Using life cycle approach to evaluate trade-offs associated with payment for ecosystem services schemes

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ABSTRACT

PES (payment for ecosystem services) schemes generally operate locally, however it is important to consider their benefits from a life cycle perspective. This paper presents insight into the application of LCA to identify net environmental gains from CAMBI – a pilot scheme for sequestering soil carbon on-farm. A life cycle approach is applied by considering above ground GHG emissions from project implementation for a case CAMBI paddock in relation to soil C sequestration. The results suggested that increased soil C sequestration under CAMBI was sufficient to offset GHGs from project implementation and resulted in 0.58-0.7 t CO_2-e ha^{-1} yr^{-1} of avoided emissions under business-as-usual scenario. Further studies are needed to assess indirect impacts to identify environmental trade-offs from 1) land use changes in other areas of the farm or beyond; 2) farming input supply chain; or 3) other environmental impact categories. LCA can assist to identify net environmental gains from PES by addressing these issues.

Keywords: LCA, CAMBI, leakage, GHG emissions, Australia

1. Introduction

Agriculture is a dominant form of land management globally, covering nearly 40% of terrestrial land area (FAO stat 2010). Environmental impacts on ecosystems from agriculture are a function of: agricultural expansion into areas of natural ecosystems, agricultural intensification (higher yields from same or lesser land area), land use zoning schemes (which allocate land to restricted uses to ensure that natural ecosystems are not converted), and farming practices which can have both positive and negative impacts on the environment. Contrary to the belief that agricultural intensification and land use zoning reduces agriculture's impacts on ecosystems by halting agricultural expansion into natural ecosystems, studies suggest otherwise. Agricultural intensification or land use zoning in one geographical area potentially triggers compensating changes in trade flows of agricultural commodities and thus affect land use in other areas or countries (Lambin and Meyfroidt 2011; Pfaff and Walker 2010; Ramankutty et al. 2010). For example increases in import of cereals and wood products have been associated with countries that introduced conservation policies to keep land out of cultivation compared to countries without such policies (Gan and McCarl 2007; Mayer et al. 2005; Rudel et al. 2009). Thus in the era of globalization where there is worldwide interconnectedness of people and markets, and a greater separation between point of supply and demand, there is a greater need to understand and model outcomes of land use policies using a systems thinking approach.

Payment for ecosystem services (PES) is one such conservation tool that could benefit from a systems thinking approach to identify if such schemes are able to achieve net environmental benefits. PES offers monetary incentives to the landholders in exchange for some sort of ecosystem benefit in addition to food production. The idea is to bring otherwise free gifts of nature such as, clean air, climate regulation, pollination and so on, more in synchrony with the market, and in this way signal their importance in decision making. While PES schemes are increasingly being considered in sustainable agricultural practices both in developed and developing countries around the world, a need consistently reported is that of identifying environmental effectiveness of such schemes (Arrigada and Perrings 2009; Farley and Costanza 2010; Hajkowicz 2009; Tallis et al. 2008). A challenge which constrains the environmental assessment of local PES proposals is that of additionality and leakage. Additionality refers to the net impact on the biophysical provision of ecosystem benefits in comparison with the baseline[1] scenario or hypothetical situation where the PES scheme is not in place

[1]For example in Australia's Carbon Farming Initiative baseline refers to the carbon changes one would expect under business-as-usual condition that is those anticipated to occur in the absence of carbon policies or carbon projects. Setting the baselines is important as only carbon sequestered above and beyond the baseline will be counted for crediting purposes.

(Pascual et al., 2010). Leakage occurs when the actions to reduce environmental damages are merely displaced outside the geographic area of the project boundary typically resulting in offsetting or undermining environmental gains. For example, at the farm scale, leakage can potentially occur where project participants alter land use and farming practices in parts of their estate which are outside the technical boundary of the PES scheme. This could occur if land outside the PES scheme is managed more intensively to compensate forgone yields within the PES boundary.

In this paper a life cycle perspective - which is indicative of net environmental outcomes is applied in the assessment of CAMBI (Catchment Action Market Based Instrument) - a pilot project tested at the level of individual farmers and landholders for sequestering soil carbon (C) at the paddock scale. The aim of the CAMBI project is to design and test the cost effectiveness of a market based instrument (MBI) to support land holders adopt practices that increase soil C. This paper builds on previous and on-going work on modelling soil C levels through changed land management practices under CAMBI and considers the changes to above ground carbon emissions from project implementation. In this way the results indicate net potential gains from CAMBI intervention at the project boundary. This paper is organised as follows. In the next section a description of CAMBI and the methods to estimate net environmental impacts are presented. Section 3 and 4 reports and discusses the results of net environmental gains at CAMBI case paddock, followed by a final section on concluding remarks.

2. Methods

2.1. Description of CAMBI (Catchment Action Market Based Instrument)

Soil is a major sink of carbon; the size of the soil carbon pool and the annual flux of carbon passing through the soil are two reasons that soil organic carbon can play a significant role in mitigating GHG emissions. Soil C sequestration has been acknowledged to play an important role in reducing GHG emissions from agricultural systems in Australia (www.daff.gov.au/reducing-greenhouse-gas-fsheet.pdf). In addition to mitigating atmospheric GHG emissions, improving soil C levels has other benefits for increasing soil fertility, minimizing soil erosion, improving water holding capacity and ecosystem services and increasing farm productivity. With this background, the CAMBI pilot project, henceforth referred to as CAMBI, was designed and implemented in the Central West NSW to test the viability and cost effectiveness of a MBI to support landholders to adopt practices that increase soil carbon (Pearson et al. 2012). The premise is that potential changes to soil C occur if changes in land management are made. Accordingly, CAMBI has focused on assessing existing soil C levels under different combinations of land management, climate and soil landscapes. The predictions for soil C sequestration are based on the best available scientific knowledge and consider specific environmental conditions on specific soil types under different land holder defined actions and land uses (Murphy et al. 2012). Accordingly the CAMBI pilot scheme is also a test case to identify whether the current state of soil C science can support the practical implementation of MBI. The CAMBI pilot project was concentrated on the Cowra trough of NSW that has a temperate climate with a seasonally uniform rainfall distribution and porphyry-derived clay loam soils. The net soil C sequestered at the paddock scale from changed land management is the unit upon which payments were based. Contracts were finalized for eligible farmers through a reverse tender auction which provided best value in terms of soil C sequestered per dollar. The contract was between a farmer entity (proponent) and the Catchment Action NSW for a period of 5 years - from 2012 to 2017.

2.2. Data collection and analysis

Information was collected through a face-to-face interview from a CAMBI participant – a mixed farming enterprise with cropping and grazing of sheep on improved pasture. The farm is located in the Cowra region of NSW, Australia. Data was gathered on: 1) general information of the farm such as total land area, crop types, typical yields, irrigation availability, soil types and so on; 2) land management history of paddocks contracted under the CAMBI project – area, type of enterprise, typical calendar of operations, energy and material inputs used, typical yields; and 3) land management under CAMBI contract and the resources used therein.

Net environmental benefits of CAMBI intervention at the contracted paddock were estimated as the balance between GHG emissions from land management changes and predicted soil C sequestration rates expressed as t

CO_2-e ha^{-1} yr^{-1}. GHG emissions from cropping were modelled using LCA Simapro software (version 7.3) and both the Australasian LCI database and the Swiss Ecoinvent database (version 2.2) were used. Nitrous oxide emissions factor from N fertilization in cropping was estimated to be 1% (Australian Government 2011; IPCC 2006). Nitrous oxide emissions from crop residues (which are not burnt) is based on the National Inventory Report (Australian Government 2012) and takes into consideration factors such as yield, dry matter content and C:N ratio. GHG emissions from sheep grazing included GrassGro® modeled enteric methane and nitrous oxide emissions from excreted N and unutilized plant material. Historic climate information and data on-farm were used to model GHG emissions for an average year for the case farm.

Modelling soil C sequestration in CAMBI paddocks is part of the work based on SCaRP (Soil Carbon Research Program) – the largest and most extensive Australia wide program undertaken to measure stocks of soil carbon. As a part of this project a consistent method for sampling and a rapid and cost-effective way of analysing soil samples for soil organic carbon has been developed. Specifically, SCaRP-NSW was intended to assess the potential for agricultural land management practices (including emerging “carbon farming” practices such as the pilot CAMBI project considered in this study) to influence soil carbon on cropping and grazing land in NSW agricultural systems (Cowie et al. 2013). Sampling scheme for CAMBI project was developed to estimate the initial level of soil carbon in a paddock being assessed for a contract and its change after management actions have been undertaken (Murphy et al. 2012). This led to the development of a soil carbon metric that was used to assess rates of soil carbon sequestration for land managers which received payment under CAMBI contract.

3. Results

3.1. Historical GHG emissions on CAMBI paddocks (cropping)

The case farm is typically a mixed enterprise with cropping (wheat, canola, alfalfa) and sheep grazed on improved pasture. The property is not irrigated and is dependent on an average annual rainfall of 520 mm. Soil type is a combination of sandy and red clay loams. The paddock contracted under CAMBI is 80 ha, historically managed under a wheat-canola rotation for over a decade. Typically canola and wheat are sown in April and May and harvested in November and December respectively. The GHG emissions from wheat and canola in a typical cropping cycle are presented in Table 1. Typically wheat and canola yields are 3.5 t ha^{-1} and 1.75 t ha^{-1}. The stubbles for both wheat and canola are grazed and not incorporated into the soil prior to the next crop being sown.

3.2. Current GHG emissions under CAMBI contract

In summary, land management at CAMBI case paddock was converted from a wheat-canola cropping to sheep grazing on improved pasture. The improved pasture is sown once every 20-30 years with a mixture of grasses in combination with legumes. Typically, grasses included *phalaris, fescue, cocksfoot* and *prairie grass sp.* respectively, while the legume is *sub-clover sp.* Lime application of 1 t ha^{-1} was undertaken at the time of sowing, with a re-application frequency once every ten years. The stocking rate on the CAMBI paddocks was 3.8 ewes and 4.98 lambs per ha typically grazed for three months of the year. Total CO_2-e emissions for the above number of animals allocated over the time of year spent grazing on the CAMBI paddocks is estimated using GrassGro model to be 0.54 t ha^{-1} (Table 1).

Table 1. Net effect of CAMBI intervention at the paddock scale (project boundary)

GHG emissions before CAMBI - cropping			GHG emissions under CAMBI	Soil C sequestration
	GHG emissions			
Activity	**Wheat**	**Canola**	**Grazing**	**From cropping to grazing**
	t CO_2-e ha^{-1} yr^{-1}	t CO_2-e ha^{-1} yr^{-1}	t CO_2-e ha^{-1} yr^{-1}	t CO_2-e ha^{-1} yr^{-1}
Production and transport of fertilizers	0.25	0.4	0.10	
Production and use of diesel on farm	0.15	0.16	-	
Production and transport of pesticides	0.023	0.023	-	
Production of machinery	0.009	0.005	-	
Production of seed	0.008	0.002	-	
Soil nitrous oxide emissions from fertilizer application	0.140	0.116	-	
Nitrous oxide emissions from crop residues	0.007	0.003	-	
GHG emissions from livestock	-	-	0.44	
	0.58	0.70	0.54	1.27

3.3. Net environmental benefits at CAMBI paddocks

The predicted net changes to soil C sequestration under land management changes from cropping to improved pasture is estimated to be 1.27 t CO_2-e ha^{-1} yr^{-1} based on the soil C level monitored in the paddock and the equilibrium rate for the pasture system. The results suggest that soil C sequestration from changed land management under CAMBI paddocks did offset the emissions from project implementation (net sink of 0.73 t CO_2-e ha^{-1} yr^{-1}). In addition, changed land management from cropping to grazing under CAMBI further avoided 0.62 t CO_2-e ha^{-1} yr^{-1} (average emissions considering crop rotation of two wheat crops followed by a canola) which would have otherwise occurred under wheat-canola rotation. Thus, soil C sequestration from conversion of cropping to grazing was a net sink of GHG emissions considering the project implementation (grazing) and the avoided practices (cropping). This implied that the land management changes under CAMBI resulted in overall net benefits at the paddock scale.

4. Discussion

4.1. CAMBI - net environmental outcomes at paddock scale

The individual results for GHG emissions under business-as-usual scenario (wheat-canola cropping) are comparable with the published literature. For example previous work on carbon footprints undertaken in the same region of NSW reported between 0.56 to 0.70 t CO_2-e ha^{-1} (Brock et al. 2012) for wheat cropping as compared to 0.58 t CO_2-e ha^{-1} estimated in this research. Similarly for canola carbon footprints estimated in this study (0.70 kg CO_2-e ha^{-1}) are comparable with previous reported studies of 0.61 to 0.98 t CO_2-e ha^{-1} (Gan et al. 2012). Sheep grazing sector usually correspond to a higher above ground carbon footprints compared to white meats (pigs, poultry) and even with beef (Ledgard et al. 2011). The carbon footprint for sheep is dependent upon the management such as stocking rate, soil type, grass or grain-fed, climate characteristics and has been reported to vary widely ranging from 0.4 to 3 t CO_2-e ha^{-1} yr^{-1}(Edward-Jones et al. 2009). With the current stocking rate and the amount of time spent in the CAMBI paddocks used in this study suggested that carbon footprint for sheep grazing was lower than wheat-canola cropping on an area basis (Table 1). It is anticipated that similar number of stock would be grazed for an entire year in CAMBI paddocks in the future which will affect the GHG emissions; however the reason for short period of grazing (3 months) as was the case in this research was due to the establishment phase of CAMBI paddocks which were sown ten months earlier. On the other hand transitioning land management from cropping to grazing resulted in higher soil C sequestration than business-as-usual. This is consistent with the generally acknowledged understanding that soil C sequestration increased with management in the order: continuous cropping < crop-pasture rotation < pasture grazed by sheep and cattle (Chan et al. 2011). The result that grazing had net environmental gains at the CAMBI paddock scale is thus consistent with the above insights.

Based on the empirical work undertaken in this research, CAMBI intervention resulted in an overall net sink of GHG emissions at the paddock scale as compared to business-as-usual scenario. The system boundary for assessment used in this research was the paddock to coincide with the CAMBI project's system boundary. However, the paddock is not a stand-alone area and there is continuous exchange of information and resources between different areas of the farm. For example sheep grazed on the CAMBI paddocks for three months of the year; however the rest of the time they were dependent upon other areas of the farm. Hence it is important to understand the dynamics of GHG emissions outside CAMBI paddocks to identify whether CAMBI intervention has net environmental benefits at the farm scale. This means identifying 'leakage' in terms of GHG emissions from changed sheep numbers at the farm scale as compared to business-as-usual. Similarly information on land management changes to other areas of the farm from CAMBI intervention also needs to be identified.

4.2. Application of life cycle approach for assessing net environmental impacts of PES schemes

Although it is not unusual for empirical research to not develop hand in hand with the theory, policy design and implementation, the current state to measure environmental effectiveness of PES schemes is a cause of concern (Pattnayak 2010). For example the Australian Government's Carbon Farming Initiative in principle requires that the project participants discuss the issue of leakage. This implies that the project must not cause material increases in emissions outside the project's boundary, which nullify or replace the abatement that would otherwise result from the project. In theory this would involve estimation of a leakage deduction in the calculation of the net abatement or sequestration quantity (Australian Government 2010). In practice however, there is a need to include the criteria of LCA in the operational assessment of projects eligible under the CFI if the net benefits from such schemes are to be assessed. There are several potential advantages of life cycle approach implemented through LCA can offer in operationalizing environmental assessment of PES schemes. Firstly, LCA can handle environmental trade-offs across system boundary; this is especially relevant to agriculture where specific policy measures which are directed towards a single goal can lead to trade-offs elsewhere. For example the aim of CAMBI project is to test the implementation of MBI by paying farmers to adopt land management practices which enhance soil C sequestration. An application of life cycle thinking at the CAMBI paddock scale suggested that although for every ton of soil C sequestered there are 43% emissions from project implementation, there was a net benefit from CAMBI intervention. Secondly, LCA can assist to identify trade-offs with other environmental indicators such as water use and land use footprint; this enables overall environmental assessment of PES schemes. In this way, LCA can be a useful tool to identify the consequences of a decision such as PES intervention at the farm scale and beyond by considering off-site environmental impacts. Thirdly, life cycle approach can be potentially useful in discussing the issue of 'permanence' usually associated with sequestration projects. For example, the CAMBI participants have to comply with the project activities for a period of five years only. Potential land management changes beyond the temporal scope of the project using a life cycle approach can help to further identify net consequences of PES intervention in the longer term.

5. Conclusion

PES is an important and increasingly considered policy tool to encourage conservation from agriculture. However, continued poor evaluation in terms of additionality and leakage suggest paucity in the evidence of PES program's net environmental effectiveness. Life Cycle thinking applied through Life Cycle Assessment can offer advantages by considering net environmental gains from changed land management practices associated with PES schemes. The application of LCA suggests that GHG emissions from project implementation were not sufficient to undermine environmental benefits from CAMBI at the paddock scale. The CAMBI project resulted in being a net sink of GHG emissions as compared to business-as-usual scenario at the contracted paddock scale. However, the effect of CAMBI intervention on net environmental benefits at the farm scale and beyond needs to be considered in future studies under LCA framework. This would include the identification of tradeoffs with other ecosystem benefits from PES intervention such as reduction in food production or increased use of water and land resources. Thus future studies should reflect as closely as possible the consequences of changes to ecosystem services on other areas of the farm and elsewhere resulting from PES intervention. This implies using LCA to identify whether provision of ecosystem benefit at the farm scale is offset by a reduction in ecosystem benefit: 1) from project implementation; 2) in another area of the farm and beyond; 3) upstream in the farming input supply chain (from potential intensification); or 4) from trade-offs with other environmental impact categories.

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