AN INTEGRATED SPATIAL TECHNOLOGY APPROACH FOR AUSTRALIAN AGRICULTURE – USING LIFE CYCLE ASSESSMENT, GEOGRAPHICAL INFORMATION SYSTEMS AND REMOTE SENSING TOOLS

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ABSTRACT

On an international front, agriculture has been found to contribute to environmental impacts such as land use change, loss of biodiversity, greenhouse gas emissions, increased soil salinity, soil acidity and soil erosion. In Australia, agriculture is the second largest emitter of Greenhouse Gases (GHGs).Western Australia (WA), which is the largest grain producing state, could increase the overall GHG emissions from the agricultural sector. With the impending introduction of the Carbon Taxation Policy (although agriculture is not now included) the agricultural sector will need to develop appropriate GHG mitigation strategies to maintain and improve its competitiveness in the green commodity market.

This paper proposes the use of Integrated Spatial Technologies (IST) involving tools such as Life Cycle Assessment (LCA), Remote Sensing (RS) and Geographical Information Systems (GIS). The IST applies the concept of cleaner production for the formulation and application of cost-effective GHG mitigation options in WA. As most research projects conduct research at research stations, this project proposes obtaining data at a farm level over various agro-ecological zones. The framework was tested using data from previously reported research and consisted of a baseline study and two mitigated options, (or cleaner production strategies) namely good housekeeping and input substitution. In the baseline study, the production and use of fertiliser was identified as the “hotspot”, in option 1 the use of fertiliser was replaced with manure and option 2 considered crop rotation methods as mitigation methods.

Keywords: Remote sensing, geographical information systems, life cycle assessment, integrated spatial technology, agriculture, CF

INTRODUCTION

The agriculture sector has been found to be one of the key economic sectors resulting in environmental degradation through land use change, loss of biodiversity, increased soil salinity, soil acidity and soil erosion. For example, the greenhouse gas (GHG) emissions from the use and production of agrichemicals such as fertilisers are causing climate change (Middleton, 1999; Biswas *et al*. 2008; Biswas *et al*., 2011). The major GHG emissions from crop production are usually soil nitrous oxide (N_2O) emissions and enteric methane (CH_4) emissions (Biswas *et al*., 2010). In addition to climate change, other environmental impacts, such as eutrophication, eco-toxicity, water scarcity, loss of biodiversity and carbon dioxide (CO_2) from fertilisation products and urea hydrolysis etc., may result due to the use of agricultural inputs and farm machinery operation (Adler *et al*., 2007; Ugalde *et al*, 2007; CSIRO, 2010; Anderson, 2011), which further challenges sustainable agriculture. In Australia the scenario is much the same as on the international scene.

The GHG emissions from Australian agriculture currently contributes to 15.5 per cent of its total national emissions and is the dominant source of GHGs which includes methane (57.9%) and nitrous oxide (74.5%) (Ugalde *et al.*, 2007; Biswas and John, 2008; NGGI, 2010). In 2009 crops and soils accounted for approximately 10.2 per cent of the total agricultural emissions (2.4 per cent of the net national emissions) and livestock for 41.9 per cent (9.7 per cent of the net national emissions) (Sparkes *et al.*, 2011). Western Australian (WA) agriculture, despite its legacy of poor soils and low rainfall, is the largest grain producing state in Australia, producing 40 to 50 per cent of the annual grains. The growth is concentrated in the wheat belt areas where mostly wheat, barley and lupins are produced (ABS, 2006; DLGRG, 2007; Biswas *et al.*, 2008; Islam, 2009; van Gool, 2009). The agricultural emissions for WA in 2006 were 20 per cent of the total for Australia, and with the use of coal for electricity generation, contributed the most to the high per capita emission yield in WA (CLAN, 2006; Eckard, 2007; Barton and Biswas, 2008; AGRIC, 2010).

From the aforementioned text it can be seen that the agricultural industry in Australia is adversely affected by climate change and therefore, continual improvement in the face of these adversities is required to maintain international competitiveness in the green commodity market and to prevent further environmental degradation. In 2011 a carbon taxation policy was proposed in Australia and will be implemented in June 2012. This policy is directed to respond to the climate change impacts by reducing environmental pollution and drive the transformation of the Australian economy to a clean energy future (Johnson, 2011; Packham and Vasek, 2011). As the agricultural sector is currently excluded, but may benefit from the emission trading scheme later, different options to sustain agricultural productivity and evaluate its environmental impacts and increase agriculture and livestock sectors efficiency should now be investigated. This is especially important since the agricultural productivity is expected to increase in the next few years (Biswas *et al*., 2010; NGGI, 2010). The implementation of carbon footprint (CF) mitigation strategies, which include cleaner production (CP) and eco-efficiency (EE), into all facets of agricultural production (specifically grain production) could aid in the reduction of the use of chemicals, transportation costs and reduce energy use.

This paper proposes the use of Integrated Spatial Technologies (IST) framework involving tools such as Life Cycle Assessment (LCA), Remote Sensing (RS) and Geographical Information Systems (GIS) and highlights the use of CP as part of an IST approach for the formulation and application of cost-effective GHG mitigation options in WA. Most research projects reviewed have been conducted at research stations which are neither representative of the diversified agro-ecological zones or topography of the broader farming areas, nor represent a regional environmental management strategy or plan. This project has therefore been conducted at farm level ensuring that the sample is representative of specified agro-ecological zone/s, the soil types, climate and typical farming practices (Gregory and Ingram, 2000; CLAN, 2006; Hajkowicz, 2009).

Firstly, this paper briefly describes the tools for carbon footprint (or GHG) reduction from the grain industries. Secondly, it discusses how these tools have been applied in the IST framework. Finally, the framework has been tested using a hypothetical example consisting of a baseline study and two mitigated options.

TOOLS FOR CARBON FOOTPRINT REDUCTION

The tools used for developing the IST framework have been briefly illustrated below:

Life cycle assessment is defined as an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying energy and materials used and waste released to the environment, it is also used to evaluate and implement opportunities to effect environmental improvements (UNEP, 2011). The methodology to be used is the ISO 14040:2006 and 14044:2006 (ISO, 2006) methodology, and consists of four distinct steps i.e. goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation of results (Curran, 2006; ISO, 2006). The goal of the project is to reduce the CF resulting from grain industries in WA. The functional unit could be the assessment of one tonne of wheat in a rainfall region for crop legume rotation system. As the LCI is a pre-requisite flow diagrams will be used to illustrate all the inputs (e.g. fertilizers, machinery etc.) and outputs (e.g. harvested crops, emissions from crops and machinery) into the production of the crop. Once the inventory is developed, inputs and outputs will be inserted in the Simapro software for determining the carbon footprints (CF) of grains. The interpretation of results is the final stage of the LCA analysis where the most significant impacts will be identified, analysed and reported on. The impact of each emission will be evaluated and mitigation measures suggested (DEAT, 2004; ISO, 2006; UNEP, 2011). Life cycle assessment has been used by various researchers in the agricultural sector to investigate aspects such as N_2O emissions from fertilisers and pesticides (CLAN, 2006; Barton and Biswas, 2008; Barton *et al.*, 2011; GRDC, 2011), methane emissions from livestock, CO_2 emissions arising from agricultural energy use and from vegetation sinks and the manufacture of products such as corn chips following the production of maize (Grant and Beer, 2008).

Remote sensing is defined as the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand, *et al.*, 2004). In agriculture RS images have previously been used to classify crop types and area variability from the resulting spectral response patterns and image textures obtained from the satellite image (Lillesand, *et al*., 2004; Ahmad, 2010)

Geographical Information System is defined as a tool for analysing and simulating environmental data and information, linking geographic information (where things are) with descriptive information (what things are) and creating new multi-layer environmental information (Yousefi-Sahzabi *et al*., 2011). In accord with this definition Lillesand *et al*, (2004) state that GIS is a computer-based system, which is able to process and aid with the analyses of virtually any type of information about features that can be referenced by geographical location (Lillesand *et al.*, 2004). In agricultural applications GIS images have been created and used to illustrate a wide variety of agricultural practices and interests such as climatic zones, soil types, land cover and crop variability (Lillesand, *et al*., 2004). It has also been used to model GHG emissions from Chinese rice paddies (Yao et al, 2006) and the annual direct biogenic GHG emissions from European agriculture were assessed using GIS (Freibauer, 2003).

Cleaner production is the continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment (van Berkel, 2002). Cleaner production attempts to reduce wastes and emissions at the source by making more efficient use of natural resources. The prevention practices generally employed to bring about CP is product modification (on site processing), input substitution (use of alternatives), technology modification, good housekeeping (reduction of energy, raw materials etc.) and recycling and reuse (packing material, water) (van Berkel, 2002; van Berkel 2007, Biswas *et al*., 2010). Cleaner production strategies will be integrated as mitigation measures into the IST to propose environmentally benign and cost-effective farm management practices for different agro-ecological zones. This will ultimately offer growers environmentally benign production, but they will obtain cost-effective farm management practices

INTEGRATED SPATIAL TECHNOLOGY FRAMEWORK

The proposed framework is named Integrated Satellite Technology or IST framework as it extracts data from the satellite images (RS) for different agro-ecological zones then converts them to CFs using LCA software, and finally these CFs will be super-imposed on the satellite images (GIS) for the documentation of an EMP. Cleaner production strategies will be integrated as mitigation measures into the IST to propose environmentally benign and cost-effective farm management practices for different agro-ecological zones.

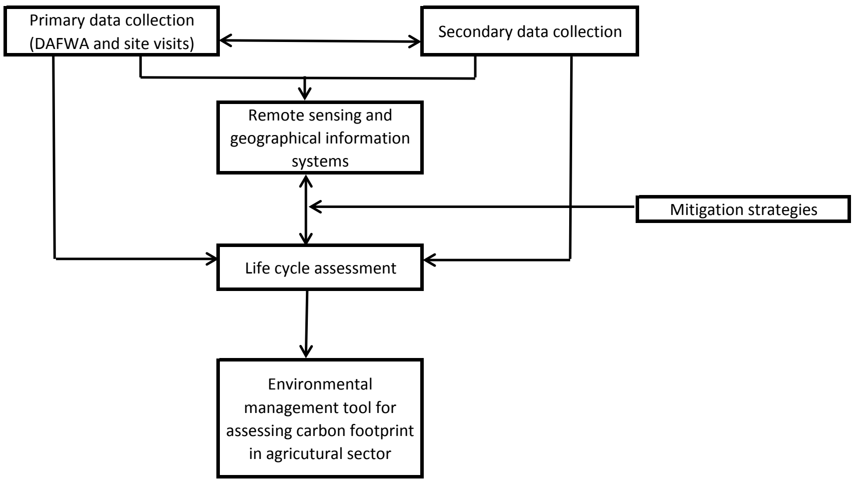


Figure 1. Integrated spatial technology framework

Data collection: This study is linked to a crop sequencing project currently carried out by the Department of Food of Western Australia (DAFWA). This project commenced in 2010 and involved 144 participating farmers. In consultation with DAFWA a sub-sample of 44 paddocks will be selected to evaluate the working of the proposed IST framework. The geographic location of the selected 44 paddocks will be registered and identified on the medium resolution SPOT satellite images to be acquired in September 2012. These paddocks will be stratified according to the predominant soil type, rainfall gradient and farm management practices (e.g. minimum till, crop rotation) adapted for the production of different crop types (wheat, barley, lupin, peas and oats etc) of the selected farms. In order to ascertain a true picture of the factors of production used and specific management practices applied for the production of agricultural crops, pre-structured questionnaires were prepared by the DAFWA field staff and istributed to all participating farmers. Additionally, face to face interviews and field site visits are scheduled to collect additional primary data and hand-held based multispectral data to be used as an input for the classification of remotely sensed data sets at paddock level. The secondary data will be d concurrently collected during the acquisition of the remotely sensed images. Both quantitative and qualitative data collection methods include questionnaires, desktop studies, interviews, observations and field validation data. Stage 2 of this project involves data processing of RS, GIS and LCA analysis to be carried out individually and in an interactive manner.

Data processing: The geographic location of the selected 44 paddocks will be registered and identified on the medium resolution SPOT satellite images to be acquired in September 2012. These paddocks will be stratified according to the predominant soil type, rainfall gradient and farm management practices (e.g. minimum till, crop rotation) adapted for the production of different crop types (wheat, barley, lupin, peas and oats etc) of the selected farms. Thereafter all input/output data required for the LCA analysis will be collected and captured using Simapro, a software program developed by Pré-Consultants in the Netherlands. The LCA methodology will follow the ISO 14040:2006 and 14044:2006 steps and will use the Australian GHG library to calculate the GHG emissions from the grain industries. The information generated through RS and LCA based analysis will then be fed into a GIS to determine the spatial distribution of agricultural system CFs for different agro-ecological zones in WA. Geographical information systems will be used to create various layers (maps) that will be overlayed to identify the areas of concern (hotspots). On identification of the hotspots in the study area, the cost-effective mitigation strategies will be investigated and tailored to suit the farm management practice, climate and soil types. Mitigation strategies will primarily be based on CP methods. The primary form of acquiring mitigation strategies will be via literature and interviews with both local and international specialists. The appropriate mitigation strategies will be selected using choice modelling methods (used to estimate non-market environmental benefits and costs), by presenting the farmers with different choice sets from which the most appropriate alternatives will be selected (Bennett, 2005). In order to estimate the reduced CFs, the mitigation strategies will be used to revise the data for carrying out the LCA analysis until an economically viable and environmentally benign strategy is obtained. Finally an EMP will be documented in which the results from each of the stages will be incorporated to bring about a simplified plan which will aid in the reduction of emissions from crop production in WA, and maximise profit where possible.

WEST AUSTRALIAN AGRICULTURE BASED CASE STUDY

This section deals with the implementation of the above described IST framework for the identification of an appropriate farm management practice for wheat production in West Australia. in the analysis, the dependent variable (wheat crop yield) was kept constant for all scenarios. Moreover, for this case study pre-farm and on-farm stages were considered as the analysis concentrates on the This framework will enable grain farmers to reduce their GHG emissions and claim carbon credits in the near future.

Collection of data and carbon footprinting

Following is the baseline study and the two mitigation options used for validating the IST framework.

Baseline scenario

A baseline scenario was modelled based on data reported by Biswas *et al.* (2008).This study assessed the life cycle global warming potential of wheat production in WA and provided the background information and input data used for testing the IST framework. Figure 2 illustrates the location of the study area (yellow marker) and the insert is a magnification of the paddock. This study quantified CO_2, N_2O and CH_4 emissions per tonne of wheat produced for each stage of the pre-farm and on-farm stages.

Figure 2. Location of paddock used for hypothetical example

Each of these GHG values were converted to CO_2 equivalents (CO_2-e) by using the latest conversion factor's, then summed to determine the resulting CF (Table 1). The functional unit was the production of one tonne of wheat from 0.37 hectare of land.

The results in Table 1 show that the most GHG emissions are generated in the pre-farm stage (137.32 kg CO_2-e vs 133.51 kg CO_2-e) and on further investigation the area of concern (hotspot) can be identified as the production and supply of urea. If mitigation measures are to be applied they should concentrate on reducing the GHG production in the pre-farm stage and should specifically target the urea production and use. Alternatively, if the on-farm stage was to be targeted, the CO_2 emissions generated from the paddock

Table 1. Total carbon footprint for each of the agricultural stages

	Greenhouse gases			kg CO_2 equ-			Total
Stages	CO_2 (kg)	N_20 (kg)	CH_4 (kg)	CO_2	N_2O kg CO2 eq-	CH_4	kg CO2 equ-
Pre-farm							
Farm Machinery Production	0.93	0.00	0.00	0.93	0.01	0.00	0.95
Production and supply of urea	79.25	0.06	0.25	79.25	17.88	6.25	103.38
Production and supply of superphosphate	2.93	0.00	0.00	2.93	0.00	0.00	2.93
Production and supply of pesticide	17.15	0.04	0.04	17.14	11.92	1.00	30.06
Subtotal	***100.26***	***0.10***	***0.29***	***100.25***	***29.81***	***7.25***	***137.32***
On-farm							
N_2O emissions from paddock (Barton et al. 2007)		0.09		0.00	26.82	0.00	26.82
CO_2 emissions from paddock (IPCC 2006)	81.00			81.00	0.00	0.00	81.00
Diesel supply and utilization for spraying ferilizer	4.65	0.00	0.00	4.65	0.03	0.02	4.69
Diesel supply and utilization for spraying herbicide	2.32	0.00	0.00	2.32	0.01	0.01	2.34
Diesel supply and utilization for spraying seeds	9.24	0.00	0.00	9.24	0.06	0.03	9.32
Diesel supply and utilization for harvesting	9.24	0.00	0.00	9.24	0.06	0.03	9.32
Subtotal	***106.45***	***0.09***	***0.00***	***106.45***	***26.98***	***0.07***	***133.51***
Grand Totals	**206.71**	**0.19**	**0.29**	**206.70**	**56.80**	**7.33**	**270.82**

(Source: adapted from Biswas et al., 2008)

should be addressed. From this it can be seen that mitigation measures can focus on different aspects of farming.

Carbon dioxide mitigation options

On reviewing existing literature, two mitigation options or cleaner production strategies were identified that could be applied to reduce the overall GHG emissions from the baseline scenario.

1. Input substitution CP strategy: The substitution of urea with organic fertiliser in the pre-farm stage (option 1)
2. Good housekeeping CP strategy: Crop rotation methods in the on-farm stage (option 2)

Option 1 applies input substitution CP strategy. In this scenario the urea from the baseline study was replaced with manure containing an equivalent amount of nitrogen and thus could reduce GHGs from urea production. Data on GHG emissions during the anaerobic production of manure were extracted from Hansen *et al*., (2006) and Chadwick *et al*., (2011). It was assumed that the piggery supplying the manure was in close proximity to the paddock in question, the manure was distributed on the land using the same machinery used for fertiliser spraying and the wheat yield was also assumed to be the same as in the baseline scenario. The calculated results are tabulated in Table 2.

When the results in Table 2 for option 1 are compared with those in Table 1 it can be seen that there is a reduction in the CO_2-e results for the pre-farm stage but with an increase in emissions from the on-farm stage. The total GHG emissions show an overall decrease. It can be seen that the use of manure could reduce the GHG emissions from the pre-farm stage possibly due to the variation in production methods. In contrast the increase in GHG emissions in the on-farm stage show that manure generates more N_2O than urea and this could increase the overall GHG emissions.

The results calculated for option 2 are tabulated in Table 3. In the second option of crop rotation system that considered the plantation of legume crops, (e.g. lupins) before wheat in for the deposition of nitrogen into the soil for the following year of the rotation. The nitrogen then becomes available to crops

Table 2. Option 1, carbon footprint resulting from the use of manure

	Greenhouse gases			kg CO_2 equ-			Total
Stages	CO_2 (kg)	N_20 (kg)	CH_4 (kg)	CO_2	N_2O kg CO2 eq-	CH_4	kg CO2 equ-
Pre-farm							
Farm Machinery Production	0.93	0.00	0.00	0.93	0.01	0.00	0.95
Production and supply of manure	22.91	0.05	0.75	22.91	14.21	18.68	55.80
Production and supply of superphosphate				2.93	0.00	0.00	2.93
Production and supply of pesticide	17.15	0.04	0.04	17.14	11.92	1.00	30.06
Subtotal	***40.99***	***0.09***	***0.79***	***43.91***	***26.15***	***19.68***	***89.73***
On-farm							
N_2O emissions from paddock (Barton et al. 2007)		0.51			152.43		152.43
CO_2 emissions from paddock (IPCC 2006)				0.00			0.00
Diesel supply and utilization for spreading manure	4.65	0.00	0.00	4.64	0.03	0.02	4.68
Diesel supply and utilization for spraying herbicide	2.32	0.00	0.00	2.31	0.01	0.01	2.33
Diesel supply and utilization for spraying seeds	9.24	0.00	0.00	9.23	0.06	0.03	9.31
Diesel supply and utilization for harvesting	9.24	0.00	0.00	9.23	0.06	0.03	9.31
Subtotal	***25.45***	***0.51***	***0.00***	***25.41***	***152.59***	***0.07***	***178.07***
Grand Totals	**66.44**	**0.60**	**0.79**	**69.32**	**178.74**	**19.75**	**267.81**

Table 3. Option 2, carbon footprint for crop rotation using lupin

	Greenhouse gases			kg CO_2 equ-			Total
Stages	CO_2 (kg)	N_20 (kg)	CH_4 (kg)	CO_2	N_2O kg CO2 eq-	CH_4	kg CO2 equ-
Pre-farm							
Farm Machinery Production	0.93	0.00	0.00	0.93	0.01	0.00	0.95
Production and supply of urea	66.70	0.05	0.21	79.25	15.05	5.26	99.56
Production and supply of superphosphate	2.93	0.00	0.00	2.93	0.00	0.00	2.93
Production and supply of pesticide	17.15	0.04	0.04	17.14	11.92	1.00	30.06
Subtotal	***87.71***	***0.09***	***0.25***	***100.25***	***26.98***	***6.26***	***133.50***
On-farm							
N_2O emissions from paddock (Barton et al. 2007)		0.09		0.00	26.82	0.00	26.82
CO_2 emissions from paddock (IPCC 2006)	68.17			68.17	0.00	0.00	68.17
Diesel supply and utilization for spraying ferilizer	3.91	0.00	0.00	3.91	0.03	0.01	3.95
Diesel supply and utilization for spraying herbicide	2.32	0.00	0.00	2.32	0.01	0.01	2.34
Diesel supply and utilization for spraying seeds	9.24	0.00	0.00	9.24	0.06	0.03	9.32
Diesel supply and utilization for harvesting	9.24	0.00	0.00	9.24	0.06	0.03	9.32
Subtotal	***92.88***	***0.09***	***0.00***	***92.88***	***26.98***	***0.07***	***119.93***
Grand Totals	**180.59**	**0.18**	**0.25**	**193.13**	**53.96**	**6.33**	**253.43**

planted after the legumes have been harvested and subsequently the urea (nitrogen) dosages can be reduced in the following year (Shah *et al*., 2003). Research reported by Bowden and Burgess, (1993) was used for data and calculation purposes. This targeted the application rate of the fertiliser and it was assumed that the lupin yield on the paddock was 1.2 t/ha (Bowden and Burgess, (n.d.), the residue with organic nitrogen from the lupin totalled 46 kg N/ha, of which 15.84 kg N/ha was available in the shoots and roots of lupin for the wheat in the following year and the application of urea could be reduced by 15.84%.

When the CF resulting from wheat/lupin rotation (Table 3) is compared to the CF in the baseline scenario (Table 1) a considerable reduction in the overall CF total is observed. Both the pre-farm and on-farm stages appear to emit less GHGs when a crop rotation system is applied. Thus, it appears that the crop rotation option is the best cleaner production strategy for reducing GHG emissions from wheat production.

Capturing of carbon footprints using GIS

In Figure 3 the CF results from the LCA are summarised for all three options as bar graphs and pie graphs using the values in Tables 1-3. The bar graphs show the quantity of GHGs emitted from each broad emissions sources (or inputs) namely machinery, chemical (production), paddock and diesel emissions. The pie graph presents the emissions as a percentage of the total emissions from all stages (pre-farm and on-farm) during the production of one tonne of wheat from 0.37 hectare plot of land.

Graphs (in Figure 3) clearly illustrate the hotspot (i.e. bigger CF(s)) for each input as well as the input with the largest CF. It is apparent that by altering one aspect in the production line, the consequent emissions of the individual GHGs could change. For example by substituting a product generated naturally (Baseline study vs. option 1), the paddock emissions may increase and the emissions associated with chemicals use decrease. Alternatively, by using crop sequencing methods (Baseline study vs. Option 2) overall GHG emissions may increase but paddock emissions decrease.

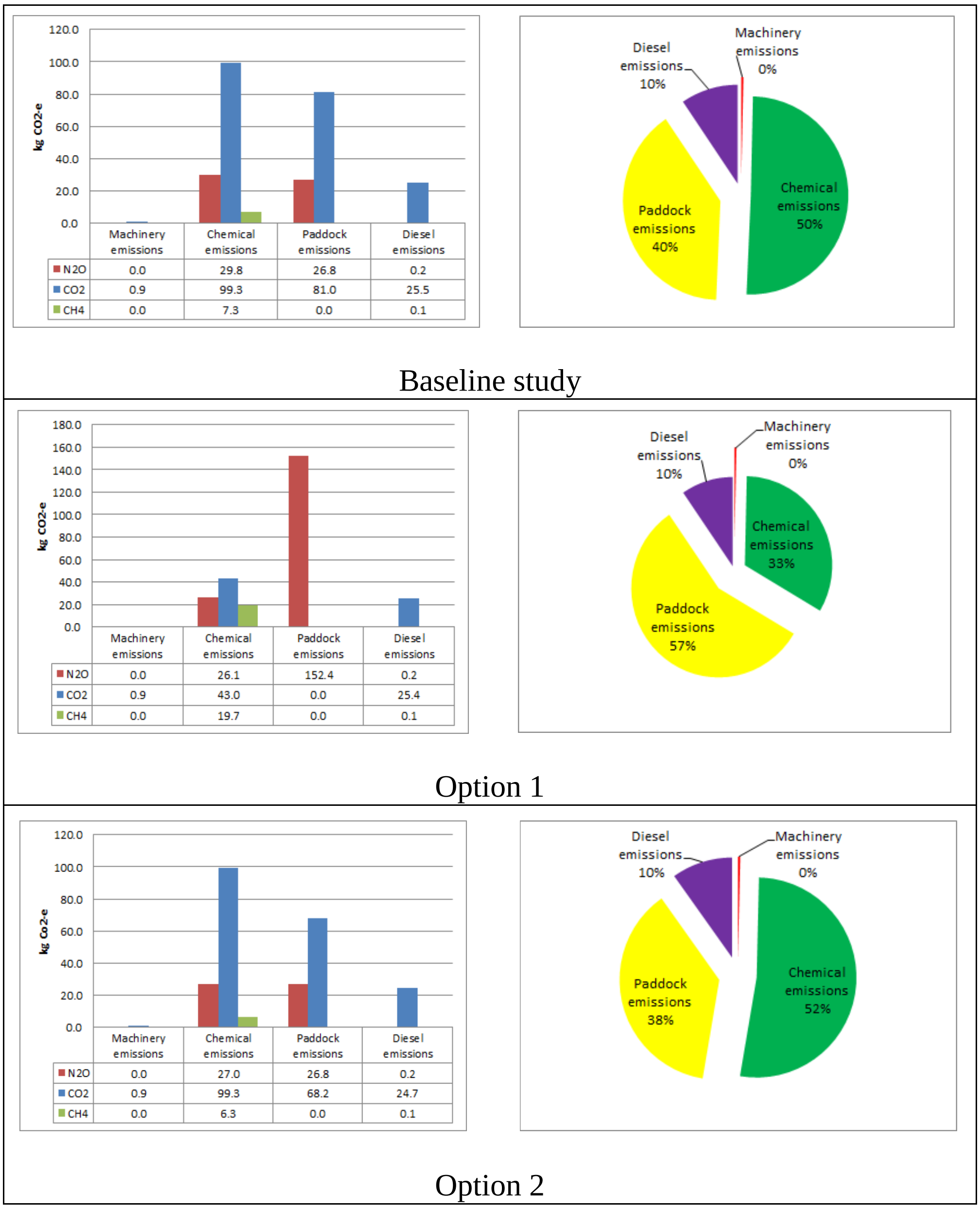
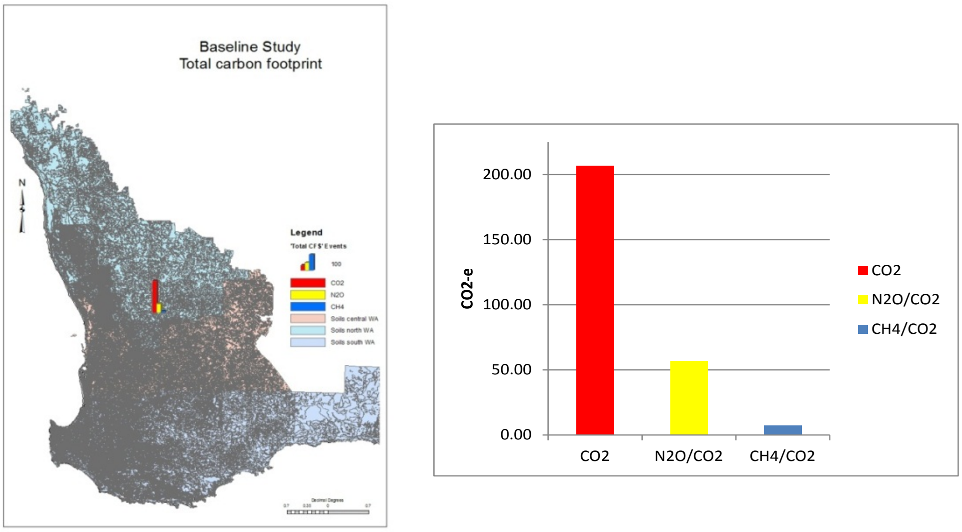


Figure 3. Bar graphs and pie charts showing the GHG emissions for each emission category for all three options

Calculated CF in Tables 1-3, were mapped using GIS (Figures 4-6). The bar graph shows the individual GHGs as CO_2-e and is presented for a locality where the project was completed. The inserts to the right of the images are enlargements of the graph found at the locality, for each scenario

The image in Figure 4 clearly shows that the CO_2 emissions resulting from the production and use of urea for the baseline study produces the highest emissions, followed by N_2O emissions. The image pictorially identifies the sources requiring the reduction of CO_2 emissions.

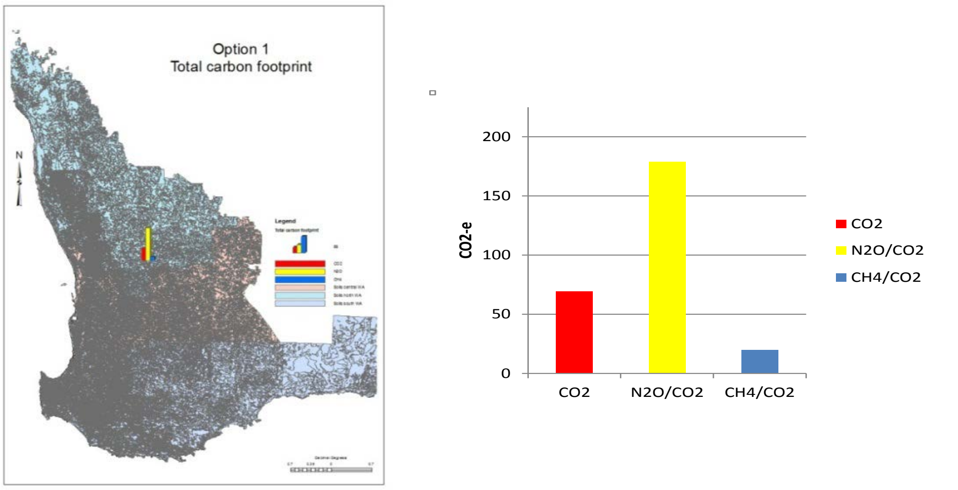


Baseline Study

Figure 4. GIS image for the baseline study showing the bar graph at the study location

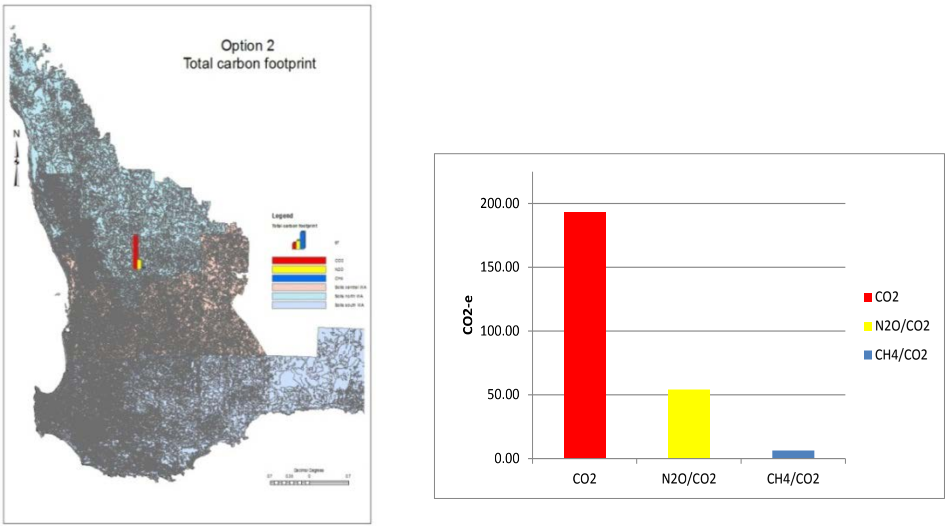
Figure 5 presents option 1 wherein the production and use of urea was replaced with the production and use of manure. It can be noted when comparing Figure 5 with Figure 3 that the CO_2 emissions have been reduced considerably, yet the N_2O emissions have increased. Overall the total CF is still less in this option than in the baseline assessment (Table 2 and Table 3).

The mitigation CF resulting from crop rotation is depicted in Figure 6. When compared to Figure 4 and Figure 5 it becomes apparent that the CO_2 and N_2O emissions have decreased in option 2.



Option 1

Figure 5. GIS image for mitigation option 1 showing the bar graph at the study location



Option 2

Figure 6. GIS image for mitigation option 2 showing the bar graph at the study location

When comparing the results in Figures 4-6 with those in the graphs in Figure 3, it appears that the IST tool can assist with the identification of the hotspots at a glance. It also clearly shows that the mitigation measures if applied at that location could be effective. If more than one set of data is presented it will be able to clearly identify at which locality which specific GHG is concerning and if the data is broken down into smaller categories (e.g. chemical emissions, machinery emissions etc. as in Figure 3) and layers generated for each of these, it will even aid with the identification of other aspects (such as individual GHGs, eutrophication and other impacts) at each locality.

CONCLUSIONS

If the agricultural sector is required to reduce GHG emissions in the future, effective methods and policies need to be developed and implemented into each stag,e using methods such as CP outlined above. Integrated with these methods the use of IST framework can serve an important purpose in highlighting the areas of concern and the concerning factor, thereby identifying and mapping the GHGs and proposing applicable mitigation measures. Furthermore, IST based approach generates images (at paddock and farm scale) highlighting the spatial distribution of crops along the rainfall gradient and thereby provides information that will enable farm enterprises to reduce their CF using specific management practices. Considering the current carbon-constrained economy, the framework has been developed to address only CF modelling, but will later be extended to include other relevant impacts identified during the LCA, such as water scarcity, land use changes etc.

Down the track, by evaluating the sensitivity of the proposed approach in different agro-ecological zones and varying rainfall gradient can lead to the development of an automated tool where grain farmers can be in a position to evaluate their cost efficiency pertinent to the farm management practices adopted for specific farming operations at paddock, farm, catchment and regional scales, using handheld based information and communication technologies e.g, i-phone, PDA or online PC.

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