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Review

Greenhouse gas accounting for inventory, emissions trading and life cycle assessment in the land-based sector: a review

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Abstract. Governments, organisations and individuals have recognised the need to reduce their greenhouse gas (GHG) emissions. To identify where savings can be made, and to monitor progress in reducing emissions, we need methodologies to quantify GHG emissions and sequestration. Through the Australian Government's Carbon Farming Initiative (CFI) landholders may generate credits for reducing emissions and/or sequestering carbon (C).

National GHG inventories for the United Nations Framework Convention on Climate Change, and accounting under the Kyoto Protocol use a sectoral approach. For example, fuel use in agriculture is reported in the transport component of the energy sector; energy use in producing herbicide and fertiliser is included in the manufacturing section of the energy sector; sequestration in farm forestry is reported in the land use, land-use change and forestry sector, while emissions reported in the agriculture sector include methane (CH_4) from ruminant livestock, nitrous oxide (N_2O) from soils, and non-carbon dioxide (CO_2) GHG from stubble and savannah burning. In contrast, project-level accounting for CFI includes land-use change, forestry and agricultural sector emissions, and significant direct inputs such as diesel and electricity. A C footprint calculation uses a life cycle approach, including all the emissions associated with an organisation, activity or product. The C footprint of a food product includes the upstream emissions from manufacturing fertiliser and other inputs, fuel use in farming operations, transport, processing and packaging, distribution to consumers, electricity use in refrigeration and food preparation, and waste disposal.

Methods used to estimate emissions range from simple empirical emissions factors, to complex process-based models. Methods developed for inventory and emissions trading must balance the need for sufficient accuracy to give confidence to the market, with practical aspects such as ease and expense of data collection. Requirements for frequent on-ground monitoring and third party verification of soil C or livestock CH_4 estimates, for example, may incur costs that would negate the financial benefit of credits earned, and could also generate additional GHG emissions.

Research is required to develop practical on-farm measures of CH_4 and N_2O, and methods to quantify C in environmental plantings, agricultural soils and rangeland ecosystems, to improve models for estimation and prediction of GHG emissions, and enable baseline assessment. There is a need for whole-farm level estimation tools that accommodate regional and management differences in emissions and sequestration to support landholders in managing net emissions from their farming enterprises. These on-farm 'bottom-up' accounting tools must align with the 'top-down' national account. To facilitate assessment of C footprints for food and fibre products, Australia also needs a comprehensive life cycle inventory database.

This paper reviews current methods and approaches used for quantifying GHG emissions for the land-based sectors in the context of emissions reporting, emissions trading and C footprinting, and proposes possible improvements. We emphasise that cost-effective yet credible GHG estimation methods are needed to encourage participation in voluntary offset schemes such as the CFI, and thereby achieve maximum mitigation in the land-based sector.

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Introduction: why do we need greenhouse gas (GHG) accounting methods?

Recognising that urgent action must be taken if we are to avoid catastrophic climate change, governments, organisations and individuals are introducing measures to reduce emissions of GHG. We need to be able to quantify GHG emissions in order to make informed decisions and monitor the success of these actions. This paper reviews the current methods and approaches used for quantifying GHG emissions for the land-based sectors, and current applications in emissions reporting, emissions trading and carbon (C) footprinting. We highlight the challenges in the current methods and applications, and discuss possible improvements.

Climate change policy

United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC), agreed through the UN Conference on Environment and Development convened in Rio de Janeiro in 1992, aims to stabilise GHG emissions 'at a level that would prevent dangerous anthropogenic interference with the climate system' (UNFCCC 1992). The 1997 Kyoto Protocol to the UNFCCC strengthened the commitment to action on climate change, with developed nations taking on binding targets for emissions reduction (UNFCCC 1998). More recently, the Copenhagen Accord[1], agreed by 114 parties to the UNFCCC, resolved that deep cuts in global emissions are required so as to hold the increase in global temperature below 2°C.

Under the UNFCCC all parties are required to submit an annual inventory of GHG emissions. Parties report emissions from each of the sectors, categorised as energy, industrial processes, waste, agriculture, and land use, land-use change and forestry (LULUCF). In the LULUCF sector, net emissions are reported after subtracting removals due to forest growth. Reporting is intended to isolate the anthropogenic component of emissions and removals. As a proxy, this is done by reporting the emissions and removals on all managed lands. The Intergovernmental Panel on Climate Change (IPCC) develops methods for estimating emissions and removals for national inventories, which are published as guidelines (IPCC 1997, 2006).

Under the Kyoto Protocol Annex I parties[2] submit GHG accounts that cover a subset of the emissions and removals included in the national report. All emissions on land affected by deforestation are included. The Kyoto Protocol allows parties to offset emissions from other sectors with removal credits generated through afforestation and reforestation, cropland management (CM), grazing land management (GM), forest management and revegetation (RV). Significantly, parties were able to choose whether or not they included C stock changes on grazing land, cropland and existing forests. Australia chose not to include these 'Article 3.4' activities, due to the perceived risk that they may be a net source rather than net sink. Under the Clean Development Mechanism, Annex I parties can offset their emissions through projects implemented in developing countries. Afforestation and reforestation projects are eligible under the Clean Development Mechanism, though other land management measures are not.

It is worth clarifying the terminology used in the UNFCCC context: the term 'reporting' is used to refer to submission of national GHG inventories to the UNFCCC, whereas the term 'accounting' applies specifically to comparing emissions and removals with commitments assumed under the Kyoto Protocol (Cowie *et al*. 2006). Expanding the latter definition, GHG accounting is here used to mean the assigning of responsibilities for emissions and removals, in order to calculate debits and credits.

Emissions trading

Regional and national emissions trading schemes (ETS) are being introduced or at least contemplated, to assist countries in meeting their emissions reduction commitments. An ETS creates an economic incentive for emissions reduction: it allows those emitters who can reduce their emissions at low cost to trade emissions rights with others who can only do so at a higher cost, thus allowing the market to identify and implement practices that achieve mitigation at least overall cost. Examples include the European ETS, the New Zealand ETS, and state-based schemes in the US (on the east coast, the Regional Greenhouse Gas Initiative, and on the west coast, the Western Climate Initiative). The Australian state of New South Wales (NSW) has the longest-running mandatory ETS in the world, the NSW Greenhouse Gas Reduction Scheme (GGAS), which imposes emissions reduction requirements on the state's electricity retailers.

A national C pricing mechanism will commence in Australia from 1 July 2012, under the Clean Energy Future legislation (Commonwealth of Australia 2011). For the first 3 years the C price will be fixed, commencing at A$23 per t of CO_2, and rising at 2.5% each year. From July 2015 a 'cap and trade' ETS will commence, with the price determined by the market. The scheme is comprehensive, covering all sectors except for agriculture, although the C price will not apply to household transport fuels, light vehicle business transport and off-road fuel use by the agriculture, forestry and fishing industries. Liable parties are those with emissions greater than 25 kt carbon dioxide equivalents (CO_2-e). To meet their obligations, liable parties will be able to utilise credits generated through the Carbon Farming Initiative (CFI, see below).

The schemes mentioned above are compliance schemes, imposing mandatory emissions reduction requirements on liable parties. Voluntary schemes have also emerged, to cater for organisations and individuals who wish to offset their emissions. In Australia, the National Carbon Offset Standard (NCOS) provides a framework to support voluntary emissions trading (DCCEE 2010*a*). The NCOS specifies requirements for offset projects and facilitates the trade in emission reduction credits. It is intended to provide confidence to those purchasing voluntary offsets, and regulate those making claims of 'C neutrality'. Eligible activities that can earn offset credits include a range of land management and agricultural practices, promoted through the CFI (DCCEE 2010*b*), which commenced in December 2011. Under the CFI, storing C in soil, reforestation and better management of livestock emissions are some of the activities that could generate C credits. These activities include

[1]http://unfccc.int/files/meetings/cop_15/application/pdf/cop15_cph_auv.pdf

[2]Industrialised nations and those with 'economies in transition'.

actions that Australia can include in its national accounts, as well as 'non-Kyoto-compliant' activities. Kyoto-compliant offset credits are expected to attract a higher price, as they can be sold into the domestic compliance scheme or exported to other foreign registries.

Once verified by approved independent auditors, the credits, known as Australian Carbon Credit Units will be tradable through the Australian National Registry of Emissions Units, generating revenue while reducing GHG emissions. Buyers of offset credits will include businesses with a liability under the Clean Energy Future Act, and those that are not liable but that choose to go C neutral, companies that sell C-neutral products, and individuals who choose to compensate for their own emissions. However, the demand for offset credits on the voluntary market will be limited, and the price paid correspondingly low, compared with prices paid in compliance markets. As part of the Clean Energy Future package, the CFI Non-Kyoto Carbon Fund has been established to purchase non-Kyoto compatible CFI C credits.

Approved methodologies for GHG quantification are fundamental to the operation of both mandatory and voluntary schemes.

Life cycle assessment (LCA) and C footprinting

There is increasing demand from consumers and industry for more information about the environmental impacts of products. LCA is a method that has been developed to quantify the environmental impact of a product during its life, 'from cradle to grave'. Carbon footprint is a colloquial term applied to a LCA that examines the global warming impact of a product, organisation or event. It is calculated as the quantity of GHG emitted, less GHG sequestered, and expressed in units of CO_2-e. A C footprint for a product considers GHG emissions during the production, use and disposal of the product, commencing with the raw materials drawn from nature through to end-of-life waste flows back to the environment. A C footprint for food and fibre production typically includes the upstream emissions from manufacturing fertiliser and other inputs, from fuel used in farming operations, from transport, processing and packaging, distribution to consumers, electricity use in refrigeration and food preparation, and waste disposal. The GHGs considered include non-biogenic CO_2 (from burning fossil fuels), methane (CH_4) and nitrous oxide (N_2O). Each of these GHGs has a different warming potential, with CH_4 and N_2O having 25 and 298 times the warming effect of CO_2, respectively, when considered over 100 years (Forster *et al.* 2007). Emissions of these gases are converted to CO_2-e units for ease of comparison. Hydrocarbons used as refrigerants are also included. Biogenic CO_2 emissions are only included when they result in a decline in biomass or soil C stock, for example, felling a forest to plant crops. Otherwise biogenic C is assumed to cycle between the atmosphere and plant, soil and animal matter in a balanced manner.

Global warming impact LCA is used in a range of applications:

(1) To label a product with a C footprint for marketing purposes;
(2) To compare two products and the consequences of shifting from one to the other;
(3) To analyse the contribution that a life cycle stage makes to the overall environmental load so that product and processes can be improved.

Standard methods have been developed for LCA by the International Standards Organisation (ISO 2006*a*, 2006*b*), and are being devised specifically for C footprinting (e.g. PAS 2050: 2008, developed by British Standards; ISO 14067 under development by ISO; product accounting and reporting standard under development by GHG Protocol). These standards set out the 'rules' when determining the C footprint for a product or service, so as to give a consistent approach across businesses and applications.

Some product manufacturers in Australia have already undertaken C footprinting. For example, a pet food manufacturer has undertaken a C footprint for two of their products to help identify the key parts of the supply chain that contribute to global warming, enabling them to investigate ways of reducing this impact. A New Zealand sportswear provider that uses Australian Merino wool is undertaking a C footprint so that they know how much C they need to offset to be able to produce 'C-neutral' garments.

Sustainable management

Besides those who require GHG estimation methods for inventory reporting, for participation in mandatory or voluntary emissions trading, or to calculate their C footprint for communication to consumers, some producers want access to GHG estimation methods simply to guide their own decision-making. Having recognised that their activities generate GHG emissions, they are interested to know how they can directly reduce their emissions, or offset emissions from one part of their property, for example, through tree planting.

Current approaches/methods in GHG reporting/accounting

National Inventory

Australia prepares a National Inventory Report (known as the National Greenhouse Gas Inventory, NGGI) each year under its UNFCCC and Kyoto Protocol reporting requirements, using methods which conform to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The IPCC Guidelines allow for three tiers of complexity in estimation methodology.

Tier 1 methods are designed to be the simplest to use, with equations and default parameter values provided by the IPCC. Only country-specific activity data are needed to complete the national inventory. For example, the amount of C sequestered by a forest can be estimated from data on the area of forest and a table of default sequestration rates. Tier 2 can use the same methodology as Tier 1 but applies country- or region-specific emission factors. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialised land-use or livestock categories. At Tier 3, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data, disaggregated at sub-national level. These systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. Australia monitors and accounts for its GHG emissions from land-based sectors using a combination of Tier 1, Tier 2 and Tier 3 methods. Emissions of CH_4 and N_2O from agricultural activities are estimated using Tier 1 and Tier 2 methods, through the Australian Greenhouse Emissions Information System (AGEIS). Carbon dioxide emissions and removals from agriculture, land clearing and forestry are estimated using the National Carbon Accounting System (NCAS), a Tier 3 method (DCCEE 2010*c*). The NCAS uses a spatially referenced mechanistic model based on process-level understanding of factors that drive plant growth and turnover of C in the soil, to estimate C fluxes from data on climate, soil and land management.

National GHG inventories for the UNFCCC, and accounting under the Kyoto Protocol, use a sectoral approach. For example, fuel use in agriculture is reported in the transport component of the energy sector; energy use in producing herbicide and fertiliser is included in the manufacturing section of the energy sector; sequestration in farm forestry is reported in the land use, land-use change and forestry sector, while emissions reported in the agriculture sector include CH_4 from ruminant livestock, N_2O from soils, and non-CO_2 GHG from stubble and savanna burning.

With the introduction of the CFI and the consequent development and approval of methodologies for agricultural entities to claim offset credits, it is vital that these 'bottom-up' accounting methods reconcile with the national account (NGGI). Thus reconciling top-down national accounting (AGEIS plus NCAS) with bottom-up reporting under the CFI and under the National Greenhouse and Energy Reporting System will remain a challenge.

Life cycle inventory for LCA

A life cycle inventory (LCI) is the basis for undertaking LCA. The inventory documents the material and energy flows, in the form of inputs and outputs, associated with a product system. LCA differs from national-level accounting for GHG emissions because the inputs and outputs of a product system are not constrained by geographical boundaries. For example, the C footprint for French cheese imported into Australia will include emissions from the dairy livestock in France as well as the transport to Australia. These values are not included in Australia's national accounts even though the cheese is consumed here. What will be included in the national accounts is the transport and refrigeration from the Australian entry port to a wholesaler, then retailer, then consumer. Any GHG emissions associated with disposing of the packing and spoiled cheese will also be included. Emissions from the production phase in France will be part of the French national accounts. Emissions due to international transport are not accounted under the Kyoto Protocol, so are not included in any country's national inventory at this stage!

Project-level accounting

Credits generated through offset projects must be calculated sufficiently accurately to ensure that the abatement value of offsets is equivalent to (or greater than) the emissions released, to fulfil the objective of climate change mitigation. Furthermore, to create confidence in the market, and thus demand for offset credits, offsets must *be seen to* represent genuine abatement. Therefore, the methods used to estimate emissions reduction and removals must be scientifically-based, transparently applied, and suited to independent verification. If the credits are to be traded on the compliance market, then the methods must be compatible with the methods applied in that market. Thus, the methods used in the CFI, for Kyoto CFI credits, must be consistent with methods accepted under the Kyoto Protocol so that the credits may be traded on national and international compliance markets.

Accounting for agricultural offset projects under the CFI will cover primarily those GHG sinks or sources that arise in the agriculture sector – such as livestock CH_4, C stored in trees or soil and emissions from savannah burning. Accounting will also include emissions due to direct inputs such as electricity and diesel but, unlike LCA, will not include a full 'cradle-to-grave' inventory of emissions associated with a particular product or practice being applied in the offset project[3]. Hence, offset projects are somewhat of a hybrid between the national accounts and LCA.

However, much of the same information is needed to arrive at our national accounts, establish an offset project or calculate a C footprint. The pieces of information are combined differently because each has a different purpose. Figure 1 uses an example of a livestock production enterprise to illustrate the differences between national accounting, project-level accounting and C footprint calculation.

Problems in UNFCCC inventory reporting and Kyoto Protocol accounting for LULUCF

Activity-based approach with voluntary election and net-net accounting

The following are limitations of the current requirements for LULUCF reporting and accounting (for detail see Schlamadinger *et al*. 2007; and Cowie *et al*. 2007):

- The Kyoto Protocol Article 3.4 allows for voluntary inclusion of GM, CM, forest management and RV. This provides the opportunity for parties to choose only those activities that they anticipate will be a net sink, and ignore other activities that may be net emitters. Thus there is potential that significant sources of emissions will be excluded from accounting.
- For GM, CM and RV, accounting is on a 'net-net' basis, that is, the emissions and removals for these activities in the current year are compared with the emissions and removals in the base year. This means that the rate of sequestration must be increasing in order to earn a credit. As biomass and soil C pools approach saturation, and rate of sequestration diminishes, these activities will incur a debit. This was a crude attempt to factor out indirect effects [e.g. nitrogen (N) deposition, CO_2 fertilisation]. It is an unattractive solution, as it creates limited incentive for participation.

[3]However, the CFI criteria do require 'leakage' to be considered, that is, emissions associated with upstream and downstream processes. See section *Leakage* for further discussion of 'leakage' in relation to offset projects.

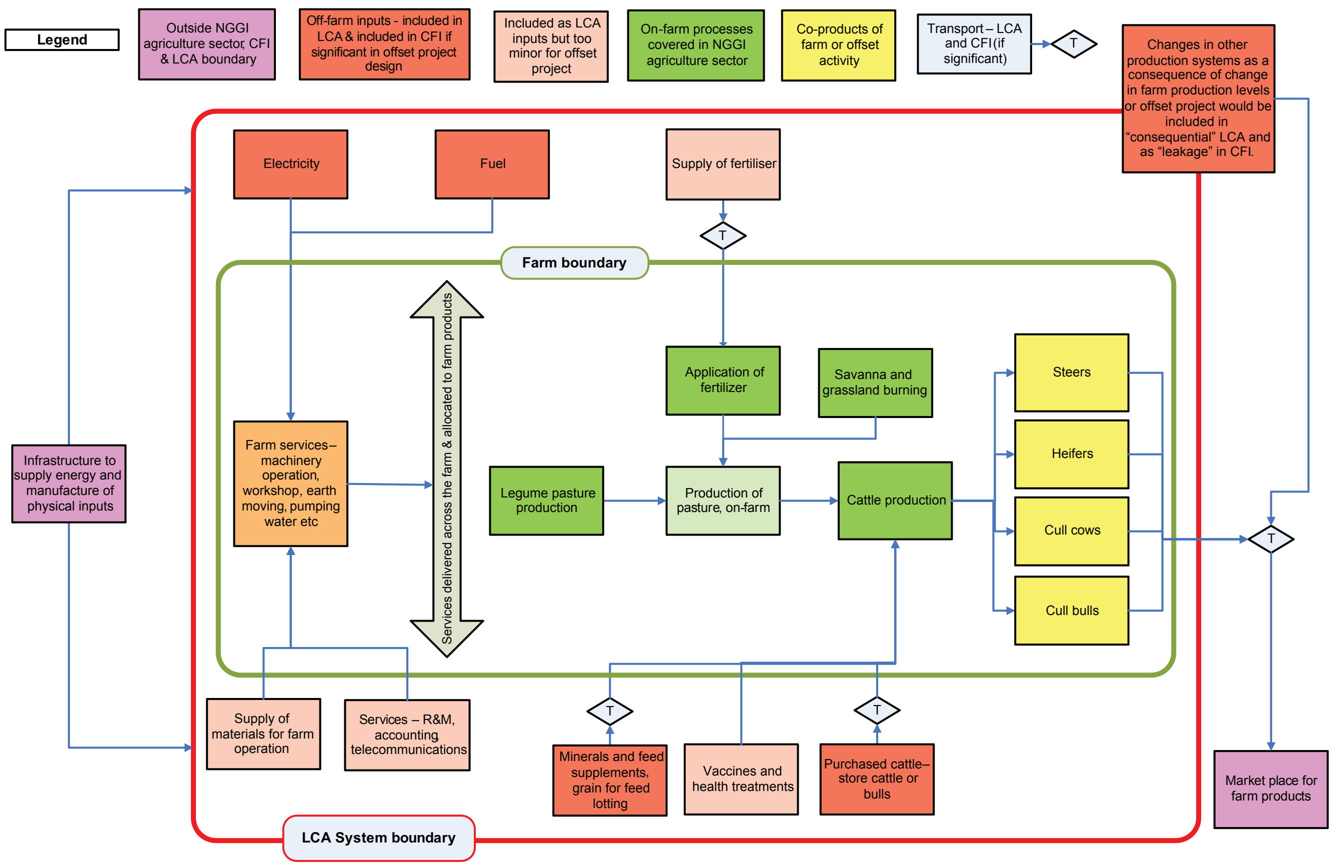


Fig. 1. Diagrammatic representation of an extensive grazing property showing those processes included in the National Greenhouse Gas Inventory (NGGI) accounts for agriculture (dark green boxes), an offset project under the Carbon Farming Initiative (CFI) for livestock production (orange boxes) and a 'cradle-to-farm gate' life cycle assessment (LCA) (every process within the red boundary).

Sectoral approach

Because the national inventory uses sectoral boundaries, the full impacts of activities are often obscured. For example, adoption of bioenergy technologies involving additional biomass removal from the forest will reduce the forest C stock. The combustion of biomass is counted as C neutral in the energy sector, and the reduction in forest biomass is counted in the LULUCF sector (IPCC 1997). It will not be apparent that actions by the electricity generators are responsible for this emission from LULUCF.

Positive impacts are also not obvious: conversion from conventional tillage to zero tillage will reduce on-farm diesel usage, but this reduction in emissions will be seen in the energy sector, and thus not readily attributed to modified agricultural practices. When neither the positive nor negative impacts of actions are readily attributed to those responsible, there is reduced incentive to act.

Pitfalls of combining different tiers

Australia's National Greenhouse Accounts are in transition to a mix of Tier 2/Tier 3 methods for many sectors, but still contain a mix of Tier 1 and 2 methods in the agricultural inventory methodology (DCCEE 2010*c*). This does create some undesirable anomalies, for example where emission factors for N fertiliser from pastures (0.004) and crops (0.003) are now based on locally published research (Tier 2), while emission factors for N fixation by legumes remain at the Tier 1 default of 1.25%. The net effect of mixing these Tier 1 and 2 emission factors is that applying N fertiliser is deemed to produce less N_2O than using legumes; this has potential to send a very wrong message to farmers seeking guidance on actions to reduce their emissions. In fact, research is showing that supplying N via inclusion of legumes in crop rotations results in lower N_2O emissions (G. Schwenke, pers. comm.). In future this research is likely to be reflected in modified emissions factors applied through Tier 2 methods.

Temporal variability

Particularly in Australia, C stocks in biomass and soil vary widely from year to year as a result of climatic conditions such as drought and wildfire. The Kyoto Protocol net-net accounting, in which the commitment period emissions and removals are compared with a single reference year (1990), thus fails to recognise this variation. As it happens, 1990 was a better than average rainfall year; therefore, there is a high probability that C stocks during the commitment period may be lower, leading to net emissions from GM, CM or RV. This was one of the major reasons that Australia did not elect to include these activities in its national accounts.

Challenges in project-level accounting

Uncertainty

GHG accounting methods are generally not based on direct measurement. For example, to estimate the emissions from fuel use, the quantity of fuel consumed is multiplied by the accepted emissions factor for that fuel (e.g. Commonwealth of Australia 2010). Similarly, to determine the emissions of N_2O from applied fertiliser, the quantity of fertiliser used is multiplied by an emissions factor expressing the quantity of N_2O emitted per unit of N applied (IPCC 2006). For N_2O from fertiliser or urine from gazing animals, as for many other source and sink processes in the land sector, there is large uncertainty associated with the estimates of emissions, due to naturally wide ranges, and spatial and temporal variation, in the values of factors that control biological processes (de Klein and Eckard 2008). Current methods tend to be based on simple averages, with resolution at regional or country level, and broad categories of management. Research is under way to improve scientific understanding of source and sink processes with the aim of reducing uncertainty of estimation methods.

Until improved methods with finer resolution are available, it will commonly be found that actual emissions and removals at a specific site vary widely from the estimates. This is not a problem for inventory: as long as the method is unbiased, the estimates are right on average, so the sum of emissions will be correct. However, it can lead to dissatisfaction in project-level emissions trading: for example, at those sites where the method underestimates removals, the project proponent may feel cheated. The NSW GGAS applies a discount for uncertainty: accredited providers can only generate credits for that quantity of C for which there is 70% probability that actual C sequestered is greater (IPART 2010).

Estimating true abatement

Schemes designed to support project-level abatement of GHG emissions must ensure that accounting captures all GHG emissions that are affected by the project. For example, a landholder may increase N fertiliser application to increase biomass growth and, consequently, soil C. The increased emissions of N_2O due to the increased fertiliser application must be subtracted from the removal credit for increased soil C, to determine the net value of abatement resulting from the project. In this example, the N_2O is emitted as a part of the project, so should be accounted within the project boundary, and is not considered as 'leakage' (see section *Leakage*).

Additionality

Offset schemes generally impose eligibility requirements to ensure that credit is given only for abatement that would not otherwise have occurred. These are generally known as additionality requirements. Additionality tests can be:

- Environmental: would the abatement have occurred in the absence of the project?
- Financial: would the project have been financially viable in the absence of abatement credits?
- Common practice: is the activity widely adopted by others in the region?
- Regulatory: is there a legal requirement for the activity to be undertaken?

Different schemes require some or all of these tests to be applied. If the answer to the additionality test questions is yes, then the project may not be eligible.

A strict application of financial additionality to agricultural offsets could effectively rule out 'win-win' mitigation strategies, where there is some profitability driver for adoption by farmers, and which has been the primary focus of most of the research to date. In the absence of production or profit drivers, many mitigation strategies (e.g. feeding dietary oils or spraying nitrification inhibitors) will require a C offset price one or two orders of magnitude greater than current EU ETS C prices, before farmers would receive sufficient incentive to engage in providing the offset. However, if feeding dietary oils or spraying nitrification inhibitors delivered a modest increase in animal production or pasture growth, this, together with a C offset could be sufficient to reduce the risk and enable farmers to adopt the technology. It is important that offset schemes do not adopt strict criteria that exclude such measures that could deliver significant abatement and sustainability advantages, merely on the basis of financial additionality. The CFI does not apply a strict financial additionality test. Rather, additionality is assessed for project types, and projects deemed to go beyond common practice are included on a 'positive list'.

Baselines

Calculating the credit generated by an offset project involves comparing the project emissions and removals with a baseline, representing the emissions and removals that would have occurred in the absence of the project. The baseline may be the land use before the project commenced. However, a counterfactual moving baseline developed from assumptions about how the land use would have changed in the absence of the project, while more complex to apply, may be more realistic (Gustavsson *et al*. 2000).

In recognition of wide inter-annual variability in many Australian farming and forestry systems, it is appropriate that baselines be calculated from the average of at least several years of data.

Leakage

Besides accurately reflecting the emissions and removals resulting directly from project activities, it is critical that 'leakage' is also assessed. Leakage refers to emissions that occur off-site, beyond the control of the project proponent, as a result of the project activity. For example, if a project involves increased application of N fertiliser to enhance plant growth and pasture quality, to build soil C and reduce CH_4 emissions from ruminant livestock, there will be additional emissions due to the manufacture of N fertiliser, a greenhouse-intensive process[4]. These additional emissions should be debited in calculating the benefits of the project. A more complex example of leakage is indirect land-use change: if land used for food production is converted to biofuel production, this may indirectly lead to deforestation, to supply land to grow food crops. The loss of biomass and soil C stocks due to deforestation is leakage that should be deducted in calculating the benefit of the project. While the emissions due to fertiliser manufacture, in the first example, are readily estimated from emissions factors for fertiliser production (e.g. Wood and Cowie 2004), leakage due to indirect land-use change is challenging to quantify, as it is impossible to attribute a specific deforestation incident to a specific project. In such cases, it may be more appropriate to quantify and manage leakage at a program rather than project level. For example an average discount factor could be determined by the scheme operator on the basis of assessment of the regional or national rate of deforestation relative to the rate of expansion of biofuel plantations. This factor would then be applied to all projects of this type.

Permanence

A particular challenge in estimating the abatement value of an offset project involving C sequestration in biomass or soil is the potential that the C sequestered may be re-released. This possibility of non-permanence must be factored into the accounting methodology, and mechanisms to manage the risk of non-permanence must be devised by the ETS. In contrast, permanence is not an issue for offsets involving reduction in CH_4 or N_2O emissions, as there is no risk of reversal of abatement.

Models based on long-term empirical observations tend to capture the typical variation in biomass and soil stocks due to drought and managed fire; process-based models driven from historical weather records can reproduce such variation, and be used as a guide to future ranges. Accounting rules could require that conservative sequestration estimates are applied, to limit the risk that abatement is reversed. Different schemes deal with non-permanence in different ways: under the Clean Development Mechanism of the Kyoto Protocol, credits generated from reforestation are temporary; the Australian Government's formerly proposed Carbon Pollution Reduction Scheme (www.climatechange.gov.au/government/reduce/carbon-pricing/cprs-overview.aspx) proposed that credit for reforestation be limited to the projected increase in average C stock, where calculation of the average captures the variation anticipated in a forest managed for timber extraction, i.e. across rotations; under the CFI, the sequestration is discounted by 5% to create a 'risk of reversal buffer', of unsold sequestration; the Alberta Greenhouse Gas Reduction Program Offset Credit Scheme (Government of Alberta 2011) applies an 'assurance factor' to estimate the proportion of soil C sequestered that can be considered 'permanent'; the NSW GGAS specifies that credit from reforestation can be generated only for the amount of C that will be sequestered for 100 years (IPART 2010). In GGAS, unintentional losses are reported, and no further credits can be created until C stocks have recovered – that is, the project proponent is required to make good the abatement, though only in the time frame required for regeneration. Effectively this could mean small profits now but inter-generational liabilities as a result. GGAS allows participants to manage permanence across their estate, which could cover multiple locations. A similar approach could perhaps be applied under CFI with aggregators managing a pool of sequestered C, in biomass or soil, comprising a portfolio of abatement projects across multiple properties.

Adequacy v. *accuracy*

There is an inevitable trade-off between striving for accuracy, to ensure credibility, and minimising costs of estimation, to encourage participation and therefore lowest cost abatement. Essentially, methods should be sufficiently accurate to satisfy market requirements, but not more so, because greater accuracy tends to come at a higher price. The higher the cost of estimation, the lower the return to the landholder, and the less attractive the scheme. It must be remembered that the fundamental purpose of an offset scheme is to encourage abatement action – precise quantification is less important, as long as there is a demonstrated scientific basis for the abatement claimed. One approach to minimising costs while maintaining credibility is the use of conservative default methods.

Schemes can be designed to maximise efficiency in estimation, for example by investing resources to develop default models, such as the National Carbon Accounting Toolbox[5], and allowing landholders to participate through aggregators, so that monitoring, calculations and verification can be applied strategically across a large pool involving multiple landholders. Models could be used to estimate emissions and removals under specific practices, with verification targeted at assessing implementation of the practice, rather than directly assessing emissions and removals. However, it has yet to be resolved whether the market finds modelled estimates sufficiently credible, or whether on-site measurements will be demanded – either for establishing baselines, determining emissions and removals, or for verifying reported emissions and removals. An example of the value markets place on a non-Kyoto soil C credit based on modelled estimates is the Chicago Climate Exchange, which closed after trading prices fell below US\$0.05/ CO_2-e.

Distinguishing anthropogenic impacts

A basic principle of GHG accounting is that credit should be given only where it is deserved – that is, for intentional activity that leads to abatement. Using the same logic, it is reasonable that debits are also incurred only where they are intentionally human-induced. Therefore, losses due to natural factors (drought, wildfire) should

[4]In this scenario there will also be additional emissions of N_2O from applied fertiliser. However, these emissions are not considered to be leakage, because they occur within the project boundary, and should therefore be included in accounting the emissions and removals of a project.

[5]www.climatechange.gov.au/government/initiatives/ncat/ncat-toolbox-cd.aspx

be excluded from accounting. Net-net accounting for GM, CM and RV is a crude measure intended to factor out trends in C stocks due to non-anthropogenic or indirect anthropogenic factors for national accounts. This principle has not been applied at the project level, either to factor out non-anthropogenic removals or emissions. The Average Carbon Stocks approach (Kirschbaum and Cowie 2004) could be utilised for this purpose; this method calculates credit based on the difference in long-term average C stock between the reference and project case, estimated through modelling.

Narrow focus v. *consideration of multiple objectives*

Schemes designed to support project-level abatement of GHG emissions often recognise that abatement activities in the land sector can have additional environmental and social benefits, though they could also have negative impacts. Therefore, some schemes impose additional eligibility requirements, in an effort to ensure positive outcomes for other factors, such as biodiversity. While it can be more efficient to pursue multiple objectives simultaneously, it should be recognised that there is often a trade-off between maximising abatement and other environmental benefits.

Compatibility with inventory reporting v. *local relevance*

One of the challenges facing the CFI is the need to develop specific, yet nationally consistent, project-level accounting methodologies. The huge variation in climatic and edaphic conditions and farm management practices between the ~150 000 individual farms across Australia means that national averages, applicable for national inventory, are not relevant at farm scale. Several greenhouse accounting tools have been developed in Australia including the Dairy, Beef, Sheep and Grains Greenhouse Accounting Frameworks[6], FarmGas[7], DGAS[8], Cotton Greenhouse Calculator[9], the HortCarbonInfo and BananaCarbonInfo[10] and the Wine Carbon Calculator[11]. While most of these calculators use the Australian NGGI methodology (DCCEE 2010*c*), these methods are not likely to be acceptable at a project scale, as they do not include methodologies for recognising abatement action, apart from through reduction in livestock numbers and fertiliser input. National inventory methods are designed to use nationally available data to estimate emissions at state and national scale and, by their nature provide a national approximation, but at a project level they are unable to predict specific soil, plant or animal differences to guide mitigation management.

Knowledge gaps in methodology

Methods for estimating emissions and removals from reforestation are relatively well developed, especially for commercial plantation species. These are commonly based on forestry models that have been devised to estimate stem volume growth, which are readily adapted to estimate C sequestration. These are less accurate in their estimates of litter and forest soil C, and for non-commercial species. The National Carbon Accounting Toolbox, based on NCAS, has been developed for project-level accounting.

Models for estimating soil C dynamics in agricultural systems are also fairly well established [e.g. Roth C (Coleman and Jenkinson 1996), Century (Parton *et al*. 1987)], though they are recognised to have limitations. Effort is underway to improve soil C models: in Australia, the National Soil Carbon Research Program is gathering data on the impact of management practices on soil C, for the most significant soil types and land uses. The data generated will be available to enhance soil C models, including the NCAS, which incorporates Roth C.

Nitrous oxide is currently predicted in the NGGI using static Tier 2 emission factors. These methods are therefore not suitable for project-level accounting or the development of offset methodologies, as they are not sensitive to modified practices, apart from reductions in N fertiliser use or stocking rates. Although enteric CH_4 is predicted using a more dynamic set of algorithms, these algorithms also do not include parameters for recognising specific abatement actions. Dynamic empirical or mechanistic modelling methods will therefore be needed to predict these emissions and facilitate the development of offset methodologies. However, the challenge will be to provide a method of sufficient rigour that can capture these abatement actions without being too complex.

Effectiveness as incentive for action

As discussed previously (Section *Permanence*) an offset scheme will only provide an effective incentive for action if the financial returns are attractive, and the risks minimised. This is a particular challenge for voluntary schemes, as the prices tend to be very low compared with compliance markets. Under the CFI, it is unlikely that non-Kyoto offset credits will trade at the same price as Kyoto-compliant credits.

In some cases the returns from offsets credits, net of transaction costs, will not cover the cost of abatement actions. In the case of soil C, there may be hidden costs. For example, increasing soil C means that the pool of soil organic matter is increased. This has many positive effects on chemical, physical

[6]www.greenhouse.unimelb.edu.au/Tools.htm

[7]http://farminstitute.org.au

[8]www.dairyingfortomorrow.com/index.php?id=47

[9]www.isr.qut.edu.au/tools/

[10]www.horticulture.com.au/areas_of_investment/environment/climate/climate_tools.asp

[11]www.wfa.org.au/entwineaustralia/carbon_calculator.aspx

and biological properties of soil. But because there is a remarkably stable ratio between concentrations of C, N, phosphorus (P) and sulfur (S) in the humic fraction of the soil (Kirkby *et al*. 2011), building organic matter sequesters nutrients that must be supplied from external inputs if existing supplies are inadequate. For example, to build 1 t of humus (60% C, 600 kg C or 2.2 t CO_2-e) will require 48 kg N, 12 kg P and 8 kg S. At a urea fertiliser price of $675.00 delivered ($1.47/kg N), the offset return would need to be $32/t CO_2-e just to pay for the N 'invested', or $60/t CO_2-e if the P and S are also included. While this is a substantial cost, well in excess of anticipated value of C on the voluntary market, this investment in building soil fertility will increase the resilience of the system. Thus, weighing the costs and benefits is not simple.

Factors that will increase attractiveness of offsets to landholders are:

- Minimised transaction costs, through use of publicly available default tables, emission factors and models based on publicly funded research;
- Streamlined legal processes;
- Provision for aggregators;
- Reputation of credibility, to maintain demand and therefore price;
- Risks of non-permanence managed e.g. through establishment of a buffer; and
- Environmental or productivity co-benefits.

Challenges in LCA

System boundary

The system boundary chosen for the LCA will depend on the goal of the study and needs to be clearly articulated so that sensible comparisons can be made between studies. A 'cradle-to-grave' LCA includes all the phases of the life cycle from the extraction of natural resources through to the final end-of-life disposal of the product and the return of substances to the environment. In comparison, a 'cradle-to-gate' LCA includes all the phases in the production of the product, but excludes the use and disposal phases.

An example of where a cradle-to-grave study would be appropriate would be the assessment of the C storage life of a woollen carpet or a timber product. Eventually the C atoms in both would return to either the atmosphere or to a stable C compound in the soil. An assessment of how long the C is sequestered in the wool or wooden product would require a full LCA over the complete life of the product.

A cradle-to-gate study would be carried out by a business that wants to understand which parts of their production system contribute the most to the C footprint of their product at the factory gate.

A 'cradle-to-farm gate' LCA gives the C footprint for agricultural products up to the farm gate, once again allowing the primary producer to assess where the majority of emission are originating. More importantly 'cradle-to-farm gate' studies are crucial for building national LCI so that LCA can be undertaken for a range of purposes. Often a system boundary is incomplete because data are not available for some of the inputs. This particularly applies to food as data from other countries are not suitable, due to large differences in climate and production systems. Food makes up a significant component (15–20%) of a household's C footprint (Girod and de Haan 2009; Kerkhof *et al*. 2009).Without LCI data for wheat, rice, cheese, meat, milk, vegetables, etc., LCA as a tool for understanding GHG emissions from food cannot be implemented. Hence, internationally there is an enormous investment in building national LCI databases for agricultural products (e.g. in France and Canada); the same is needed in Australia.

Allocation – attributional v. *consequential*

The issue of how to allocate impacts to products arises when an enterprise produces multiple inter-related products. In agriculture, many animal products are inter-related at both the farm level, through the simultaneous production of meat, fibre and different classes of livestock, and at the processing level, where a range of distinct co-products is obtained from different sections of the carcass.

The ISO recommendation for allocation (ISO 14044: 2006) is to first avoid allocation altogether, if possible, by dividing the multifunction process into sub-processes or expanding the system so as to include functions related to all the products. In many instances farm activities can be divided into sub-processes – for example cropping and sheep activities on the one farm, with specific inputs identified for each. Not separating cropping and livestock processes, and instead allocating all farm emissions across farm produce, can distort results (Kanyarushoki *et al*. 2008).

After dividing the farm activities into sub-processes, there are still areas where allocation may be required. For example, a sheep flock produces several inter-related products – wool, surplus young wethers, stud rams and cull livestock. An alternative to allocation is system expansion, which allocates 100% of the environmental impacts to the primary product, in this case wool. With this approach, the co-products (young wethers, stud rams and cull ewes) would be modelled in terms of avoided products that would substitute for these co-products. This uses what is called a consequential approach to LCA modelling, where the consequence of producing an additional kg of wool results in avoidance of the substitutes for the co-products.

To do this requires a comprehensive understanding of supply and demand for a range of possible substitutes, for instance cull ewes would most likely go to the lower-value processed meat sector and substitutes could be culled cattle or pigs. However, culled cattle and pigs are going to be secondary products in their own production system and would also be modelled as an avoided product. To use system expansion it is necessary to substitute a 'primary' product from another system and this becomes more complex, for instance, what would be the avoided product for stud rams? Thus in some instances there is no clear way forward to resolving the complexities of substitution. This point is still debated among LCA practitioners, and in practice the tools/ resources needed to model substitution within such complex agricultural systems (with any certainty) are not readily available.

The alternative to system expansion (with consequential modelling) is to use an attributional approach, which adds up all of the GHG emissions along the supply chain in an accounting type framework, and applies an allocation procedure. Among LCA practitioners (Finnveden *et al*. 2009) there is some consensus that an attributional modelling approach is appropriate when the goal of the LCA is to describe the product, whereas a consequential approach is more appropriate when the goal is to investigate a change in production. As C footprinting is largely a benchmarking activity, an attributional approach is often used but then a method of allocating impacts to co-products is required.

According to the ISO guidelines, where allocation cannot be avoided the preference is to use an underlying physical cause-effect relationship to allocate inputs and outputs to co-products and the last resort is to use other relationships such as mass (e.g. Peters *et al*. 2010) or economic value to allocate inputs. Because of the complexity of agricultural production, economic allocation is often used as the default (Kanyarushoki *et al*. 2008).

Including time

Time needs to be included in a C footprint in two contexts. The first is the temporal variation that can be expected in agricultural production systems. Year-to-year variations in production, level of inputs and market prices need to be taken into account. Published studies to date indicate that for livestock enterprises, a minimum of 3 years of data should be used (Eady and Ridoutt 2009). Harris and Narayanaswamy (2009) suggest that 2 years of data is often indicative of average agricultural production for cropping systems. Data completeness is often a challenge for good LCA because of the expense in collecting data.

The second time element comes in to expressing the time profile over which emissions of CO_2-e may occur. For instance PAS 2050 (BSI 2008) uses a 100-year assessment period and if emissions occur after 1 year of use or disposal then a weighting factor can be applied to this delayed release. This would not generally apply to most food products which are used, disposed of and broken down in compost or landfill relatively quickly. However, a weighting for delayed emissions could be applicable to wood and fibre products. Although PAS 2050 has included a method for quantifying the impact of timing of emissions, there is no consensus among experts that this is the most appropriate method, and indeed there is some doubt over the validity of discounting future emissions and removals (Kirschbaum 2006; Dornburg and Marland 2008).

Completeness of data coverage for LCA

Data for an LCA are most commonly divided into several categories – primary/foreground data, which are collected directly from the production system under study (level of production, specific inputs and processes used in production such as the quantity of electricity and diesel), and secondary/background data, which are often drawn from published libraries of LCI (production of electricity and fuel, transport processes, manufacture of fertiliser, etc). However, there are often gaps in data for inputs such as insurance, accounting services, repairs and maintenance. One approach to obtaining these data is to use national account input–output data (Rebitzer *et al*. 2002). Where input–output data are combined with foreground and background data the LCA is referred to as a 'hybrid' model that is based on specific data for a process plus generalised data from the input–output table.

An economic input–output table breaks a national economy down into sectors and sub-sectors. A matrix is then set up that defines the dollar contribution that each sub-sector makes to all of the others. For example, the veterinary services sub-sector uses input from transport, electricity, drug manufacture, laboratory analysis, etc. Many input–output tables have been characterised to describe the level of GHG emissions or water use that spending one dollar in the sector contributes. Depending on the functional unit for the LCA, a whole LCA could be purely based on input–output data. However, in most instances the scale of the sub-sectors is not fine enough to give useful and specific results. Hence, input–output approaches are most commonly used to cover gaps in data with a 'hybrid' approach.

Within farming systems, it is important to include the full production cycle for a farm product rather than simply look at the growing period, for example, of a crop of wheat. There may be periods of fallow where weed control is required, or there may be a green manure crop in the cycle to help build organic matter and replenish nutrients that have been exported in grain. The C footprint for the wheat would need to incorporate the inputs of herbicide for weed control and fuel to grow the manure crop.

Complementing LCA with whole-farm systems mechanistic modelling

One of the issues with LCA is that the method of accounting for emissions from the farm system generally uses a static inventory, which fails to reflect the interactions in the system. In many cases a change to farm practices to mitigate one emission source can result in changes in other emission sources. For example, improving forage quality may reduce enteric CH_4 per unit intake, but the animals eat more, producing more enteric CH_4, while higher quality forage commonly has higher protein content and thus potentially could increase N_2O emissions from urinary sources (Eckard *et al.* 2010). A whole-farm systems dynamic mechanistic model is useful to capture these consequential dynamic interactions between sources and sinks, thus providing additional input data for a comprehensive LCA.

Developments in accounting approaches

For national accounts

Negotiations towards the agreement of a second commitment period beyond 2012 are seeking, *inter alia*, to overcome the recognised inadequacies of the current approach for accounting in the land sector. Changes that are being discussed include:

- Bringing the two sectors Agriculture and LULUCF together, as Agriculture, Forestry and Other Land Use;
- Comparing performance during the commitment period with a base period (maybe 5–10 years) rather than a single year;
- Including all managed lands in accounting rather than taking an activity-based approach;
- Allowing lands affected by *force majeure* to be excluded from accounting; and
- Allowing Annex I parties to remove the impact of inter-annual variability when accounting for GHG emissions and removals.

For project-level accounting

Developments that are being discussed in UNFCCC negotiations for application to the Clean Development Mechanism[12], to minimise transaction costs and remove barriers, include:

- Use of standardised baselines, to simplify the additionality test and calculation of emissions and removals;
- Declaration of a 'positive list' for project types that are deemed to meet additionality requirements;
- Addressing non-permanence through use of buffers, insurance or credit reserves rather than temporary credits.

These measures could also be considered for the CFI.

One option for providing incentive for abatement in the agricultural sector would be to reward adoption of a range of best practices as part of a program delivered through a network like Landcare. In this approach research quantifies the emissions impacts of various management practices, farmers focus on the adoption of improved management, while government takes the responsibility of accounting protocols to reflect the changes in the national inventory; effectively government buys the deemed credits accrued from a package of practices. This significantly reduces transaction costs at a farm scale, including the need for separate methods for national inventory and project-scale accounting.

Research priorities to fill knowledge gaps

Research is required to develop rapid and cost-effective measures of CH_4 and N_2O, so that the non-CO_2 emissions from major agricultural and forestry systems, for major climatic regions of Australia, can be determined, and used to refine models for estimation and prediction of GHG emissions. Similarly, to improve models of C dynamics, data are required on the impact of management on C in agricultural soils and rangeland ecosystems, and the potential C sequestration in environmental plantings. Rapid and cost-effective measures are also required to enable strategic sampling to establish baselines, and possibly for verification.

There is a need for whole-farm-level estimation tools that accommodate regional and management differences in emissions and sequestration, and are sensitive to modifications in management practices, to support landholders in managing net emissions from their farming enterprises. These on-farm 'bottom-up' accounting tools must align with the 'top-down' national account.

To facilitate assessment of C footprints for food and fibre products, effort is required to build a comprehensive LCI database for Australia. To date there are few publicly available LCI data for the agricultural sector. Some industries have published LCA results for particular supply chains but often the LCI

Case Study: Mark McKew, Mount Cole Creek, western Victoria.

Forewarned is Forearmed.

Mark McKew, a Wimmera sheep and beef farmer, is increasing his productivity while preparing to participate in a C-constrained economy. Mark owns a 654-ha property with over 2000 head of sheep and 77 cattle. Mark's interest in his farm's GHG emissions comes through a strong environmental consciousness and because, as he puts it, 'it's better to know what you are up against' in relation to a C-constrained future.

Mark and his father have experienced dramatic environmental change in the past 40 years. Rainfall has significantly reduced in the past 15 years, resulting in dried up creek beds. In 2006, the property recorded just less than 230 mm, far short of Mark's suggested average of 400 mm.

Mark realises that 'reversing climate change is not an option in our lifetime' and knew his farm was an emissions contributor. Using the Beef, Sheep and Grains Greenhouse Accounting Tools (Eckard *et al*. 2010), 'Project Platypus' assisted Mark in calculating the emissions from his farm. He saw working with Project Platypus as an opportunity to get on the front foot: 'being forewarned allows farmers to know what is coming and what can be done to offset it'.

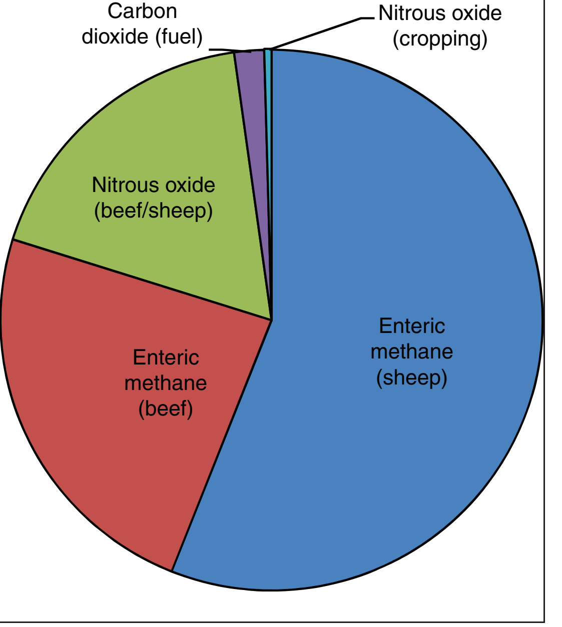
The major source of GHG emissions was CH_4 from livestock (sheep 56% and beef 24%). Nitrous oxide emissions from livestock dung accounted for 18% and CO_2 from fuel consumption accounted for 2%. Cropping (24 ha of lucerne) contributed a minor amount. The Project Platypus report suggested several ways to reduce emissions on Mark's farm, including breeding for improved feed efficiency, feeding dietary fats and forage tannins and improving the quality of feed to reduce CH_4 emissions. These emissions represent energy that could be better used for production.

Mark sees planting trees in the right places as 'low hanging fruit' and is working towards using RV as a first step to bringing his emissions profile closer to neutral. He comments that RV was a 'perceived threat to rural communities, but every farm can have more shelter belts without affecting production; in fact it would probably help their production'.

While Mark sees soil C as an important C sink in the farming system, he also understands the complexities of maintaining organic C over long periods. 'Soil C is easy to measure, hard to maintain', said Mark. While improving soil C improves water retention, Mark believes that RV is a more secure way to hold C as it is likely to be less affected by drought.

Mark's final words of advice are simple: 'Don't be afraid to measure and find out where you are at. I don't envisage making money out of C, but if you can avoid extra costs, it's best to do so.'

Source: Project Platypus (www.platypus.org.au, accessed 17 April 2012); view additional case studies at www.dpi.vic.gov.au/agriculture/farming-management/weather-climate/taking-action (accessed 2 May 2012).



[12]The Clean Development Mechanism is the Kyoto Protocol's mechanism that allows Annex I parties to meet part of their target from emission reduction projects in developing countries.

underpinning the LCA is not transparent. A concerted effort is needed to map out the important production systems within each industry, to document LCI data for these, and make them available to all LCA practitioners.

There are several anomalies in the current NGGI methods, partly due to combining Tier 1 and 2 emission factors, which need attention. Local research is required to address these and provide locally appropriate emission factors.

Research to develop abatement cost curves for various mitigation options would improve understanding of the likely uptake of CFI offsets by the farming sector, over a range of C prices and various interpretations of additionality.

Conclusions

Accounting under the Kyoto Protocol, national inventory reporting to UNFCCC, project-level reporting for emissions trading and C footprinting LCA each have different purposes, so produce different outputs. The differences relate largely to boundaries – that is, which processes are included and which are excluded from the calculations. However, they often utilise the same basic data and underlying methods for estimating emissions and removals for specific actions.

Uncertainty, and the high cost of direct monitoring are common features of land sector emissions and removals, and a challenge for all GHG accounting applications. Whole-system process-based models are being developed to provide cost-effective estimates of emissions and removals from agricultural and forestry activities.

Deficiencies have been recognised in the current framework for Kyoto Protocol accounting for the land sector: the activity-based approach with voluntary election allows significant sources of emissions to be excluded from accounting; dividing the accounts according to sectoral categories obscures the total impacts of activities; the net-net construct applied to CM, GM and RV, delivers limited incentive for participation; and the single reference year fails to accommodate the inter-annual variability that is characteristic of the Australian environment. Modifications to address these issues are being discussed in negotiating a post-2012 agreement.

The Kyoto Protocol and domestic ETS provide credit for abatement projects in the land sector. Credits traded on a compliance market command a much higher price than those traded in voluntary markets. The CFI will accommodate projects that generate 'Kyoto-compliant' credits, and also project types that generate non-Kyoto credits; the latter will only be traded in the voluntary market. Whether they are undertaken in the compliance or voluntary markets, projects must satisfy eligibility criteria in order to maintain integrity of abatement. These criteria include demonstration of additionality, and a mechanism to ensure permanence. The latter requirement is a particular challenge for projects involving soil C management, as soil C is particularly vulnerable to loss. A further difficulty for projects is the management of leakage, that is, emissions occurring outside the project boundary as a result of the project. While these issues are challenging, they are not insurmountable; solutions could involve agreement of standard methods for additionality assessment and calculating baselines, standard models for quantifying emissions and removals, and pooling mechanisms for managing permanence.

GHG accounting for any offset mechanism should:

- Include all emissions resulting from an activity for which credits are awarded, including off-site (leakage);
- Not be so onerous as to put off potential participants, as this would increase the costs of abatement for society, and preclude the potential benefits such as enhanced productivity.

A trade-off between accuracy and cost is inevitable in GHG accounting. It has yet to be resolved whether models are adequate, or measurement is also required to generate confidence in the market. A hybrid approach is possible, in which strategic measurements are undertaken to establish a baseline and at intervals through the life of the project, and models are used for interim and subsequent estimation. This approach would provide more confidence in the model estimates.

To support comprehensive GHG accounting in the land sector, research is required to improve models for estimation and prediction of GHG emissions, and enable baseline assessment. There is a need for whole-farm level estimation tools that accommodate regional and management differences in emissions and sequestration, to support landholders in managing net emissions from their farming enterprises.

C footprinting of products, using LCA methods, could generate incentive to reduce emissions from agricultural production. C footprinting utilises the same data and basic methods as are applied in national inventory and project-level accounting.

It is critical that cost-effective yet credible GHG estimation methods are devised, to encourage participation in voluntary schemes such as CFI, and facilitate C footprinting, and therefore achieve maximum mitigation in the land-based sector.

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