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AHDB Environmental and Agricultural Resource Efficiency Tool (EAgrRET)

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CONTENTS

1. ABSTRACT	5
2. INTRODUCTION	7
2.1. Background	7
2.2. Aims and objectives	7
1) Establish user requirements and confirm project scope	7
2) Identify and collate data required for calculation of LCA and carbon footprint of agricultural systems (technical, environmental, farm and economic data). 7	
3) Develop and evaluate AHDB Environmental and Agricultural Resource Efficiency Tool	7
4) Use tool to create 4 illustrative case studies to show potential uses of tool... 7	
5) Training of AHDB staff in understanding and use of the AHDB Environmental and Agricultural Resource Efficiency Tool.....	7
3. OBJECTIVES	8
3.1. Objective 1 - Establish user requirements and confirm project scope	8
3.1.1. Project team knowledge and expertise	8
3.1.2. Literature review of farm carbon and other environmental impact methods and review of carbon and resource use calculators	8
3.1.3. Review of potential farm management options and mitigation measures to be included in tool.....	11
3.1.4. Workshop of academic and industry experts	12
3.1.5. Tool Metrics.....	13
3.1.6. Define scope of tool	13
3.2. Objective 2 - Identify and collate data required for calculation of resource efficient metrics for agricultural systems (technical, environmental, farm and economic data)	20
3.2.1. Collation of farm system and background data to parameterise the tool	20
3.2.2. Data Requirements.....	21
3.2.3. Default farm definitions	22
3.3. Objective 3 - Develop and evaluate AHDB Resource Use Efficiency Calculator	23
3.3.1. Conceptual Framework behind EAgRET	23

3.3.2.	Core functionality and structure of EAgRET.....	24
3.3.3.	The EAgRET Interfaces (<i>23758 lines of code</i>).....	28
3.3.4.	The metrics calculation process.....	33
3.3.5.	Look Up Tables	35
3.3.6.	Error handling within EAgRET	36
3.3.7.	Debugging of EAgRET	36
3.3.8.	Comparison with SRUC AgRECalc tool and with HGCA Carbon Calculator tool	36
3.4.	Objective 4 – Create a set of illustrative case studies to show potential uses of the AHDB Environmental and Agricultural Resource Efficient Tool.....	39
3.4.1.	Define test scenarios (case studies) in conjunction with AHDB.....	39
3.4.2.	Structure of Case Studies.....	42
3.4.3.	Case Studies	42
3.5.	Objective 5 - Training of AHDB staff in understanding and use of the AHDB Environmental and Agricultural Resource Efficiency Tool.....	45
3.5.1.	EAgRET Training.....	45
3.5.2.	Introduction to the tool	45
3.5.3.	Guided scenario work using a mixed farm system	46
3.5.4.	Guided sector specific examples	46
3.5.5.	Quick Start guide for AHDB users.....	47
3.5.6.	User support for 6 months (Feb-July 2015).....	47
4.	CONCLUSIONS	48
5.	ACKNOWLEDGEMENTS.....	49
6.	REFERENCES	49
7.	LIST OF APPENDICES.....	52

1. Abstract

The aim of this project was to develop a resource use efficiency calculator to build awareness of how farm management decisions on the use of resources affects the environmental and economic performance of farm businesses. The tool needed to be user-friendly and had to have the ability to be used by the AHDB team in their interactions with UK farming and supply chain businesses to investigate scenarios of potential changes in farming systems and determine the environmental and economic impacts of these scenarios.

The AHDB Environmental and Agricultural Resource Efficiency Tool (EAgRET) is the resulting outcome from this project. We believe that this is the first tool of its kind that is able to produce a suite of metrics for assessment of resource use and efficiency at multiple summary levels (Farm Business, Farm Enterprise, Farm Activity and Product). EAgRET has been designed primarily for the assessment of the relative impacts of different scenarios on the resource use and environmental impact of farm businesses. The primary design, and hence use, focus of EAgRET is to examine the direction of change of emissions of a farm business over a period of time or to examine the potential impact of different management scenarios for a farm business. Whilst EAgRET can be used to provide “one-off” assessments of a farm business, this is not what it was designed for and use in this way could provide a misleading assessment of emissions from a farm business.

The tool uses a hierarchical structure to define farm businesses, consisting of farm business, farm enterprise and farm activities, where a farm activity is considered to be the lowest unit at which a farm is managed (e.g. a crop within an arable system or a herd type within a livestock system). This hierarchical structure means that EAgRET is able to represent a wide range of farm business structures and allows EAgRET to define and assess the impacts of transfer of resources between farm activities within a farm business. EAgRET contains a library of default farm activities, farm enterprise and farm business that can be used as the starting point for the development of scenarios of agricultural change or farm business structure change. The default data represents the average UK case for a number of crop and livestock systems.

EAgRET uses current best practice for calculation of metrics, with IPCC Tier 1 and Tier 2 calculations used for greenhouse gas emissions, the Defra/ADAS soil surface nutrient balance methodology used to provide nutrient balances, and life cycle analysis methodology and emission factors used to represent other key environmental impacts. EAgRET splits emissions into three categories: embedded emissions from purchased resources, embedded emissions from transferred resources and emissions resulting from farm management processes. This allows greater interpretation of the results, particularly in relation to determining which components of

the farm business have the greatest impact on the overall emissions. EAgRET is the first tool that we are aware of that provides this split in the emissions. EAgRET uses an economic basis for assigning metrics to products (and for calculating emissions associated with transferred resources). This is the most common methodology used for assignment of metrics.

EAgRET is a powerful tool for assessment of the environmental impacts for scenarios of changes in agricultural farm businesses. Four example case studies were developed to show how EAgRET can be used to identify the potential impacts of changes to a number of agricultural systems. The case studies developed for the project were:

- Transfer of ware potato waste to alternative use (anaerobic digestion or animal feed)
- Transfer of straw and manures between livestock and arable farm enterprises
- Use of sexed semen in dairy production
- Protein content in diet and use of home-grown protein versus imported protein

The results from these case studies confirmed that there are likely to be some environmental gains from greater integration of crop, livestock and renewable energy (AD) enterprises, through greater displacement of bought in feeds, fertiliser and grid electricity. The results also illustrated that more efficient use of resources through effective transfers may not always produce gains across all environmental measures and that the most environmentally beneficial resources transfers may not always deliver the best financial returns. Therefore trade-offs will need to be made between economic and individual environmental impacts in selecting appropriate strategies for greater resource use efficiency and integration within agricultural systems.

It is important to note that part of using EAgRET requires a consideration of the question that needs to be answered and the development of appropriate baselines to allow the relative impacts to be determined.

2. Introduction

2.1. Background

The AHDB commissioned this project to develop a new environmental impact calculator, covering all agricultural systems, but tailored to the needs of each of the AHDB sectors. The new calculator has been developed by examining existing state of the art resource use and environmental impact decision tools and then combining selected approaches and metrics to create a new tool that is as comprehensive as current knowledge and budgets allow, and is able to make assessments at a range of scales from product through to whole farm. The tool is primarily designed for the development and analysis of farm business scenarios, allowing for resource transfers between components of the farm business, but can also be used as a simple assessment tool or for benchmarking.

2.2. Aims and objectives

The aim of this project was to develop a resource use efficiency calculator to build awareness of the environmental and associated economic impacts of farm management decisions on the use of resources within a farm business. A further aim was for the tool to be able to be used by AHDB staff in their interactions with UK farming and supply chain businesses to investigate the outcomes of scenarios for potential changes in UK farming systems.

The expertise of the consortium was supplemented with output from an industry workshop where key scientific and commercial stakeholders across a range of sectors were consulted to define the metrics to be used within the tool and potential uses of the tool. The project was also supported by the Cool Farm Alliance (CFA), Sustainable Agricultural Initiative Platform (SAI) and their member companies.

The specific objectives of the project:

- 1) Establish user requirements and confirm project scope
- 2) Identify and collate data required for calculation of LCA and carbon footprint of agricultural systems (technical, environmental, farm and economic data)
- 3) Develop and evaluate AHDB Environmental and Agricultural Resource Efficiency Tool
- 4) Use tool to create 4 illustrative case studies to show potential uses of tool
- 5) Training of AHDB staff in understanding and use of the AHDB Environmental and Agricultural Resource Efficiency Tool

3. Objectives

3.1. Objective 1 - Establish user requirements and confirm project scope

3.1.1. Project team knowledge and expertise

The project team members provided a significant body of expertise to support the development of the calculator. ADAS and SRUC were the core contractors with expertise in decision support tools, environmental impact assessment, farming systems and benchmarking for all sectors. They were supported by University of Aberdeen for guidance on tool modelling and calculator development, IBERS for expertise in resource use in mixed farming systems, NIAB for expertise in arable farming systems and FEC and Eugeos for on-farm energy use and life cycle analysis. SAI Platform and CFA members were kept apprised of project progress and were invited to attend meetings and conference calls to provide industry feedback.

3.1.2. Literature review of farm carbon and other environmental impact methods and review of carbon and resource use calculators

To supplement the project team's knowledge of existing standards and tools a literature review was carried out to ensure a comprehensive review of existing farm carbon and resource use efficiency calculation methods. This included examination of existing published literature (Colomb *et al.*, 2012; Deneff *et al.*, 2012; Driver *et al.*, 2010, Scottish Government, 2010; Soil Association, 2013a,b, Whittaker *et al.*, 2013), UK and international industry standards, AHDB's own benchmarking and carbon footprinting tools and other sources of published literature.

Standards reviewed included [PAS 2050](#) (Specification for the assessment of the life cycle greenhouse gas emissions of goods and services), [ISO14064](#) (quantification and reporting of greenhouse gas emissions and removals), [ISO14067](#) (Carbon footprint of products), GHG protocols and IPCC guidelines for GHG inventories (IPCC, 2006). An excel matrix was prepared to review each standard to gain an understanding of the parameters for which monitoring and reporting is required.

The review of carbon and resource efficiency tools was limited to those where the methodology was freely available and where the tool was free to use in the UK. Of the wide range of tools reviewed most focused on carbon footprinting. Generally tools that include other aspects such as biodiversity or water, include only that element and did not integrate with a carbon tool. In addition to carbon footprinting, other metrics present in some standards and tools included: emissions mitigation, water use, productivity, economics, carbon sequestration, soil carbon storage, land use change, primary energy use, global warming potential, eutrophication potential, abiotic resource use, pesticide use, land requirement, and extracted water use. A variety of different methodologies

were followed including IPCC and LCA approach. For a summary of tools and metrics reviewed see Appendices 1 and 2.

Review of AHDB’s existing carbon footprint benchmarking tools

AHDB’s existing benchmarking tools and associated data sets were also reviewed ([Milkbench](#), [Stocktake](#), [Cropbench](#), [HGCA carbon footprinting tool](#) and Agrosoft data from BPEX) as well as other tools currently used by AHDB ([Cool Farm Tool](#), , [Cranfield LCA tool](#), and [ECO-2](#)) to consider the feasibility of importing the data from these tools into EAgRET.

The aim of this review was to be aware of the functionality of the tools currently available to AHDB and to see what data is collected and to identify any gaps in the data required by sector to calculate GHG emissions and other sustainability indicators.

Data fields from five benchmarking tools, namely Milkbench, Stocktake, Cropbench, HGCA carbon footprinting tool and Agrosoft were provided by AHDB and were collated into a matrix. Data fields from SRUC’s GHG emissions calculator and the data required to calculate carbon sequestration, soil carbon storage, renewable energy, biodiversity scoring, land use change, primary energy use, global warming potential, acidification, eutrophication, abiotic resource use, pesticide use, land requirement and water use were also added to the matrix. Methodologies in the Sustainable Performance Assessment (SPA) version 1¹ and those used by Cranfield LCA studies were reviewed to determine data requirements for the wider indicators. A comparison of the collated data fields was undertaken to identify any gaps in data requirements.

An excel matrix was prepared (AHDB data matrix and data required), see accompanying excel document illustrating the data available from AHDB in their benchmarking tools and the data required to calculate the various indicators.

Enterprises covered by AHDB benchmarking tools are illustrated in Table 1. At the time of the assessment, an AHDB benchmarking tool for potatoes was not available.

Table 1 Enterprise covered by the various AHDB benchmarking tools

	Milkbench & Stocktake Physical and financial benchmarking tool	Crop Bench Financial benchmarking tool	HGCA carbon footprinting tool Carbon footprinting	AgroSoft Herd recording and management tool
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¹ <http://www.saiplatform.org/activities/alias/sustainability-indicators/SPA>,

			decision support tool	
Dairy	Y			
Youngstock	Y			
Suckler herds	Y			
Beef finishing	Y			
Breeding ewe	Y			
Store lamb	Y			
Cereals & oilseeds		Y	Y	
Pigs				Y

GHG emissions

Data collated from Milkbench and Stocktake is comprehensive however in order to calculate GHG emissions additional cropping data and manure management data would be required. Financial data for energy use would also need to be converted to units of energy used at an assumed price per unit.

Data collated from Crop Bench is very limited and would have to be combined with data collated by HGCA carbon footprinting tool to allow GHG emissions to be calculated.

Performance data collated from AgroSoft is comprehensive however no data is available for land area (relevant for outdoor units or where feed is home-grown), quantities of bedding and energy use, all required to calculate GHG emissions.

Other indicators

Limited data is collated by the AHDB benchmarking tools to calculate carbon sequestration, soil carbon storage, renewable energy, biodiversity scoring and land use change.

Data required to calculate acidification, eutrophication, abiotic resource use and primary energy use is the same as some of the data required to calculate GHG emissions however, as per the GHG emission calculation data requirements, there are some gaps.

Although information is collated about pesticide use by HGCA carbon footprinting tool and E-CO2 (sheep), it is not in the correct format required i.e. number of full label dose rates.

Water charges is collated by Milkbench and Stocktake only and would need to be converted to units of water used in order to calculate extracted water use.

Data collated by the AHDB tools are reasonably comprehensive for the livestock enterprises and less so for the arable crops. Despite the overall quantity of data and range of data fields collated, in order to calculate GHG emissions and the other sustainability indicators, many gaps were identified. Alternative sources of data will be used to obtain the required information.

Several conclusions were drawn from this comprehensive review of existing research and available tools and standards.

- 1) Only one tool, Cranfield LCA tool was found that incorporated land requirements, eutrophication potential, acidification potential, abiotic resource use, and pesticide use (from more than just a carbon perspective).
- 2) None of the current tools included the transfer of resources between enterprises
- 3) There is a need for a user friendly tool that incorporates a wider range of metrics beyond carbon, that builds on the strengths of existing tools and that allows for resource transfers between farm activities and enterprises.
- 4) The project team should aim to build on the strengths of existing tools.

3.1.3. **Review of potential farm management options and mitigation measures to be included in tool**

A review of potential farm management options and mitigation measures was undertaken to identify what options could be potentially be assessed by the EAgrRET calculator. A comprehensive list of potential mitigations actions structured around the Farming for a Better Climate (FFBC) five key action areas² was prepared. For each action the outcome of the change in management and the requirements to quantify the outcome were stated. This was prepared based on knowledge within the project team organisations. Discussions were also held with AHDB to identify what management options and mitigation measures they would like the tool to be able to assess. The full list of mitigation actions can be found in in Appendix 3.

Changes in management or implementation of a mitigation action generally result in a change in inputs and/or outputs and for their impact to be assessed assumptions have to be made about what the inputs and outputs should be adjusted to. Input from AHDB sector specialists was required to assist with this.

Increasing or decreasing inputs generally has a direct impact on emissions and can easily be quantified by existing carbon calculators³. Examples of management options that may result in a change in inputs include (**bold** indicates core priorities desired by AHDB):

² Farming for a Better Climate. For more information see: http://www.sruc.ac.uk/info/120175/farming_for_a_better_climate

³ SRUC's AgRE Calc ©. For more information, see: www.agrecalc.com

- soil analysis and nutrient budgeting - reduced fertiliser usage or change in fertiliser type
- feed analysis and prepared rations - reduced feed usage
- improved grain drying and storage - reduced energy usage
- **production for different markets i.e. reduced N requirement – reduced fertiliser usage**

When a change in management increases or decreases the quantity of outputs, for the impact on emissions to be quantified, emissions should be expressed on a per unit of output basis. Example of management options that have the potential to result in a change in output include:

- improved feed conversion efficiency - increase in sale weight of livestock
- **improved housing ventilation - increase in sale weight of livestock**
- **improving land drainage - increased crop yields**
- **production for different markets i.e. specified weight – increase in sale weight of livestock**

There are some management changes, whereby the impact on emissions cannot accurately be assessed by existing tools as the relevant co-efficients are not yet available in relevant inventories or Intergovernmental Panel on Climate Change (IPCC) guidelines. Examples of management options include:

- Improved timing of fertiliser applications on N₂O production
- Reduced soil compaction on N₂O production
- Injection of slurry on CH₄ and N₂O production

Management changes or mitigation actions AHDB specified they would like to the tool to assess are indicated in **bold**. These along with a further 35 identified management changes and mitigations actions could potentially be assessed by the tool (See Appendix 3).

3.1.4. **Workshop of academic and industry experts**

A workshop was held in September 2013 for the project team to seek the views of key stakeholders which included academics, government officials, farmer representatives, commercial food business, and environmental organisations. The results of the project team's tool review and initial thoughts on tool framework were presented and stakeholder and sectorial needs in terms of resource efficiency evaluation were identified. Stakeholders were asked to give critical feedback to the project team on proposed tool metrics and data sources.

Industry participants were asked to state their views on drivers for resource use efficiency evaluation. Some of their comments included: *managing volatility and security of supply of resources, need for more information to assist in farm management, uncertain impact of climate change now and in the future, having the potential to benchmark and learn.*

Workshop participants were split into groups to analyse all potential metrics for inclusion in the tool. After detailed and considered discussion an agreed list of metrics was compiled by the project team

to recommend to AHDB for inclusion in the tool. The project team, together with industry participants also determined that some metrics were beyond the scope of the tool.

3.1.5. Tool Metrics

Metrics to be included:

- Crop Protection and veterinary medicines
- Primary energy use
- Carbon Footprint and Global Warming Potential (CO₂eq)
- Abiotic resources
- Water usage
- Land use
- Acidification and Eutrophication
- N and P budgets

Metrics outside of project scope

Metrics that were considered to be outside of the project scope included biodiversity, carbon sequestration (including the contribution of grasslands in livestock systems), labour, and social and community well-being. In general the lack of data and degree of complexity required to capture this information were the primary reasons for omitting these metrics from the tool.

3.1.6. Define scope of tool

The review of available tools and standards, published literature and industry and academic input provided the basis for the project team to develop the specifications of the new resource efficiency calculator tool. A tool specification plan was drawn up that outlined the proposed approach for representing farming systems within the tool, the metrics to be included, the methodology for calculating the metrics, the rationale for metrics that would be omitted, the boundaries for metric calculation, the proposed approach to the development of scenarios, proposed approach to data entry and reporting of calculations (See Appendix 4) A summary of the final scope of the tool is provided below.

The structure of the tool

EAgRET has a modular structure (Figure 1) that separates the main functions of the tool into individual components. This was done as it means that improvements to one component of the tool can be made without affecting the other components of the tool. A detailed description of the components of the tool is provided in section 3.3 of this report.

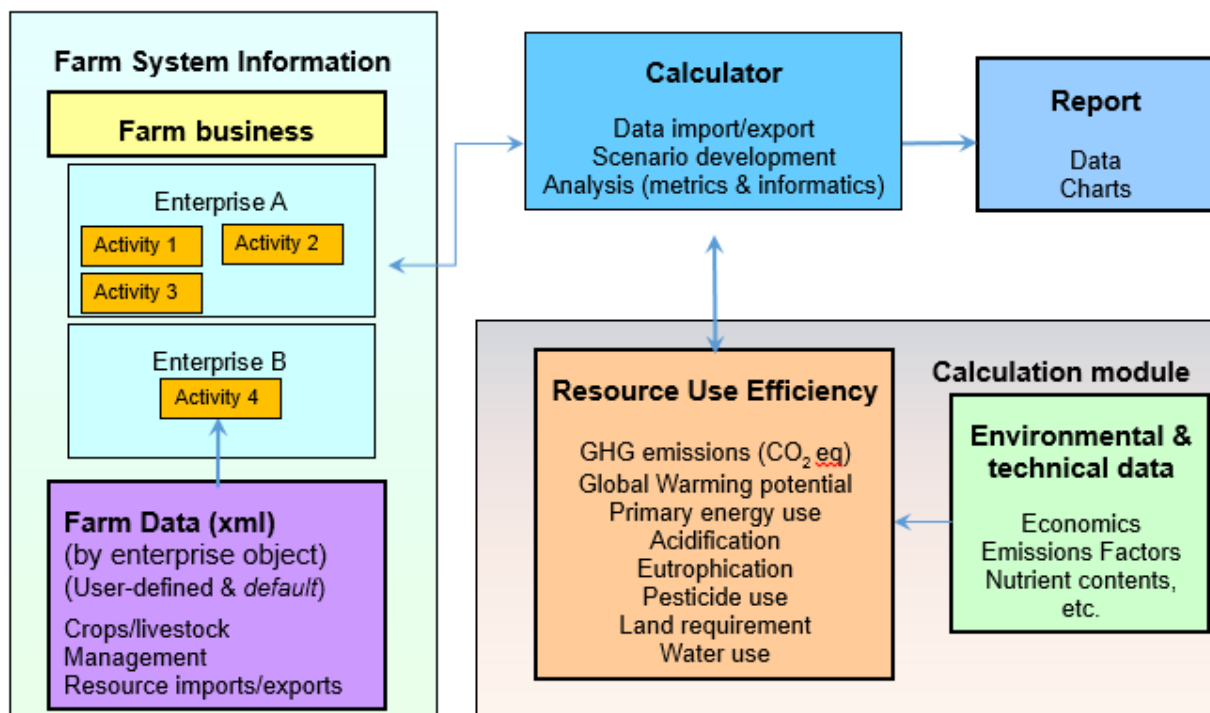


Figure 1 Tool Framework and Components

One of the key design points for EAgRET was the ability to represent and assess impact of the transfer of resources within a farm business and the conceptual framework for the representation of the farm business (Figure 2) was used to achieve this. This hierarchical framework considers a farm business to be one or more farm enterprises. Each enterprise can be further split into one or more farm activities that describe the main management activities within the enterprise (e.g. arable cropping includes farm activities for each individual crop within the rotation) and is characterised by its inputs and outputs. The hierarchical structure allows resource transfers to be specified as a feature of the farm business, with transfers occurring between farm activities within the farm business. Grazing is also considered to be a feature of the farm business as grazing information needs to be accessible to all enterprises and farm activities within the farm business.

The farm activities, enterprise and businesses included within the tool are described in section 3.2 of this report.

Tool interfaces

Data entry

The original intention within EAgRET was to use a modified version of the SRUC [AgRECalc](http://www.agrecalc.com) (www.agrecalc.com) for livestock data and HGCA carbon footprinting spreadsheets for cereals data to provide data entry for the tool. However, due to the speed limitations and complexity of running spreadsheets as data entry interfaces, combined with potential future compatibility issues, the decision was taken to create windows forms based interfaces instead, but to ensure that these capture the same data as the spreadsheets.

In order to provide a structured approach for data entry and data modification within EAgRET, it was decided to split farm enterprises and farm activities into a set of groups based on common agricultural systems: cropping (all fully harvested crops, including fodder), grazing (including fodder crops that are fully or partially grazed), livestock, on-farm energy and other (to capture diversification). For each of these farm activity types a data entry interface was developed that captured the key data required for the farm activity. This stayed faithful to the original intention to use the farm activity as the main point of data entry. Interfaces for defining farm enterprises and farm businesses across all sectors (arable, dairy, beef, sheep, pigs, poultry, potatoes and horticulture), specifying resource transfer within and between enterprises and displaying the calculated metrics at business, enterprise and enterprise activity level have also been developed.

During development it became clear that certain elements of data entry could not be done at the farm activity level as the data were effectively features of a higher level in the hierarchy. Data on land grades and areas was felt to be a feature of the farm enterprise as enterprises could contain multiple farm activities with different land area and land grade requirements. After consultation with AHDB it was decided that data on cropping and grazing farm activities should be entered on a per hectare basis (originally it had been proposed to include area at the farm activity level) since this allowed the same farm activity to be used across several farm enterprises, with the enterprises providing the land grade and area information for scaling the emissions appropriately. Data on resource transfers and grazing were considered by the consortium to be a farm business feature and so were specified at this level in the hierarchy. Initially it was thought that resource transfers would be defined in a separate interface, but as resource transfers can potentially take place between any pair of farm activities within the farm business, then they have to be specified at the farm business level as it is not possible to specify them at a level below this in the hierarchy and they are a core feature of the farm business. Additionally, by specifying the resource transfers as part of the farm business, the tool can evaluate the farm business both with and without the resource transfers, reporting the results simultaneously, rather than having to have two separate scenarios. For grazing, it was originally intended to specify grazing at the livestock enterprise level, but this was felt to be impractical if the grazing was part of an arable rotation and hence needed to be in both an arable and livestock enterprise at the same time. This issue was overcome by specifying grazing at the farm business level since the grazing enterprise could be contained within the arable enterprise but also shared with the livestock enterprise within the farm business level.

“What if?” scenarios

The original intention was to have specific interfaces for running key scenarios. However, it soon became clear that the majority of scenarios would require modification of data at one or more levels within the tool hierarchy. The consortium decided that key scenarios should be embedded

as default farm businesses within EAgRET. By taking this approach, the tool control interface was simplified into two components, one for defining the farm activities, farm enterprises and farm businesses and one for selecting the business(es) for assessment and the level at which they needed to be assessed.

Results reporting

The reporting of results is done at a range of levels, from product through to whole farm business as was originally envisaged in the specification document. Also, the splitting of emissions into embedded emissions from purchased inputs, embedded emissions from transferred inputs and emissions from the production process have been retained as this split has significant benefit in determining the emissions that can be influenced by farm management decisions.

A more detailed description of the interfaces is provided in section 3.3 of this report, with full details of the data required by the interfaces and how it is processed on saving included in Appendix 8.

Calculation module

The original specification assumed that the calculation module would be based on a modified version of the SRUC AgRECalc© spreadsheet. However, potential future issues with compatibility between Microsoft office versions and the complexity and speed limitations of transferring data in and out of a spreadsheet meant that it was felt to be more appropriate to create a set of coded algorithms for the tool. The algorithms for the calculation of the metrics were based on IPCC calculations for GHGs (using the SRUC AgRECalc© tool as a guide for the structure and order of the calculations), standard LCA calculations, and the ADAS nutrient balance methodology. The algorithms have been embedded into a software class so that they are all in one place and can be easily updated and modified with minimal impact on other components of EAgRET.

Using the software class instead of a spreadsheet means that the results of the individual calculations are stored internally within the tool and are therefore not visible as they would be within a spreadsheet. However, since it was the final outputs that were of greatest interest and based on the resources available for tool development, the pragmatic decision was taken not to output or show the results of the individual calculations.

A more detailed description of the calculation module is given in section 3.3 of this report.

Conceptual Framework

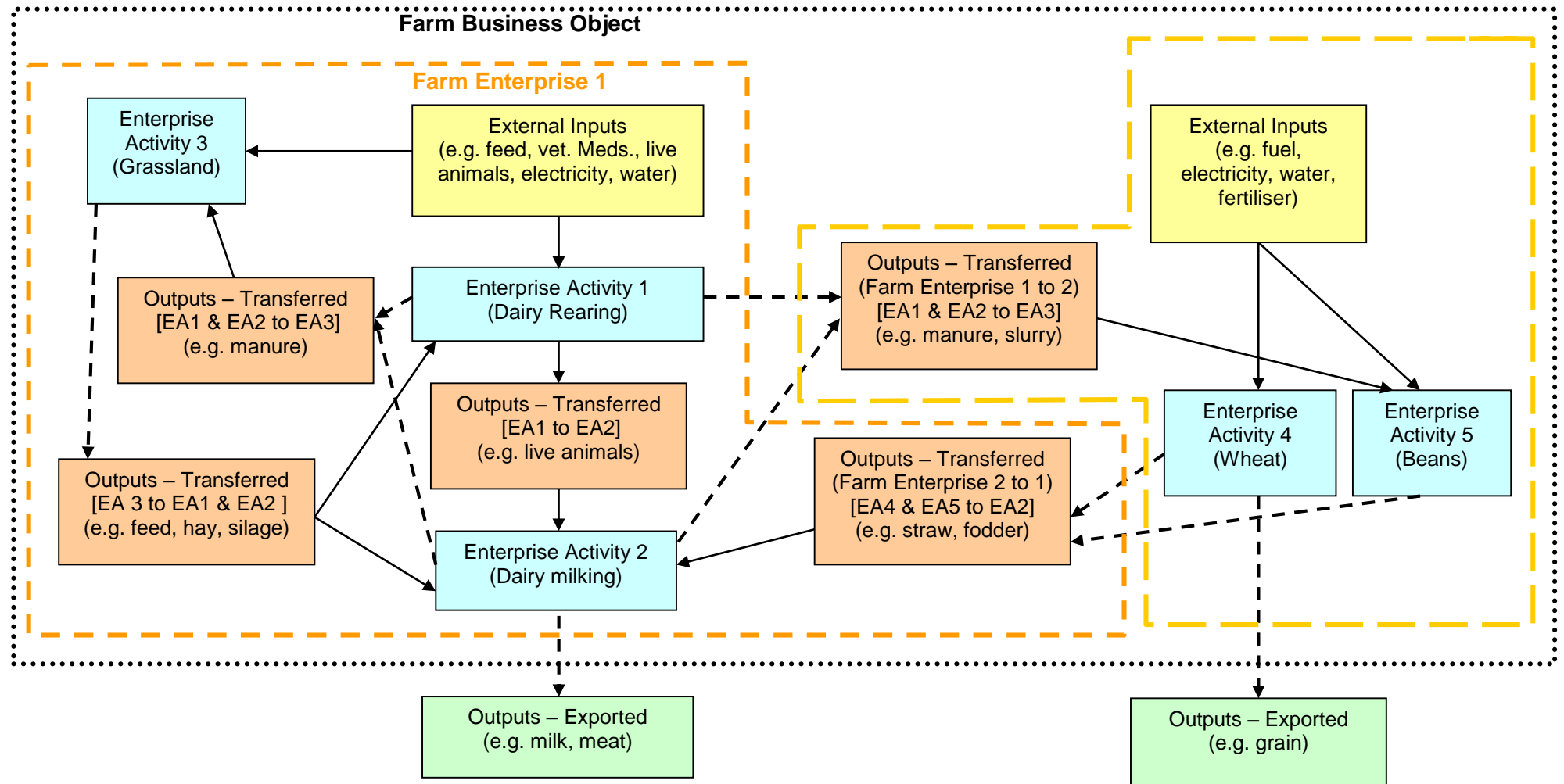


Figure 2 Conceptual Framework for EAgRET showing the farm activity, farm enterprise and farm business hierarchy and the transfer of resources between farm activities within a farm business.

Metrics included and methodology for calculating them

During development there has been no change in the metrics used and a few minor changes to the methodology used to calculate them. A summary of the methods used to calculate each of the metrics is given below.

Carbon footprint and global warming potential

The tool uses IPCC methodology at the most appropriate tier for the calculation of carbon footprints and global warming potential. The approaches mirror those used in the SRUC AgRECalc© calculator which operates at the enterprise level.

Acidification and eutrophication

Acidification and eutrophication are included to capture embedded emissions within inputs from a life cycle analysis perspective. The tool uses emissions factors for the calculation of embedded SO₂ equivalents (acidification) and PO₄ equivalents (eutrophication). Ammonia (NH₃) emissions to air, nitrate (NO₃) and phosphate (PO₄) leaching to water are contributors to acidification and eutrophication from agricultural systems, since these predominantly come from fertiliser and manure applications plus manure management on farm. EAgRET uses an emissions factor approach to determine the acidification and eutrophication potential from these activities.

Nitrogen & Phosphorus Budget

EAgRET calculates the nitrogen (N) and phosphorus (P) balances using the ADAS soil nutrient balance methodology (Lord *et al.*, 2010). Losses of N and P are calculated at farm activity level, using coefficients and data from a range of ADAS models and tools (Psychic, NeapN, PLANET and MANNER). For enterprise and product levels, the losses are calculated by summing across the farm activities within the enterprises or business.

Abiotic resources and synthetic fertiliser use

The tool uses the methodology developed by the Institute of Environmental Sciences (CML) at Leiden University for the calculation of abiotic resource use in units of Kg Antimony (Sb). If the extraction of fossil fuels used for energy, and the extraction of materials used for construction of farm infrastructure is excluded from abiotic resource use (as farmers can do little to affect this), then primary use of resources on-farm on an on-going basis will be through usage of synthetic fertilisers. Therefore EAgRET also reports the synthetic fertiliser use, sub categorised to indicate amount of N, P and K used on farm.

Water usage (abstracted/metered, blue water only)

The tool only provides assessment of blue water usage as data on abstraction licences and metered usage is more readily available from the agriculture industry. EAgRET reports the water usage entered into the tool, scaled according to the area of the farm activity.

Land use

The land use is included in the tool as it allows comparison of changes to production systems. It is calculated using the Life Cycle Analysis approach used within the Cranfield LCA tool (Defra project IS0205), which provides conversion factors to convert different land use grades to grade 3 equivalents, based on expected crop yields. This approach allows comparison between enterprises with varying amounts of different grades of agricultural land by providing a common unit for farm area.

Crop protection

This is included as it provides a measure of the environmental impact of agricultural systems. Since the use of a system based on toxicity requires significant input of toxicity data and the ability to look up toxicity by product and active ingredient and this approach is not well developed for some areas, such as veterinary medicines, then it has been decided to use a full label doses per hectare approach.

For this approach, the number of full label doses per hectare for different product categories (herbicide, fungicide, insecticide) are reported based on information regarding the number of sprays/applications and the dosage per application for the different categories. Veterinary medicines have not been included as the consortium felt that full doses of veterinary medicines was not a meaningful metric for inclusion in the tool. Further work is required to develop an appropriate metric for assessment of animal health and environmental impact of veterinary medicines.

Primary energy use

EAgRET calculates the primary energy usage using standard LCA methodology with appropriate conversion factors for the sources of energy generation. In this context primary energy use refers not only to the fuel or electricity used, but the energy required for extraction and supply of fuels. Data on fuel usage and electricity usage is used to determine the primary energy use, which is calculated according to the conversion rate for the source of energy (natural gas, coal, oil, renewable sources).

Metrics omitted from tool

Water usage (Green water and Grey water)

Whilst methods exist for the calculation of green water (rainfall), blue water (extracted/metered water) and grey water (dilution of pollutants), current approaches do not adequately capture rainwater-use efficiency. In addition, since agricultural pollutants, such as N and P, are directly reported by the tool then grey water is not required as the nutrient balances provide indications of the potential pollutant load from the farm business.

Carbon sequestration

Whilst methodologies exist for the calculation of carbon sequestration, primarily due to land use change, these contain large uncertainties. The project team and industry workshop participants felt that the current state of knowledge regarding carbon sequestration is insufficient to allow calculation of an accurate assessment of the impacts of agricultural system changes on carbon sequestration.

3.2. Objective 2 - Identify and collate data required for calculation of resource efficient metrics for agricultural systems (technical, environmental, farm and economic data)

3.2.1. Collation of farm system and background data to parameterise the tool

In order to populate the conceptual framework (Fig2), key farm enterprises and farm activities were identified. These were selected according to their relevance to the individual sectors of the AHDB hence included: beef, sheep, dairy, pigs cereals and oilseeds, potatoes and field fruit and vegetable crops. In order to represent typical arable rotations a number of crop enterprises from the AHDB supported sectors were also added including; peas and beans and sugar beet as well as fodder crop such as kale. Poultry activities were excluded although it was recognised that these may form part of a wider farm business of interest to AHDB. For each farm activity, the inputs, outputs and system information necessary to describe the farm activity were determined. This was then compared with the data available in the first instance from AHDB data sources and then from wider industry sources. The list of data required for all enterprise activities and for the calculation of all the metrics in the tool was used to define data required by the tool. The data required to parameterise the EAgRET farm activities can be found in Appendices 5a and 5b.

3.2.2. Data Requirements

Findings from the review of existing farm carbon calculators and methodologies for calculating GHG emissions and wider environmental indicators were used to help identify the methodologies to be used and to define the data requirements of the tool (inputs, co-efficients and factors to be used in the calculations)

The data requirements (input data fields, co-efficients and factors) used in SRUC's AgRE Calc © tool were used as a starting point for the GHG emissions, as they are consistent with PAS 2050 and IPCC. Following the review of other tools, such as The Cool Farm Tool, additional data requirements were also identified i.e. information on field operations.

Following a review of the methodologies used by Williams *et al.* (2006) to calculate indicators other than greenhouse gas emissions, a list of data requirements was then identified to calculate these metrics.

Published sources of costs of inputs and outputs were used to provide the economic data and included AHDB Cereals and Oilseeds, AHDB potatoes, Agricultural Budgeting & Costings book, SAC Consulting - The Farm Management Handbook, DEFRA, Farm Brief and DECC (carbon emissions for different fuels).

Table 2 Summary of methodologies used

Indicator and source	Methodology
GHG – CO₂ energy and embedded	Quantities multiplied by industry recognised emission factors from DECC and Footprint Expert v3.1
GHG - N₂O & CH₄	Tier 1 or Tier 2 IPCC (2006) equations and emission factors
Eutrophication	Williams <i>et al.</i> (2006) and Feedprint (2013)
Acidification	Williams <i>et al.</i> (2006) and Feedprint (2013)
Primary Energy	Williams <i>et al.</i> (2006) and Feedprint (2013)
Abiotic Resource use	Williams <i>et al.</i> (2006) and Feedprint (2013)
Land Use	Williams <i>et al.</i> (2006)
Pesticide use	Williams <i>et al.</i> (2006)
Nutrient balance	ADAS soil nutrient balance

3.2.3. Default farm definitions

Data from AHDB benchmarking tools and project team specialists was used with the aim of providing a suite of default activities, enterprises and farm businesses that can be used by AHDB.

Discussions were held with the project team and AHDB to identify the crops and livestock systems that should be included as farm activities in the tool. The selected farm activities were then used to established farm enterprises and businesses.

Input data (technical and economic) was obtained from Stocktake, Milkbench, Agrosoft, AHDB Cereals & Oilseeds (formerly known as HGCA), DECC, ABC, Farm Brief, DECC, SAC Save Fuel, SAC FMH and project team specialists. This data was collated into default spreadsheets for crops and livestock and used to generate the default activities, enterprises and businesses. Based on published information and specialist knowledge various assumptions were made about the farming systems when establishing the activities, enterprises and businesses.

A list of farm activities and assumptions can be found in 6. A summary of the number of farm activities prepared is shown below and was used to create relevant farm enterprises and a range of farm businesses.

Default data collated in the crop and livestock spreadsheets was given to AHDB; assumptions and sources of information are included as comments in the spreadsheets.

Table 3 Number of farm activities per sector

Sector	Farm activity	Sector	Farm activity
Grain, oilseed & pulse	17	Grass	33
Potatoes	4	Beef	7
Root	2	Sheep	4
Veg	3	Dairy	7
Fruit	3	Pigs	5
Forage	8		

The default data provides AHDB with a baseline which can be used to modify farm activities, enterprises and businesses to investigate scenarios.

3.3. Objective 3 - Develop and evaluate AHDB Resource Use Efficiency Calculator

The aim of this objective was to take the design specification developed as part of Objectives 1 and 2 and turn it into a working piece of software.

3.3.1. Conceptual Framework behind EAgRET

EAgRET was envisioned as a tool to allow the development, specification and evaluation of scenarios for farm businesses, both in terms of structure of the farm businesses and the movement of resources within the farm business. It also had to be sufficiently flexible to cover the majority of potential farm business structures and future changes to parameters used in the calculation of emissions. The software had to conform to the conceptual framework of a hierarchical structure to represent a farm business, with a farm business consisting of one or more farm enterprises and a farm enterprise consisting of one or more farm activities. By using this hierarchical structure it was possible to calculate metrics and emissions at the farm activity level and then summarise these at farm enterprise, farm business or product level, meeting a key requirement for the tool. A key aspect of the hierarchical framework was that each farm activity was defined by a set of inputs and outputs as well as processes that took place within that farm activity. We chose this definition of the farm activity as it allowed the tool to meet the requirement that it should account for movement of resources within and between farm enterprises, since a resource that was an output from one farm activity could be used as an input to another farm activity (either within the same farm enterprise or in a different farm enterprise). The farm activities were then classified into different system types:

- Cropping (including harvested fodder crops)
- Grazing (including grazed fodder crops)
- Livestock
- On-farm renewable energy generation
- Other (diversification)

This classification was based on the data required to specify the inputs of a system, the outputs produced by the system and the management of the land/animals in the farming system. We included horticultural crops with arable and harvested fodder crops as the focus was on field horticulture rather than protected horticulture. These farm activity types could then act as templates for the specification of a number of default farm activities that would then be used as the building blocks of a farming system.

3.3.2. Core functionality and structure of EAgRET

The conceptual framework and vision for EAgRET, described above, meant that it needs to be able to perform the following core functions:

- Creation and modification of farm businesses through changes to farm enterprises, farm activities, including the transfer of resources
- Evaluation and calculation of a suite of metrics/emissions at different levels and display of these in tabular and graphical formats
- Storage of the data defining the farm businesses, farm enterprises and farm activities
- Storage of parameters to be used in the calculations

To achieve this core functionality, a structure for the tool was defined that split the tool into a set of modules that provided aspects of the core functionality. The reason for the use of a modular structure was that it allowed separation of the code for the core functions of the tool such that future modifications could be made to individual core functions without affecting the other core functions of the tool. The modular structure also allowed multiple developers to work on the code simultaneously. The modules that were developed for the tool were:

1. *The tool interface*

- a. A main control interface*
- b. Interfaces for data entry*
- c. A results and reporting interface*

2. *A library of default farm business, farm enterprises and farm activities*

3. *A metric/emissions calculation module*

4. *A set of look-up tables for key information required by the tool*

EAgRET works on the basis of an annual snapshot of the farm. Selection of an appropriate timescale for the tool was complicated by the fact that different farming systems operate over different timescales. For most crops, an annual timescale is sufficient to capture the dynamics of the systems, whereas for livestock, there is much greater variation in the timescales that best represent the system. A common timescale was required to both the arable and livestock systems as EAgRET needed to be able to integrate across these two systems, and as most farm surveys take an annual snapshot of the farm business, the project team and AHDB representatives agreed to use an annual timescale for EAgRET.

Interfaces

For development of the tool decisions had to be made as to the format for the tool. As one of the requirements for the tool was for it to be desktop-based, and the AHDB steering group had expressed a preference for interfaces that were similar to the ADAS PLANET software, it was agreed to use Windows forms for the tool interfaces using the Microsoft .NET framework.

The Microsoft .NET framework is the current standard for programming for Microsoft operating systems and includes a large class library that provides user interface functionality, data access, database capability and web application development. This meant that any code would potentially be able to be converted for use through a web application, which was a consideration for potential future development of the tool. Also, the use of .NET meant that there was less restriction on the programming language since .NET provides a common format across several modern programming languages.

Default farm libraries

During the process of preparing the specification for EAgRET, the potential to link EAgRET to other farm management software products had been discussed with the AHDB Steering group. It was agreed that linkage to other software was beyond the scope of the project. However, by storing the farm business, farm enterprise and farm activity data in a structured manner it retained the potential to be shared with other software packages in the future.

In the initial stages of the development of EAgRET, the intention had been to have a common data structure for the storage of farm activity data that was used across all farm activity types. However, during the development of the data structures and development of the interfaces, it soon became clear that this was not the best approach for storing and manipulating the data from the different farm activity types due to large differences in the data requirements for the different farm activity system types. A pragmatic approach was taken to the storage of the data with each farm activity type having a different overall data structure, but with common embedded data structures where the same data was used in different farm activity types (e.g. for fertilizer applications, field operations, water usage, manure applications plus electricity and fuel usage).

With the data structures defined, the next step was to determine the most appropriate format for saving the data. Both text file and database options were considered. Whilst the database approach would have meant that all the data was in a single file, it had drawbacks in terms of the speed of access to the data and the ability to share the data with other software packages. Comma separated value (CSV) text files had the potential to provide compact storage with rapid read and write access, but had the drawback that a significant amount of code would need to be written to control the formatting of the data during read and operations. It was eventually decided to use the

Extensible Markup Language (XML) format as not only does it provide a compact, text-based format for data storage, but it preserves the structure of the data, using tags to provide the name of different data structures and is human readable as well as machine readable. In addition, .NET has in-built functions for automatically reading and writing data structures to XML files, which removed the need for code to control formatting of the data. XML files are based around a schema, which defines the structures in the data and can be shared with other developers, facilitating the sharing of the data between software packages.

Having defined the format for storage of the default farm files, it was necessary to determine the most appropriate location for storing these files. There were two possible options: use of a hard-coded directory structure or use of a user-specified location. Whilst a user-specified location provides a great deal of flexibility, it does mean that the tool would need to keep track of the storage locations of the farm data files, which could become complex if the user uses multiple locations rather than a single location and there are multiple files with the same name in different locations. Therefore, to make things as simple as possible the use of a hard-coded location for the storage of the farm data was chosen. We used the “My Documents” folder as the root folder for storage of EAgRET data (both farm data and look up tables) as this directory is common across all versions of Microsoft Windows.

Calculation module

The objective for this component of the tool was to provide the set of equations required to calculate the emissions and metrics. The original plan, when the specification of the tool was first determined was to use the SRUC AgRECalc© and the HGCA Carbon Calculator spreadsheets as a basis for the calculations and to enhance this with additional functions to calculate the additional metrics beyond the greenhouse gas emissions already provided within the SRUC AgRECalc© tool.

During the development of EAgRET, it became clear that the hierarchical framework, the requirement to be able to produce metrics and emissions from product level through to whole farm level and the requirement to be able to include resource transfers did not fit well with the whole farm business approach used within AgRECalc. There were also concerns about the impacts that having to copy large amounts of data between the EAgRET internal data structures and the AgRECalc spreadsheets would have on the speed of the tool. We therefore moved away from using the AgRECalc spreadsheet and decided to build a complete set of algorithms in code as a separate module of EAgRET. By doing this, any issues over speed of the tool were removed and it also meant that there would be no issues caused by variation in Excel versions on the computers on which EAgRET was to be used.

The boundary for calculation of metrics within EAgRET is the farm gate (at point of sale of products), with the inclusion of embedded metrics for inputs bought into the farm (excluding seed and transplants due to limited availability of data on these. Note, however, that functionality to include their embedded emissions is integrated into the tool, but not enabled at present.). Farm gate was chosen as the boundary as it represents a clear distinction between agricultural production and further processing as part of a product chain. Embedded emissions in resource bought in to the farm are included as these emissions are a component of the overall emissions associated with the production of the product(s) from the agricultural system. It could be argued that the embedded emissions are essentially fixed and could therefore be ignored from the point of view of understanding the emissions directly attributable to the agricultural production system and its management and how changes in this management influences emissions from the agricultural production system. They have been included for completeness, but EAgRET does characterise them as embedded so that users can separate them from the overall emissions of the farm business should they wish to do so.

For the calculation of metrics, emissions are summarised at the level selected by the user (i.e. if the user selects farm activity, then the emissions are expressed as the total for the farm activity). We agreed to use this approach rather than to express emissions per unit area to prevent issues with appropriate choice of units when dealing with mixed farming systems. To allow the user to express emissions per unit area, the area for each component are provided alongside the emissions.

EAgRET will allow users to summarise emissions per unit product for **all** products produced by the farming system (e.g. milk, male calves). If a user wishes to summarise the emissions based on a single primary product (e.g. milk) from the farming system, then the table of the amount of each product produced by each farm business generated by EAgRET can be used with the whole farm business emissions tables to manually calculate the emissions per unit of primary product.

The calculations used for each of the metrics, and the source from which they were derived (where applicable) are described in the section entitled “Calculation Module” below.

Look-up Tables

As many of the calculations and interface components require access to common data, there was a need to have some form of database of parameter values which the tool could access. In order to provide openness of the data used within EAgRET for calculation of emissions and to allow users the flexibility to modify parameter values as part of the development of more advance scenarios or updates of parameters in the future, it was decided to use comma delimited text files to store the parameter values. The use of comma delimited text files meant that these files could be opened

using Excel, making it relatively straightforward for EAgRET users to see and modify the values if required.

Since some of the look-up tables were required to provide the interfaces with default data and for pre-processing of data entered into the interfaces, separate look-up tables were created covering key groups of similar data (e.g. crop data, fertiliser data, field operations data) rather than to have a single look-up table.

On starting EAgRET all the data in the look-up tables is read into internal storage within EAgRET to ensure rapid access to the data. This approach was chosen as reading from files is a relatively slow operation, so it is better to read once and store the data rather than to read a file every time a piece of data needs to be looked up.

Details of the look-up tables, the data they store and where it is used within EAgRET are provided in Appendix7.

Coding language

Due to the use of the .NET framework as described earlier, there was a wide choice of coding languages. The language chosen for the coding of EAgRET was Visual Basic .NET, with code development being done within the Microsoft Visual Studio software. This software was used as it allowed the development of the tool across multiple developers, with full tracking of the development history of the tool via a source code repository, which is standard practice for software development.

3.3.3. The EAgRET Interfaces (23758 lines of code)

Having outlined the structure of EAgRET and the decisions that led to this structure, this section of the report will outline development of each of the components of the tool, how each component works and how it fits into the overall structure of EAgRET.

The farm activity data entry interfaces and farm activity generics

There are five data entry interfaces in EAgRET. These were designed to attempt to make data entry and modification as easy as possible, given the large amount of data required to describe each farm activity. The interfaces were designed to have a similar format across the different farm system types (Cropping (including harvested fodder), Grazing (including grazed fodder), Livestock, On-farm Energy and Other). To achieve this similarity, each interface was based on a tabbed-form, with duplication of tabs where farming systems shared the same data requirements, such as for fertilizers and manures in cropping and grazing systems.

All the data entry interfaces have the following core functionality:

- *Pre-population of drop-down menus*

All the drop-down menus are pre-populated using code that reads the data values from the appropriate look-up tables in the EAgRET Look-up table directory (to save time, the look-up tables are read in once on start-up and then stored in memory).

- *Loading of data from library of farm activities*

The user selects the farm activity to load and the interface then uses code that was written to import the data from the xml file in the farm activity library. Each of the windows controls that requires a data value (e.g. tables, drop-down menus, number boxes, etc.) are provided with the appropriate value by the underlying code behind the interface. A flag is set to say that the file has been loaded from the library, so that the tool will check if the filename has been changed if the data is modified after loading.

- *Saving of data to library of farm activities*

This operates in reverse of the loading of data, but also includes code that checks whether all the data required for the calculations has been entered prior to saving (see below). On pressing the save button, the tool checks the data and, assuming there is no missing data, then saves it to the farm activity library as xml. The code also checks whether the user has modified data from a loaded farm activity and warns the user that they will overwrite the loaded file if the filename has not been changed.

- *Checking of data when saving*

To ensure that the tool has all the data required for calculations, the interfaces contain code that checks each tab to ensure that all the data required has been entered. Where the user has not entered data, but data would normally be expected, the code will prompt the user to confirm that they did not wish to enter data. As each tab is checked, flags are set to confirm that all the data required has been entered. If any required data is missing the code provides a list of missing data to the user in a pop-up message, sets the tab to where the missing data is and tells the save code to cancel the saving of the data.

- *Pre-processing of key data for calculations on saving*

In order to speed up the calculation of metrics, a number of pre-processing steps are done as part of the saving process for all farm activity interfaces:

- Creation of a list of inputs to the farm activity with costs

- Creation of a list of outputs from the farm activity with value
- Creation of list of economic data for the farm activity
- Calculation of fuel used for field operations

These lists and calculations are stored as additional information in the saved farm activity files. For the economic calculations, where the economic data is not provided in the farm activity interface the appropriate values are taken from the economic look-up table.

- *Clickable information icons*

The information icons included within the interfaces have been included, based on consultation with users, to provide key information to aid data entry when using the tool. By clicking on the icon, a message box will appear that provides the user with key information about the section that the icon covers and how the information asked for is used by the interface.

In addition to the core functionality, each interface has specific functionality relevant to its farming type.

The farm enterprise interface

This interface was designed to represent the farm enterprise level within the EAgRET hierarchy. It is the level at which information about the farm activities within the enterprise is defined and also the area and grade of land used for each farm activity.

Farm Business interface

The farm business interface is used to define the farm enterprises that are included within a farm business, the resource transfers that occur between farm activities within the farm business and any grazing that takes place within the farm business. It was decided to specify grazing at the farm business level the specification potentially requires information from all enterprises within the farm business, which is only available at this top level in the hierarchical structure underpinning the tool.

Results interface

This interface provides a display of the results. In order to ensure that the interface met the needs of AHDB, the content of this interface was determined through consultation with the AHDB. Originally it was envisaged to primarily use tables to display the metrics and economic data. The metrics tables were sub-split to provide information on embedded metrics associated with purchased inputs, embedded metrics associate with transferred inputs and metrics arising from farm management. Graphs to show the individual metrics were included within EAgRET, along with an overall summary graph, expressing the value of the metric for a given farm business component

as a proportion of the maximum value for all farm business components (at the summary level chosen by the user) was included. Finally, tables showing the products produced, and the number of animals and/or area of crops were included in the interface to allow users to express the metrics in relation to amounts of different products, area of land used for production or number of livestock. The results interface allows the user to export all data to excel to produce a report using fixed templates built into EAgRET.

Other interfaces

EAgRET also includes a number of other interfaces for export of data and reporting of results, as well as a pop-up calculator to determine replacement of synthetic fertiliser by manures. The latter feature was included to make it easier for users to specify the transfer of manures based on plant available nitrogen within the manure, removing the need for manual calculations when specifying resource transfers.

A detailed description of the interfaces, the data they require, any processing of the data done on saving and the methods used to produce the results is provided in Appendix 8.

Farm activity generics (4569 lines of code)

For each farm activity there is an underlying set of code that defines the data that is held for each farm activity type. It includes a set of code that calls all the algorithms within the calculation module that are required to calculate emissions, passing the appropriate data to them and then returning the results provided by the algorithms within the calculation module, indexed by farm activity, farm enterprise, farm business, category (baseline or adjusted), resource type (where applicable), the metric subtype (production, embedded – purchased or embedded – transferred) and the level at which the metric is calculated (farm activity or product).

The calculation module (1710 lines of code)

The EAgRET calculation module contains the code that is used to calculate the metrics that are reported by the tool. All calculations are held in a single location which is accessible to farm activities, farm enterprises and farm businesses. The metrics are grouped into a three main types:

Metrics calculated using a set of equations

The greenhouse gas emissions are calculated using the IPCC 2006 methodology. This methodology was chosen as being the most widely accepted approach for calculation of greenhouse gas emissions.

For cattle and sheep, a Tier 2 methodology is used, which calculates nitrogen excretion and gross energy based on the protein content, digestibility and grain content of the diet. For pigs (and poultry)

a Tier 1 (emissions factor) methodology is used as there was no published Tier 2 methodology under IPCC for pigs at the point of development of EAgRET. As EAgRET is intended to generate carbon estimates in accordance with IPCC it was not considered appropriate to add the additional calculations required to bring pigs to Tier II as these would rendering the results incomparable with other IPCC standard results. A brief overview of the calculation steps for the different greenhouse gas emissions is given in Appendix 9.

Metrics calculated using single emissions factors

Acidification, eutrophication, abiotic resource use, primary energy use and land use (grade 3 equivalents) are all calculated using emissions factors. The former four have emissions factors derived from life cycle analysis studies, with the latter being derived from work by Cranfield University (Williams *et al.*, 2006).

Acidification potential is a metric that measures the potential impacts of pollutants emitted during production of a product in terms of acidification of the environment. It is expressed in terms of kg of sulphur dioxide equivalents and is based upon the hydrogen ion equivalents within the pollutants. The primary source of acidification emissions will be embedded emissions associated with purchased resources and ammonia emissions from excreta and fertilisers.

Eutrophication potential is a metric that measures the potential impacts of nitrogen and phosphorus on the terrestrial and aquatic environment. It is expressed using a number of units, but the most commonly accepted unit is kg phosphate equivalents. The main source of emissions associated with eutrophication are embedded emissions from purchased resources brought on to the farm and emissions from volatile and leached components of nitrogen from excreta and fertilisers.

Abiotic resource use measures the depletion of natural resources, such as iron ore, crude oil and rock phosphate, which are regarded as non-living chemical and physical parts of the environment that affect living organisms. The depletion is based on the ratio between the extraction rate of the resource and the estimate of the amount of resource remaining. This is then expressed relative to the depletion of the reference resource of antimony, so that abiotic resource use is expressed in kg antimony equivalents. As with acidification and eutrophication, this is primarily associated with embedded use from purchased resources brought on to the farm, particularly phosphate fertiliser. Primary energy use describes the consumption of energy within the production of a product. It is expressed in terms of mega joules.

Land use is expressed in Grade 3 equivalents and is calculated using the method developed by Cranfield University (Williams *et al.*, 2006). It is used as a means of expressing land use across the

whole farm in consistent units as the conversion factors are based upon the production capacity of the land (using average yields).

Metrics that are direct reporting of inputs

Crop protection inputs reports the number of full label doses of crop protection products applied to crops. There is no averaging across areas as label doses are generally expressed in terms of dose per hectare. At summary levels above farm activity, the full label doses are just summed together for simplicity.

Water use is reported as the cubic metres of water used from mains or abstracted under licence. Rainwater use is not included as it is difficult to accurately determine the impact of the uptake of rain water on the overall water availability without accounting for the geographical context and location of the farm business. Since any decrease in the removal of water from the mains or via abstraction will have an overall benefit on water availability and because data on these aspects is more readily available, it was decided to focus solely on mains and abstracted water

Synthetic fertiliser use reports the total amount of nitrogen, phosphorus and potassium applied based on the fertiliser application rates and their nutrient contents.

3.3.4. The metrics calculation process

For calculation of metrics a fixed process is used that was designed to ensure that appropriate adjustments could be made for resource transfers. The following steps are followed for all assessments:

- *Baseline emissions calculation (excluding any resource transfers)*
This first step calculates emissions at farm activity level by looping through every farm activity within each farm enterprise within the farm business(es) being evaluated. It takes the default assumptions that all resources are bought in and all products are sold and that there are no resource transfers. The emissions calculated from this step are referred to as baseline emissions. For livestock systems, emissions are calculated at the farm enterprise level, as potentially many farm activities will contribute to products produced within a single farm activity (depending on how the livestock system has been specified within EA_gRET).
- *Assignment of emissions from baseline calculation to products*
To allow embedded emissions associated with transfer of resources to be accounted for the next step is to assign the emissions to the products from each farm activity. This is done using an economic allocation method, where the total value of all the products produced by the farm activity is calculated and the emissions assigned based on the relative contribution of the value

of an individual product to the total value of all products. For livestock systems, as the main product is often only produced from one farm activity out of a number of farm activities within the livestock farm enterprise (depending on how the user has specified the livestock farm enterprise), the assignment occurs at farm enterprise level rather than at farm activity level.

- *Calculation of emissions adjusted to account for resource transfers*

Using the product emissions calculated in the previous step, EAgRET then redoes the baseline calculations, but this time accounting for resource transfers, using the product level emissions to substitute embedded emissions from bought in resources with embedded emissions from transferred resources.

- *Assignment of adjusted emissions to products*

The product emissions are then recalculated using the adjusted emissions calculated from the step above.

Where resource transfer are only occurring in one direction (i.e. from an arable farm activity to a livestock farm activity, but with no reciprocal resource transfer) then the recalculation will effectively replace the default emissions based on the inputs to the farm activity with emissions calculated for the transferred resource that are specific to the farming system defined. The user can therefore be confident that the emissions calculated by EAgRET are a reasonably accurate reflection of the farm system.

However, where reciprocal resource transfers exist (i.e. an arable farm activity provides straw to a livestock farm activity and the livestock farm activity transfers back manure to the arable farm activity) a feedback loop is effectively created, such that the transferred embedded emissions of the straw are dependent on the transferred embedded emissions of the manure and vice versa. In theory, EAgRET should loop through the calculation of product emissions until there is no overall change in the embedded transferred emissions of both manure and straw. Note that a feedback loop can be created via a chain of resource transfers as well as reciprocal resource transfers.

The impact of including such feedback loops on emissions is unknown as there are no other tools that account for the transfer of resources between farm activities, since EAgRET is the first tool to include such resource transfers. Since the purpose of EAgRET is to provide data to be used in a comparative manner and not to provide definitive estimates of emissions, then in practice it does not matter whether feedback loops are included as the results will always be used to express change from a baseline calculated using the same approach. It was therefore decided to be pragmatic and use a single iteration since this would provide an estimate of

embedded emissions from the transferred resource inputs based on the emissions calculated for the farm system of interest which would inherently be more representative than the average default embedded emissions from the look up tables, without imposing any performance burden on the tool.

We would recommend that further work is done to determine the potential impact that including an iterative calculation could have on emissions from different levels of summary within EAgRET.

- *Calculation of farm economics*

EAgRET calculates the economics of the farm activities with and without resource transfers at the same time. The calculations use the list of inputs and outputs for each farm activity (generated when saving the farm activity) and scales these by the area of the farm activity, where appropriate. Where resource transfers take place the economics are adjusted to account for the amount of resource replaced by the resource transferred in. It is assumed that resources transferred in do not cost anything.

- *Summary of crop, livestock and product information*

Once all the emissions and economics calculations have been completed, EAgRET summarises the crop, livestock and product information for the farm business.

- *Summary of emissions*

The final step in the process is to summarise the emissions at the level selected by the user. As farm activity emissions are stored with data defining the farm activity, farm enterprise and farm business with which they are associated, this is simply a case of summing the emissions across one of these levels. This summation is done separately for the baseline and adjusted emissions. If the user has specified a product level emissions summary, then the separately calculated product emissions are used rather than the farm activity emissions.

Having completed this process, EAgRET then sends the emissions, economics and crop, livestock and product information to the interface that displays the results.

3.3.5. Look Up Tables

As described previously EAgRET uses a number of look up tables, stored as comma delimited files in the "EAgRET\LUT_Files" folder, to provide key parameter values used within the interfaces and the calculation module.

All of the look up tables can be edited outside of EAgRET to allow updating of the values contained within them using either a text editor or Excel. It is also possible to add additional data into any of the look up tables as a new row in the file. However, where additional items are added, then the user will need to check whether additional entries are required in other look up tables, particularly the greenhouse gas calculations and economics look up tables. For example, adding a new crop type to the crop types look up table would also require the inclusion of new values within the greenhouse gas emissions calculations for the new crop type for all parameters that are related to crop calculations. Also, due to pre-processing of data during the saving of farm activity data, then changes to look up tables may also require the user to re-save all the farm activity files to ensure that the changes to the look up tables are used in the processing of the data during saving.

A description of each of the look up tables and the data they contain is provided in Appendix 7.

3.3.6. Error handling within EAgRET

All the major code and algorithms within EAgRET contain routines for handling of errors. If an error occurs, the error handling code is triggered and depending on the algorithm that was being run the error handling code either displays the error message in a pop-up message box or in the case of nested algorithms, passes the error to the algorithm above it, until the error reaches the outermost level of nesting and the error is displayed in a pop-up message box.

The error messages have been designed to provide sufficient information to narrow down the location of the error within the code such that it should be relatively straightforward for ADAS to determine which piece of code is triggering the error and correct the problem.

3.3.7. Debugging of EAgRET

As part of the development and support of EAgRET, there has been a period of debugging and updating of EAgRET based on user experience (from AHDB and the consortium) and this is described in section 3.5.4 of this report.

3.3.8. Comparison with SRUC AgRECalc tool and with HGCA Carbon Calculator tool

A sense checking exercise was carried out to test the consistency of results from the EAgRET tool. Data from model beef, dairy, sheep, arable and pig farms were entered into AgRE Calc © to obtain greenhouse gas emission results that could then be compared with the results produced by EAgRET. Input data from a combinable crops farm was also entered into the HGCA carbon tool to obtain greenhouse gas emissions results, allowing them to be compared to EAgRET. Livestock farms were selected to cover typical systems within each AHDB sector and also to allow comparison between contrasting systems types such as upland versus lowland, intensive versus

extensive. The arable farm was selected to include crops that had also been assessed by the comparator tool: HGCA Carbon Calculator. This included cereals, oilseeds and pulses. Details of the comparison results can be found in Appendix 10, a summary is given in Table 4. These two tools were chosen because AgRE Calc© uses the same IPCC methodology as EAgRET and because the HGCA Carbon Calculator uses the same methodology as the Cool Farm Tool which is a popular carbon calculator. It should be noted that these tools do not include metrics other than greenhouse gas emissions. The only other calculated metrics within EAgRET are the soil surface nutrient balances for nitrogen and phosphorus. Since none of the freely available tools calculated nutrient balance, it was not possible to compare this methodology with other tools. For the embedded emissions calculated using emissions factors, it is not necessary to compare this methodology with other tools, since any differences would be caused by differences in emissions factors. Finally, for the metrics reporting water use and the amount of nutrients applied from synthetic fertiliser, EAgRET does not make any calculations it only reports back what has been provided as an input.

Table 4 Consistency of Results

Farms	% difference between tools			
	CO ₂	CH ₄	N ₂ O	TOTAL CO _{2e}
Beef LFA breeding farm (LB02)	0%	1%	0%	0%
Beef breeding finishing farm (LB05)	0%	-1%	-5%	-1%
Beef finishing farm over 16mths (LB07)	0%	0%	-7%	-2%
Dairy farm AYR calving grass based (LD03)	0%	-5%	-11%	-4%
Dairy farm spring calving composite (LD04)	0%	-2%	-13%	-3%
Sheep lowland breeding farm (LS01)	0%	8%	2%	4%
Sheep LFA breeding farm (LS02)	0%	2%	2%	1%
Sheep store lamb finishing farm (LS04)	0%	-2%	-5%	-2%
Pig indoor breeding farm (LP01)	0%	0%	2%	0%
Arable combinable crops farm (CA01)	41%	-	31%	37%

Variances between the results of the livestock farms are due to the following:

- In the Tier 2 calculations for production of volatile solid excretion, used to calculate CH₄ emissions from manures from cattle and sheep, EAgRET adjusts urinary energy if the grain

content is greater than 85%. AgRE Calc© does not adjust urinary energy based on grain content of the diet.

- Methodology used to determine if N₂O emissions associated with manure storage on-farm is included or excluded i.e. assumed to be sold. EAgRET assumes that manures are sold, after a short period of storage, therefore the on-farm N₂O emissions are only calculated when a resource transfer occurs, retaining the manure on the farm. AgRE Calc© assumes all the manure is retained unless it is exported off the farm.
- Methodology used to calculate energy required for pregnancy in sheep in the Tier 2 calculations for CH₄ and N₂O emissions. EAgRET uses the IPCC method of calculating the coefficient based on the number of lambs, as EAgRET does not take information on the number of single, double and triple births as inputs. The method calculates the number of single and double births, but does not account for triple births. AgRE Calc© takes into consideration triplet births.

Variances between the results for the arable farm are explained as follows:

- Overall EAgRET generated total CO₂e emissions 37% higher than the HGCA carbon tool due to both higher CO₂ and N₂O emissions.
- The higher CO₂ figures for the EAgRET tool are a result of the assumption that heating with oil is required for grain drying and differences in fuel use for machinery. The HGCA tool calculates a very low energy use in drying grain which appears to be the result of the use of ambient drying. The EAgRET tool also uses higher embedded emissions for some of the inputs such as fertiliser.
- The higher N₂O figure for the EAgRET tool is a result of the tool calculating greater emissions associated with crop residues. The HGCA carbon calculator does not account for the N₂O from below ground residues nor does it include N₂O from N leaching from residues (which EAgRET does). The HGCA calculator also only considers available N from manures when calculating N₂O emissions and not total N content.
- Be aware that it was not possible to fully utilise the functionality of the HGCA tool as the slide bars within the spreadsheet could not be operated to input data on the following activities meaning emissions for these were not included in the HGCA figures;
 - Straw baling / incorporation
 - Pesticide use

AgRE Calc © and EAgRET produced very similar results for the livestock farm but there were significant differences between the results produced from EAgRET and the HGCA tool for the combinable cropping farm.

3.4. Objective 4 – Create a set of illustrative case studies to show potential uses of the AHDB Environmental and Agricultural Resource Efficient Tool

3.4.1. Define test scenarios (case studies) in conjunction with AHDB

Discussions were held with the project team and AHDB to identify four case studies to illustrate how the tool could be used to demonstrate better resource use efficiency and reduced environmental impact. The different types of scenarios that the tool can deal with were first identified. For each identified category the project team prepared various scenarios representing key questions of interest to the different sectors of AHDB. From these and from their own selections AHDB were then asked to select four scenarios that were of greatest interest to be developed by SRUC into case studies.

Initial case studies for selection

The tool is able to deal with three different types of scenarios as categorised below. Within each category the initial scenarios identified by the project team and the scenarios selected by AHDB for inclusion in the project are detailed below. Scenarios selected by AHDB are indicated in **bold**.

Category 1:

Minor adjustments of one or two parameters - only one or two parameters within an enterprise activity are changed and the changes do not have cascading effects on other enterprise activities or other components of the same enterprise activity, resulting in only limited changes to the tool outputs.

Scenarios:

Nutrient management recommendations (RB209) used to modify fertiliser inputs.

Fertiliser and manure inputs to crops in the arable rotation would be modified based on the RB209 recommendations (using the PLANET RB209 calculator) to reflect best practice in nutrient management, as opposed to using the fertiliser inputs derived from national data-sets (such as British Survey of Fertiliser Practice (BSFP)). The latter effectively averages across all nutrient management practices and does not explicitly account for the position of the crop in a rotation.

Incorporation of (straw) residues.

This scenario would adjust fertiliser and manure inputs crop residues to allow for the additional nutrients returned to the soil through incorporation of crop residues as opposed to the residues forming an output from the enterprise activity. Whilst residue incorporation can be included in the RB209 guidelines, it is a separate activity. For this reason, it is included as an additional option that could be used on its own or with the RB209 option described above.

Category 2:

Business structure and resource transfers between enterprise activities - core type of scenario that the tool has been developed to address. In these scenarios, the impact of adding or removing resource transfers between enterprise activities or farm enterprises are calculated. In addition, it is possible to modify farm business structure by removing or adding enterprise activities within a farm business and examining the subsequent impact on resource use efficiency of the farm business.

Scenarios:

Bed & Breakfast livestock systems.

In this system a farmer rents land and housing for his animals. The farmer provides the feed inputs, but the bedding is provided by the owner of the rented land and housing. In addition, the manure from the housed livestock has to be considered as an output to the system as it remains with the owner of the rented land and housing. A parameterised enterprise activity to represent the bed & breakfast systems with transfers of livestock into and out of the bed & breakfast enterprise activity was created. Manure was included as an output from this enterprise activity, but it cannot be transferred to other enterprise activities within the farm business as it is assumed that all manure produced in the bed and breakfast system has been exported from the farm business.

Rotation changes and inclusion of cover crops in cropping farm enterprises.

The tool will expect a rotation to be specified when a farm enterprise consisting of annual and multi-annual crops is defined in the interface. The tool includes a number of rotations within its default library that represent selected standard rotations and modifications to standard rotations.

Transfer of ware potato waste to alternative use (anaerobic digestion or animal feed).

The farm business would be set up to include either a livestock farm enterprise and/or an anaerobic digestion farm enterprise in addition to the potato cropping farm enterprise. The transfer of waste potatoes would be specified as a resource transfer from the potato enterprise activity to the appropriate receiving enterprise activity/activities.

Transfer of straw and manures between livestock and arable farm enterprises.

For this scenario, the proportion of the straw that is transferred into the livestock enterprise will be specified (with logic checking to ensure that the amount of straw transferred does not exceed the requirement of the livestock enterprise activity). For transfer to multiple livestock enterprise activities, the proportion of straw going to each enterprise will be specified according to requirement. Manure from the livestock enterprises will be transferred into the arable system, with the assumption that it replaces artificial fertilisers.

Use of flying herds in dairy systems.

This scenario represents a structural change to the farm business and would be represented by developing two farm businesses. The first farm business will be a standard dairy system with milking and following herds (within a single farm enterprise) that acts as a baseline. The second farm business will be a milking herd that has an input of live heifers, with associated upstream metrics (calculated from national or regional average data).

Category 3:

Large system changes - where a change in management results in a cascade of impacts through several components of an enterprise activity or between enterprise activities, it is not possible to represent this within the tool. Large system changes will inevitably lead to a change in the input data for a specific enterprise or set of enterprise activities. These scenarios have to be hand crafted through changes in the input data. The revised input data can then be loaded into the tool and the resource use efficiency calculated by the tool.

Change of sheep breed to increase number of lambs.

Changing a sheep breed to increase lamb production has significant impacts throughout the system. For this scenario, the inputs to the enterprise activities in a standard sheep system have been modified to represent the changes in inputs and other parameters that would result from a change in the breed of sheep farmed (e.g. increased feed, reduced replacements).

Use of sexed semen in dairy production.

Sexed semen is used in the dairy industry for production of heifer calves. A revised set of dairy enterprise activities that reflect the changes in inputs that would result from the use of sexed semen for a proportion of the herd (e.g. reduction of inputs associated with bull calves, increased yield, reduced replacement costs) have been developed.

Protein content in diet and use of home-grown protein versus imported protein.

This scenario focuses on how changes in the type and source of dietary protein and the efficiency of conversion affects the resource use efficiency in pig systems. Farm businesses have been developed with plausible future scenarios for dietary protein content of feeds, sources of feeds and feed conversion ratios (accounting for genetic advances in pig breeding). The resource use efficiency of the farm business can be assessed and compared to determine the potential implications of these changes for the pig industry.

Conclusions

The final list of case studies was chosen by AHDB in order to provide examples of relevance across the main sectors (beef, sheep, dairy, cereals and oilseeds, potatoes). Horticultural examples

were not included on AHDB's request. The list was also designed to cover a range of transfers and system changes to test the flexibility and capability of the tool.

3.4.2. Structure of Case Studies

Four scenarios were chosen by AHDB to be used as case studies, these were:

- Transfer of potato waste to alternative use (AD or animal feed)
- Transfer straw/manure between livestock/arable
- Use of sexed semen in dairy production
- Protein content in diet, use of home grown vs imported.

For each of these a lead project partner was assigned from the project team reflecting their relevant skills, experience and knowledge base. IBERS contributed on beef, sheep and land use change aspects of livestock feeds, NIAB-TAG on potatoes and EUGEOS on Anaerobic Digestion. SRUC provided the core enterprise data and complimentary technical expertise required to pull the overall case studies together. Each partner was then responsible for designing the case study and selecting the most appropriate default enterprise activity data from the prepared farm data. The case studies were developed and refined with input from AHDB sectors. As part of this process a number of changes were made including providing more details of the assumptions used and reducing the focus on financial results as they were constrained by their inability to account for fixed costs.

The structure for each case study was as follows (the full case studies are provided in Appendices 11, 12, 13 and 14) :

- Narrative defining the scenario
- Details of assumptions used
- Table showing which values have been changed from the default baseline
- Table showing environmental and economic results
- Explanation of results

3.4.3. Case Studies

Case study 1: Transfer of potato waste to alternative use (AD or animal feed), Developed by NIAB-TAG, EUGEOS and SRUC

This case study was designed to show environmental and economic impacts of transfers between a potato enterprise and either a beef finishing or an Anaerobic Digestion (AD) enterprise. A baseline default farm was prepared from which two scenarios were explored. In the first scenario (A) out-grade potatoes were transferred to a beef finishing enterprise to displace bought in feeds. In return,

cattle manure was transferred back to the potato enterprise displacing bought in artificial fertiliser. In the second scenario (B) out-grade potatoes were transferred to an AD plant to displace bought in feedstocks, in return AD digestate was transferred back to the potato enterprise displacing bought in artificial fertiliser.

Transfer of resources did not always result in improved environmental performance across all metrics. Transfers with the AD plant led to reduced carbon emissions as the AD plant supplied renewable electricity to displace a share of the electricity demand for refrigeration for storage. However acidification and eutrophication effects were increased. In the beef example transfers to displace synthetic fertiliser with manures resulted in increased nitrous oxide and overall carbon emissions. At the same time acidification and eutrophication effects were reduced due to lower imports of feed and hence lower embedded environmental effects.

Transfer of resources between potatoes and beef finishing resulted in improved economic performance as the out-grade potatoes displaced more expensive bought in feeds. Transfers with the AD plant led to poorer economic performance.

Case study 2: Transfer straw/manure between livestock/arable, Developed by IBERS and SRUC

This case study was designed to show how the EA_gRET tool can demonstrate the environmental and economic impact of taking two stand-alone farm enterprises in a farm business and integrating them via internal resource transfers. In this scenario there is an arable enterprise and a beef enterprise which previously had no interaction in terms of resource use. The integration of these two enterprises involves feed and straw being transferred from the arable to the beef, thus displacing some previously purchased feed, and Farmyard Manure (FYM) being transferred from the beef to the arable, thus displacing some previously purchased fertiliser.

The transfer of resources between the two enterprises and subsequent reduction in purchased inputs resulted in an environmental improvement for the total farm business with Global Warming Potential, primary energy usage, acidification, eutrophication and abiotic resource use all lower than in the baseline scenario which was with no integration.

This also resulted in an economic improvement for the farm business. This was the result of a considerable reduction in the cost of inputs with a smaller reduction in the value of outputs meaning overall economic performance was improved.

Case Study 3: Use of sexed semen in dairy production, Developed by SRUC and IBERS

This case study was designed to show how the EA_gRET tool can calculate the environmental and economic impact of sexed semen usage (increasing heifer calf production) in a dairy farm business. A baseline default farm (V1) was prepared from which two scenarios were explored. In the first scenario (V2) the impact over 5 years of an increased rate of genetic gain in milk yields was

examined with the business retaining replacement heifers and selling all other calves as soon as viable. The second scenario (V3) made the same comparison plus further changes to the farm business including more heifer calves retained and sold as in-calf heifers.

Using female sexed semen on the high yielding, all year round calving dairy herd, has the potential to result in environmental improvements per unit of output.

If the use of sexed semen results in a considerable change in the way the business operates, such as rearing more heifers for sale as in version 3 of this scenario, there are also likely to be greater environmental improvements per unit of output. The use of sexed semen also has the potential to result in economic improvements as it can improve milk production and reduce inputs. However, it should be noted that if the use of sexed semen results in a greater demand for resources such as buildings or labour this benefit may be partly or wholly offset by the impact of higher fixed costs.

Case study 4: Protein content in diet, use of home grown vs imported, Developed by SRUC and IBERS

This case study was designed to show the environmental and economic impact of substituting purchased soyabean meal with home grown protein (peas) as the main (but not the only) protein source on a mixed arable – pig finishing farm. There are two scenarios; the first is a conventional diet using soyabean meal as the main protein source and a second where home grown peas replace soyabean meal. The performance of the pigs remains the same under both diets as they were designed by an SRUC nutritionist to achieve the same livestock performance.

Replacing soyabean meal (and some wheat) with home grown peas results in a reduction in environmental burdens per unit of pig meat produced of between 3% and 20%.

The economic performance based on inputs and outputs (excluding fixed costs) of the combined arable and pig enterprise declined by 15% when home grown peas were retained for home feeding. This is because the loss in income from reduced pea sales was greater than savings from reduced soyabean meal purchases and greater income from wheat sales.

Making greater use of home grown protein sources has the potential to reduce the environmental impact of pig production but at a higher economic cost. The challenge is persuading the retailer and ultimately the consumer to pay more for pig-meat produced without soyabean meal.

Conclusions

These case studies demonstrate how the tool can be used to compare contrasting strategies and are meant to model typical farm practices. The results confirmed that there are likely to be some environmental gains from greater integration of crop, livestock and renewable energy (AD) enterprises, through greater displacement of bought in feeds, fertiliser and grid electricity. The tool also illustrated that more efficient use of resources through effective transfers may not always produce gains across all environmental measures so trade-offs will need to be made.

The results showed that the most environmentally beneficial resources transfers may not always deliver the best financial returns. Also, the economic results do not include fixed costs which would need to be taken into consideration for a full economic analysis.

Where the tool demonstrated increased costs for a particular production system the challenge will be recovering this from the market place. The EAgRET tool offers a means of demonstrating the environmental gains from more integrated and local agricultural systems to support discussions with buyers mindful to reduce their environmental impact.

3.5. Objective 5 - Training of AHDB staff in understanding and use of the AHDB Environmental and Agricultural Resource Efficiency Tool

3.5.1. EAgRET Training

The project team carried out two formal training sessions at Stoneleigh for AHDB staff. These sessions took place in September and November 2014. The aim of these training sessions was help AHDB staff who would be using the tool with members to become more familiar with the tool and to demonstrate how to modify default data and to make resource transfers. Gaining expertise with these important steps allowed staff to investigate and compare scenarios.

The training session was delivered jointly by ADAS and SRUC, split into two sessions, one dealing with arable systems and the other dealing with livestock systems. The aim of the training was to provide users with sufficient information and knowledge to enable them to be able to define scenarios using the default farm data within EAgRET, analyses scenarios at multiple scales and to build farm businesses using the default farm activity data.

3.5.2. Introduction to the tool

The introduction consisted of a PowerPoint presentation given by ADAS (Appendix 15). The presentation provided:

- An outline of the aims of the project,
- A description of the hierarchical structure that forms the basis of EAgRET's representation of farm businesses,
- A description of what EAgRET was designed for – analysis of scenarios,
- A summary of the metrics used within EAgRET, and
- A description of important assumptions and issues that users of EAgRET needed to be aware of.

3.5.3. Guided scenario work using a mixed farm system

The second part of the workshop provided a generic overview of the tool using worked examples within a mixed farming system. The aim of this part of the training was to show users how to define, edit and build farm activities, farm enterprises and farm businesses, including specify resource transfers.

Once users had defined the farm business, they were then shown how to use the analysis part of EAgRET to assess the farm business that they had built at different scales. Users were also show how to save the results and to produce a report using the results and the built-in EAgRET report template.

3.5.4. Guided sector specific examples

Worked scenarios were prepared and demonstrated for dairy, beef, sheep, pig, mixed farm, as well as an arable and potato farm. The project team went through these examples step by step with training participants and responded to questions as they arose.

The selected farms used in the training were created as part of the development of default farm enterprises. For each livestock business i.e. dairy, beef, sheep and pig, several scenarios were identified as outlined in Table 5. Using the livestock and arable default data spreadsheets the impact of the scenarios on the farm activity data was calculated. This information, along with step by step guidance on how to modify farm activities, enterprises and businesses was included into worked examples, which were provided to AHDB staff as a training exercises (Appendices 16, 17, 18 and 19). For the mixed farm and the arable and potato farm, the worked example demonstrated how EAgRET undertook resource transfers between enterprises.

For each scenario AHDB staff were provided with step-by-step instructions on how to make the changes and produce updated reports with SRUC and ADAS staff on hand to guide users through the process.

Table 5 Training examples

Farm business	Scenario 1	Scenario 2
Dairy Farm AYR Calving Grass Based	Increase number of calves produced - achieved by increasing the calving percentage from 87% to 90%	Reduce dairy cow winter housing and feeding period - the winter housing period was reduced from 196 days to 175 days
Beef LFA Breeding Farm	Increase number of calves produced - achieved by	Reduce suckler cow culling rate - achieved by decreasing

	increasing the calving percentage from 89% to 91%	the replacement rate from 16.1% to 13.1%
Sheep Lowland Breeding Farm	Increase number of lambs produced - achieved by increasing the lambing percentage from 153% to 158%	Reduce breeding ewe culling rate - achieved by decreasing the replacement rate from 22% to 18%
Pig Indoor Breeding Farm	Increase number of piglets produced - achieved by increasing the number of litters/sow/year from 2.27 to 2.41	Increase number of piglets produced - achieved by increasing the number of pigs born alive per litter from 12.12 to 13.53
Arable and potato farm	Change the cropping mix - by replacing oilseed rape with winter beans in the rotation.	Increase ware potato marketable yield - raise crop yield by 10t/ha and increase fuel use

3.5.5. Quick Start guide for AHDB users

A quick start guide was developed through an iterative process with AHDB (Appendix 20). This guide uses provides an overview of EAgrRET and how to use it. It includes screenshots combined with step-by-step guides to aid users in defining and analysing scenarios within the tool. It does not include detailed instructions for the definition of farm activities due to the large amounts of data required to be entered within the farm activity interfaces and because the primary use of the farm activities will be in modification of the defaults rather than producing one from scratch. Additionally, comments from users have suggested that the farm activity interfaces are fairly intuitive and straightforward to use.

3.5.6. User support for 6 months (Feb-July 2015)

Support has been provided to AHDB for 6 months. This has involved attendance at meetings of the EAgrRET user group and also telephone and email support for individual problems. During this support period, a number of issues were identified by users (both from the consortium and AHDB). A list of the issues addressed and bugs fixed since the handover of EAgrRET to AHDB in November 2014 is included in Appendix 21. This list provides a description of the changes made to EAgrRET in each update or revision and included in this list are revisions that were made as part of the support of EAgrRET and its evaluation through comparison with the SRUC AgRECalc© tool and HGCA carbon footprinting tool. During the comparison process a small number of errors in the implementation of the IPCC calculations were identified and addressed. These errors were primarily due to misinterpretation of the IPCC guidelines.

The main issues addressed during the support period were:

- Revision of IPCC calculations to address incorrect formulation of equations and incorrect parameter values.
- Revision of calculations of embedded emissions to force all embedded emissions to be calculated, but allow EAgRET to skip the calculation if the data for embedded emissions is not available in the look up table.
- Revision of code for assessment of resource transfers replacing synthetic fertilisers with manures to enable correct calculation of impacts when multiple replacements of synthetic fertiliser made.
- Revision of code to address functionality issues in tables, drop-down selections and graphs within the interfaces.
- Updating of values in look up tables, including addition of new entries into look up tables.
- Revision of code to include dry matter from look up tables to allow correct calculation of crop N offtake and N content of crop residues. Also included code to automatically label the crop yield according to whether fresh weight or dry weight required.
- Revision of code to ensure switching between Tier 2 and Tier 1 calculations according to livestock category.
- Addition of new crop category in look up table to ensure that whole crop fodder residues and offtake are correctly calculated by EAgRET.

A final list of issues was produced in the last month of the support period, and the majority of issues were concerned with users not being confident enough to add new entries into look up tables, modify default farms or add in data that was missing from default farms or not fully understanding how the tool works. It was decided to address this by holding additional training for staff who were experiencing these problems. The snag list and the responses to the snag list are provided in Appendices 22 and 23.

4. Conclusions

EAgRET is, as far as we are aware, the first tool to be able to calculate multiple metrics of resource efficiency and environmental impact at multiple scales within a farm business. This, combined with the fact that embedded emissions are reported separately from metrics due to farm management processes makes EAgRET a powerful tool for assessing the potential impacts from scenarios of change in agricultural farm businesses. The case studies have demonstrated how EAgRET can be used to compare contrasting strategies confirmed that there are likely to be some environmental gains from greater integration of crop, livestock and renewable energy (AD) enterprises, through greater displacement of bought in feeds, fertiliser and grid electricity. The case studies also showed

that the most environmentally beneficial resources transfers may not always deliver the best financial returns, although a full economic analysis would be required to confirm this.

In developing EAgRET a number of decisions and compromises had to be made. In making these decisions, the focus has been on ensuring that EAgRET retains the flexibility to represent the most common agricultural systems within the UK and also remains relatively easy to use. We believe that we have attained a suitable balance between ease of use, flexibility, complexity and accurate reflection of agricultural systems in the UK.

The hierarchical structure used within EAgRET (farm businesses, farm enterprises and farm activities) was chosen to ensure the flexibility to represent the most common agricultural systems within the UK and also to allow EAgRET to represent transfers of resources within farm businesses. It provides an alternative way of thinking about farm businesses and users will need to take some time to ensure that they fully understand how different farm businesses fit into this hierarchical structure. It is felt that the hierarchical structure makes sense when thinking about resource use within farm business and provides an approach for thinking in more detail about how resources are used effectively within a farm business.

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7. List of Appendices

Appendix 1	Summary of Reviewed literature and environmental impact calculation tools
Appendix 2	Summary of Reviewed Standards for Environmental Footprints
Appendix 3	Farm Management Mitigation Options
Appendix 4	Tool Specification Document
Appendix 5a	Default Data for Cropping and Grassland Farm Activities
Appendix 5b	Default Data for Livestock Farm Activities
Appendix 6	List of farm activity files with assumptions made for default
Appendix 7	Description of EAgRET Look Up Tables
Appendix 8	Description of EAgRET Interfaces
Appendix 9	Description of EAgRET Metrics Calculations
Appendix 10	Results from comparison of EAgRET with AgRECalc© and HGCA Carbon Calculator
Appendix 11	Case Study – Potatoes, beef and anaerobic digestion
Appendix 12	Case Study – Arable and beef
Appendix 13	Case Study – Dairy sexed semen
Appendix 14	Case Study – Pigs and arable protein
Appendix 15	Presentation from EAgRET training
Appendix 16	Exercises from training workshop- beef
Appendix 17	Exercises from training workshop – sheep
Appendix 18	Exercises from training workshop – dairy
Appendix 19	Exercises from training workshop – pigs
Appendix 20	EAgRET Quick Start Guide
Appendix 21	EAgRET Revision History
Appendix 22	Final issue list from AHDB
Appendix 23	Response to final issue list