Australian Government
Department of Agriculture, Water and the Environment

Future Drought Fund

Government of South Australia

A Guide to Carbon Footprint Assessment in South Australian Cropping Production Systems

AgExcellence Alliance

National Landcare Program

Landscape South Australia Northern and Yorke

Landscape South Australia Murraylands and Riverland

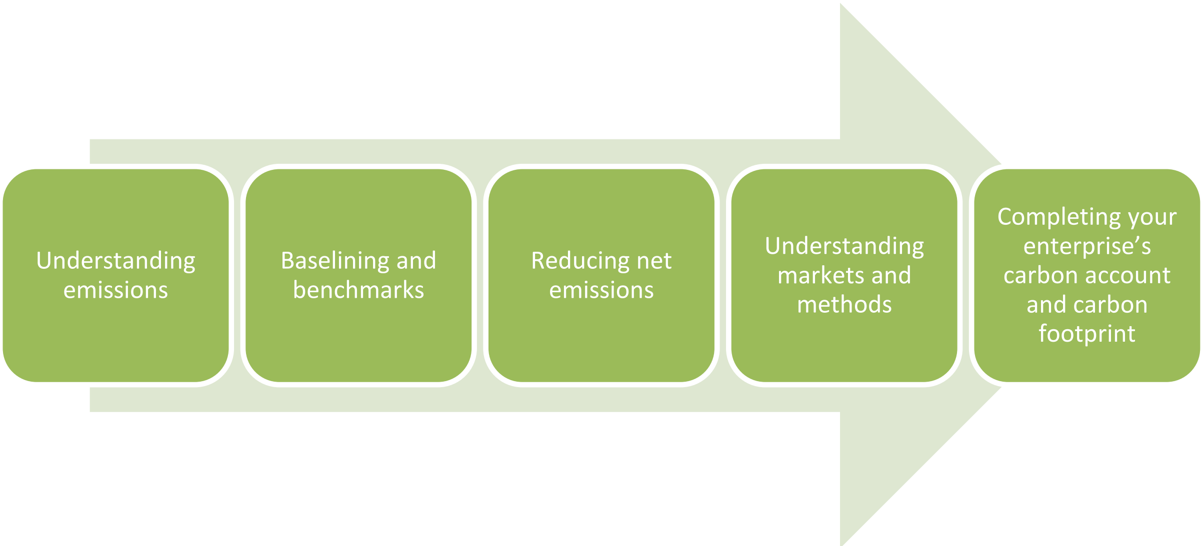
Integrity Ag & Environment

Introduction

This technical manual is based on the outcomes and feedback from a study conducted for the Department of Primary Industries and Regions (PIRSA) and a series of pilot carbon accounting workshops run in early 2022 in South Australia with Ag Excellence Alliance (Ag Ex). This manual provides background information on carbon accounting and explains how to undertake a simplified carbon account for cropping operations.

The guideline follows the process of understanding and quantifying carbon impacts and moving towards emission reduction. The steps are as follows (and these represent the section headings of this guideline):

1. *Understanding emissions*
2. *Baselining and benchmarks*
3. *Reducing net emissions*
4. *Understanding markets and methods*
5. *Completing your enterprise's carbon account and carbon footprint*



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1 Understanding emissions

Greenhouse gases (GHGs) contribute to climate change by trapping radiant heat energy within the atmosphere, leading to global warming[1]. Each gas has a different Global Warming Potential (GWP), a measure of cumulative radiative forcing (the long-term contribution of a particular gas to global warming)[2]. GWP_{100} is the global metric for assessing the average contribution to global warming over the next 100 years and is reported in carbon dioxide equivalents (CO_2-e). Most global GHG emissions come from burning fossil fuels, releasing carbon dioxide (CO_2)[1]. That is why CO_2-e is used, as it enables all different GHGs to be compared in terms of their effect on global warming. The GWP_{100} values and how these have changed over time are shown in Table 1. The last column, labelled "AR 5", shows the values in use when this guideline was published.

Table 1. Global warming potential (GWP) of the major greenhouse gases, showing changing values over time

Chemical Name	Chemical Formula	GWP values for a 100-year time horizon		
		Second Assessment Report (SAR) – pre-2015	Fourth Assessment Report (AR4) – used from 2015 to 2019	**Fifth Assessment Report (AR5) – used after 2019**
Carbon Dioxide	CO_2	1	1	**1**
Methane	CH_4	21	25	**28**
Nitrous Oxide	N_2O	310	298	**265**

While it is referred to as 'carbon accounting' for ease, these accounts also include nitrous oxide (N_2O), methane (CH_4) and other emissions and, therefore, would be more accurately termed 'GHG accounting'. In this guide, the two terms are considered synonymous. These other gases are important in agriculture, and the Australian Government's *National GHG Inventory* (also known as the National Inventory Report or NIR) also includes additional gases such as sulphur hexafluoride (SF_6) and other hydrofluorocarbons and perfluorocarbons, but these are released at negligible levels at most farms. Emission sources typical for cropping systems are shown in Figure 2.

Agricultural systems are built around a carbon cycle. Plants take up carbon from the atmosphere, and it is released when plant material 'senesces' (ages) and breaks down in the soil or is consumed. Only the 'net change' of biogenic carbon is reported in carbon accounting because only fluctuations in long-term carbon storage pools are treated as influencing global warming. Short term cycling of CO_2 is excluded because it is rapidly taken up from the atmosphere and released again, having no long-term impact on climate change.

Long-term changes in carbon pools, including soil stored carbon and carbon in plants, refer to changes occurring over decades. While not strictly defined, generally storing carbon for > 25 years is needed to be considered a ‘permanent’ change, and this timeframe is used as the minimum in carbon markets. A long-term increase in carbon within soil or vegetation is called carbon sequestration. It is included on the deduction side of a carbon account (a negative emission represents removal from the atmosphere). If carbon is lost from these pools, it is added to the emission side of a carbon account.

Carbon stock changes in soil and vegetation that occur in typical agricultural management are referred to as changes in Land Use (LU) emissions. When land use is permanently changed, such as changing from pasture to cropping or visa-versa, it is referred to as a Land Use Change (LUC).

Changes in carbon stocks can be quite difficult and expensive to measure. A change for any given year is measured by finding the difference between stocks at the beginning and end of the year (or over several years) and can be modelled based on management records. In many cases, the carbon account is simplified to assume "no change" in soil and vegetation carbon, which is often an acceptable assumption for relatively stable production systems. This guide covers modelling options for changes in vegetation carbon (see section 5.3).

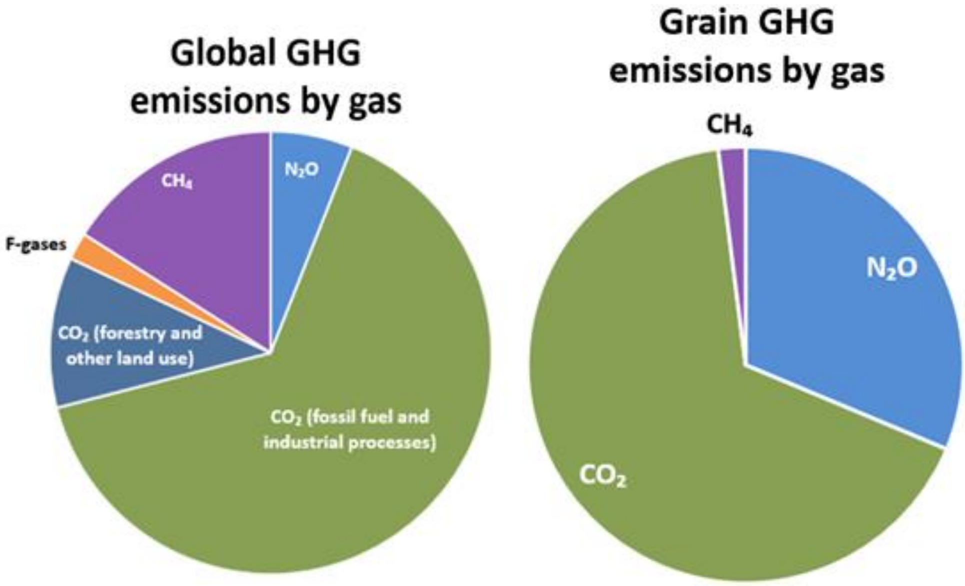

Figure 1. Global GHG emissions by gas[3]

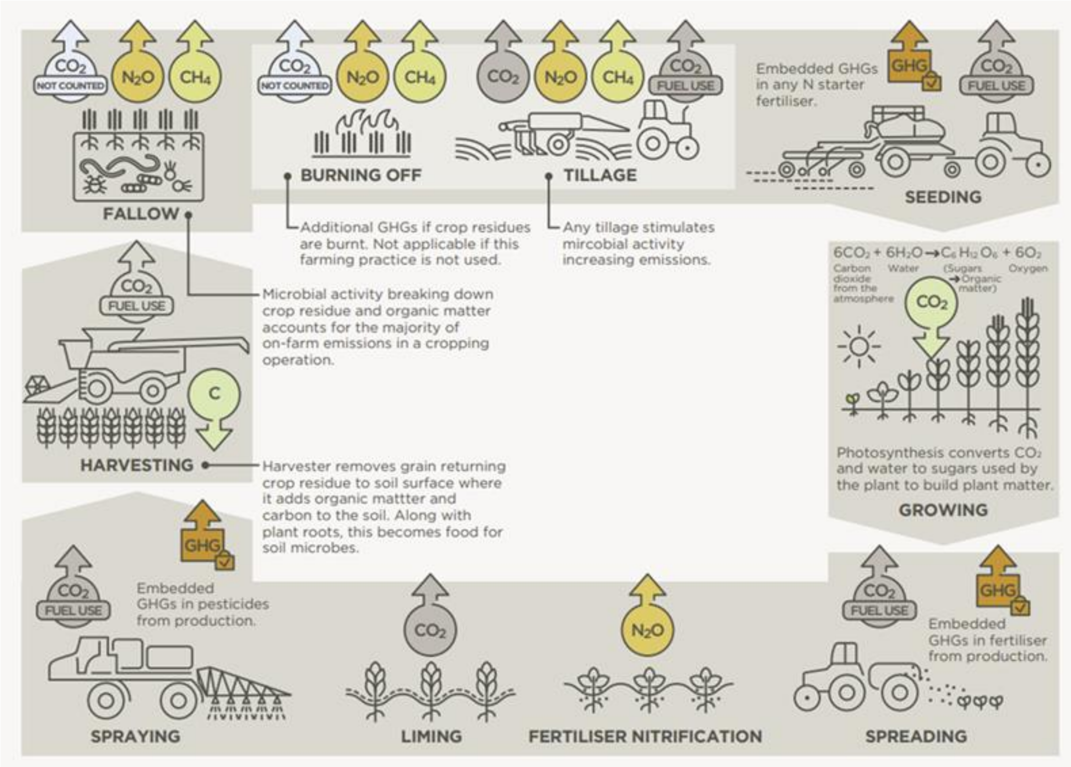

Figure 2. Sources and sinks of major greenhouse gas (GHG) emissions[4]

1.1 Emission boundaries

A carbon account must be established with a clear, stated boundary defining what is included and excluded. For an agricultural enterprise, a typical 'boundary' is the area under the operational control of the business, which may include leased land. This boundary includes scope 1 and 2 emission sources (described below). Additionally, upstream scope 3 emissions (described below) are included and reported separately in an enterprise carbon account.

A carbon footprint is most commonly used to describe the product leaving the farm (i.e. the product carbon footprint). By definition (ISO 14067), a carbon footprint is the sum of GHG emissions and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment (LCA), using the single impact category of climate change.

These guidelines cover both an enterprise carbon account and the carbon footprint of products leaving the farm. For clarity, when describing the carbon footprint, it includes all impacts from the "cradle" to the point at which products leave the farm. These impacts are typically reported relative to a "reference flow" of product leaving the farm (for example, for a kilogram of grain). This reporting method enables benchmarking against other businesses and products because it is independent of the scale or type of enterprise.

It is standard practice in carbon accounting for businesses to report emissions using different classifications, depending on where they arise and how they relate to the business. According to the GHG Protocol, these are termed emission 'scopes'[2]. Standards developed by the GHG Protocol govern the reporting and accounting of these GHG emissions.

According to the GHG Protocol, emissions are defined into three scopes:

- **Scope one**: direct GHG emissions from sources owned or controlled by the company.
- **Scope two**: GHG emissions from the generation of purchased electricity consumed by the company.
- **Scope three**: emissions that are a consequence of the company's activities but occur from sources not owned or controlled by the company. In this guide, only upstream scope 3 emissions are considered.
  NOTE: Examples of scope three activities are those arising from the extraction and production of purchased materials, the transportation of purchased fuels, and the use of sold products and services. These can be further broken down into upstream and downstream sources, as shown in Figure 3.

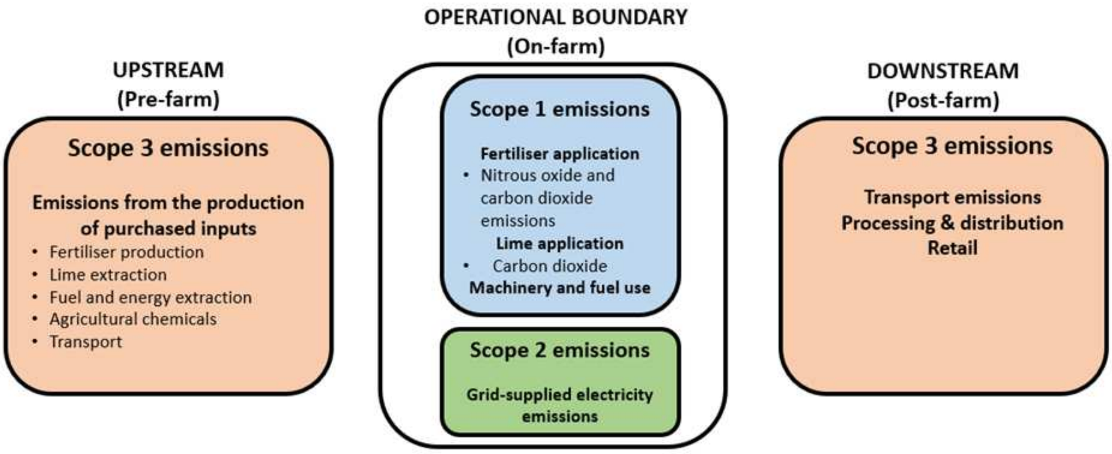

Figure 3. Examples of scope 1, 2 and 3 emissions for a cropping operation

1.2 Key elements of a carbon footprint assessment

A carbon footprint assessment involves modelling farm data to determine the emissions profile of a farm operation and can be thought of simply with the following equation:

Carbon footprint = emissions – carbon sequestration

It is a measure of the net emissions of an entity, though as described in later sections, carbon sequestration may be zero from some sources and may not need to be calculated to complete a carbon footprint.

It is important to understand the differrence between a carbon footprint and the concept of carbon neutrality. Carbon neutrality can be thought of in simple terms with the following equation:

Carbon neutral = carbon footprint (+ offsets) = 0

If the carbon footprint of an entity shows zero emissions, that entity can be considered carbon neutral.

The role of carbon offset credits complicates these simple calculations. Offsets are a way of trading carbon between businesses (see section 4.2). In a market facing carbon neutral assessment (see section 4.1), offsets sold to other entities are deducted from the sellers’ carbon footprint. On the other hand, carbon neutrality may be achieved by purchasing additional carbon offset credits from another entity.

1.2.1 Assessing emissions

A carbon footprint assessment reports the emissions across the operational boundary, including scopes 1, 2 and 3. These are often broken down across primary sources of emissions to identify 'hotspots' for further action. Figure 4 provides an example of a GHG footprint highlighting emissions sources for Australian wheat production.

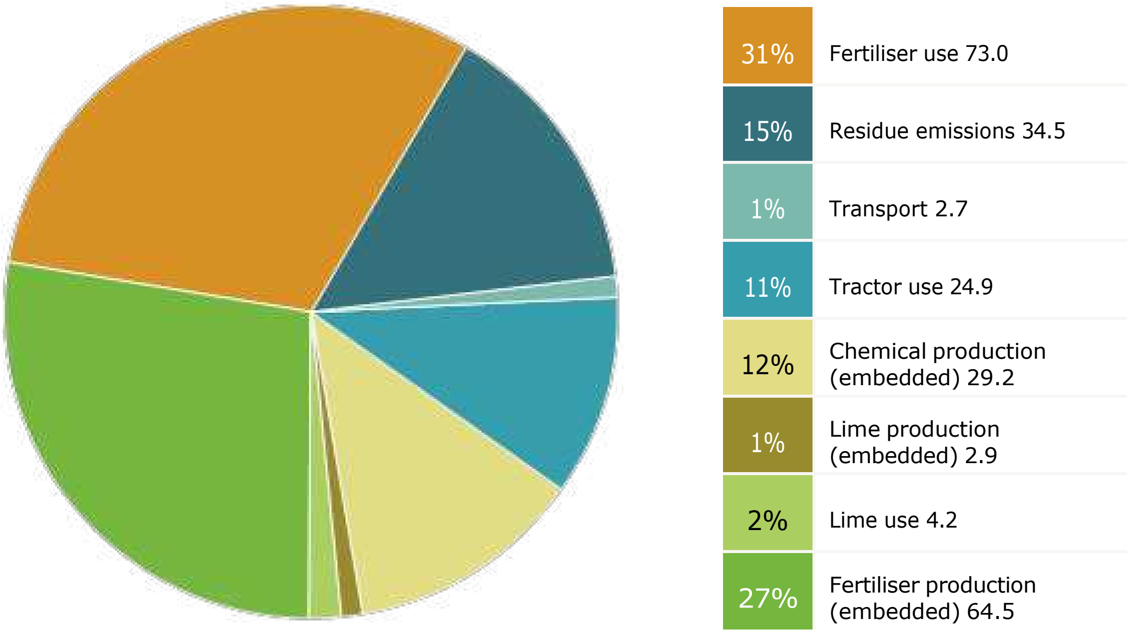

Figure 4. Breakdown of GHG footprint for Australian wheat production, weighted by regional production [4]

Calculating emissions is done by multiplying inputs with emission factors. Examples of common, simple emission factors for some product types are listed in Table 2 and Table 3. These values are subject to change over time and are an example only. Field emissions and indirect nitrous oxide emissions are much more complicated to calculate. The methods used to calculate these are embedded in the calculators, and more detail can be found in the National Inventory Report (see section 5.6.2, pg 345-6, section 5.6.3, pg 346-7, section 5.6.9, pg 352-3 and section 5.6.10, pg 353-5[5]).

Table 2. Emissions factors for common energy inputs

Input	Scope 1	Scope 2	Scope 3	Total
Diesel (kg CO2-e / L)	2.71	-	0.14	2.85
Petrol (kg CO2-e / L)	2.32	-	0.12	2.44
SA electricity (kg CO2-e / kWh)	-	0.3	0.07	0.36

Emission factors for common energy inputs in 2021 [6]

Table 3. Example emissions factors for embedded emissions of some common farm products

Inputs	Unit	Example GHG per unit (kg CO_2-e)
Urea	t	933[1]
SSP	t	216[2]
Lime application	t	3.13[3]

[1] Cradle-to-NZ port for urea produced in the Middle East [7].[2] Cradle-to-manufacturing-plant-gate in NZ [7]. [3] Crushed limestone rock production [8].

1.2.2 Assessing carbon in native vegetation

Trees can sequester large amounts of CO_2 from the atmosphere that can be used to offset GHG emissions from agricultural operations. Planting trees to offset emissions is only a long-term solution. It takes several years to establish trees and achieve the carbon storage benefits. Vegetation offers additional benefits such as increased biodiversity and erosion and salinity control.

Higher carbon sequestration rates occur in younger trees, however, mature trees and forested areas continue to sequester carbon over their lifetime at a very slow rate[9]. An indicative carbon sequestration potential of existing native vegetation can be estimated with simple tools such as FullCAM and LOOC-C programs (see section 5.3).

1.2.3 Assessing carbon in soils

Small variations in soil carbon can lead to large carbon sequestration potential[10]. Understanding soil carbon and the factors that cause it to change is a big learning area. Some useful materials have been provided in the “future reading” section. Here the basics are considered.

Australian soils are generally very low in soil organic carbon (SOC), with agricultural soils typically ranging from 0.4-4% SOC[11]. Soil carbon increase is a function of the quantity of carbon added to the soil and how much is retained. Without organic matter inputs to the soil, there is typically a 2-3% reduction in soil organic matter per year[4]. Even with continued inputs, microbes respire a significant portion of the carbon input as CO_2, meaning that good management is needed to maintain soil carbon levels. Increasing soil carbon levels requires more carbon to be added, or less carbon to be lost from the soil carbon balance. This generally requires a change in management to practices that support increases in soil carbon (see section 3.2).

The only reliable way at present to include carbon change in a carbon account is to baseline soil carbon levels and re-test periodically (for example, every 3-5 years). The change is measured as the difference between the two testing periods. Costs associated with a robust soil carbon testing program can be a significant barrier to adoption for many producers because soil carbon is often variable across a paddock and a large number of tests are needed to be confident in measuring a change in the level.

Before conducting soil carbon testing, consideration should be given to the desired output. If testing is being done for your own purposes to indicate soil health and carbon levels, following good practice for agronomic testing may be adequate. It is beneficial to include bulk density testing and test to a depth of

30cm (at a minimum). It is also helpful to map fixed testing points (GPS locations that can be returned at another time) to reduce variability.

If the testing is being done to develop carbon credits (Australian Carbon Credit Units), a project must first be registered with the Clean Energy Regulator (CER) and baselining must be done according to the method requirements for this program. This is quite an involved process and may require professional assistance. For further information about the ERF, see section 4.

2 Baselining and benchmarks

Different cropping systems, crop types and locations tend to lead to relatively varied emissions intensities within cropping operations in Australia. Figure 5 displays typical emissions intensity ranges within Australian cropping systems, highlighting the spread amongst crop types between low and high values[4]. These values ranged from 167 to 260 kg CO_2-e tonne yield^{-1} for Barley and 74 to 351 kg CO_2-e tonne yield^{-1} for legumes, to 439 to 967 kg CO_2-e tonne yield^{-1} for canola.

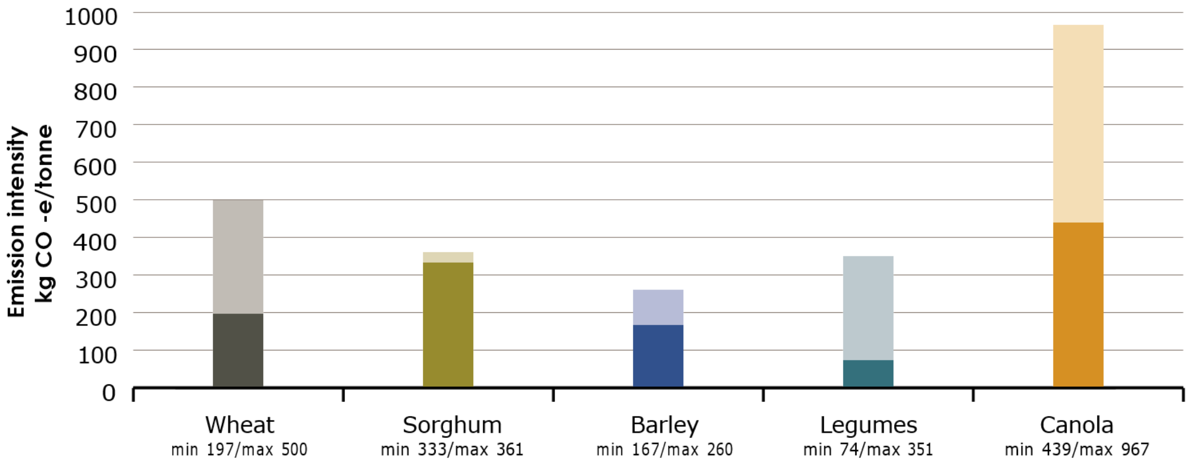

Figure 5. The GHG emissions profile of some major grain crops in Australia[4]

Further research funded by the GRDC into Australian cropping operations highlighted the variability in emissions profiles seen across different regions, as shown in Figure 6. This preliminary three-year analysis discovered a range of 197 kg CO_2-e tonne yield^{-1} in SW QLD/NW NSW to over 500 kg CO_2-e tonne yield^{-1} in WA Eastern[4].

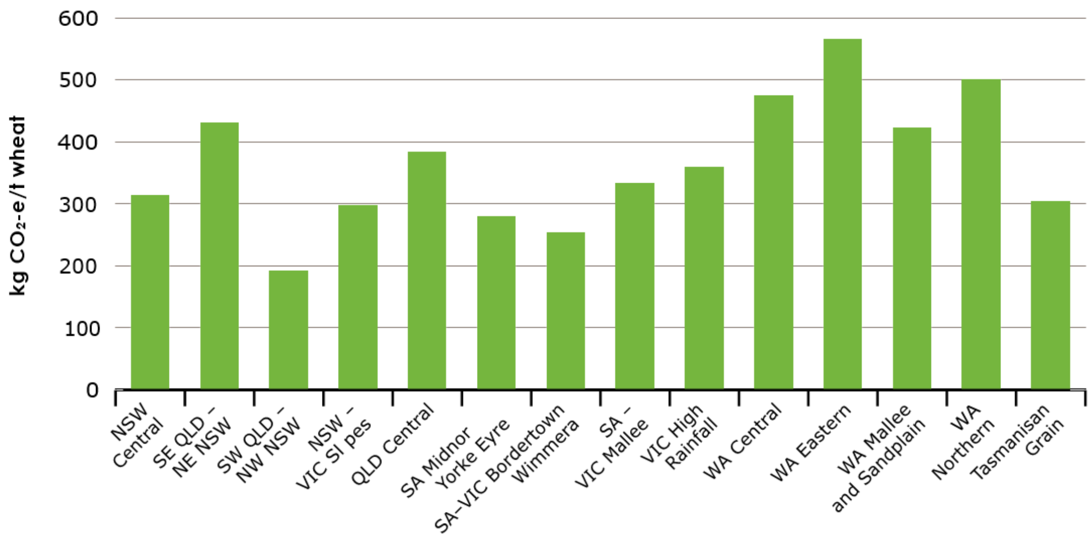

Figure 6. GHG emissions from Australian wheat production by region[4]

3 Reducing net emissions

Producers can become carbon neutral by reducing emissions and increasing carbon storage in vegetation and/or soil carbon. If branding a product as carbon neutral, it is also possible to purchase carbon credits to offset emissions. The Federal Government Climate Active carbon neutral certification requires scope 1, 2 and 3 emissions (full carbon footprint) to be included in an assessment of carbon neutrality for a product, and offsets must equal emissions.

3.1 Reducing carbon emissions

Reducing emissions in Australian cropping operations should typically focus on optimising inputs, primarily fuel use, water use, and purchased inputs (such as nitrogen fertilisers, herbicides and pesticides) relative to yield, and developing options to use less emission-intensive inputs.

The highest proportion of emissions are typically from fertiliser use (a mix of in-field emissions and embedded emissions from production), embedded emissions in pesticide use, crop residues, and fuel emissions from machinery use. The single largest area to potentially reduce emissions is optimising the use of purchased inputs, such as fertilisers and pesticides, particularly in areas of higher rainfall. The utilisation of greater control over nitrogen and pesticide application (such as through variable rate application), precision farming techniques, enhanced efficiency fertilisers, and the implementation of nitrogen-fixing rotations may reduce fertiliser and pesticide use and associated emissions. Fuel use for machinery could be reduced through management procedures such as controlled traffic farming and a reduction in vehicle passes or the investment in improved fuel efficiency (and in future, electric) farming machinery; however, this is currently expensive and may either not be available or not be a short-term solution for many enterprises. While crop residues may lead to emissions as they break down or are burnt, the retention of stubble may provide the added benefit of increasing soil carbon to help offset these emissions (as covered in the 'Storing carbon' section).

3.2 Storing carbon

Achieving carbon neutrality requires carbon storage in soil and/or vegetation, as emissions reduction strategies cannot achieve a zero-emissions profile in isolation. In cropping enterprises, soil carbon storage may provide an opportunity to reduce net emissions.

Soil carbon increase is a function of the quantity of carbon added to the soil and how much is retained. While there are multiple factors in the potential of soil carbon increases at a location, many practices that are undertaken in best-practice management of cropping operations also achieve soil carbon increases, such as reduced tillage, cover cropping and stubble retention.

Carbon levels generally stop increasing and reach an equilibrium over time, with the upper limit generally determined by climatic conditions and soil type[13,14] (Figure 7). There may be greater potential for carbon sequestration in previously degraded soils than in soils that has already been under best management practices for some years. Previous management practices may have caused carbon losses, allowing the opportunity to reverse these losses and build carbon back towards an attainable carbon level. The main contributors to carbon loss in agricultural soils are direct losses through soil erosion, indirect losses through organic matter decomposition influenced by climate (e.g. rainfall and temperature) and soil disturbance, such as tillage[12].

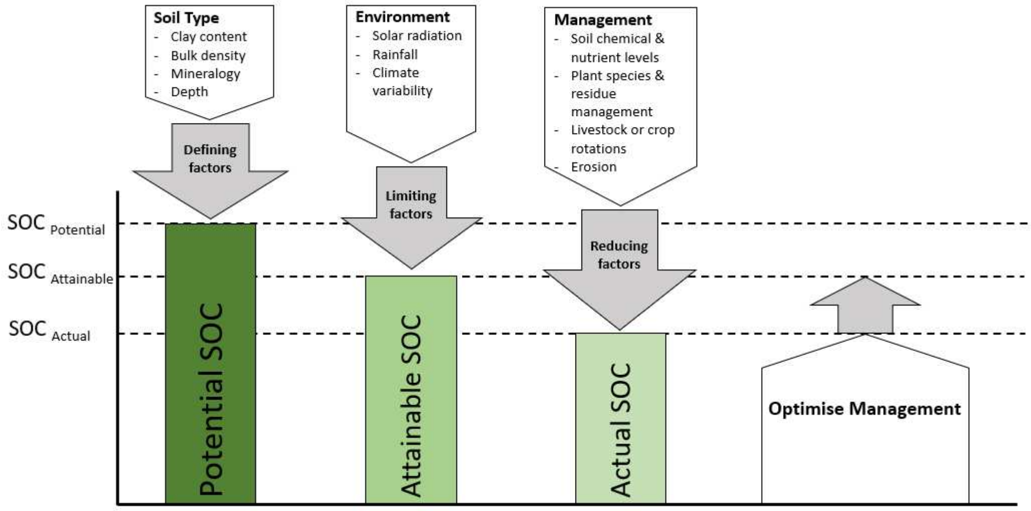

Figure 7. A representation of the factors influencing potential SOC, attainable SOC and actual SOC, and change expected from altered management practices [15]

Changes in soil carbon can be estimated based on soil factors and regional knowledge, and paired sites between different management systems can provide insight.

The greatest opportunities for SA's agricultural zones exist in areas of higher rainfall, however, all cropping districts have at least a small potential to increase SOC compared to existing baselines, as shown in Figure 8 and Figure 9. Carbon credits from increased soil carbon will need to be generated if considering a branded carbon neutral program.

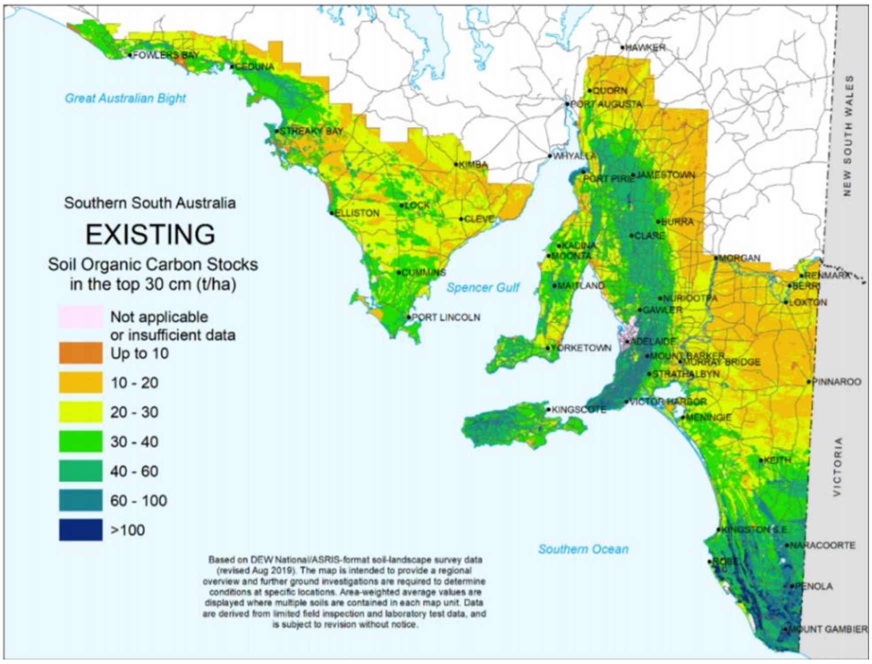

Figure 8. Existing surface SOC 1990-2000[16]

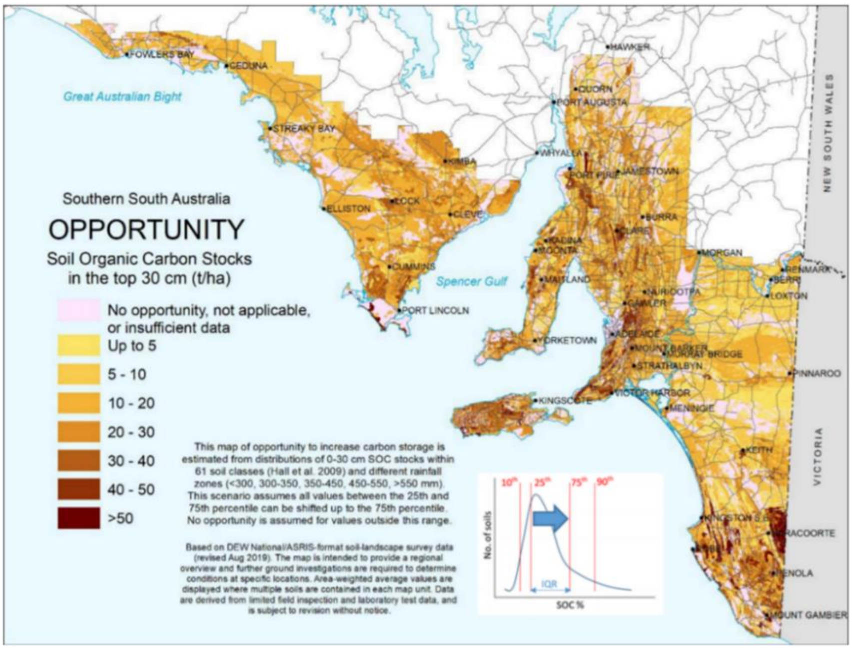

Figure 9. Opportunity for surface soil OC % - all values between the 25th and 75th percentile can be shifted to the 75th percentile[16]

Vegetation carbon storage may provide further opportunities to reduce net emissions. Carbon storage opportunities such as native vegetation plantings or regeneration of native forests may be possible within cropping operations, either through the use of marginal or unused land or reallocation of unproductive cropping land. Existing established native vegetation is not eligible to be counted towards formal Climate Active certification, however, this may change in the future.

4 Understanding markets and methods

4.1 Climate Active certification process

One way to claim carbon neutrality in the marketplace is by engaging with the Climate Active program. Climate Active is managed by the Australian Government Department of Industry, Science, Energy and Resources (DISER). Climate Active certifies businesses, products and services that have credibly reached a state of carbon neutrality by measuring, reducing, and offsetting their carbon emissions. A business must meet the Climate Active Carbon Neutral Standard requirements to be certified and receive Climate Active accreditation (for a product or as an organisation).

The standard requires the calculation of a carbon footprint prior to offsetting emissions through the purchase of approved carbon credits or the retirement of existing carbon offset credits owned by the entity (see Figure 10).

Climate Active's certification requires an independent third party to verify the carbon footprint and offset measures. Cropping producers must meet ongoing certification and reporting requirements (e.g. annual reporting) to use the Climate Active trademark on their products.

To include carbon sequestration in soil or native vegetation, a farm must generate certified carbon offset credits and then retire these against their carbon neutral certification. It is impossible to generate carbon credits, sell them to another entity, and then claim the same carbon credits against the farm's carbon neutral certification. This practice would result in double-counting of abatement.

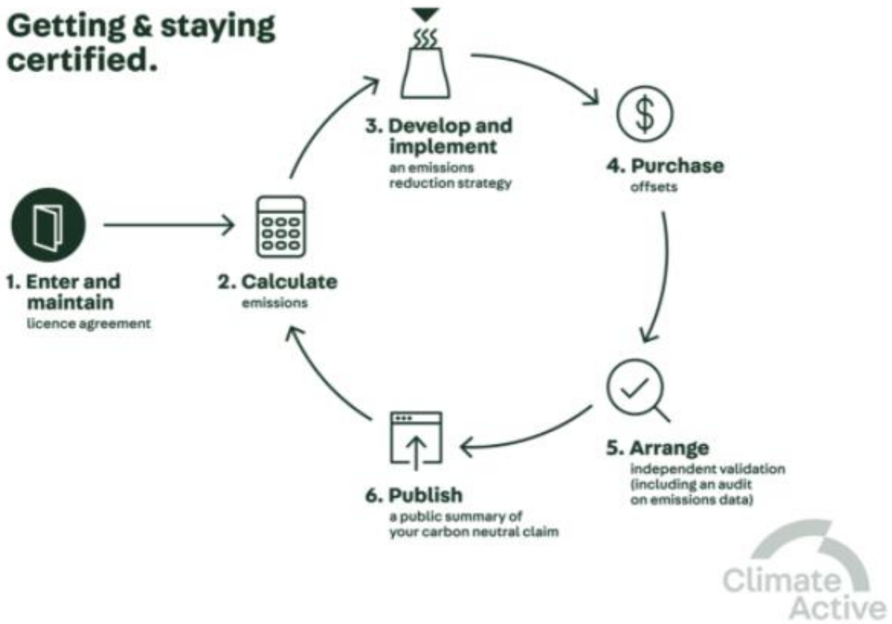

Figure 10. Climate Active Carbon Neutral project flow chart

4.2 Emissions Reduction Fund (ERF)

The ERF is a voluntary program that provides financial incentives for companies to adopt approved methodologies to reduce their GHG emissions. Methodology determinations (methods) under the ERF are the rules for estimating emission reductions to ensure they are valid strategies used in addition to normal operational procedures.

Projects are focused on one of two streams: avoiding emissions, which is focused on reducing the emissions that would have transpired had the project not occurred, such as covered ponds, burning methane gas and ceasing ongoing tree clearing events; and storing or sequestering carbon, such as storing carbon in vegetation through tree plantings or regenerating native forest, or storing carbon in soil through undertaking actions that improve the organic carbon content of the soil in a particular area. Projects yield Australian Carbon Credit Units (ACCUs), with one ACCU being the equivalent of 1 tonne of carbon dioxide equivalent (1 t CO_2-e) either prevented from being emitted (avoidance) or being stored (sequestered) in vegetation or soil. Earned ACCUs can be sold to organisations looking to offset their carbon footprint or meet emissions reduction obligations, or to the Federal Government through the Clean Energy Regulator (Figure 11).

Signing up for a sequestration project requires committing to a permanence obligation, meaning the carbon stored by a project must be maintained for the chosen period, either 100 or 25 years. Management of vegetation and practices that increase soil carbon sequestration must be maintained over this period. Navigating the carbon project requirements generally requires professional assistance from a project developer or consultant. Carbon yield and project scale typically need to be reasonably large to cover project costs.

In addition to the ERF, secondary offset or voluntary markets exist where alternative forms of carbon credits can be traded, such as Verified Carbon Units (VCUs) and Voluntary Emission Reductions (VERs).

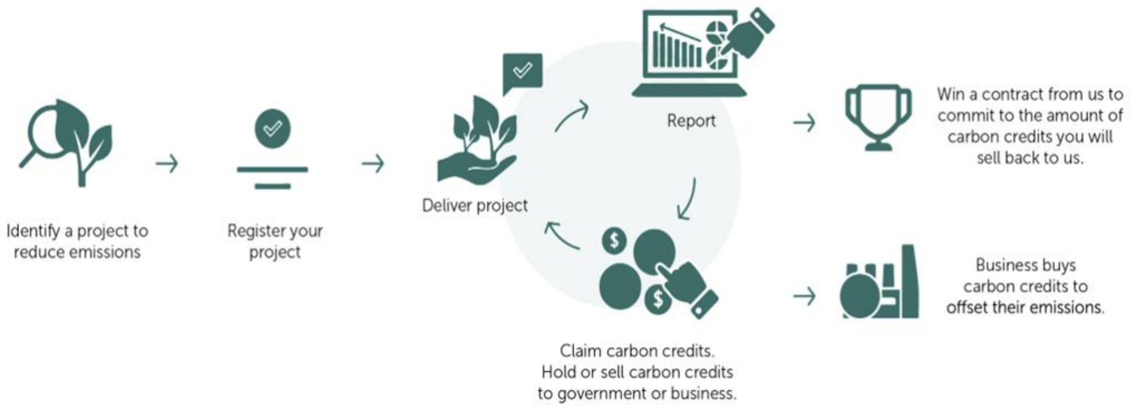

Figure 11. ERF project flow chart

5 Completing your own enterprise carbon account and carbon footprint

In completing an enterprise carbon account and carbon footprint, the first question is: "What is the purpose of this carbon account/footprint?".

There are three common purposes (requiring different levels of effort): an internal baseline for indicative purposes, a baseline for public release or an audited carbon footprint for market purposes. Note that the guidelines in this document suit purpose 1 below, and some description is given for more detailed purposes.

Purpose 1: Internal business carbon baseline assessment. For many businesses, carbon is a new consideration in the business. The best first step is often an **internal business carbon baseline assessment** for company use only to define impact hotspots and to act as a general guide for the level of emissions. This assessment can be done reasonably easily in many cases with little guidance. However, any calculator is only as useful as the data used to generate results. The old saying holds: "garbage in, garbage out". Many unrealistic results have been generated by users' missing necessary inputs or "making up" the input values. If the purpose is to get a general estimate for indicative purposes, with results within 30-40% of an in-depth carbon account, this can often be done fairly quickly with average numbers that are quick to collate.

While this is a good start, it won't give a result that can be transferred for purposes 2 or 3 without further work to ensure the data inputs are verifiable and methods suit the requirements.

Purpose 2: The second purpose is a **formal business carbon baseline for public release**. This assessment is typically done for investors (including banks) or supply chain partners. A publicly released carbon account should be done to clear standards to have credibility. If a particular stakeholder has requested the carbon account, the first step is to ask if they list specific requirements and follow these. Some industries are in the process of developing sector-specific guidelines which can be used, but these vary in their level of detail and purpose. For instance, many may have been developed for purpose 1 because they may not use a clear, auditable method.

Good general practice is to comply with the National GHG Inventory for agricultural emissions, the GHG Protocol business accounting and Agricultural guidance, and/or ISO 14064 for carbon accounting. For product carbon footprints, ISO 14067 is the global standard. In late 2022, Climate Active plan to release specific guidance for agricultural businesses, which is useful, particularly if intending to move to a market reporting assessment. All input data should be accurate, verifiable, and sourced from farm records to achieve.

The assessment should be done to a standard that could be audited, though an audit may not be necessary depending on the requirements of the external stakeholders you plan to share the carbon account with. In most cases, professional carbon accounting and/or auditing skills are required to ensure this is done correctly, particularly to set up the account in the baseline year and to work through business-specific assumptions.

Purpose 3: Audited carbon account or carbon footprint. The highest requirement is an audited carbon account or product carbon footprint. This is required for market-based programs (ERF, Climate Active) where the account is being used to make specific claims around the business or product. Audited accounts must meet an audit standard and have verified data sources to enable an audit to be conducted. This process is often significantly more work than purpose 2, and costs to complete this form of assessment may be high. It is usually only done where there is a clear demand or opportunity for such a process.

Once the purpose has been established, you can move on to generating the carbon account. As noted, this guidance has been produced for purpose 1, to develop an **internal business carbon baseline assessment.**

5.1 Accessing the cropping GHG accounting tool (G-GAF)

Producers can create carbon accounts for their farms using publicly available online tools. One such tool currently available for calculating emissions from cropping is the Cropping Greenhouse Accounting Framework (G-GAF) tool. This section outlines how to use the G-GAF tool, which can be downloaded from https://piccc.org.au/resources/Tools.html. Once downloaded, open the file, rename it to include your farm's name and the year the carbon account is for, and then save it. The downloaded and saved file will now be available for offline use.

5.2 Data you will need

The following data will be needed to determine your carbon account with the G-GAF tool:

- **Farm inputs:** fertilisers, lime, pesticides, fuel, and electricity.
- **Tree planting:** area planted to trees (ha), species and planting date (to determine age).
- **General crop and farm information:** crop type, production system (e.g., non-irrigated crop), crop yield, fraction of burnt crop residues, area cropped.

The G-GAF tool is limited to cropping systems. Other enterprises operating on-farm, such as cattle grazing on forage crops, require a different tool. The tool can be used to create a carbon account for any year where data are available. We suggest selecting a recent, "representative" year for the farm, where farm inputs and outputs are not highly variable compared to the yearly inputs and output, and setting this as the baseline year.

5.2.1 Step one: Data input – crops

Each data item listed in the *Data input – crops* sheet (Figure 12) is required to calculate the farm's total emissions. At the top of the sheet, add the farm name and use the drop-down menu options to select the associated region, electricity source, farm cropping details and production systems. You may input up to five production systems, with each new production system representing a new column of white cells. Next, refer to the map to the right of the sheet to determine if your farm is in the orange zone and use the drop-down menu to enter accordingly.

Delete the pre-filled values in the white cells. For each production system (column), enter the values that correspond to the details in that row. Pay attention to the parameter (purple column on the left) and the units (purple column on the right). Proceed to input the average yield, area sown, fertiliser applications, the mass of lime applied, the fraction of lime as limestone vs dolomite and the fraction of the annual production of a crop that is burnt (the latter two parameters must be entered as a ratio between 0 and 1). For any parameters with a value of zero, input a 0 into the corresponding cell.

Input the amount of diesel, liquid petroleum gas and electricity used. For the latter, only input the electricity use into the first column, regardless of whether you used electricity in other production systems (other columns). In the row below, designate the estimated percentage split of electricity for each production system over the year. If only one production system were farmed, the value in cell C20 would be 100%. Under "General Herbicide/Pesticide use", enter the total kg of the active ingredient in the pesticide applied that is not glyphosate, as glyphosate is added in the following row.

Enter your farm data	Farm Name	**Joe Bloggs's**				
Choose your region in Australia	SA					
Electriticy Source	State Grid					
Farm cropping details	Wheat	Lucerne	Other legume	Triticale	Oilseeds	
Production System	Non-Irrigated Crop	Non-Irrigated Crop	Irrigated Crop	Irrigated Crop	Irrigated Crop	
Is the crop in orange zone? (Ref Map. 1)	Yes	No	No	No	No	
Average grain yield	3.00	2.50	2.00	3.00	2.50	t/ha
Area sown	1000	200	500	800	300	ha/farm
MAP Application	60	50	0	80	50	kg product/ha
DAP Application	50	10	5	20	30	kg product/ha
SOA Application	20	10	30	20	10	kg product/ha
Urea Application	50	40	20	30	50	kg product/ha
Single Superphosphate	20	20	20	20	20	kg product/ha
Mass of Lime Applied	500	400	500	200	100	kg/ha
Fraction of Lime as limestone vs dolomite	1.00	0.00	1.00	0.00	0.00	Limestone/dolomite
Fraction of the annual production of crop that is burnt (F)	0.00	0.00	0.00	0.00	0.00	ha/total crop ha
Annual Diesel Consumption	20000	4000	10000	15000	5000	litres/year
Annual LPG Use	500	250	400	100	250	litres/year
Annual Electricity Use	4000					KWh
Allocation to crop	20%	40%	20%	10%	10%	
General Herbicide/Pesticide use	20	10	5	10	20	kg total
Glyphosate use	10	30	10	50	15	kg total

Figure 12. Data input – crops sheet with example data

5.2.2 Step two: Data input – Planted trees

To determine carbon from vegetation for an **internal business carbon baseline assessment**, the *Data input – vegetation* sheet (Figure 13) can be completed from top to bottom as items within certain drop-down boxes are dependent on previous options selected. Fill in the drop-down boxes, in order, for State, Region, Species of Tree, and Soil Type. Then fill in the data for Area of Trees (ha), Age of Trees (years) and Allocation % to each crop entered on the *Data input – crops* sheet.

Not all tree species are available for modelling through this tool, and the results are indicative only. Additionally, see section 5.3 below.

Vegetation	State		SA	
	Region		South East	
	Species of Tree		Mixed species (Environmental Plantings)	
	Soil Type		Duplex Soils	
	Area of Trees		5	ha
	Age of Trees		20	years
	Allocation to crop	Wheat	60%	
	Allocation to crop	Lucerne	20%	
	Allocation to crop	Other legume	5%	
	Allocation to crop	Triticale	5%	
	Allocation to crop	Oilseeds	10%	

Figure 13. Data input – vegetation sheet with example data

5.3 Other vegetation carbon sequestration methods

The G-GAF tool calculates potential annual carbon sequestration in native trees. Another tool, LOOC-C, is available for calculating potential vegetation carbon sequestration resulting from running an ERF project on the land. The LOOC-C tool can be accessed from https://looc-c.farm/. Click on "Explore your options" to use the tool and enter your property details. The first step to using LOOC-C is to select a project area on the map provided, using the "Area tool" at the top left of the map. Answer the questions on the webpage below the map and click next to receive an assessment of your property for available ERF methods, including potential vegetation carbon sequestration rates for applicable methods.

For a more accurate estimate of the carbon sequestered in trees, skilled users may choose the Full Carbon Accounting Model (FullCAM). FullCAM will provide a robust estimate of sequestration when it is used as described in the FullCAM guidelines of an Emissions Reduction Fund (ERF) method. There are easy-to-follow FullCAM guidelines written for environmental plantings, for the regeneration of native vegetation, and for forestry plantations. The correct calculation of sequestration will require reference to the 'calculations' section of the matching ERF Determination. This may be as simple as summing carbon sequestered in above- and below-ground biomass (plus coarse woody debris), or as complex as modelling the contrast between 'baseline' and 'project' scenarios. FullCAM is free to use, and is available, along with links to the above-mentioned ERF methods, from the Australian Government website: https://www.industry.gov.au/data-and-publications/full-carbon-accounting-model-fullcam.

5.4 Soil organic carbon sequestration

For an **internal business carbon baseline assessment,** it is possible to calculate carbon sequestration potential in soil and include this in the carbon account. This will require a soil testing program, including a baseline and subsequent testing rounds. Sequestration is reported by measuring the soil carbon at the beginning and end of a sampling period (often 3-5years). Accounting for bulk density is important for adjusting carbon levels to an equivalent soil mass[12]. Changes in bulk density over a soil sampling interval may occur with soil compaction and needs to be captured.

To calculate SOC, you will need to know your soil's SOC % and bulk density by analysing soil samples taken at a specific depth. If SOC % is known, the carbon stored in the soil can be calculated by following the approach in Equation 1. The standard depth for soil carbon sampling is 0 – 30 cm.

Soil organic carbon can vary throughout a property due to various factors, such as different management practices and history, season, time in the year, and varying soil types. To improve the accuracy of SOC determination, advice should be sought from a suitably qualified practitioner familiar with the requirements of baselining soil carbon. A representative number of samples across the focus area should be collected. Note that many more requirements around soil sampling must be followed to generate carbon credits under the ERF soil carbon method. Users must refer to these guidelines if the purpose is to develop a soil carbon project to generate carbon credits.

Equation 1. Soil organic baseline and change equation

$$\boldsymbol{Tonnes\ carbon\ per\ hectare} = \boldsymbol{SOC}\ (\%) \times \boldsymbol{bulk\ density}\ (\boldsymbol{g\ per\ cm^3}) \times \boldsymbol{depth}\ (\boldsymbol{cm})$$

For example, the total tonnes of carbon per hectare of soil with a SOC of 1.2 % and a bulk density of 1.3 g cm^{-3} sampled to a depth of 30 cm can be determined as follows:

$$1.2 \times 1.3 \times 30 = 46.8\ tonnes\ of\ carbon\ per\ hectare$$

If SOC % after a subsequent sampling event increased by 0.1% to 1.3%, the total tonnes of carbon per hectare would be:

$$1.3 \times 1.3 \times 30 = 50.7\ tonnes\ of\ carbon\ per\ hectare$$

This equation amounts to an increase of 3.9 tonnes of carbon per hectare, equivalent to 14.3 tonnes of CO_2-e per hectare. It shows a very large increase in carbon, despite the small change in carbon percentage. Results should be interpreted with caution because season and sampling variability or a change of laboratories can all result in changes in reported soil carbon levels that may be false or may be reversed in subsequent years. As a guide, the ERF method does not allow baselining in drought conditions (because this provides a below long-term average baseline) and discounts the first reported change in soil carbon by 50% until a clear improvement trend has been established.

5.5 Data summary

Upon completion of data entry into the *Data input – crops* and *Data input – vegetation* sheets, the *Data summary* sheet will be populated with your farm's emissions results (Figure 14). Your farm's emissions are broken down in the *Data summary* sheet into Scope 1, 2 and 3 emissions, carbon sequestration in tree plantings, net farm emissions, and emissions intensity.

Grains Greenhouse Accounting Tool

Crop	Wheat	Lucerne	Other legume	Triticale	Oilseeds	
Outputs	t CO_2e/farm	t CO_2e/farm	t CO_2e/farm	t CO_2e/farm	t CO_2e/farm	otal t CO2e/farm
Scope 1 Emissions (on-farm)						
CO_2 - Fuel	55.12	11.37	27.90	40.70	14.07	149.16
CO_2 - Lime	0.20	0.18	0.20	0.09	0.05	0.71
CO_2 - Urea	36.67	5.87	7.33	17.60	11.00	78.47
CH_4 - Field burning	0.00	0.00	0.00	0.00	0.00	0.00
CH_4 - Fuel	0.08	0.02	0.04	0.06	0.02	0.23
N_2O - Fertiliser	8.79	19.33	29.03	83.82	37.70	178.65
N_2O - Atmospheric Deposition	0.97	2.13	3.19	9.22	4.15	19.65
N_2O - Field Burning	0.00	0.00	0.00	0.00	0.00	0.00
N_2O - Crop Residues	125.99	9.33	16.62	117.94	64.92	334.80
N_2O - Leaching and Runoff	0.00	1.67	9.01	57.17	28.85	96.71
N_2O - Fuel	0.29	0.06	0.15	0.21	0.08	0.78
Scope 1 Total	**228**	**50**	**93**	**327**	**161**	**859**
Scope 2 Emissions (off-farm)						
Electricity	0.352	0.704	0.352	0.176	0.176	1.76
Scope 2 Total	**0.352**	**0.704**	**0.352**	**0.176**	**0.176**	**1.76**
Scope 3 Emissions (pre-farm)						
Fertiliser	161.52	15.48	29.36	95.44	40.10	341.91
Herbicides/pesticides	0.71	1.18	0.42	1.84	0.87	5.01
Electricity	0.08	0.16	0.08	0.04	0.04	0.4
Fuel	2.84	0.59	1.44	2.10	0.73	7.69
Lime	0.216	0.17	0.22	0.09	0.04	0.73
Scope 3 Total	**165**	**18**	**32**	**100**	**42**	**356**
Carbon Sequestration						
Carbon sequestration in trees	-190.65	-63.55	-10.18	-15.89	-31.77	-312.04
Net Farm Emissions	**203**	**5**	**115**	**411**	**171**	**905**
Emissions intensity	**0.07**	**0.01**	**0.12**	**0.17**	**0.23**	**t CO2-e/t crop**

Summary t CO2e/farm	
CO_2	566
CH_4	9
N_2O	632

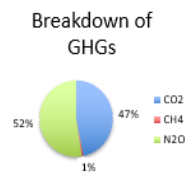

Figure 14. Data summary sheet with example data

A pie chart hotspot analysis is provided to the right of the tables on this sheet. It provides a visual breakdown of the proportional contributions from various source categories toward the farm's overall emissions. The categories include fuel, fertiliser & urea, burning, crop residues, indirect N_2O, electricity, and pre-farm emissions (Figure 15).

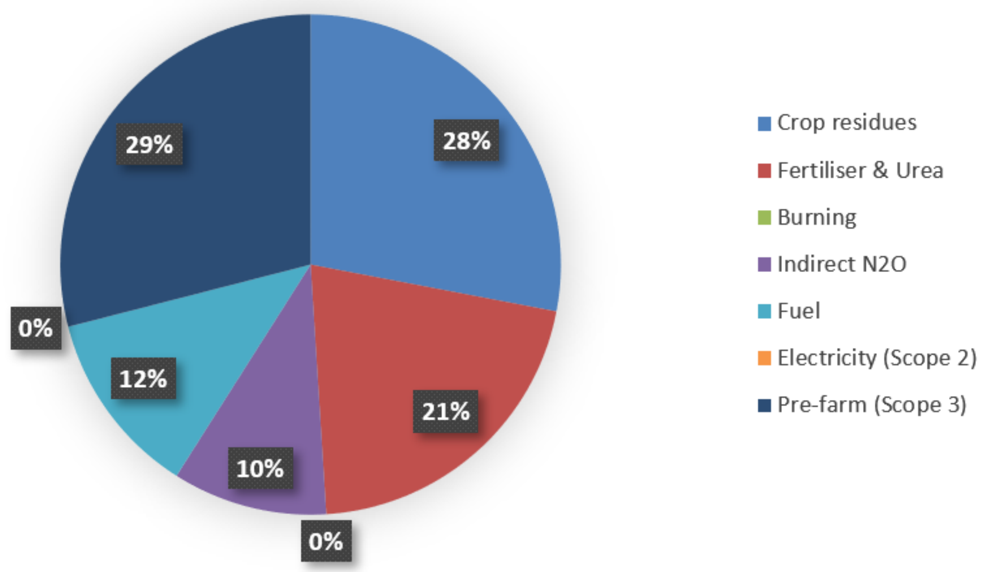

Figure 15. Pie chart of Hotspot Analysis in Data summary sheet with example data

Combining the outputs from the GAF calculator with potential changes in vegetation and soil carbon enables the formulation of a net emissions value. Utilising this understanding and tailoring emission reduction options to an operation enables an operation to determine potential carbon improvements to the overall carbon account and emissions intensity profile. For example, implementing a program to reduce tractor passes by 30% would potentially reduce fuel by 30%, enabling a deduction of 30% of the fuel carbon emissions from the overall account. The calculator can be used as needed and can also be used to test management changes to indicate the different emission outcomes.

5.6 Calculator limitations

Due to the complex nature of carbon accounting, the available calculators have different limitations that vary depending on the chosen tool. No one tool is ideal, and none can currently meet the needs for formal carbon accounts without additional information.

Here are some points to note. Firstly, check which version you have. Factors change regularly, especially for electricity and occasionally for GWP values, and methods are periodically updated. A calculator that is 3 years old is out-of-date.

Second, check the purpose. You can calculate an enterprise carbon account focused on scope 1 and 2 emissions, but it's difficult to benchmark performance against other businesses with these results, and you can't report a product carbon footprint. Most of the available tools are variable in their handling of scope 3 emissions and give indicative results at best.

Some scope 3 emissions are calculated in the G-GAF tool, including emissions from the production of purchased inputs; however, other scope 3 emissions are not calculated (e.g. transport of purchased inputs, employee commuting, waste, downstream emissions, some fertiliser related emissions and some herbicide/pesticide inputs). Scope 3 emissions are an important part of a carbon account and must be reported on under certain standards. These tools do not currently allow for calculating carbon sequestration in soils.

If you wish to conduct carbon accounting for a formal process (reporting to markets or stakeholders), data inputs must be verified, and in that case, a more comprehensive list of scope 3 emissions may need to be collected depending on the boundary for the assessment.

6 References and further reading

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