with current knowledge and technology.

1.2 Aim and Objectives

The overall **aim** of Objective 1.1 was to develop improved indicators and standardised methodologies for land managers and their advisers to measure the economic, environmental and social performance of farms. The main objective of Work Package 1.1A (covered by this report) was to build on existing and, where appropriate, develop new farm performance assessment methodologies.

1.3 Deliverables and Tasks

The key deliverables for Work Package 1.1A were usable methodologies for farmers (or advisers) to be able to assess the economic, environmental and social performance of their farms, and indicators that can be used in data-poor or data-rich environments. The key tasks undertaken were to:

1.1A1 Review available methodologies. This was undertaken as part of the SIP Project 1 Scoping Study.

1.1A2 Identify overlaps in the above and create an inventory

1.1A3 Compare approaches and hold a data mashing workshop

1.1A4 Select and refine core methodologies

1.1A5 Ground truth the selected indicators

2. GENERAL METHODOLOGY

2.1 The nature of the Farm Business Survey (FBS)

The FBS uses Management Accounting methodologies to convert real farm financial data, together with some physical data, into annual output and input values that accord closely with an economic definition of these terms: all inputs and outputs are adjusted so that outputs relate directly to the inputs that produced them. Given the biological nature of agriculture, this is no easy task: some outputs (*e.g.* crop sales, meat from extensive livestock systems) are separated by more than a year from the relevant associated inputs (*e.g.* fertiliser, forage for young-stock in a 24-month beef system). Where inputs have no direct financial cost – *i.e.* where land is owned and family labour is used – an imputed, 'opportunity cost' value is included. Thus, the FBS gives a true economic, rather than financial, cost of producing farm commodities and other farm outputs. Data provided through the FBS are therefore very suitable for further development and integration into the ISIM work undertaken in Strand 2.

The methodology produces indicators that are very effective at capturing economic performance. Through the FBS, data are also collected across the social (*e.g.* education levels of farmers) and environmental (*e.g.* area of permanent pasture, woodland, location in Environmentally Sensitive Areas - ESA) pillars of SI. Through add-on modules carried out in some years, further information is obtained on farm practices such as on-farm energy use, animal health and welfare, countryside maintenance and management practices to prevent water pollution. The FBS methodology is specifically designed to elicit data at differing levels of richness, where richness achieved is a function of both existing information on-farm and other factors such as the sensitivity of the information collected. Our core objective in Work Package 1.1A was therefore to *augment* the existing FBS methodology, starting with the indicators and management interventions currently collected within the Survey.

2.2 Augmenting the FBS: the concept

Following the original guidelines for the Project, we take a data source that is rich across one of the pillars of SI and augment this across the second, environmental pillar. Although requiring 'rich' data in the first instance, this is information that is already being collected as part of the FBS (and more widely across Europe, as part of the FADN). Furthermore, outputs from on-farm accounting packages such as *FarmPlan* are already being used in the industry to provide environmental indicators (*e.g. Promar International* use farm account information to generate 'carbon footprints' for dairy farms supplying milk to supermarkets). Drawing on the recommendations of the SIP Project 1 Scoping Study and following approaches used by others (*e.g.* Gibbons *et al.*, 2006; Firbank *et al.*, 2013) we use mechanistic environmental models as our main augmentation tool. In addition to generating environmental indicators, this approach also allowed us to involve the relatively large number of work package partners in the modelling process, and a number of mechanistic models and other methodologies were provided by them for use with FBS data. The main difference in our approach here, and those used by authors such as Gibbons and Firbank, is that we start with value data and work back to the physical inputs normally required in mechanistic models. This secondary data approach has the advantage of being part of a long-running and ongoing resource, standardised across different times and years, without the need to commission additional surveys.

The methodology allows for augmentation at different tiers of data richness, although as noted, data can be rich for one pillar and poor for another. The mechanistic models provided by partners differ, but generally distinguish between i) how much of an input is used (*e.g.* kg of organic nitrogen applied) and ii) how the input is managed (*e.g.* whether manure / slurry is incorporated into the soil after spreading). FBS methods record some management practices, particularly when an add-on module is part of the Survey, but not all that are required by the more highly specified models. However, our methodology allows for this, in that we can run models for both data poor and data poor situations, using default settings available within the models. We ground-truth results by comparing values with those available in the literature. We can also compare rankings for FBS-derived results across different models, to test whether indicators derived through different methods give the same ranking: for example, for GHG emissions per litre of milk or nitrate loss per hectare.

The above approach works best for air and water quality indicators and, with annual data, allows tracking and benchmarking by farmers over time. Indicators for biodiversity are available through the FBS in a data-poor form: *e.g.*, area of permanent grassland, but generally the management information that ecologists agree is needed to generate indicators for biodiversity is lacking. Under Objective 1.1 we have therefore utilised two biodiversity indicators: a simple 'data-poor' Shannon index, which has been used with Strand 2 and a 'data-rich' biodiversity index, drawing upon an industry-backed scoring mechanism (see section 2.4) that was used in Strand 1 and also in SIP Project 1 Work Package 1.2A (reported separately).

Partner models/methodologies initially involved in Strand 1 were as follows.

- The University of Hertfordshire 'IMPACCT' support tool
- The ADAS 'FarmScoper' decision support tool
- The Agri-Environment Footprint Index (AFI)
- The InVEST toolkit, developed at the University of Leeds
- The Organic Research Centre 'public good tool'
- The Farm Scale Resource Use Efficiency Calculator (FSREC, subsequently renamed as EAgRET), developed by ADAS for AHDB
- The CALM model (presented by the University of Newcastle upon Tyne)
- LEAF auditing methodologies

Other partners, including CEH and Fera, provided data that were used as part of the augmentation methodology.

After the data-mashing workshop (see below) a selection of models were subsequently used in the augmentation procedures; these were: IMPACCT, FarmScoper, the public good tool and EAgRET. The following section describes the FBS data augmentation methodology in more detail.

2.3 Augmenting the FBS: methods and indicators

Using a standardised FBS dataset, a 'data mashing' workshop involving project partners and the above models and methodologies, was held at the University of Nottingham on the 10-11 September 2014. The objectives were to test the 'augmented FBS' approach; to identify methodologies suited to different levels of data richness and to complete the process, started in the SIP Project 1 Scoping Study, of identifying a set of indicators that could be used for the case study commercial farms in Work Package 1.2A. As anticipated, in terms of implementation, the augmented approach worked best with mechanistic-type models (IMPACCT, FarmScoper, EAgRET); the ORC 'public good tool' and the Agri-Environment Footprint Index both required further information than provided in the test dataset. The 'public good tool' was identified as being appropriate for further testing and work on ground-truthing (see Appendix 3). The IMPACCT, FarmScoper, EAgRET and 'public good tool' models/methodologies were selected for further analysis with specific (anonymised) FBS data for two core farm types: mainly cereals farms and dairy farms.

Following the workshop, the approach was refined and three types of indicator, dependent on the data environment and level of augmentation, were identified: i) data-poor (data available from existing on-farm sources); ii) data-moderate (data-poor information augmented with available secondary data); and iii) data-rich (data collected for use in augmentation models or direct collection of data on-farm). These indicators were presented and discussed at a workshop in Leeds, on March 20 2015, with participation from project partners and industry representatives. The full indicator set was then refined at the workshop using the following criteria: ease of use, prioritisation and targeting of interventions, extent to which existing on-farm information can be harnessed and suitability for different data availability on farm, with particular emphasis on the anticipated data availability on commercial farms in the study areas. The final set of core indicators and methodologies that arose from this process is presented in Table 1. Note that, in particular, the social indicators are a relatively small sub-set of the original full indicator set.

2.4 Biodiversity

The Shannon Index methodology is described in the report for Work Package 1.1B. This index was used for the full 2012 FBS dataset in Strand 2 and to generate results for the sub-set of farms used in Strand 1. In addition, an augmented biodiversity index, developed in collaboration with Work Package 1.2A was used in the survey of study area commercial farms; an overview of this index is provided here.

Designing comprehensive, scientifically justified biodiversity proxies is a significant challenge, with several different schemes available (*e.g.* Jeanneret *et al.*, 2014). Organic farming methods and areas of flower-rich habitats have been linked with an increase in biodiversity, particularly pollinators (Scheper *et al.*, 2013). This type of information (type of farm system, area of habitat) is relatively quick and reliable, although there will be variation in the extent of, for example, species diversity in meadows and the impact that this has on pollinators. Some agri-environment scheme measures have also been linked with an increase in biodiversity across the EU, particularly for arthropods (Kleijn and Sutherland, 2003); again, area of land under a particular management practice can be used as an indicator. A further step would be to weight land areas by management practices: different agri-environment schemes are then assumed to have differing benefits for biodiversity.

Building on this existing work and the Leeds workshop, biodiversity indicators were constructed using the 'Farm Wildlife' scoring scheme (www.farmwildlife.info). The scheme is industry backed and supported by many of the UK's leading conservation organisations (including the *RSPB*). Sympathetic management practices, such as providing pollinator and nectar flower mixes in field margins or leaving seed-rich habitats cereal stubbles over winter, receive points. Diverse farms undertaking multiple biodiversity promoting practices will therefore score highly. If more specific biodiversity interests are required for different areas, or as part of future studies, the biodiversity indicator can easily be changed to reflect this. Full details of the methodology will be included in the final report for Work Package 1.2A.

Table 1. Environmental, Economic and Social Indicators developed in Strands 1 and 2 of the integrated sustainable intensification methodology

	Indicator	Data and modelling where indicator not obtained directly	Strand
Environment			
Air and water quality	Nitrate losses Phosphorus losses Ammonia emissions	Physical inputs/outputs and relevant management details for mechanistic modelling software (e.g. FarmScoper) or nutrient balance calculations (the latter also includes N_2O emissions)	1,2
Biodiversity limiting: use of pesticides	Number and general type of pesticide applications and area left untreated	Additional information on pesticides used and toxicity	1
Energy and water use efficiency	Quantity of energy used and sources; water use and sources	Modelling captures wider system effects on *e.g.* air and water quality as measured by relevant indicators	1,2
Climate change regulation	CO_2 emissions CH_4 emissions N_2O emissions	Physical inputs/outputs and relevant management details for IPCC Tier 2 carbon accounting software (*e.g.* CALM)	1
Biodiversity	Shannon Index (data poor) or external weighted scoring system	Land use areas and land use counts; data on environmentally sensitive management and specific practices relevant to individual farms, according to external scoring system	1,2
Soil quality	External weighted scoring system based on external models	Relevant management details such as cultivations, timings, and choice of crop for farm soil type	1
Level of knowledge	*E.g.* use of advisory services, proposed land-use change	Additional modelling to capture wider system effects on e.g. biodiversity	1
Economic			
Performance	Management and Investment Income, Farm Business Income per farm hectare; Gross Margin per enterprise hectare	Data required in a Management Account format and compatibility with the FBS; (already part of the existing FBS benchmarking tool)	1
Financial efficiency	ROCE, Return on Tenant's Capital, Output per unit Input	As above	1
Resilience	Gearing Ratio, Owners' Stake, Current Ratio, Interest Cover, Shannon Index, Proportion of Output as external support	As above	1

Economic *Cont.*			
Intensity	Variable Costs, Fixed Costs (excluding land), Total Costs (excluding land) per hectare	As above	1
Technical Efficiency	Efficiency score (0-1)	Data Envelopment Analysis (DEA) methodology, efficiency scores show a farm's position relative to the technically feasible frontier of production for a given combination of inputs	2
Economic Efficiency	Efficiency score (0-1)	DEA methodology, efficiency scores show a farm's position relative to the optimal combination of inputs on the technically feasible frontier of production	2
SI Efficiency	Efficiency score (0-1)	DEA methodology, efficiency scores show a farm's position relative to the technically feasible frontier of production while allowing for nutrient use efficiency and biodiversity	2
Social: Business Sustainability			
b	Date of birth of farmer	Age	1
b	Nominated successor	Yes/No	1
b	Number of hours worked by farmer	Hours	1
b	Unpaid hours worked, spouse and other family	Hours	1
b,c	Farmer education	Level (eight available in the FBS)	1
b,c,d	Training, including staff	Type and number per unit of labour	1*
Social: Social Capital			
a	Number of paid workers on farm	Count	1
c,d	Membership of farm assurance schemes	Yes/No	1
c,d	Membership and level of membership: LEAF	Yes/No/Level	1
a	Labour and machinery sharing	Yes/No	1
a	Contracting arrangements (crops, livestock, labour, machinery)	Yes/No/Count	1
a	Hours worked on diversification (farmer, spouse, family)	Hours	1
a	Paid management used on farm	Yes/No	1

Social: Social Capital *Cont.*			
a	Output from general retailing	Yes/No	1
a	Output from retailing: Pick Your Own	Yes/No	1
a	Output from retailing: farm shop	Yes/No	1
a	Output from equine and livery activities	Yes/No	1
a	Output from golf	Yes/No	1
a	Output from sport	Yes/No	1
a	Output from camping and caravan sites	Yes/No	1
a	Output from Bed and Breakfast enterprises	Yes/No	1
a	Output from holiday cottages	Yes/No	1
a	Level of diversification	Count, proportion of total output in diversified activity	1
a	Output from hiring out labour and/or machinery	Yes/No	1
a	Output from hiring out labour and/or machinery for non-agricultural use	Yes/No	1
c	Length of regularly maintained pathways	Length relative to farm area	1*
a	Membership of local agricultural groups and societies	Count	1*
a	Membership of national agricultural bodies and societies	Count	1*

Notes – the letters in column 1 under 'Social' show whether the indicator also covers other social issues, as follows: a) Business Sustainability; b) Social Capital – People; c) Social Capital – Environment; d) Animal Welfare. In column 4, an asterisk indicates that the information is not available through the existing FBS.

2.5 Methodology and indicators for benchmarking with the FBS

Dawson and Smith (2007), Cameron and Moir (2013) and Schoumans *et al*. (2014) demonstrate the importance of, respectively, carbon, nitrogen and phosphorous loss from agricultural systems. If the list of environmental indicators in Table 1 is re-categorised in these terms, a slightly different result is obtained as shown in Table 2, below. In this format, we can focus on what drives the environmental problem (or benefit in the case of biodiversity) and the key role of nutrient and carbon flows and the potential for management practice to influence these flows. It also allows farmers and advisors to concentrate on aspects of the farm system over which they have *some* control and that potentially have tangible economic effects on the farm, particularly when considered over the longer term: both loss of nutrients and reduced soil organic matter content have financial implications. For example, using our sample farms and the augmented FBS methodology, we estimate these benefits for nitrogen to be between £300 and £12,000 per farm, depending on extent of loss and farm size. Note that by focusing on flows rather than the environmental problem (air quality, water quality) we do not reduce the extent of our coverage of environmental problems; rather, the emphasis shifts to what is causing the problem.

Part of our objectives in Strand 1 was to provide a methodology that could be used by farmers to benchmark their performance. The benchmarking component of the SIP has been undertaken as part of SIP Project 2 (reported separately). Following a meeting between relevant partners on 25 May 2016, we adopted the above approach, together with the economic and social indicators listed in Table 1. The GHG calculation methodology follows the augmented FBS approach, as described in this report. However, for P and K we adopt the nutrient balance methodology for the following reasons.

- Data for calculation of nutrient balances is available from the FBS without the additional 'augmentation step' if we use a mechanistic model such as FarmScoper.
- As noted, the FBS attempts to capture all inputs and all outputs for a 12 month period. This is a relatively data-rich source if we restrict calculations to total nutrients going in and total nutrients flowing out of the system (the 'balance'). A disadvantage with augmented modelling approach is that the additional detail required by the models is not always available.
- Nutrient balance approaches are familiar to some farmers through existing tools such as PLANET (http://www.planet4farmers.co.uk/)

Nutrient balance methodologies have also been used with FBS-type data in Ireland (Buckley *et al.* 2015). The modelling approach is retained for the calculation of GHG emissions and we use the augmented biodiversity indicator methodology used in the case study area commercial farm survey undertaken within Work Package 1.2A. The FBS benchmarking site can be found here: http://www.farmbusinesssurvey.co.uk/benchmarking/

The list of indicators to be used in the SIP Project 2 benchmarking is given in Table 2.

Table 2. Indicators to be taken forward as part of the benchmarking component of SIP Project 2.

	Indicator	**Data and modelling where indicator not obtained directly**
Nutrients	Nitrate Phosphorus Ammonia Nitrous Oxide emissions	Nutrient balance calculations
Greenhouse Gas Emissions	Carbon Dioxide Methane Nitrous Oxide	IPCC Tier 2/3 carbon accounting methodologies
Biodiversity	Augmented Shannon Index	Land use areas and land use counts; data on environmentally sensitive management and specific practices relevant to individual farms, according to external scoring system

3. METHODS

3.1 Augmented farm performance measures - protocols for using FBS data

In line with procedures developed at the September 2014 data-mashing workshop (section 2.3), sample data-sets of individual dairy farms in the south west and cereal farms in the east of England, were used to develop the augmentation protocol. A detailed description of the protocol can be found in Appendix 1.

Here we provide a summary of the approach; Results are shown in section 4. In general, conversion has been required to estimate *physical* inputs from *financial* costs, using standard prices. Where gaps in FBS data exist, assumptions and default settings were used; where possible, these were consistent across partner models.

3.1.1 Background information and economic indicators

The FBS contains fully costed and allocated data that capture the financial value of all farm inputs and outputs over a 12 month period. There are four broad categories of Fixed Costs: land (owned and rented); labour (full time, casual and supplied by the farm family); capital (plant and machinery depreciation and running costs, miscellaneous overheads) and capital and labour combined (contract labour and machinery). There are five broad Variable Cost categories: seed, fertiliser and crop protection costs; high energy feeds (‘concentrates’); low energy feeds (‘coarse fodder’); veterinary and medicine costs and miscellaneous costs not captured in other categories. Most costs are actual on-farm values as collected by FBS researchers; some values (family labour, land under family ownership) are imputed using current market values. Outputs are the values achieved by farmers over the same 12 month period and reflect market prices, crop yields, physical animal sales and other outputs, including diversified enterprises such as those based around tourism. There is thus a complete representation of the each farm system in terms of inputs and outputs that can be used for the efficiency analysis in Strand 2.

A conversion method was developed for Strand 1, as partner models required physical information. This is described below. Note that the fertiliser method was not required for the 2012 data, as physical values were collected for FBS farms in this year. It should also be noted that metrics are not considered for outputs beyond the farm-gate. Tracking goods (and associated performance metrics) beyond the farm is outside the scope of the FBS data, and involve factors upon which individual farms can have little impact (*e.g.* transport and refrigeration-based emissions for milk processing). Though these may be important to consider in whole food supply chain life cycle analysis approaches, they were deemed separate to the purposes of appraising farm performance as part of the SIP.

3.1.2 FBS data and conversions for external models

The core FBS data supplied to external models included details of farm structure, food and by-product production, physical inputs and resource use, and local environmental conditions (Table 3). The main data inputs and outputs, and procedures to derive them, are summarised in below.

3.1.3 Farm structure and production data

The FBS contains multiple land use classifications for major and minor crops grown in the UK, including multiple cropping (more than one crop in one year), forage crops for livestock, temporary and permanent grasses and rough grazing. Each farm then has one or multiple crop and livestock output entry, linked to this land use. Thus it is possible to identify an output and its components (*e.g.* yield per hectare, by-products such as cereal straw) for use in partner models. Livestock types, on-farm numbers, purchases and sales are also available, with livestock recorded similarly for different age and sex categories, which are important to distinguish in order to model processes such as enteric fermentation and manure production. Transfers between farm enterprises are recorded to track where outputs are used and avoid double counting; for example, the weight of different home-grown crops used as animal feed is assigned to specific livestock enterprises.

Table 3. Summary of FBS derived data for input into the FARMSCOPER decision support tool.

Input data	Units	Source	Notes/conversion
Farm Structure			
Main Farm Type	n/a	Direct extraction	Defined as enterprises accounting for >2/3 total Standard Output
Utilised Agricultural Area	Ha	Direct extraction	Total area of main crops, grass, fodder crops, etc.
Land Use	Ha	Direct extraction	Individual main crop, fodder crop, grass and grazing areas
Livestock counts	No.	Direct extraction	Numbers of cattle in different categories
Crop Production			
Total production of major crop product	T	Main crops: direct extraction Fodder crops: typical yields	For each crop type
Straw production	T	Direct extraction	For each crop type
Livestock and dairy production			
Livestock sales	No.	Direct extraction	Sales of cattle for different categories
Milk Production	Litres	Direct extraction	Separated into milk and milk products (litres milk equivalent)
Inputs / resource use			
Fertiliser inputs	Kg N Kg P Kg K	Either direct extraction or Conversion from expenditure	Where fertiliser input data available, extracted directly (includes fertiliser source) Where not available, expenditure used to estimate inputs
Slurry and other organic fertilisers	m^3 or kg		Derived from fertiliser input data. Only derived for farms with fertiliser data
Electricity	kWh	Conversion from expenditure	Assumes rate of £0.0069/kWh
Machinery and vehicle fuels	Litres	Conversion from expenditure	Assumes all red diesel, at a cost of £0.63/litre
Heating fuels	Litres	Conversion from expenditure	Assumes all kerosene, at a cost of £0.53/litre
Water use	m^3	Conversion from expenditure	Rate of £0.95/m^3
External geo-referenced data			
Long-term annual precipitation	mm	Geo-referenced extraction	Correlated farm location with Met Office UKCP09 observed climate data
Dominant soil type	n/a	Geo-referenced extraction	Correlated farm location with British Geological Survey Soil Parent Material Model

3.1.4 Inputs and resource use

For the 2012 FBS data, for some farms (approx. 70%), physical information was also available from a supplementary FBS module on fertiliser use. Total N, P and K applied to the farm was recorded, separated into categories of: inorganic fertilisers, manure and slurry, composts, green manures, bio-solids, and anaerobic digestate. As the majority of farms had this data, and it continues to be collected, it was included in the analysis. However, to provide the same inputs for farms where this module was not completed, and demonstrate that the technique could be 'back cast' to years before its introduction, an alternative method was also developed to estimate N P and K inputs from fertiliser expenditure. Total fertiliser costs are available from the FBS for each farm enterprise, which were compared to standard costs for each fertiliser input from the SAC Farm Management Handbook.

A similar method was derived to estimate applications of crop protection products, but these did not contribute to principal outputs of the models tested here, so were not pursued. However, details are available in the full conversion protocol document.

Expenditure on imported animal feeds and bedding was available, econometrically allocated to different livestock enterprises. Weights were estimated from this expenditure by assuming appropriate feed types (*e.g.* dairy concentrates derived from wheat), and converted using standard prices. Fuel volumes, electricity usage and volume of water used were also estimated from expenditure, using standard costs to convert to litres of fuel (both red diesel and kerosene), kilowatt hours and litres of water, respectively.

3.1.5 External data

Precipitation and local soil type, important in order to model run-off of agricultural pollutants, were obtained by aligning FBS farm location (in the form of the 10km OS grid reference that the farm is within, to preserve anonymity) with relevant maps. The precipitation map was obtained from the Met Office, while soil type was derived from the British Geological Survey Soil Parent Material Model. The protocol for this data processing is outlined, with appropriate steps for those less familiar with GIS, in the archived SIP document *Adding geospatial data to FBS farms using ArcMap 10* (see Appendix 2).

4. RESULTS AND DISCUSSION

4.1 FBS data to derive augmented farm performance measures – example results for FarmScoper

A full version of the augmented FBS approach and results is under preparation for submission to *Agricultural Systems*. Here we present example results using the FarmScoper model.

FarmScoper was developed as a decision support tool by ADAS, funded by Defra and is designed to help farmers to i) assess diffuse agricultural pollutant loads and ii) quantify the impact of mitigation on these pollutant loads (Defra, 2010). It has already been used by others (Firbank and Elliot, 2013) in an investigation to determine existing levels of SI on a sample of British farms; here we use the model with the augmented FBS approach described above to generate pollutant loadings for FBS cereal and dairy farms in East Anglia and the South West of England respectively.

4.1.1 Results for pollutant loading and greenhouse gas emissions

Table 4 shows pollutant loadings for each farm type (average and standard deviation for the sample); Table 5 shows results for GHGs. Standard deviations, particularly for dairy farms, suggest that results differ according to the farm-specific information provided and are not simply a consequence of using FarmScoper default values. An example of the range in estimates is shown below in a boxplot of nitrate loading for each farm type (Figure 1).

Table 4. Annual pollutant loadings estimated using FarmScoper for a sample of cereal and dairy farms from the Farm Business Survey

Main Farm Type	NO_3- (kg ha^{-1})		P (kg ha^{-1})		Sediment (kg ha^{-1})		NH_3 (kg ha^{-1})	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Cereals	21.2	5.6	0.30	0.17	162	114	11.6	5.38
Dairy	24.0	10.6	0.91	0.74	361	326	37.2	15.36

Table 5. Annual greenhouse gas emissions estimated using FarmScoper for a sample of cereal and dairy farms from the Farm Business Survey

Main Farm Type	CH_4 (kg ha^{-1})		N_2O (kg ha^{-1})		Total GHG (t CO_2e ha^{-1})	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	Σ
Cereals	1.65	5.77	5.68	1.58	3.26	0.93
Dairy	296	127	10.12	2.78	12.0	4.38

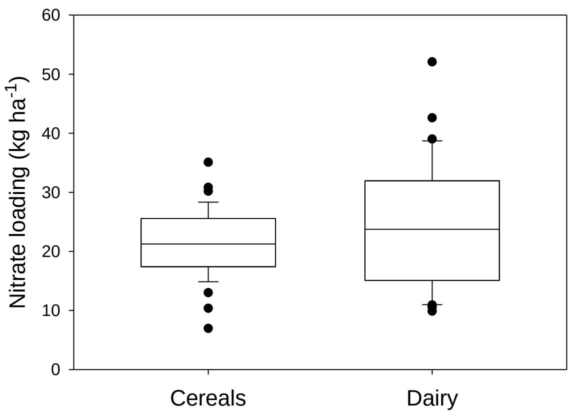

Figure 1. Boxplot demonstrating the range in estimated nitrate loading between the two farm types

Environmental impacts for dairy farms typically use metrics scaled per litre of milk produced. As these data are available from the FBS, this metric is demonstrated for GHG emissions in Table 6.

Table 6. Annual greenhouse gas emissions estimated using FarmScoper for a sample of dairy farms from the Farm Business Survey, expressed per litre of milk produced

CH_4 (kg l^{-1})		N_2O (kg l^{-1})		Total GHG (kg CO_2e l^{-1})	
$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
0.03	0.01	0.001	0.0005	1.38	0.41

4.1.2 Ground truthing - comparison with literature values

The main sources of methane from dairy systems are enteric *i.e.* from the cow itself, and from slurries and manures. FarmScoper has the functionality to capture both aspects of the farm system and as described in the augmentation protocol, FBS data provides some information on the amount of slurry and manure produced on-farm. The average methane value of 0.03 kg l^{-1} is higher than values reported by Bell *et al.* (2011; circa 0.02 kg l^{-1} for both manure and enteric methane) but comparable to those reported by Enriquez-Hidalg (2014; *circa* 26 g l^{-1} enteric methane only). Total emissions, at 1.38 kg CO_2e l^{-1}, are comparable to Gibbons *et al*. (2006) (1.25 kg CO_2e l^{-1} after adjusting for non-dairy livestock) and the average found for 415 farms in Great Britain by DairyCo (2012; 1.31 kg and 1.32 CO_2e l^{-1} depending on methodology). With respect to nitrate loading, Zhang *et al*. (2012) used Farmscoper in the Hampshire Avon Demonstration Test Catchment (DTC) and report values for nitrate loading of 38 kg ha^{-1} $year^{-1}$ for cereal farms and 40 kg ha^{-1} $year^{-1}$ for dairy farms. In the protocol, we used average precipitation values, rather than the wetter than average data that was a feature of the 2012 cropping season in England. Taylor *et al.* (2016) in a predominantly arable catchment present estimates for annual nitrate run-off of between 3 and 12 kg ha^{-1} $year^{-1}$. This variability makes it difficult to establish whether we are dealing with model error (of some form) or with the natural variability in environmental outcomes in agriculture. As shown by Gibbons *et al.* (2006), variability in model results does not necessarily invalidate recommendations as to what farming practices should be adopted: recommendations can be robust to model and data uncertainty.

We ground truth the data more fully in forthcoming journal papers and in a separate report outlining augmentation of FBS data with the Organic Research Centre 'Public Good Tool' (see Appendix 3).

4.1.3 Measuring Sustainable Intensification

The environmental metrics obtained as described above are important in their own right, but can also be linked with food outputs to identify where and how agriculture demonstrates, or can move towards, sustainable production. Following the methodology used by Firbank *et al*. (2013), a unifying measure of food production was obtained by converting all foodstuffs produced on farm to gross energy per unit area (crops fed to livestock are not included to avoid double counting). Two key environmental metrics, nitrate run-off and GHG emissions, are shown with the associated food energy content from each farm, as below (Figure 2).

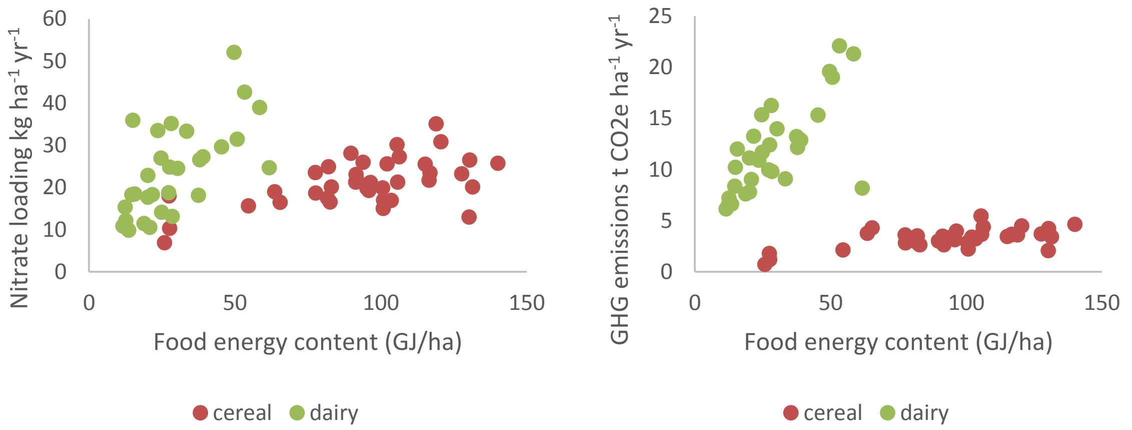

Figure 2. Nitrate loading, GHG emissions and food energy content for the sample dairy and cereal farms

Figure 2 demonstrates both the wide range in food energy content per hectare between farms and how this relates to nitrate run-off and GHG emissions. It is interesting to note that the two negative environmental impacts seem quite strongly linked to energy content for dairy farms, whereas on some cereal farms relatively low levels of environmental loss are associated with high food energy content. Caution must be taken in drawing conclusions from food energy content, as other important attributes of food production are not considered, and farms are constrained by their location in what can be feasibly be produced; however an assessment of the robustness of this finding would be worthy of further research, as would the degree to which food energy content per hectare correlates with the Strand 2 efficiency scores.

These results can be used to highlight farm characteristics associated with greater efficiency and track changes in SI on individual farms over time. For example, Firbank *et al.* (2013) used changes in the relationship between environmental metrics and food energy content to demonstrate SI across a survey of farms in England. The work in Strand 1 demonstrates that the same approach can be undertaken using mechanistic models (in this example, Farmscoper), based on a pre-existing source of secondary data (the FBS).

4.2 Potential proxy indicators

Having demonstrated that mechanistic models can be used to generate estimates of important environmental impacts, further work addressed the extent to which possible 'proxy indicators' could be used in data poor environments. In a first test, we examined how well N applied across the whole farm corresponded to the whole farm nitrate loading (both scaled per hectare). This analysis was performed for those cereal farms where N, P and K application was recorded in the FBS. As shown below in Fig. 3, nitrogen applied is a reasonable predictor of nitrate loading, and so may be of use for farmers (or farm advisors) needing to make a quick estimate of nitrate run-off without having to use an in-depth modelling approach.

The relationship between phosphorus applied and runoff was also tested. Phosphorus applied is not a clear predictor of phosphate runoff, as within FarmScoper the phosphorus loading sub-model is more strongly influenced by additional farm structural factors, and environmental conditions have a relatively greater effect. As a consequence, simple data on P applications would not be of use to make an approximate estimate of phosphate run-off.

A second test was performed to assess whether expenditure on fertilisers could be used as a proxy for nitrate and phosphate loadings: records of fertiliser applications may be more difficult to acquire or process and again, expenditure – if presented in a Management Accountancy format (*i.e.* expenditure is relevant to a particular set of crop outputs) – may serve as a suitable proxy variable in a data poor environment. Fertiliser expenditure is also available for a greater number of FBS farms than records of N, P and K applications, and has been collected for significantly longer, thus could be used for analyses of a greater number of FADN farms over time. As shown in Fig. 4a, total fertiliser expenditure correlates with nitrate loading, and although the relationship was less clear than using N applied as a predictor, the indicator is useful where an approximation is sufficient. As might be expected due to the greater complexity of modelling phosphate run-off, as described above, there was no clear relationship between total fertiliser expenditure and phosphate loading (Figure. 4b). These nutrient proxy analyses were not performed for dairy farms, as a lack of information on in-field excretion, and other manure transfers, would make relationships too unreliable to take further. Thus, the appropriateness of data-poor and data-rich approaches is dependent on the type of farm system being assessed.

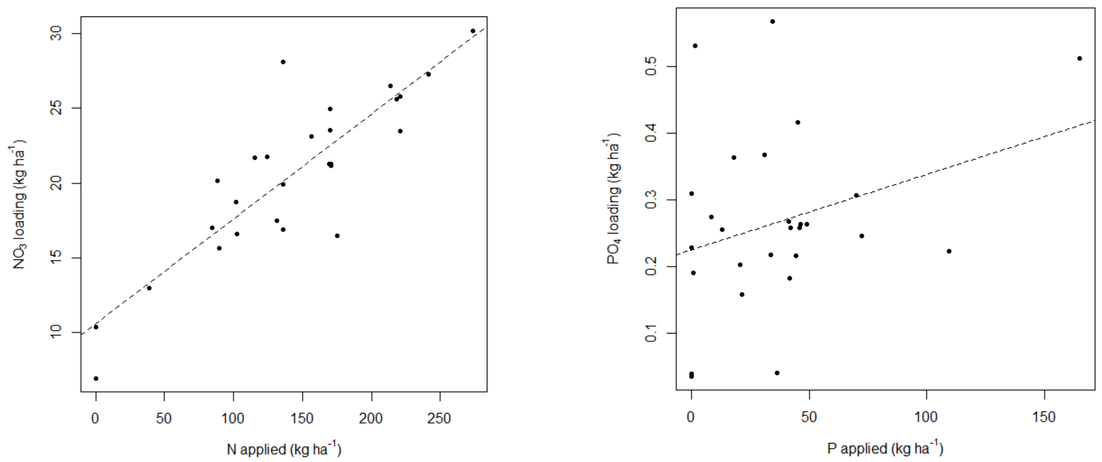

Figure 3. Relationships between (a) nitrogen applied and nitrate loading and (b) phosphorus applied and phosphate loading for a sample of cereal farms from the Farm Business Survey.

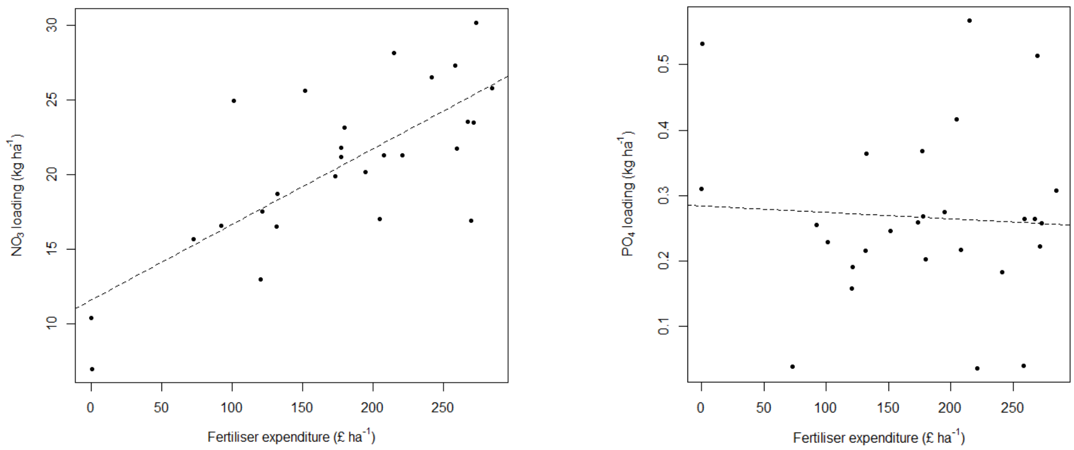

Figure 4. Relationships between (a) nitrogen applied and nitrate loading and (b) phosphorus applied and phosphate loading for a sample of cereal farms from the Farm Business Survey

For the dairy farms, methane emissions were identified as a key output, and so were used as a basis for proxy relationships instead of nutrients. Stocking rate (using the same stocking unit equivalents as in the FBS) was shown to correlate very strongly with methane emissions (Figure 5). This would suggest that a farmer or farm advisor could very quickly estimate methane emissions using simple emissions estimates per livestock units. However, the FBS data supplied contained limited or no information on livestock diets, manure storage and manure applications, which are all important aspects in determining methane emissions. Therefore, while a simple proxy would be useful to estimate methane at a very broad level, more detailed data not typically recorded in the FBS would need to be collected to ensure it was reliable, and better inform management decisions.

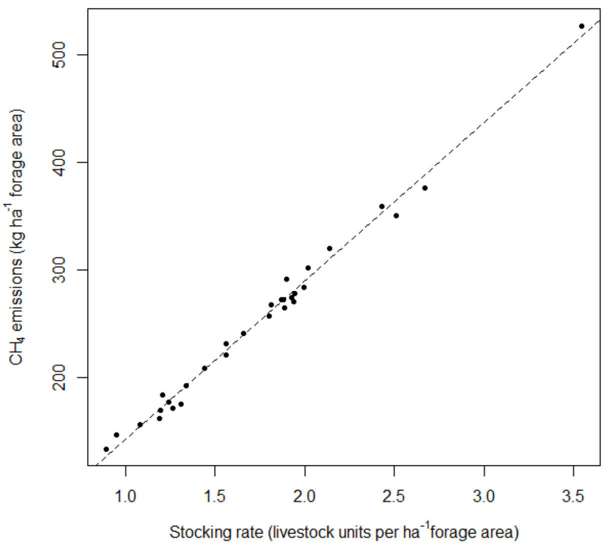

Figure 5. Relationships between stocking rate and methane emissions for a sample of dairy farms from the Farm Business Survey

Furthermore, if total GHG emissions are considered beyond just methane, additional factors such as farm structure and fertiliser-use become important and stocking rate is no longer a reliable proxy (Figure. 6).

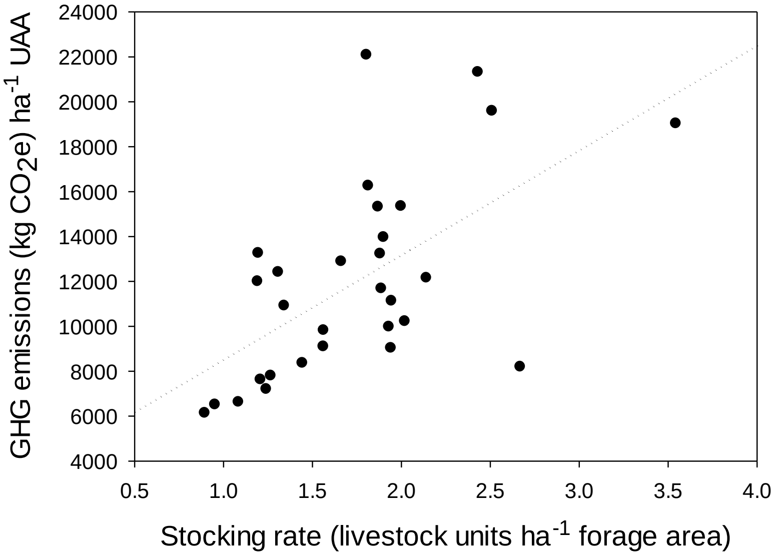

Figure 6. Relationships between stocking rate and whole farm greenhouse gas emissions for a sample of dairy farms from the Farm Business Survey

4.3 Ground-truthing - comparison between different mechanistic models

The results above focused on FarmScoper, but a similar range of environmental outputs have also been generated for the software EAgRET (Environmental and Agricultural Resource Use Efficiency Tool, formerly the Farm Scale Resource Use Efficiency Calculator, developed by a consortium led by ADAS– see Berger 2013). To demonstrate this approach, Figure 7 illustrates GHG emission estimates for all farms for both FarmScoper and EAgRET. Estimates generally match fairly closely as they are built on the same IPCC standards; however, it is clear that at higher emission levels, EAgRET generates larger values than FarmScoper. GHG emissions have also been estimated from a third model, IMPACCT, and similar comparisons will be explored with this model and presented in a paper to be submitted to the journal *Agricultural Systems.*

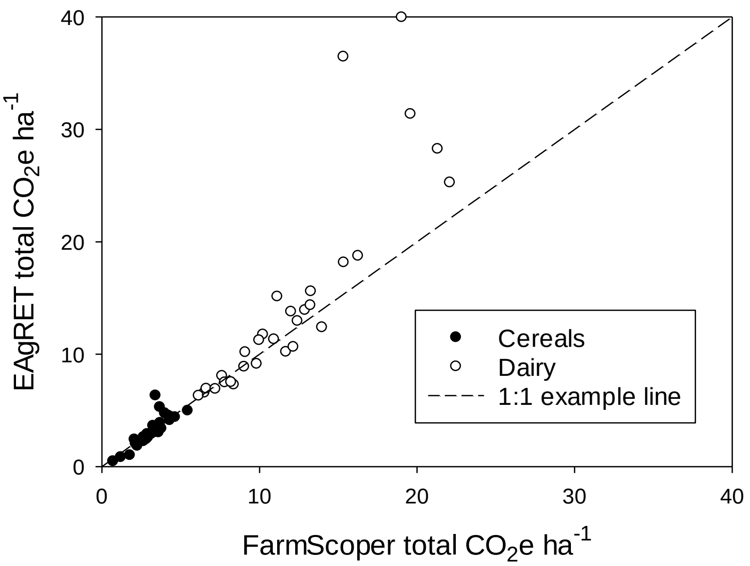

Figure 7. Greenhouse gas emission estimates from Farm Business Survey derived data for both FarmScoper and EAgRET

4.4 Integrating mechanistic modelling of environmental outputs with economic efficiency models

Where farms fulfil the data requirements, as is the case with FBS farms, the modelling approaches demonstrated here can also be used in the efficiency analysis undertaken as part of Strand 2. This enables comparison of the indicators used in Strand 1 with the economic efficiency indicators generated in the Strand 2 work. As an example, Figure 8 shows that that there is a weak but significant relationship between economically-modelled nutrient use efficiency (here measured as 'inefficiency' *i.e.* a measure of how farms are falling short of what is technically and allocatively efficient) and total GHG emissions. Table 7 presents a preliminary ranking analysis that suggests that economically efficient nutrient use is also associated with reduced environmental externalities (lower nitrate and phosphorus run-off, ammonia and GHG emissions), greater profitability and, from a social perspective, farmers who are younger and work fewer hours per hectare. The type of comparisons presented here show the potential for future work comparing performance across pillars, and can be built upon as modelling is refined and/or more detailed data become available from farm surveys.

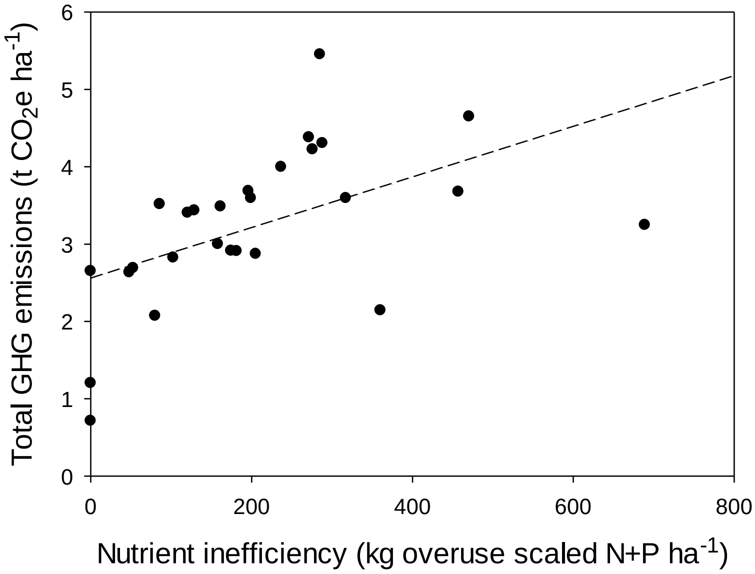

Figure 8. GHG estimates compared with economic models of nutrient use inefficiency

Table 7. Comparison of farm outputs according to ranked economically modelled nutrient efficiency for a sample of FBS farms. Nutrient efficiencies provided from Work Package 1.1B

Nutrient efficiency ranking	NO_3- (kg ha^{-1})	P (kg ha^{-1})	Sediment (kg ha^{-1})	NH_3 (kg ha^{-1})	Total GHG (t CO_2e ha^{-1})	Profit (£ ha^{-1})	Farmer age	Family hours worked (incl. farmer)
Top 1/3	17.6	0.29	193	7.3	2.41	290	53	11.5
Median 1/3	21.3	0.28	154	12.0	3.21	164	60	17
Bottom 1/3	22.9	0.22	89	16.1	3.96	76	62	13.5

5. CONCLUSIONS

There are considerable strengths in using the FBS dataset and the integrated framework presented here. From an industry or government perspective, Strand 2 approaches can be used to assess the productivity of UK farms and, for individual farms, their efficiency in relation to feasible levels of production with current technologies. This information can be used to compare performance over time and between UK agriculture and agriculture in other countries. Innovatively, the methods developed here allow for two core elements of the environmental pillar of SI to be included: nutrient loss and biodiversity. From a farmer or advisor perspective, Strand 1 methodologies can be used to estimate environmental impacts of agriculture at the (complete) farm system level; by using FBS data, the 'Economic' pillar of SI is also captured. Benchmarking approaches that are already recognised in the farming community to evaluate Economic performance can be applied to the environmental indicators – for example, farmers can assess their environmental position relative to their peers for a particular region, soil type or farm type.

For both Strands 1 and 2, social indicators relating to business sustainability, social capital and animal welfare can be associated with either the economic or environmental rankings. There will be trade-offs between the three pillars, in particular, economic efficiency, where driven by labour use efficiency, will reduce social capital as measured by the number of paid employees or levels of farmer and spouse supplied labour and management inputs. It may be that, for wider societal objectives, we choose to accept this lower level of economic efficiency. The objective of the exploratory analysis presented here was to demonstrate the augmented FBS approach and to derive a protocol for doing this. However, results suggest that economic efficiency is correlated with reduced environmental impact as measured by nutrient loss and GHG emissions.

A limitation to the Strand 1 methodology is that FBS data are not collected for use in models. The case study presented in Appendix 3 illustrates this point well. Thus, there is an opportunity to tailor the survey more closely towards model data requirements, particularly as many of the models tested as part of Work Package 1.1A have been funded by Defra or by industry, or by collaborative partnerships involving Defra and industry. However, mechanistic models of nutrient loss are not the best methodologies for use with FBS: the advantage of the completeness of the Survey – its capture of outputs and inputs across the farming year – is lost. Furthermore, the degree of additional information that would be needed would be prohibitive, both in expense and in farmer recruitment to the survey. More effective use of the survey would be to make use of nutrient balance methodologies that explicitly require the type of input and output data that the Survey is designed to collect. Additional information would be helpful in this respect, particularly information on livestock weights: these are collected as part of other FADN data sets, for example, those collected in Ireland.

GHG emissions can also be generated directly from Survey data, using standard IPCC methodologies. Better farm-based information than is currently collected is needed to take indicators of biodiversity closer to what is advocated by the Ecology community. In particular, more information on farm management practices is required than is currently available. These limitations can be overcome with a Survey that is more focused on environmental data collection for specific environmental indicator methodologies. With increasing use by farmers of farm management software that allows data to be presented in a management account format, it should be possible to free up resources within the FBS that could be directed towards the acquisition of a greater amount of appropriate environmental information.

6. KEY MESSAGES

1. An integrated methodology has been developed for use with the economically rich Farm Business Survey dataset for England and Wales. The methodology has two strands that deliver different, but complementary measures of the economic, environmental and social performance of farms.
2. Strand 1 provides farmers and advisors with a methodology and associated indicators that can be used with standard industry benchmarking approaches to assess farm performance across individual components of the three Sustainable Intensification (SI) pillars.
3. Strand 2 generates a composite farm SI indicator for policymakers that shows the position of an individual farm relative to what is achievable by the best farms in the FBS.
4. An augmentation procedure was developed, using FBS data and models and methodologies from SIP partners, to generate six environmental indicator categories: air and water quality; climate change regulation, energy and water use efficiency, biodiversity and level of knowledge.
5. Economic (7) indicators, capturing financial performance and efficiency, farm resilience, intensity of input use together with economic efficiency indicators from Strand 2; and Social (28) indicators, including business sustainability, social capital and animal welfare, were also generated.
6. A test of the augmentation procedure was conducted; results showed considerable variation across the different indicators, both per hectare and per unit of food energy content. Results for both air and water quality and climate change regulation were comparable to the literature.
7. Analysis of indicators from both strands of the integrated methodology suggests a positive correlation between financial and economic performance and environmental performance, particularly for air and water quality and climate change regulation.
8. Tests with proxy variables – simplified 'data poor' metrics – showed that in some cases there was a strong correlation with more 'data-rich' modelling approaches. However, these proxies are limited as indicators for farmers as they cannot capture the effect of management interventions.
9. A simplified, but comprehensive set of indicators was developed for the FBS Benchmarking site (http://www.farmbusinesssurvey.co.uk/benchmarking/).
10. Results are indicative of what could be achieved with the fuller FBS dataset: farms could track their performance over time, characteristics of 'top performing' farms could be identified and benchmarking frameworks that are routinely used to determine economic success could be extended to include environmental and social performance.

7. FUTURE WORK AND RECOMMENDATIONS

Both Strands 1 and 2 offer considerable scope for further work. The main opportunities are to:

- Apply the methodologies more widely
- Address the need for better information for use in both the economic and environmental analyses embodied in Strands 1 and 2.

With respect to Strand 1, the methodologies outlined in section 2.5 are being applied as part of the Project 2 benchmarking work. When complete, individual farm data will be available on climate change regulation, air and water quality and biodiversity for representative farms of different types across England and Wales. These data are directly linked to the economic and social information for each farm as currently collected in the FBS and thus indicators across the three pillars will be available for benchmarking by farmers through the FBS Farm Benchmarking website. It would also be relatively straightforward to conduct Strand 2-type efficiency analyses to generate efficiency scores for each farm, giving a more complete set of indicators across the three pillars. Further work could address the following types of question.

1. Is high performance consistent across the three environmental pillars?

2. What are the characteristics of joint high performance farms?

3. How do management practices change performance over time?

With respect to question 1, the results presented here suggest some correlation across indicators (Table 7). Studies explaining technical and economic efficiency have a long pedigree and it would be relatively straightforward to extend these approaches to address environmental and even social performance. With respect to question 3, it would already be possible to track management changes over time using augmented historical FBS data (*i.e.* augment existing data over a series of years; in the work here we have just used 2012 data). For the future, and particularly with better information collection, it would be possible to assess the effect of more recent management changes, or the adoption by farmers of industry standards aimed at promoting sustainable agriculture. The most prominent of these is LEAF and there are already sufficient LEAF farmers across some farm types within the FBS to do some useful work. A study conducted by the University of Nottingham over summer 2016 will assess the extent to which technical efficiency and other indicators of farm performance are linked to LEAF membership.

8. OUTPUTS AND PUBLICATIONS

Knowledge Exchange

Data mashing workshop, 10-11 September 2014, University of Nottingham

Indicator selection workshop March 20 2015, University of Leeds

Agricultural Economics Society 89th Annual Conference, April 13-15 2015, University of Warwick. Full presentation across SIP Objective 1.1 as part of a symposium organised by Richard Tiffin and Stephen Ramsden to an audience of international researchers, research organisation leaders, policy-makers (Defra), supply chain representatives (AHDB), international organisation representatives (OECD) and farmers.

Text for SIP web pages, May 2015

Newsletter articles (Lynch, Ramsden) for *SIPScene*, October edition 2015.

Presentation *indicators and benchmarks* given at the SIP 1 core workshop, NIAB Park Farm, Histon, Cambridgeshire, on 27 April 2016.

Presentation on sustainable farm practices and agricultural economics (built around SIP concepts) given at the Anaerobic Digestion and Biogas Conference, *Building a World Class AD Industry*, Birmingham NEC, 6 July 2016.

Academic Papers

The following papers are planned:

Indicators for Sustainable Intensification: to be submitted to *Agriculture, Ecosystems and Environment*.

Augmenting Farm Business Survey data to measure sustainable intensification: to be submitted to *Agricultural Systems*.

9. REFERENCES

Bell MJ, Wall E, Simm G, Russell G. 2011. Effects of genetic line and feeding system on methane emissions from dairy systems, Animal Feed Science and Technology, 166–167, 699-707.

Berger L. 2013. ADAS develops Farm Scale Resource Use Efficiency Calculator for AHDB. http://www.adas.uk/News/adas-develops-farm-scale-resource-use-efficiency-calculator-for-ahdb Accessed 22 August 2016.

Buckley C, Wall DP, Moran B, Murphy PNC. 2015. Developing the EU Farm Accountancy Data Network to derive indicators around the sustainable use of nitrogen and phosphorus at farm level *Nutr Cycl Agroecosyst* 102, 319-333. doi:10.1007/s10705-015-9702-9

Cameron KC, Di HJ, Moir JL. 2013. Nitrogen losses from the soil/plant system: a review, *Ann Appl Biol*, 162: 145–173. http://dx.doi.org/10.1111/aab.12014

DairyCo. 2012. Greenhouse gas emissions on British dairy farms. DairyCo carbon foot-printing study: Year one. http://dairy.ahdb.org.uk/media/623464/greenhouse_gas_emissions_on_british_dairy_farms.pdf

Dawson JC, Smith P. 2007. Carbon losses from soil and its consequences for land-use management, *Science of The Total Environment*, 382, 2–3, 165-190. http://dx.doi.org/10.1016/j.scitotenv.2007.03.023

Defra. 2010. Developing the Farmscoper Decision support tool - SCF0104. http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18702 Accessed 22 August 2016.

Enriquez-Hidalgo D, Lewis E, Gilliland T, Hennessy D. 2014. Effect of grass-only compared to grass-white clover swards on cow rumen function and methane emissions. In: *EGF at 50: The Future of European Grasslands*, Volume 19, Grassland Science in Europe. Eds. A Hopkins, RP Collins, MD Fraser, VR King, DC Lloyd, JM Moorby, PRH Robson, 792-794.

Firbank L, Elliott J, Drake B, Cao Y, Gooday R. 2013. Evidence of sustainable intensification among British farms, *Agriculture, Ecosystems and Environment*, 173, 58-65.

Gibbons JM, Ramsden SJ, Blake A. 2006. Modelling Uncertainty in Greenhouse Gas Emissions from UK Agriculture at the Farm Level. *Agriculture, Ecosystems and Environment*, 112, 347-355.

Jeanneret P, Baumgartner DU, Knuchel RF, Koch B, Gaillard G. 2014. An expert system for integrating biodiversity into agricultural life-cycle assessment, *Ecological Indicators*, 46, 224-231.

Kleijn D, Sutherland WJ. 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology*, 40, 947-969.

Knight S, Whitmore A, Tiffin R, Ang F, Areal F, Ramsden S, Firbank L, Lee M, Sutherland W, Dicks L, Moorby J, Drummond C, Midmer A, Parker C, Preston J. 2014. Defra Sustainable Intensification Research Platform Project 1: Integrated Farm Management for Improved Economic, Environmental and Social Performance (LM0201) – Scoping Study. Unpublished.

OF Schoumans, WJ Chardon, ME Bechmann, C. Gascuel-Odoux, G. Hofman, B. Kronvang, GH Rubæk, B Ulén, J-M Dorioz. 2014. Mitigation options to reduce phosphorus losses from the agricultural sector and improve surface water quality: A review, *Science of The Total Environment*, 468–469, 1255-1266. http://dx.doi.org/10.1016/j.scitotenv.2013.08.061

Scheper J, Holzschuh A, Kuussaari M, Potts SG, Rundlöf M, Smith HG, Kleijn D. 2013. Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis, *Ecology Letters*, 16, 912-920.

Taylor SD, He Y, Hiscock KM. 2016. Modelling the impacts of agricultural management practices on river water quality in Eastern England, *Journal of Environmental Management*, 180, 147-163. http://dx.doi.org/10.1016/j.jenvman.2016.05.002

Zhang Y, Collins AL, Gooday RD. 2012. Application of the FARMSCOPER tool for assessing agricultural diffuse pollution mitigation methods across the Hampshire Avon Demonstration Test Catchment, UK, *Environmental Science & Policy*, 24, 120-131. http://dx.doi.org/10.1016/j.envsci.2012.08.003

10. APPENDICES

Appendix 1: Protocol for use of FBS data to derive augmented farm performance measures

A copy of this protocol can also be found in the SIP archive:

SIP1_WP1.1A_Nottingham_JL_151215_1_Overview of FBS data for farm performance augmentation.docx.

Introduction

The Farm Business Survey (FBS) is a long-running and comprehensive resource, primarily focussed on the economic performance of farms. The FBS records many details of physical farm structure and inputs, which can be used to derive indicators of economic, environmental and social performance of farms. This document aims to list the relevant data available for a subset of dairy and cereal farms, in order to compare performance metrics using different models provided by SIP Project 1 partners.

Data are described as recorded by the FBS, with notes on conversion to forms more suitable for models. In general, conversion has been required to estimate physical inputs from financial costs, using standard prices. Gaps in FBS data may necessitate assumptions and defaults in order for models to be run; some 'workarounds' are described below. In line with procedures developed at the autumn 2014 'data-mashing' workshop at Nottingham, these data will be for individual dairy farms in the south west and cereal farms in the east of England, from the 2012 FBS.

Data Confidentiality and Protection

These data are drawn from the FBS for England; while anonymised they still refer to individual farm level data, and are being supplied to colleagues for development work as part of the SIP project. These data are not to be released to third parties or shared beyond the recipient and moreover cannot be made available in their raw form as part of the open access data procedure that will be developed as part of the SIP project. Any queries relating to data confidentiality should be addressed to paul.wilson@nottingham.ac.uk

Overall Farm Characteristics

Farm number – Farms are coded with individual reference numbers to compare outputs between models. These are not the original FBS farm reference numbers.

Total Utilised Agricultural Area (hectares) – Total area of farm. Areas of individual crops, grazing, etc. are provided below in the land-use and enterprise-specific sections.

Main Farm Type – Dominant enterprise on farm. If a model uses different classifications within individual farms these should be apportioned by land use and/or livestock numbers.

Farm Business Income – Total Farm Output less the sum of Variable and Fixed costs. Broadly equivalent to net profit in financial accounts.

Net Farm Income – Farm Business Income after adding back interest and ownership charges, less unpaid labour costs, emoluments, rental value and interests from separable diversified activities. Allows comparison of farms with different business organisation, tenure and indebtedness. Represents return to the farmer and spouse alone for their manual and managerial labour and on tenant-type capital invested in the farm business.

Region/Government office region/County – The sample farms include dairy farms in Devon and Somerset, and cereal farms in Cambridgeshire, Norfolk and Suffolk.

Dominant soil type – Soil information for OS 10km grid square in which farmed area is located. Soil group, texture, depth and carbonate content provided, taken from British Geological Survey Soil Parent Material Model.

Average annual rainfall (mm) – Average of annual precipitation between 2002 and 2011, using met office UKCP09 observed climate data.

Note: Agricultural land classification – Grades cannot be separated for different areas within a farm, so to avoid false comparisons all sites have been considered as grade 3.

Enterprise-Specific Output and Costs

More detailed information for crop, livestock and dairy enterprises is described in relevant sections below, but all enterprises will also have overall costs and output described as:

Total enterprise output (£) – Total value of all crop/livestock outputs (including secondary products) sold or used on farm, plus closing value of any outputs in store.

Total enterprise variable costs (£) – Costs which vary approximately in direct proportion to the scale of the enterprise, such as fertilisers, seeds and concentrate feeding stuffs for livestock.

Total enterprise fixed costs (£) – Costs which do not vary with small changes in the scale of the individual enterprise, such as machinery repairs and general expenses. Where fixed costs cannot readily be allocated to an individual enterprise, the FBS uses econometrically allocated fixed costs among different enterprises according to enterprise outputs.

If a model does not distinguish between variable and fixed costs these can be summed to give total enterprise costs.

If whole farm and enterprise specific costs can be separated, variable costs should be considered as specific to individual enterprises, and fixed costs summed to give whole farm costs.

Land-Use

Land-use on the farm is divided into several categories, listed below (all in hectares). Not all farms will have all land use types, particularly when specific to individual crops or dairy practices.

- Principal crops [listed individually under crop type]
- Fodder maize
- Fodder roots and kale
- Other silage cereals
- Other fodder crops
- Temporary Grass – Hay [note: temporary areas are < 5 years]

- Temporary Grass – Silage
- Temporary Grass – Grazing
- Permanent Grass – Hay
- Permanent Grass – Silage
- Permanent Grass – Grazing
- Rough grazing
- Fallow
- Bare land let for less than 1 year
- Forage let for less than 1 year
- Turf
- Un-cropped land, excluding fallow & including voluntary set-aside
- Woodlands [note: does not include short rotation coppice]
- Buildings, Roads, Other

Multiple crop areas (ha) – If the crop type is harvested annually, this section will be recorded as 0 and the cropping area found under land use for the principal crop. If a farm uses second or multiple cropping, the non-primary crop type will be listed as 0 in primary land use, but have a value for multiple cropping areas. Note that this area is already included in overall farm area under the principal crop, so care must be taken whether or not to include it in the model. Crop-specific cultivations or yield information may require an area, but it should not be incorporated, for example, as an additional area contributing to annual soil fluxes.

Livestock Counts

For each livestock category below, **livestock numbers**, **purchases** and **sales** are provided. Replacement rates can be estimated within models from numbers of individuals in different categories. Killing out rates cannot be reliably estimated, as sales numbers include revenue from casualties. No weight data is recorded.

All counts are averages across the whole year, and incorporate transfers between categories (*e.g.* dairy calves -> dairy cattle). As such, where models use periods of time animals are in a system, a duration of 12 months should be assumed for all FBS counts.

Dairy-specific livestock categories:

- Breeding bulls for dairy herd (1 year +)
- Dairy cows
- Dairy calves
- Dairy heifers in calf (rearing)

Other cattle:

- Other male cattle (excluding bulls) 2 years and over
- Other female cattle 2 years and over
- Other male cattle 1-2 years
- Other female cattle 1-2 years
- Cattle under 1 year for slaughter as calves
- Cattle under 1 year: other cattle and bull calves

- Beef cows (graze on less-favoured areas)
- Beef cows (lowland – not LFA)
- Beef heifers in calf
- Breeding bulls for use with the beef herd (one year and over)

At the whole-system level, dairy farms are defined as primarily:

- Producer retailer
- Wholesaler
  - Producer retailer and wholesaler systems are split into:
    - Channel Islands breeds (Jersey, Guernsey)
    - Other breeds (assume Holstein-Friesian)
    - Mixed Channel Islands breeds and other breeds
- Mixed wholesaler/producer retailer – all breeds (assume Holstein-Friesian)
- Farms which lease out part of, or all of their milk quota and produce no milk

At the whole-system level, other cattle enterprises are defined as primarily:

- Beef cows (all of herd kept on land in receipt of Hill Farm Allowances)
- Beef cows (none of herd kept on land in receipt of Hill Farm Allowances)
  - Systems where all/none of herd receiving HFAs are split into:
    - Single suckling – spring calving selling weaned calves/stores
    - Single suckling – autumn calving selling weaned calves/stores
    - Single suckling – mixed autumn and spring calving and other selling fat cattle
    - Single suckling – mixed autumn and spring calving and other selling store cattle
    - Multiple suckling and mixed single and multiple suckling
- Beef cows (part of herd kept on land in receipt of Hill Farm Allowances)
- Dairy followers
- Young stores (3-6 cwt) **note: 1 cwt = 50.8 kilograms**
- Forward stores (6 cwt or more)
- Veal calves (3-6 months)
- Fat cattle – intensive cereal beef (8-14 months)
- Fat cattle – semi-intensive beef (15-24 months)
- Fat cattle – traditional mainly grass beef (2 years +)
- Other/mixed (including calves for rearing, reared calves, etc.)

Dairy systems cannot be split into different seasonal calving patterns. If a model requires seasonal categorisation, consider all dairy systems as all year round calving.

Dairy Farm Output

Milk production (hectolitres) – Total milk output from the farm. Separated into **milk** and **milk products** (in hectolitres of milk equivalent).

Milk used on farm (hectolitres) – Volume of milk used on farm, including milk fed to calves and farmhouse use. This should be subtracted from total milk production if model only considers milk sold.

Milk revenue (£) – As recorded on farm, does not include milk used on farm.

Total milk value (£) – Equivalent value of total milk production, including milk used on farm.

Milk composition is not recorded in the FBS. If required for a model, and defaults are not available, average values from the 2012/13 SAC Farm Management Handbook should be used:

- **Butterfat %** – 4.0
- **Protein %** – 3.30

Manure Management

The FBS does not record any direct data on manure management. However, farms involved in an additional fertiliser calculation component go through a series of on-farm questions to estimate organic fertiliser application (see fertiliser section below). The fertiliser calculation questions estimate manure or slurry production from time spent in different livestock housing systems, then use standard values to estimate N P K content, depending on application method. Broad assumptions have been made to work back from these values in order to estimate slurry produced on farm, giving the following data:

- **Slurry volume used on farm (m^3)** – Cannot be attributed to different livestock categories
- **Slurry exported from farm (m^3) and (£)** – SAC 2012/13 value of £5.11/per m^3 cattle slurry
- **Total slurry volume produced on farm (m^3)** – Sum of two categories above

Conversion operates with two key assumptions:

- all excreta is collected as slurry and immediately exported or used on farm
- 'miscellaneous cattle revenue' is entirely composed of slurry sales

Three further caveats are acknowledged:

- no information is provided on excretion on grazed areas
- if waste goes into an on-farm anaerobic digester it is not recorded
- imported slurry/manure cannot be separated from home-produced, and may result in over-estimation of slurry production

If models include default manure management and excreta volumes for different livestock categories these are likely to be more accurate, and should be used instead.

Livestock Inputs

There is limited information on livestock diet recorded directly in the FBS. Many details, such as composition of imported feedstuffs cannot be obtained, and the distribution of feedstuffs between different livestock categories is unavailable. As a result, model-default dietary information should be used.

However, volumes of some home-grown feedstuffs can be tracked, and so the information described below allows models to transfer products between crop and livestock activities, and more accurately apportion embedded emissions to imported feedstuffs.

Principal crops used as on-farm feedstuffs (t) – weight of feedstuffs derived from on-farm crops. Multiple values will be provided if multiple crops are used as feed.

Home-grown straw used on farm (t) – weight of straw used on farm. Cannot be allocated between different principal crops or split between on-farm use for feed, bedding or other activities.

Forage / home-grown fodder (t)
The broad fodder and forage land-use types listed above are assumed to correspond to the following individual crops in order to estimate yields and be of use in models:

- **Fodder roots and kale – autumn kale**
- **Other silage cereals – whole crop wheat**
- **Other fodder crops – Lucerne**

Typical DM yields are used from the 2012/13 SAC and ABC handbooks. The assumption that these categories all correspond to a single crop type is also acknowledged as a limitation of the current approach.

Fodder crop enterprise outputs are converted back to a weight and subtracted from yield estimates in order to remove fodder crops sold, and add any crops from the previous year used as feed.

Note: these are very rough estimates, as little fodder crop data is available from FBS, and should only be used if required by models and area-based defaults are not available.

Grass areas, including grazing, are provided in the land-use section. They cannot be separated between different livestock categories. Livestock grazing inputs/outputs should use model defaults.

Imported concentrated feedstuffs (£) and (t) – price and weight of concentrated feedstuffs imported from off farm. Weight calculated from cost of concentrated feedstuff imports * typical 2012 price of £220 per tonne from Nix Farm Management Pocketbook 2012. If necessary for a model, assume concentrated feedstuffs are cereal (wheat). Econometrically allocated between different livestock categories using FBS defaults.

Imported bulk feed and coarse fodder (£) and (t) – Total cost and weight of imported bulk feed and coarse fodder available. Weight assumes all imported bulk feed coarse fodder is stockfeed potatoes, and uses the SAC Farm Management Handbook 2012/13 price of £15/t. (Note: stockfeed potatoes used instead of kale as limited standard price information on other fodder crops). Econometrically allocated between different livestock categories.

Purchased bedding litter (£) and (t) – Uses 2012 FBS market price for wheat straw of £45/tonne to convert from cost of important bedding litter to weight. For models assume all bedding litter is wheat straw. Econometrically allocated between different livestock categories using FBS defaults.

Veterinary and medicine costs (£) – Total costs – available if case used in a model. Econometrically allocated between different livestock categories using FBS defaults.

Crop Outputs

Each farm may have multiple crop output entries, split by specific crop types (with the same definitions in land-use). Fodder/forage categories assume the same crop-types described above.

Total crop production (t) – Total production of major crop products for a harvest year. Note that crops used as on-farm feedstuffs, provided above in the livestock category, are included in this total crop production, thus it is necessary to ensure that a model does not 'double count'. **Note**: fodder crop production values are estimates based on typical yields, and should be avoided unless required for model.

Crop enterprise output (£) – Total monetary value of crop production for harvest year, including equivalent costs for crops used on farm and any subsidies.

Crop by-product output (£) – Total monetary value from production of crop by-products (straw and sugar beet tops) for any relevant principal crops.

Straw production (t) – Total straw production from all crop types (cannot be allocated between different principal crops). Note that home-grown straw used on farm, as described above in the livestock category, is included in this total straw production, so ensure model does not double count.

Straw sold (£) and (t) – Amount of straw sold and revenue from its sale, from all crop types (cannot be allocated between different principal crops). This is included to provide additional crop revenue information, but this volume is also included in the total straw production section above, so ensure model does not double count.

Costs of seeds/young plants (£) – Total cost of seeds or young plants for given crop type. Costs are econometrically allocated between different principal crop types using FBS defaults.

Crop Protection Products

Total cost of CPP (£) – FBS records include overall crop protection product costs (including growth regulators). CPP costs are econometrically allocated between different principal crop types using FBS defaults. For fodder/forage crops (where there is no standard FBS econometric allocation) costs have been assigned by proportion of crop areas and expected costs.

This cost is split, for each crop, into **herbicides**, **fungicides**, **insecticides**, and **growth regulators**, according to typical applications described in the 21012/13 SAC Farm Management Handbook. These individual costs are treated as if entirely spent on the most commonly used herbicide, fungicide and insecticide for an individual crop, according to the 2012 Pesticide Usage Survey (growth regulators and other sprays are not taken further, as they are not expected to be a major component of models). Pesticide volumes are then estimated from the relevant expenditure, according to average pesticide prices in the SAC Farm Management Handbook 2012/13. This volume is then compared to a label rate for a given cropping area to provide numbers of label rate applications for each pesticide category. This series of assumptions provides the following data:

Herbicide, fungicide, insecticide, growth regulator and other costs (£) – all provided individually.

Amount of herbicide, fungicide and insecticide applied (kg or l, depending on pesticide) – provided individually, each assuming entire crop protection cost for crop is spent on single most commonly applied pesticide for each category.

Number of label rate herbicide, fungicide and insecticide applications for specific cropping area – provided individually for each pesticide category, assumes each composed of single most commonly applied pesticide for each category.

Fertilisers

Total cost of imported fertilisers (£) – cannot be broken down into individual fertilisers.

The following details are only available for farms involved in an additional fertiliser calculation component of the FBS. See fertiliser data diagram for alternative presentation.

Inorganic Fertiliser N, P and K (kg) – Total amounts of N, P and K (individually) applied over the year, excluding organic fertilisers (slurry, farm yard manure, seaweed, anaerobic digestate, etc.). Individual compounds not available.

Slurry and farm yard manure N, P and K (kg) – Total amount of N, P and K (individually) from slurry and farm yard manure. As in manure management section, these are derived by 'reversing' the loss of nutrients assumed in airborne application of slurry.

Slurry volume applied (m^3) – Assumes all slurry and farmyard manure N P K (above) is slurry, applied to the soil surface, and uses N to convert to total volume.

On-farm digestate N, P and K (kg) – Nutrient content of digestate applied from on-farm anaerobic digestion.

On-farm digestate weight (t) – Uses N content of on-farm digestate to convert to weight, using standard FBS value of 2.9kg N per tonne of digestate.

Imported digestate N, P and K (kg) – Nutrient content of digestate applied from off-farm anaerobic digestion.

Imported digestate weight (t) – Uses N content of imported digestate to convert to weight.

Other organic N, P and K (kg) – Nutrient content of any other organic fertilisers not included in above categories (e.g. seaweed, biosolids, compost).

Compost (food/green/composted biosolid) weight (t) – Assumes all other organic fertilisers are food/green composts, or composted biosolids. Converted to weight using FBS value of 0.6kg available N per tonne of compost.

Total organic N, P and K (kg) – Nutrient content from all organic categories described above.

Total N, P and K (kg) – Sum of N P K from organic and inorganic sources.

For farms not involved in the additional fertiliser calculation component, fertiliser costs per enterprise are compared with typical expenses from SAC Farm Management Handbook 2012/13 to give a proportion of 'standard' costs. This proportion of relative total fertiliser application is then applied to standard N, P and K applications for each crop (also from SAC) to estimate inputs. Fertiliser costs use FBS standard econometric allocations to split between different principal costs. If farms are involved in the fertiliser calculations component, these values should be used instead of the cost-based estimates.

Allocation of CPP and Fertiliser Costs for Fodder & Forage Products

There is no default econometric allocation of CPP and fertiliser costs for fodder and forage crops. They have been allocated using the following formula:

$$propotion\ spending\ on\ crop\ A = \frac{crop\ A\ area * typical\ crop\ A\ costs}{\sum_i (crop\ i\ area * typical\ crop\ i\ costs)}$$

It is assumed that CPP and fertiliser inputs (and yields) are the same for principle and multiple cropping areas.

Total Farm Electricity, Fuel and Water Use

Some electricity, fuel and water use recorded in the FBS can be apportioned to individual enterprises and/or processes, but the most comprehensive and accurate data is on total usage across the whole farm, as described below. If possible this data should be used in models. Fuel volumes and electricity usage are estimated from costs, converted using SAC Farm Management Handbook 2012/13 fuel prices.

- **Electricity (£) and (kWh)** – 6.937 p/kWh (assumes non domestic rates)
- **Machinery and vehicle fuels and oil (£) and (l)** – 63 p/litre (assumes all red diesel)
- **Heating fuel (£) and (l)** – 53 p/litre (assumes all kerosene)

Note: additional FBS categories including propane, gas, coal, derv and white diesel are recorded from 2013/14 onwards. These can be added if using more recent sample data.

Water use (£) and (m^3) – Total costs relating to water usage, converted to volume assuming £0.95m^3 (Dairy Co DIY full water audit pack, 2011).

Note: This is a very rough conversion, without considering sewerage rates, abstraction, rainwater collection, etc. Consequently, water use efficiency and other water use metrics cannot be considered very reliable at present. Standard farm water rates are not provided by most sources (e.g. DEFRA, SAC), and further complications arise as abstraction licensing varies by region, and does not necessarily give details as to volumes used (the system has also changed over the last year). Moving forward, farm receipts and some extra FBS data (section A: primary water sources) may be used to provide superior information on water use, and separate between different sources.

Note on external haulage and refrigeration costs: these are not measured as part of the FBS, and if possible models should be run excluding them, so that when products leave the farm-gate no further outputs are recorded.

Appendix 2: Summary of archived documents

This section provides a brief description of documents / files relating to Objective 1.1 that have been uploaded to the SIP archive (accessible at www.environmentdata.org), along with details of where and how data were obtained and/or processed, where necessary.

Farm Business Survey (FBS) data are archived as averaged data containing not less than n=10 farms, in order to preserve confidentiality. Any queries relating to data confidentiality should be addressed to Paul Wilson (paul.wilson@nottingham.ac.uk).

Files and processes were quality controlled through internal review at Nottingham with Stephen Ramsden and Paul Wilson, review with named project partners for specific output files, and presentation/discussion of concepts at SIP and other meetings.

File descriptions

SIP1_WP1.A_Nottingham_JL_151215_1_Overview of FBS data for farm performance augmentation.docx

Describes all data obtained through the FBS as part of the project, including explanations and sources for assumptions/conversions.

SIP1_WP1.A_Nottingham_JL_151215_1_conversion illustrations.pdf

Illustrates data processing for the more derived conversions of FBS data.

SIP1_WP1.A_Nottingham_JL_151215_1_Collated working sheet – locked.xlsx

Spreadsheet used to process FBS extracted data, also contains default coefficients for conversions, and FBS extract codes for data used.

SIP1_WP1.A_Nottingham_JL_151215_1_Collated working sheet info.docx

Provides summary of 'collated working sheet' described above.

SIP1_WP1.A_Nottingham_JL_151215_1_Adding geospatial data to FBS farms using ArcMap 10.docx

Guide to using GIS package ArcMap to add geospatial data (specifically soil and precipitation) to FBS extracted farm locations.

SIP1_WP1.A_Nottingham_JL_151215_1_empty FBS GridRefconvertor + Easting Northing.xlsx

Spreadsheet used to convert FBS-extracted location codes to OS grid references and Easting Northing values.

SIP1_WP1.A_Nottingham_JL_151215_1_FBS derived data – averaged.xlsx

Averaged data (n>10) for a sample of East Anglian cereal farms and South West dairy farms, extracted from the 2012 FBS using the above documentation/tools.

SIP1_WP1.A_Nottingham_JL_151215_1_FarmScoper results from FBS sample data - averaged and minmax.xlsx

Averaged and min/max outputs of interest running the FBS-derived data summarised in "FBS derived data – averaged.csv" through the FarmScoper tool. Data run through FarmScoper by Dave Skirvin (ADAS).

SIP1_WP1.A_Nottingham_JL_151215_1_EAgRET results from FBS data - averaged and minmax.xslx

Averaged and min/max outputs of interest running the FBS-derived data summarised in "FBS derived data – averaged.csv" through the EAgRET tool. Data run through EAgRET by Dave Skirvin (ADAS).

SIP1_WP1.A_Nottingham_JL_151215_1_IMPACCT results – averaged.xslx

Averaged outputs of interest running the FBS-derived data summarised in "FBS derived data – averaged.csv" through the IMPACCT tool. Data run through IMPACCT by Doug Warner (Hertfordshire).

Appendix 3: Use of Farm Business Survey data in the Organic Research Centre Public Good Tool

Introduction

The Farm Business Survey (FBS) collects detailed annual accounts data for almost 2000 farms across England and Wales, as part of the EU Farm Accountancy Data Network (FADN). FADN is primarily financial data, but has also been used to estimate environmental impacts, for example to compare the performance of organic and conventional farms (Gerrard *et al.* 2012). A component of the SIP work on measuring sustainable intensification (SI) sought to continue with this approach, utilising as much FBS data as reliable in external models of farm performance. The augmented FBS approach has primarily used mechanistic models to estimate physical quantities of various environmental impacts. An interesting alternative form of model is provided by the Organic Research Centre (ORC) Public Goods (PG) Tool, which provides a broader, more qualitative assessment of farm performance. This report provides an overview of how FBS data was used in the PG Tool and demonstration of results for a small number of sample farms. Limitations arise due to the difference in approach and objective between the FBS and PG Tool, but the exercise is a useful means of considering the strengths and weaknesses of the FBS for additional purposes. The work also allows us to 'ground truth' results from FBS data across different methodological approaches.

Organic Research Centre Public Goods Tool

The PG Tool is a "comprehensive sustainability assessment tool for farming systems" (as described on the PG Tool page on www.organicresearchcentre.com). It was developed by the Organic Research Centre as part of a Defra funded project through Natural England. The tool appraises farms on a wide range of agricultural practices, split into separate scores for 11 "spurs": soil management, agri-environmental management, landscape and heritage, water management, fertiliser management and nutrients, energy and carbon, food security, agricultural systems diversity, social capital, farm business resilience, and animal health and welfare management (Gerrard *et al.* 2011). Each spur is scored based on basic farm structural information, and whether specific practices or mitigations are carried out. The individual activities are grouped into relevant categories with one or more questions for each (for example, under the 'water management spur', there are sections on: measures to minimise pollution and maximise water use efficiency, flood defence and runoff prevention, water audit and management plan, water harvesting, and irrigation). Applicable activities receive a score which contributes to a total for that spur reflecting to what extent the farmer provides a 'public good'. Scoring is on a 1-5 scale, where 5 is the highest score, signifying the best provision of public goods, and 1 the lowest, signifying poor provision of public goods, (or, potentially negative effects, depending on the attribute in question).

The tool was designed to be used on farm, with advisors completing an excel workbook covering data needs for all spurs through farmer interview. Although the tool is intended to use data which the farm can readily provide, many of the spurs are scored primarily on specific activities which are not recorded as part of the FBS. Despite this, some details from the FBS, for instance areas and yields of different crops and numbers of livestock, are relevant to the PG Tool, and aspects of some other scores can be inferred. The process of using FBS data in the PG Tool is described below, running through each spur individually.

Methods

FBS data in PG Tool

FBS Sample farms

The means of data entry into the PG tool is primarily based around specific questions, with one Excel worksheet per farm. As a result, data could not be readily converted and entered for multiple farms within the scope of the project, and so only a small selection FBS sample farms were selected for manual entry. Previous work had tested a subset of dairy and cereal farms from the 2012 FBS in the decision support software 'FarmScoper', from which estimates of environmental impacts such as greenhouse gas (GHG) emissions and nitrate and phosphorus run-off were generated. The top and bottom ranking farms of each type for estimated nitrate run-off (scaled per hectare) were selected for comparison in the PG tool. By using extremes, we reveal the maximum potential difference for similar types of farms when using FBS data in the PG tool. Nitrate loading was selected as the means of ranking farms, as it is driven by on-farm management more than local environment (*c.f.* phosphorus loading) or stocking rate alone (for GHG emissions on dairy farms). Only farms with fertiliser applications recorded in the FBS were ranked.

Table A1. Summary of major FBS data used in PG Tool

Input data	Units	Source
Farm Structure		
Main Farm Type	n/a	Direct extraction
Utilised Agricultural Area	Ha	Direct extraction
Land Use	Ha	Direct extraction
Livestock counts	No.	Direct extraction
Crop Production		
Total production of major crop product	T	Main crops: direct extraction Fodder crops: typical yields
Straw production	T	Direct extraction
Livestock and dairy production		
Livestock sales	No.	Direct extraction
Milk Production	Litres	Direct extraction
Inputs / resource use		
Fertiliser inputs	Kg N Kg P Kg K	Direct extraction
Slurry and other organic fertilisers	m^3 or kg	Conversion from N input value
Animal feed / bedding	Kg	Conversion from expenditure
Electricity	kWh	Conversion from expenditure
Machinery and vehicle fuels	Litres	Conversion from expenditure
Heating fuels	Litres	Conversion from expenditure
Water use	m^3	Conversion from expenditure

FBS data used in PG Tool

As much relevant physical and structural FBS farm data as possible was used to test in the PG Tool. For some areas, only financial data were available, and assumptions were made to convert to physical values. A short summary of main areas of data is provided in Table A1 above, with further specifics described under 'inputting data' for the relevant spurs.

PG Tool data entry

The following sections describe how FBS data was entered into the PG Tool. As stated below, for individual spurs, a large number of questions could not be answered from FBS data, so these were selected to give answers resulting in the intermediate value of '3', on the 1-5 scale used by the PG Tool.

Initial data collection sheet
Farm physical and structural data from the FBS were added to this section. For land use, most crop areas and yields could be entered directly. In the FBS, wheat is not separated between milling or feed wheat, but for simplicity and consistency data were all entered as milling wheat.

Permanent grass for hay or silage data from the FBS was allocated as 'permanent pasture – low clover' in the PG Tool. Similarly, fallow was entered as 'temporary pasture 1st year' in the PG Tool, and 'woodland' as 'mixed woodland'.

Livestock numbers were as recorded in the FBS, with the exception of the 'cattle under one year' category which was divided equally into 'calves 0-6 months' and 'calves 6-12 months' in the PG Tool.

Imported feeds were entered as close as possible to the same assumptions as used in FarmScoper, using the same financial conversions where necessary. Concentrate feed from the FBS was entered as 'mixed cereals/grain' and 'imported coarse fodder' as potatoes.

Fertiliser imports (from the FBS section F3 fertiliser section) were allocated as 'other fertilisers' to give exact N, P and K quantities. As the PG Tool requires fertiliser inputs and exports as a farm gate balance, rather than total applications, on the dairy farms FYM/slurry fertiliser quantities were excluded, under the assumption that these were applications of manure generated on-farm.

Soil management
The soil management section of PG covers whether the farm undertakes soil analysis, if it has a soil management plan and to what extent this is acted on, whether this is winter grazing, and to what extent the farmland is at risk of erosion, and if any actions are undertaken to minimise this risk. No FBS information could reliably be used in this spur, either directly or inferred, so answers were all selected to give the average score of 3.

Agri-environmental management
Some land-use based details relevant to the 'habitat' section of agri-environmental management were available from the initial data collection sheet: the proportion of land that is permanent pasture, and the area of woodland consisting of native species (following the assumption made that all farm woodland was mixed woodland, it was further assumed that this was composed of native species). The 'crop protection and pesticides component' could be partially scored for some farms, including the top ranked cereal farm.

No other FBS data could reliably be applied to the agri-environmental management spur, which covers specifics of agri-environment agreements, designated areas, rare species and conservation plans. Therefore, all other questions were answered as 'not applicable' or selected to give the average score of 3.

Landscape and heritage

FBS information could not reliably be used to complete the Landscape and Heritage Features spur, which covers historic features, JCA and landscape features, management of boundaries and genetic heritage, so all questions were answered as not applicable or selected to give the average score of 3.

Water management

For dairy farms with only hay and silage grown on farm, 'no irrigation' was selected as it was unlikely there would be any irrigation. For cereal farms, irrigation options were selected to give the mean score of 3. Questions in the water harvesting component were also selected to give a score of 3, for both farm types.

NPK budget

The PG Tool estimates total NPK budgets based on imports and exports completed in the initial data collection tab. The totals were scored according to the guidance provided in the PG Tool (for instance, a nitrogen surplus, or potentially deficit, between 0-50 kg/ha scores 5, 50-70: 4, 70-90: 3, 90-110: 2, and 110 kg/ha or greater scores 1).

Fertiliser management

The remaining fertiliser questions cover management specifics regarding fertiliser management and application, nutrient planning, manure management and farm waste disposal, which were unavailable from the FBS; questions were therefore answered as not applicable or selected to give the average score of 3.

Fuel use input data

Volumes of red diesel and quantities of electricity were added, following conversion from expenditure using the same coefficients as used with FarmScoper. The farms tested were entered as exclusively arable or exclusively dairy, rather than broken down between enterprises on the PG Tool, as the cereal farms had no other enterprises using or exporting energy, and the only non-dairy energy flux on the dairy farms was a negligible amount of hay exported.

Energy and carbon benchmarks

Energy use benchmarks and energy input/output ratios using the data from the 'fuel use input data' and 'initial data collection sheet' tabs were scored according to the PG guidelines (including embedded standards) for each enterprise.

Energy and carbon spur

The remaining energy- and carbon-based questions relate to management specifics around energy saving, GHG audits, land use changes to or from woodland or grassland in the last 20 years, and renewable energy. These details are unavailable from the FBS, so were answered as not applicable or selected to give the average score of 3.

Food Security

Off farm feed was entered as 0% for the cereal farms tested, which had no livestock present. For the dairy farms, a simple approximation of the proportion of off farm feed was made by comparing the amount of concentrate feed imported with a standard (Nix, 2012) requirement of average yielding dairy cows consuming £450 of concentrates per year, and assuming the remaining feed need was supplied by on-farm production.

All of the farms tested were entirely combinable crops, pasture/forage and dairy and thus were allocated zero output under ‘hectares of farm used to grow fruit, roots and other vegetables’.

The ‘total productivity’ question asking ‘how would you describe your yield compared with average yields for similar types of farm?’ was answered as ‘average’ (score 3) as without directly asking farmers (as would be done by an advisor using the PG Tool) there is no means of establishing their perception from the FBS. However, a benchmarking approach among similar farm types could be used to give a very accurate relative productivity estimate between FBS farms.

The remaining food security questions relate to food destination and 3rd party endorsements, which could not be derived from the FBS, and so were answered as not applicable or selected to give the average score of 3.

Agricultural systems diversity
The agricultural systems diversity tab asks a number of questions about number of crop types in a crop rotation, different species/varieties of crops grown, different breeds/crossbreeds of livestock, how many outlets produce is marketed through and whether there is any on-farm processing. Although the FBS can provide information that is relevant to these categories, for this run they were set as ‘not applicable’ or selected to give the average score of 3.

Social capital
The first set of questions on social capital ask how many staff are employed on farm, separated into casual, long term, and family labour, recorded in hours per year (for casual staff) or Annual Labour Units (long term staff and family labour). These data are available from the FBS, but were given average scores of 3 in the current run.

The remainder of the social capital spur covers skills and knowledge (training), community engagement, Corporate Social Responsibility, public access, and human health issues. There is little to no relevant data on these topics from the FBS, and so all remaining answers were selected to give the average score of 3.

Farm Business Resilience
The ‘financial viability’ section of the farm business resilience tab scores the farm’s prices for different products relative to in-build standards. FBS data was used to generate prices per unit of relevant products. The other component of the ‘financial viability’ section asks “how have your net assets changed in the last year?” This could be established from the FBS if the farm was in the survey the previous year, but in keeping with the single year assessment of the project, the answer selected was “not much change from previous year” to return a score of 3.

The remainder of the spur, ‘farm resilience’ primarily asks around business management, plans, and perceptions not available from the typical FBS, and so all remaining answers were selected to give the average score of 3.

Animal Health & Welfare
For farms without livestock this spur is excluded.

Under the ‘animal health’ section, the question “How much do you spend on veterinary medicines” was completed using FBS expenditure on medicines and veterinary costs. These are scaled per livestock unit and scored in the PG Tool. It is not possible to determine what proportion of these costs are preventative, which can be a basis to increase the score received at the advisor’s discretion.

In the ‘staff resources’ section, although the FBS does not allocate staff to different enterprise, with some farms it may be possible to estimate a number of full-time equivalent labour units working with livestock from the staffing data, but as noted above for the ‘social capital’ spur, these details were not extracted for this study, and so values were used to return an average score of 3.

The remainder of the animal health and welfare spur asks specific questions around grazing, health plans, housing and biosecurity, which cannot be reliably obtained from the FBS, and so all remaining answers were selected to give the average score of 3.

Results

Using FBS data in the PG Tool is constrained by the different objectives and topics covered between the two. Consequently, even when using dairy and cereal farms from the extremes of nitrate loading (as ranked by FarmScoper) showed similar scores in the PG Tool, though there were some differences, as illustrated in Figure A1. A brief summary of the different results for each spur is provided below.

The top cereal farm receives a slightly higher score in ‘agri-environmental management’ as there was no expenditure on pesticides, so the answer for “how do you control pests?” involving no chemical pesticides gave a relatively higher score than the default option selected for the second farm. Both dairy farms receive higher relatively higher scores for agri-environmental management, as neither had any expenditure on pesticides, and score points for having a significant proportion of land as permanent pasture.

All farms receive the same scores for landscape and heritage and soil management as there were no areas in which the FBS data could reliably answer these questions.

For water management, all farms receive default scores for all details, but cereal farms score lower than dairy, as a result of the question ‘do you irrigate crops?’ This was presumed ‘no’ for the two dairy farms tested, which had no arable or horticulture enterprises.

For the cereal farms, the fertiliser management score is higher for the N loading top ranked farm (*i.e.* the farm with the lowest loading). This difference is due to their NPK budget scores. The lower performing farm has a much greater N surplus, in particular, as would be expected given the greater nitrate run-off as estimated through FarmScoper. The same difference arises in the dairy farms, but with a smaller difference and both farms receiving below average scores for NPK budget. This demonstrates an area of overlap between the two tools, where a fundamental farm efficiency measure available through the FBS – N surplus – is an important factor in both tools.

The ‘top’ performing cereal farm performs relatively poorly in its energy and carbon score. This is a result of relatively high fuel use per hectare for arable production, greater than the ‘bottom’ ranked farm. One explanation is, that without the use of pesticides, a greater number of more intensive cultivations were required for pest control as a potential trade-off. The two dairy farms did not show a difference in energy scores, with both comparing slightly unfavourably with the average dairy benchmark.

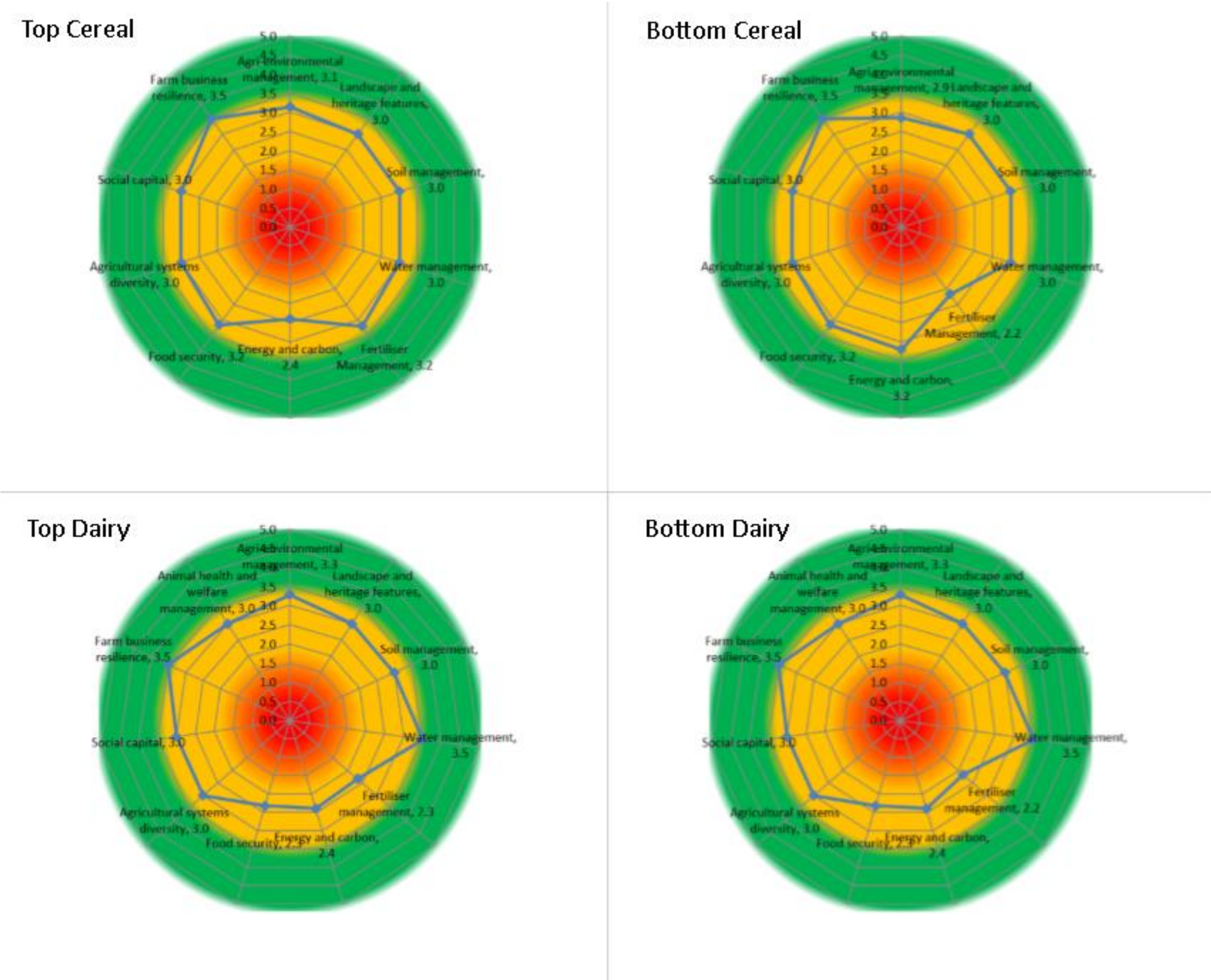

Figure A1. Results for the top and bottom dairy and cereal farms, ranked by estimated nitrate run-off in the FarmScoper decision support software

Both cereal farms appear to perform slightly above average scores for food security, but this is an artefact of the PG Tool, as the only non-default answer was for "What percentage of your total feed is bought in form off-farm?" which is 0% by default for farms without livestock. The opposite is true for the dairy farms, where the estimate of total feed bought in from off-farm was 100% in both cases, resulting in relatively lower scores for this spur.

The agricultural systems diversity score is entirely reliant on average scores, as is the social capital score, although as noted above, FBS data on number of employees and hours worked could potentially be used in this section, but was not used here.

The farm business resilience scores are the same for all farms, and both quite high, as the price per tonne for the farm produce was much greater than the default values. This may be because the PG Tool uses standard prices from 2009-2010, and the 2012 FBS values here are greater overall. For the top performing cereal farm, there is likely also an organic premium, which is compared with a single uniform standard price for both conventional and organic products in the PG Tool.

Finally, 'animal health and welfare management', only scored on the dairy farms, received the same score, as the only area with non-default answers, expenditure on veterinary medicine costs per livestock unit, received the same score for both farms. As noted for social capital, FBS data could potentially also contribute to the staff resources per livestock unit component of this spur, but was not extracted within this study.

Discussion

As a result of their contrasting aims and structure, only a limited subset of the PG Tool can be addressed using FBS data. Even the two highly contrasting farms of each type tested here show only subtle differences. However, it is a useful exercise to consider how the data is used by the PG Tool, and which areas are largely unaddressed in the FBS.

Broadly, the clearest differences that were picked up by the PG Tool were around basic efficiencies that could be tracked using physical data in the FBS (or estimates of physical data based on expenditure). Nutrient, and especially N, budgets were clearly different between farms, and this was highlighted through both the PG Tool, and mechanistic models of environmental effects, such as those contained within FarmScoper. Farm-gate nutrient balance is a promising area to expand with the FBS, as the fertiliser component allows a reliable estimate of this. For benchmarking or other farmer/farm advisor appraisal, comparison with a standard balance, along with a simple scoring system, as demonstrated in the PG Tool, may be a more practical output, rather than the more data intensive mechanistic modelling.

Fuel use also came through as an important contributing factor in the PG Tool energy and carbon score, reflecting whether farms used relatively more or less energy than expected for a given enterprise and/or farm type. Fuel expenditure can be relatively simply converted to an estimate of fuel volume (although some uncertainties remain), and so represents another area where the FBS dataset can provide insight. However, fuel use also demonstrates some of the difficulties in extrapolating from the FBS, as it cannot be established why fuel use was greater than average. As suggested above, one of the cereal farms appearing to have greater than average fuel use was potentially a result of extra cultivations necessary for non-chemical pest control. A simple benchmarking of estimated fuel use can identify if it is something a farmer might want to look into or address, but cannot state exactly what actions to take, as it is unknown whether the extra fuel use is a result of, for example, deliberate extra cultivations for separate aims, or inefficiencies in, for instance, tractor tyre pressure.

Land-use based indicators could, in some cases, also be reliably derived from the FBS, such as the dairy farms scoring highly in the agri-environmental management spur as a consequence of the large proportion of permanent pasture. Similar approaches were taken by Barnes and Thomson (2014), where they used FADN data to derive environmental indicators including the proportion of rough grazing area to total area, and the ratio of permanent to temporary grass, as proxies of environmental outputs and relative carbon capture, respectively. The PG Tool, again in common with Barnes and Thomson (2014), also scores for the proportion of woodland on farm. It was assumed this was a mixed, native woodland, but the species composition is unknown from the FBS, and so although relevant land use data being available, it could be questioned how meaningful this is as an agri-environmental indicator, especially if desired environmental outputs (e.g. carbon capture, biodiversity) are highly dependent upon woodland management.

The remainder of the PG Tool covers specifics of management which were not covered in the FBS. The range of topics covered are widely recognised as important indicators of agricultural performance beyond food output, including adoption of various mitigations (e.g. in conserving soil and/or water), practices relevant to animal welfare, and the role of the farm in the local community. In considering weaknesses in the FBS, the PG Tool is a useful resource to consider the scope of other potential indicators, and the kinds of data required to appraise them. The PG Tool brings together these strands into a comprehensive survey, and the radar chart output condenses into a relatively easily understood single figure per farm. Some of the scores relating to employment could also be extracted from the FBS. Although not available every year, some of the rotating modules in the FBS have covered relevant topics in the past, for example the animal health and welfare module covering 2011/2012. The PG Tool could also offer insight into the topics and content required for further potential modules for future farm surveys (either connected to the FBS or as standalone projects).

References

Barnes AP, Thomson SG. 2014. Measuring progress towards sustainable intensification: How far can secondary data go? *Ecological Indicators* 36, 213-220.

Gerrard CL, Padel S, Moakes S. 2012. The use of Farm Business Survey data to compare the environmental performance of organic and conventional farms. *International Journal of Agricultural Management* 2, 5-16.

Gerrard CL, Smith LG, Padel S, Pearce B, Hitchings R, Measures M, Cooper N. 2011. OCI Public Goods Tool Development, Report for DEFRA.

Nix J. 2012. *Farm Management Pocketbook*. Agro-Business Consultants Ltd