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Abstract: Abstract
The International Panel on Climate Change (IPCC) predicts an increase of 0.2 °C per decade for the next two decades in global temperatures and a rise of between 1.5-4.5 °C by the year 2100. Related to the increase in world temperatures is the increase in Greenhouse Gases (GHGs) which are primarily made up of carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and fluorinated gases. In 2004, the GHGs from agriculture contributed 14 % of the overall global GHGs made up mainly of methane (CH4) and nitrous oxide (N2O) emissions. In Australia, the dominant source of CH4 and N2O emissions for the year ending June 2012 was found to be from the agricultural sector. With the recent introduction of the Clean Energy Act 2011, the agricultural sector of Australia is expected 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) framework by linking Life Cycle Assessment (LCA), Remote Sensing (RS) and Geographical Information Systems (GIS). The IST approach also integrates and highlights the use of Cleaner Production (CP) strategies for the formulation and application of cost-effective GHG mitigation options for grain production in Western Australia (WA). In this study, the IST framework was tested using data from an existing study (the baseline study) and two mitigation options. The analysis results revealed production and use of fertiliser as the "hotspot", and for mitigation purposes was replaced with pig manure in option 1, whereas option 2 emphasised crop rotation system/s.

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Journal of Cleaner Production

Dear Dr Meyer

In reference to your correspondence dated 12 May, we are thankful for the detailed comments provided by the referees for our paper entitled "**An evaluation of Integrated Spatial Technology framework for Greenhouse Gas mitigation in Western Australia**".

When considering the comments from yourself and reviewer 1 we have rewritten parts of this manuscript, concentrating mainly on clarifying the LCA concern raised. We have also changed the title now to "**An evaluation of Integrated Spatial Technology framework for Greenhouse Gas mitigation in Grain Production in Western Australia**".

Following the reviewers' comments, we have clarified further that our current LCA is best termed as streamlined LCA as it does not take into account downstream activities and thus we have limited the scope to the production of one tonne of wheat. A cradle-to-grave was not conducted as this streamlined LCA focuses only on the GHGs originating from the pre-farm and on-farm activities and endeavours to provide a structure for the grain growers to mitigate these GHGs. Also this LCA concentrated only on carbon footprints/global warming impacts due to the recent climate change policy introduced in Australia.

In submitting this improved manuscript we hope that we have now addressed all the concerns raised and it will meet with your approval.

Best regards,

Deborah Engelbrecht

Wahid Biswas (Dr)

Waqar Ahamd (Dr)

Responses to Reviewer 1 comments

Reviewer #1: This paper has not been adequately revised. The authors failed to address the main concern made by all the reviewers about the approach. The reviewers made it very clear that they want a clear description of how LCA was not used since the focus is on GHGs and global warming. The paper is very misleading by referring to LCA and the need to "link" LCA to other tools but then not following the ISO standard approach that is referred to. Justification to focus on GHGs is not provided, as requested by the reviewers. The description of "other impacts" comes much too late in the paper.

Authors' response: We agree with the respected reviewer that we have not yet provided a clear description of how LCA was not used since the focus of our paper was on GHG emissions and also how ISO standard was used to conduct the LCA analysis.

Following the reviewers' comments, we have clarified further that our current LCA is best termed as streamlined LCA as it does not take into account downstream activities (inserted in page 6, lines 133-136). This LCA analysis considered all activities up to the production of wheat, which does not include the storage of grains in the retail outlet and the conversion of grains to different food items (e.g. bread, noodles). Also it does not consider the consumption stage (e.g. use of refrigerator at home) and the disposal of produce waste (e.g. left over in the bin) into landfill (possible methane emissions etc.).

We have clarified what a functional unit is and how it was used to carry out a mass balance in order to develop an inventory, which is a prerequisite for conducting an LCA analysis. Since GHG emissions have been considered as a high priority environmental impact, most of our LCA research focused on GHG emissions. We have discussed this issue on page 8 (Lines 175 -182). The functional unit of this LCA was one tonne of grain production and this functional unit was developed to assist grain farmer to reduce GHG emissions from grain production. This approach has been supported by Todd and Curran (1999), who have explained that the process of streamlining can be viewed as an inherent element of the scope-and-goal definition process.

Although the LCA has been designed to calculate nine environmental impacts, including eutrophication, acid rain, water pollution, land use, photochemical smog, solid waste, resource scarcity, global warming impact and ozone layer depletion which can result from the production of grains (Department of Climate Change, 2006), this current LCA has considered only the global warming impact due to the Government's recent climate change policy (Carbon pricing) and Australia's commitment for meeting GHG emission targets. We have clearly stated this issue at the beginning of the paper (page 5, lines 87-106). Like Finkbeiner et al (2011), we have considered that the carbon footprint is an LCA with the limited focus on one impact category only, i.e. climate change. We have also referenced all methodological requirements and principles for applying the LCA to determine carbon footprint (page 8, lines 173-183). We have clearly stated these references in page 24 (line 551), 26 (line 595), 27 (line 609) and 28 (line 632)).

References included for responding the reviewers' comments are as follows:

Todd J.A. and Curran M.A. 1999. Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup. Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Pensacola, FL 32501-3370 Available at: ftp://cee.ce.cmu.edu/HSM/Public/WWW/lca-readings/streamlined-lca.pdf (Page 29, line 664)

Department of Climate Change, 2006. Australian methodology for the estimation of greenhouse gas emissions and sinks, Australian Government, Canberra. Page 25 (line 573)

Responses to Subject Editor's comments

Subject Editor: First, I apologise about the "percent" comment. I have never come across the English use (per cent) in my career. It goes to show you are never to old to learn something new.

Authors' response: Following the editor's comment, we have used percent throughout the paper.

Subject Editor: With regard to the revised manuscript, I have to agree with Reviewer #1.

Author's response: We have already responded to the reviewer's comments in the previous section.

Subject Editor: In places you mention a "life cycle approach".

Authors' response: We have checked this error throughout the paper.

Subject Editor: However you still describe your work (erroneously) as doing an LCA. For example, I'm guessing you only collected inventory related to GHGs. In LCA, the LCI should include all material flows. So you really didn't collect a LCI. Instead, you collected life cycle GHG data. I believe the reviewers (and I) are wanting you to either better define how the proposed methodology will use full ISO LCA (all impacts), or remove the discussion of ISO LCA and describe your work as a new carbon footprint (CF) tool.

Authors' response: We agree with both the Subject Editor and reviewer one's comments. As we have explained in the response in the previous section, we have classified our carbon footprint analysis as a streamlined LCA and we have provided reasons for assessing the global warming impact. We have also referenced other published articles which have used both the streamlined LCA and the full LCA for assessing global warming impact or carbon footprints only. A list of these articles is detailed below:

> W. K. Biswas, L. Barton and D. Carter (2011). Biodiesel Production in a Semiarid Environment: A Life Cycle Assessment Approach, Environ. Sci. Technol., 45 (7), pp 3069–3074
>
> W. K. Biswas, J. Graham, K. Kelly and M. B. John (2010), Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia- A life cycle assessment, Journal of Cleaner Production, Vol 18 (14), pp. 1386-1392
>
> W. K. Biswas, L. Barton and D. Carter (2008). Global warming potential of wheat production in South Western Australia: A life cycle assessment. Journal of Water and Environmental Management, Vol 22, pp. 206 – 216.
>
> Grant, T. and Beer T. (2008): Life Cycle Assessment of Greenhouse Gas Emissions from Irrigated Maize and their Significance in the Value Chain, Australian Journal of Experimental Agriculture, 48, 375–381.
>
> P. Brock, P. Madden, G. Schwenke, D. Herridge (2012), Greenhouse gas emissions profile for 1 tonne of wheat produced in Central Zone (East) New South Wales: a life cycle assessment approach Crop Pasture Sci., 63, 319–329
>
> M. Gunady, W. Biswas, V. A. Solah and A. P. James (2012) Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactuca sativa), and button mushrooms

(Agaricus bisporus) in Western Australia using life cycle analysis (LCA), Journal of Cleaner Production 28, 81–87.

E Ghafooria, P C. Flynna and M. D Checkela 2006 Global Warming Impact of Electricity Generation from Beef Cattle Manure: A Life Cycle Assessment Study International Journal of Green Energy 3, 257–270

Seungdo Kim, Bruce E. Dale, Robin Jenkins (2009) Life cycle assessment of corn grain and corn stover in the United States, The International Journal of Life Cycle Assessment 14 (2), 160-174

The reason we did not include the material flow chart was that we used the results from Biswas et al (2008) for testing this IST framework. However, we have clearly mentioned on page 12 (lines 260-276) that it was required to estimate the quantitative values of inputs and outputs of all processes associated with the production of 1 tonne of wheat production.

According to Todd and Curran (1999), the process of streamlining can be viewed as an inherent element of the scope-and-goal definition process. Since the purpose of this SLCA is to provide mitigation strategies for providing mitigation strategies for the grain farmers, the scope or boundary of this research is limited to one tonne of wheat production. With due respect, we would like to mention that we have followed the LCA approach that one of our co-authors Wahidul Biswas and other LCA researchers have applied for assessing the single impact which is the carbon footprint or global warming potential of agricultural production in Australia for different functional units and system boundaries. Some of these publications that we have already referred in this paper (Page 9, line 181)

Subject Editor: Also, I tend to agree with the reviewers that you have established a reference flow and not a functional unit. What is the function of the produced wheat?

Author’s response: Our system boundary is limited to farm gate. We have not considered any activities after the harvesting of wheat. Since our research focused on grain production only, we have not considered any grain made product such as bread, noodles etc. We have considered a 1 tonne equivalent of wheat production as a functional unit for developing an inventory of this LCA analysis. Since we did not complete the fieldwork prior to the writing of this paper, we have used data from a published article to test this framework.

Subject Editor: Is it for a specific food? What GHGs are associated with achieving this function. How is the wheat processed? How is the food transported and consumed? Is it cooked with electricity or gas?

Authors’ response: As we have mentioned before, we did not consider the post-farm stage including the storage of wheat, transportation of wheat and then processing it into different products. This methodology has only been developed for the grain growers for mitigating GHG emissions. However, we have now clearly stated this in the introduction section of the paper (page 6, lines 110-112).

Subject Editor: All of these processes should be included in the life cycle GHG emissions if you are doing ISO LCA (cradle to grave). That's why it's important to formulate a "functional" unit and not a reference flow for LCA. You only look at the raw material stage and exclude the manufacturing, use and disposal which are crucial to a true LCA.

Author’s response: We have not conducted cradle to grave LCA but this streamlined LCA was meant to be done for the grain growers. Also we agree with the reviewer that our approach does not follow ISO 14040-44 as this guideline takes into account all stages from mining to disposal or cradle to grave.

We needed to consider a functional unit for our proposed IST framework as the functional unit was the basis for calculating inputs and outputs of different processes of the production of 1 tonne of wheat. Since we used Biswas et al. (2008) LCA results, we did not need to show how Biswas had developed the inventory of chemicals and energy for determining carbon footprints results. However, we have now clearly mentioned in the paper that the results of carbon footprints in Biswas’ paper were obtained through the development of an LCI, which consists of the amount of inputs and outputs for producing 1 tonne of wheat – the functional unit of this LCA. We have clearly mentioned in the paper that a mass balance or material flow chart is required for developing an inventory.

Subject Editor: For me to accept this manuscript, you must address this concern.

Authors’ response: We believe we have tried our best to respond all reviewers’ useful comments in an appropriate matter.

Amount of words: 8326

An Evaluation of Integrated Spatial Technology Framework for Greenhouse Gas Mitigation in Grain Production in Western Australia.

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Abstract

The International Panel on Climate Change (IPCC) predicts an increase of 0.2 °C per decade for the next two decades in global temperatures and a rise of between 1.5-4.5 °C by the year 2100. Related to the increase in world temperatures is the increase in Greenhouse Gases (GHGs) which are primarily made up of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and fluorinated gases. In 2004, the GHGs from agriculture contributed 14 % of the overall global GHGs made up mainly of methane (CH_4) and nitrous oxide (N_2O) emissions. In Australia, the dominant source of CH_4 and N_2O emissions for the year ending June 2012 was found to be from the agricultural sector. With the recent introduction of the Clean Energy Act 2011, the agricultural sector of Australia is expected 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) framework by linking Life Cycle Assessment (LCA), Remote Sensing (RS) and Geographical Information Systems (GIS). The IST approach also integrates and highlights the use of Cleaner Production (CP) strategies for the formulation and application of cost-effective GHG mitigation options for grain production in Western Australia (WA). In this study, the IST framework was tested using data from an existing study (the baseline study) and two mitigation options. The analysis results revealed production and use of fertiliser as the "hotspot", and for mitigation purposes was replaced with pig manure in option 1, whereas option 2 emphasised crop rotation system/s.

Keywords: Remote sensing; geographical information systems; life cycle assessment; integrated spatial technology; agriculture; carbon footprint

Abbreviations:

CFI	Carbon farming initiative
CH_4	methane
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalents
CP	Cleaner Production
DAFWA	Department of Agriculture and Food, Western Australia
GHG	Greenhouse Gas

GIS	Geographical Information Systems
IPCC	International Panel on Climate Change
IST	Integrated Spatial Technology
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
N_2O	nitrous oxide
RS	Remote Sensing
SLCA	Streamlined LCA
SPOT	Systeme Pour l’Observation de la Terre
WA	Western Australia

1. Introduction

The International Panel on Climate Change (IPCC) predicts an increase of 0.2 °C per decade for the next two decades in global temperatures and rise of between 1.5-4.5 °C by the year 2100 (IPCC, 2007). According to the World Bank these higher temperatures can cause changes in precipitation, rising sea levels and weather-related disasters which in turn can pose risks for agriculture, food and water supplies (World Bank, 2012). Related to the increase in world temperatures is the increase in greenhouse gases(GHGs) which are primarily made up of CO_2, N_2O, CH_4 and fluorinated gases (EPA, 2013).

In 2004, the GHGs from agriculture contributed 14 % of the overall global GHGs made up mainly of CH_4 and N_2O emissions (EPA, 2013). The GHGs originate from the use and production of agrochemicals, such as fertilisers, along with the use of other agricultural inputs (such as agrochemicals) and farm machinery operations (Adler *et al*., 2007; Anderson, 2011; CSIRO, 2010; Ugalde *et al*, 2007).

In Australia, the dominant source of CH_4 and N_2O emissions is agriculture, accounting for 16 % (86.5 Million Tons (Mt) CO_2-e (carbon dioxide equivalents)) of total national GHG emissions in 2010 and 16.4 % (90.1 Mt CO_2-e) for year ending June 2012. The total national GHG emissions for 2012 were 551 Mt CO_2-e (AuGOV, 2012, DCCEE, 2012). For 2010 these agricultural GHG emissions can be attributed to enteric fermentation in livestock (67 % of agricultural GHG emissions), manure management (4 % of agricultural GHG emissions), rice cultivation (0.2 % of agricultural GHG emissions), agricultural soils (17 % of agricultural GHG emissions), savannah burning (11 % of agricultural GHG emissions) and field burning of agricultural residues (0.4 % of agricultural GHG emissions) (NGGI, 2012; DCCEE, 2013).

The production of grain in WA, despite its legacy of poor soils and low rainfall, has resulted in 40-50 % of the annual grains production for Australia. This growth is concentrated in the Wheatbelt areas where mostly wheat, barley and lupins are produced (ABS, 2006; Biswas *et al.*, 2008; DLGRG, 2007; Islam, 2009; van Gool, 2009).

In July 2012, the Australian government commenced with carbon pricing by introducing the Clean Energy Act 2011 (CEA, 2011). This act is directed to respond to the climate change impacts by reducing environmental pollution and to drive the transformation of the Australian economy to a clean energy future (CEA, 2011; CELP, 2012; Johnson, 2011; Packham and Vasek, 2011). Within this act, a Carbon Farming Initiative (CFI) has been designed specifically for the land sector to reduce pollution and to manage the impact of climate change on the Australian economy and landscape (CFI, 2012). This initiative has been designed for farmers and landholders to generate carbon credits and sell these credits in the carbon market. It is anticipated that the CFI will create a new source of revenue by implementing projects that restore degraded soils and landscapes or the adoption of farm management practices that build carbon stores and reduces harmful greenhouse gases (CFI, 2012). Currently, the approved methodologies for the CFI include manure management in piggeries, establishing environmental plantings, the capture and combustion of landfill gas and the management of savannah fires, but others may be proposed in the future (CFI, 2012).

As the worldwide population escalates and more pressure is applied to farmers for increased agricultural productivity, management of their carbon footprint (or life cycle GHG emissions) becomes paramount (Biswas *et al.*, 2010; NGGI, 2010). Without negating the importance of these above-mentioned methodologies other options should also be investigated and developed to assist farmers to reduce their pollution and manage their carbon footprint, thereby generating carbon credits and reducing harmful GHG emissions. The implementation of carbon footprint mitigation and CP strategies into all facets of agricultural production, especially grain production, could assist in reducing chemical and fertiliser use, transportation costs, energy use and in the quantification of the environmental benefits pertinent to the overall Australian production systems. Thus, this research has attempted to develop a tool for grain growers and policy makers to mitigate GHG emissions from grain production.

Numerous environmental management tools, including Life Cycle Assessment (LCA), Remote Sensing (RS) and Geographical Information Systems (GIS) have been widely-used, separately, to address the aforementioned GHG mitigation issues (Ahammed and Nixon, 2006; Biswas, *et al.*, 2008; Grant and Beer, 2008; Biswas *et al.*, 2010; Biswas *et al.*, 2011; Yousefi-Sahzabi et al., 2011). However, the integration of these tools could possibly offer accurate but also time and cost effective means for assessing GHG mitigation strategies from the agricultural sector and therefore warrants further investigation. The Integrated Spatial Technology (IST) framework has been developed to integrate these tools with CP strategies to aid with the formulation and application of cost-effective GHG mitigation options pertinent to the WA grain industry. As part of the IST, an internet site which calculates the carbon footprint will be developed. This internet site will allow farmers to select different combinations of inputs (chemicals, machinery etc.) at different farming stages (pre-farm, on-farm) thereby allowing them to make informed choices based on soil type, farm management practices and climate. The IST will initially only focus on calculating and presenting the carbon footprint in an easily understandable manner but may later be extended to include other environmental impacts.

The IST framework (Figure 1) primarily consists of two stages. Stage one involves the use of remotely sensed data originating from the satellite images and aerial photographs as an input to a GIS. In the GIS other data layers such as paddock and farm boundaries, corresponding rainfall, temperature, soil types and administrative shire boundaries are stored.

Stage two involves the application of a Streamlined LCA (SLCA)-based approach to calculate the carbon footprint of the paddock. The SLCA approach has been considered as current research which considered cradle-to-gate studies, ignored activities after the production stage (Todd & Curran, 1999). This carbon footprint is integrated with RS-based GIS so that CP strategies are able to be identified as mitigation measures for the quantification of environmentally benign and cost-effective farm management practices for the selected paddocks.

Figure 1. Flow diagram showing Integrated Spatial Technology Approach

RS is defined as the science and art of obtaining information about various objects (targets) on earth with the help of a device placed onboard a number of aerial and space-borne platforms. Remotely sensed data are being used worldwide for a number of agricultural and livestock applications including crop area estimation, crop type identification, crop yield estimation and crop sequence monitoring and pastures growth rates (Lillesand *et al.*, 2004; Mkhabela et al.; 2011; Mo et al., 2005; Peña-Barragán, 2011; Yang et al. 2011; Donald et al., 2012). GIS on the other hand, has emerged as a tool for capturing, editing and analysing multi-layered environmental and ancillary data layers along with its geographic location and temporal variation. This tool enables diversified users to establish and analyse scientific relationships between different data layers entered into the database (Lillesand *et al.*, 2004). Integration of RS data with GIS enables the user to generate varied scale outputs. These outputs may vary across paddock[1], farm[2], shire [3]and larger [4]administrative boundaries and

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[1] A paddock is field or plot of land, on a farm, enclosed by fencing or defined by natural boundaries. Livestock or different crops can be raised or grown on each (Oxford, 2013).

[2] A farm is an area of land (within the shire) and its buildings, used for growing crops and rearing animals (Oxford, 2013)

[3] A shire is a rural district having its own local council (Dict, 2013). Each state and territory is made up of a number of shires.

[4] The administrative boundaries of Australia are made up of the six states with their own constitution, namely Western Australia, New South Wales, Queensland, South Australia, Tasmania, Victoria and two states with limited self-governance, namely Australian Capital Territory Northern Territory (AusGov, 2013)

can be used to illustrate a wide variety of geo-referenced data layers such as agricultural practices, climatic zones, soil types, agricultural crops and pasture types and its temporal and spatial distributions. 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 the European agriculture (Freibauer, 2003).

LCA is a tool for the systematic evaluation of the environmental impacts of a product or service system through all stages of its life cycle i.e. from the raw material acquisition, through production and use to waste management. It is used to evaluate and implement opportunities to bring about environmental improvements by comparing existing products and developing new products (ISO, 2006). It has been used by various researchers in the agricultural sector to investigate aspects such as N_2O emissions from nitrogen fertiliser applications, methane emissions from livestock, CO_2 emissions arising from agricultural energy use, CO_2 emissions from vegetation sinks and the manufacture of products such as corn chips following the production of maize (Barton &Biswas, 2008; Barton et al., 2011; CLAN, 2006; Grant & Beer, 2008; GRDC, 2011). The SLCA (Streamlined LCA) is accomplished by limiting the scope of the study (e.g. determining the GHG emissions from one tonne of wheat production instead of one loaf of bread production) in order to support decision making for a particular group (Todd & Curran, 1999). The current research has applied this SLCA approach to enable grain growers, who are in the middle of the supply chain, to take appropriate strategies for mitigating GHG emissions from grain production. There are other environmental impacts, such as eutrophication, acid rain, eco-toxicity, water pollution, which may result from the production of these products, (Alder et al, 2007; Finnveden et al., 2009) however, only global warming impacts have been considered because of governments recent climate change policy (carbon pricing) and Australia’s commitment for meeting GHG emission targets (DCC, 2006). Like Finkbeiner et al (2011), this research considers carbon footprints in terms of an LCA, with the limited focus on one impact category only, i.e. climate change. All methodological requirements and principles of the LCA can be applied to estimate carbon footprints, as evidenced by local and international literature (Biswas et al. 2008; Biswas et al. 2010; Biswas et al. 2011; Brock et al. 2012; Grant and Beer, 2008; Finkbeiner et al. 2011; Ghafooria et al. 2006; Gunady et al. 2012; Kim et al. 2009).

Cleaner production attempts to reduce wastes and emissions at the source by making more efficient use of natural resources. CP production is the continuous application of an integrated preventative environmental strategy to process, products and services to increase efficiency and reduce risks to humans and the environment (van Berkel, 2002). Prevention practices generally employed to bring about CP are 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) (Biswas et al., 2010; van Berkel, 2002; van Berkel 2007). By integrating CP into the IST framework, users could select alternatives which focus on one or more of the above mentioned practices. Thereby they should be able to ascertain whether, for example, by choosing an alternative product, or a product using a different production method, their carbon footprint could be altered.

The following sections present the development of the IST framework, the testing of the framework using a hypothetical example, the results obtained for the hypothetical example and conclusions and recommendations.

2. Methods and materials

The methodology is presented as two separate sections. In the first section the theoretical IST framework methodology is explained and the progress in the development thereof detailed.

The second section makes use of data from a case study to illustrate the workability of the IST framework.

2.1. Outline of the Integrated Spatial Technology Framework Methodology

Currently, the above mentioned IST framework is being developed in collaboration with the Department of Agriculture and Food Western Australia (DAFWA) and some farmers in the central Wheatbelt region of WA. This IST framework involves three key steps i.e. data collection, data processing and data integration.

Prior to and divorced from the IST development, DAFWA initiated a comprehensive crop sequencing project involving 144 paddocks located across different rainfall zones of WA. This crop sequencing project is scheduled to collect and analyse data over a period of five years (2010-2015). To ascertain a true picture of the factors of production used and specific management practices applied for the production of agricultural crops, structured questionnaires were prepared by the DAFWA field staff and distributed (for years 2010-2012) to all participating farmers for each selected paddock. These questionnaires provide data on critical aspects of farming and farm management practices such as paddock and farm details, land preparation methods, seed and sowing information, farm machinery use, chemical use, fertiliser use, crop rotations and the consequent crop yields obtained specific to the adopted farm management practices.

For the evaluation of the IST framework, 44 paddocks were selected by DAFWA from the initial 144 paddocks and geographic locations provided. The geographic locations for these 44 paddocks were registered on two medium resolution SPOT (Systeme Pour l'Observation de la Terre) satellite images acquired in September 2012. This registration allowed for the identification of a final sample of 24 paddocks (nine farmers) falling within the boundaries of the satellite images.

DAFWA provided the crop sequencing questionnaires to be used in the IST framework validation for this final sample of 24 paddocks. All applicable data was extracted from the crop sequencing questionnaires and an additional primary data collection questionnaire was generated and distributed. This second questionnaire addressed data required for the IST framework that was not included in the initial crop sequencing questionnaire. Overall the data requirements from both questionnaires included detailed information (paddock-wise) on the inputs used and management practices applied for the production of different crops for 2010-2011. Additionally, face to face interviews and field site visits were scheduled (November 2012) to discuss these questionnaires and to collect field data using a hand-held GPS and multispectral radiometer. These field-based data sets will be used as an input for the classification of remotely sensed data i.e. the identification and mapping of agricultural crops at specific paddock and farm levels as well as for input for carbon footprint calculations in the SLCA.

The second step of the IST framework focuses on the processing of the collected data in three tiers. Firstly, using advanced digital image processing methods and GIS analysis, a series of ground control points will be identified in 2013, from the satellite images, aerial photographs and 1:50 000 topographic maps of the study area. This will enable the accurate demarcation of individual paddocks and farm boundaries on remotely sensed images. This in turn will allow the application of advanced image classification techniques (Lillesand et al, 2004) for the identification, mapping, quantification and accuracy assessment of agricultural crops sown by the participating farmers during the 2012 crop calendar. With the advent of medium to high resolution remotely sensed images with improved spatial (sub-meter) and spectral resolution, and the introduction of advanced digital image processing techniques, this has enabled scientists to accurately identify and map agricultural crops at paddock and farm level (Ahmad, 2010; Ahmad et al., 2010).

Secondly, working in a GIS environment, the RS data based crops classification results will be cross-checked (overlayed) with the paddock-wise detailed information provided by the participating farmers and the ground-data collected during field surveys. Using the above mentioned data layers, the subsample i.e. 24 paddocks will be stratified according to the rainfall gradient, soil type and specific farm management practices such as minimum till, crop rotation etc., adapted for the production of agricultural crops (e.g. wheat, barley, lupin, peas and oats etc.). This attempt will result in an inventory list describing full details of inputs used and outputs produced at a paddock and or farm level along with the details of farm management practices applied.

Thereafter, in the next tier, the following four steps were conducted to carry out the SLCA (Biswas et al. 2008; Gunady et al. 2012): 1) goal and scope definition; 2) inventory analysis; 3) impact assessment; and 4) interpretation (as presented in the 'Results' section of this paper).

The goal was to mitigate the GHG emissions from the grain production under different soil and climatic conditions. This was achieved by establishing the functional unit, which is the production of one tonne of grain. This functional unit helps carry out a mass balance for developing a life cycle inventory (LCI). A life cycle inventory (LCI) consists of totalling the amount of each input (e.g. fertilizers, pesticides, machinery etc.) and output (e.g. crop yield, emissions) for processes which occur during the life cycle of a product. Undertaking an LCI is a necessary initial step in order to carry out a carbon footprint analysis.

The input and output data in LCI were inserted into the Simapro 7.3 software, a software program developed by Pré -Consultants in the Netherlands, to calculate GHG from, or carbon footprint of wheat production. The carbon footprint assessment of wheat production for pre-farm and on-farm activities included two stages. The first calculated all the GHG emissions produced in each process and the second converted these gases (CO_2, CH_4, N_2O) to CO_2

equivalents (Biswas et al., 2008). The input/output data of LCI were linked to relevant emission databases in Simapro 7.3. The Australian GHG emission database for agricultural inputs will be used to calculate the GHG emissions from the grain industries. Where emission factors are not available in the Australian database, other databases such as the EcoInvent database or CML methodology, will be used as surrogates for calculating equivalent values, alternatively equivalent values will be calculated using manufacturer supplied data. As part of the SLCA approach flow diagrams will be generated to illustrate all inputs used (e.g. fertilizers, pesticides, machinery etc.) and outputs produced (e.g. crop yield, emissions) in the life cycle stages of crops production. Normally an impact assessment assesses about nine environmental impacts and forms part of the SLCA, but will not be included here as the focus is on global warming impact (or carbon footprint) only. The SLCA has been used here as a tool to capture all GHG emissions in the product cycle.

The last stage of this framework involves the integration of carbon footprint information with the RS- and GIS-based database. This will allow for the identification and reporting of the geographic location of the most significant "hotspots". Such a database also allows the scientific analysis and evaluation of the alternative mitigation measures pertinent to different production zones. Finally, the LCI-based data will be fed into a RS and GIS database to determine and map the spatial distribution of agricultural system related carbon footprints for different zones prevalent in the sample used. Such a consolidated IST database analysis will assist in generating geo-referenced hotspots (carbon footprints) for the selected paddocks and farms. The final output may be produced, using colour graduated schemes or bar graphs for the agro-ecological zone, farm management practices and corresponding carbon footprints.

The above mentioned approach provides a feasible framework to accurately identify and quantify dynamic carbon footprints. Therefore with IST, natural resource managers will be equipped with a tool to evaluate alternative mitigation strategies for different agro-ecological and environmental zones, enabling thereby reduced carbon footprints with a minimum level of GHG emissions and the identification of CP strategies to be incorporated into the WA production system pertinent to specific agronomic environments.

2.2. Application of IST methodology to an existing case study

Workability of the above explained IST framework was evaluated for the identification of appropriate farm management practices for wheat production in a WA based case study. This was carried out by using datasets associated with a previously completed study by Biswas et al, (2008), here named as the baseline study. The datasets involved are pertinent to a small paddock area and may not be representative of a larger West Australian based zone but are considered sufficient to test IST workability.

Using the given geographical co-ordinates from Biswas et al., (2008) the generalised location of the study area was identified using RS methods (Figure 2a) and marked with a yellow circle. By clicking on the yellow marker and allowing the software to enlarge (zoom in) the area, the detailed location and shape of the paddock was highlighted (Figure 2b). In Biswas et al. (2008) the area was identified as having a semi-arid climate with an annual rainfall of 368 mm, which mainly falls in the winter months. Mean daily temperatures varied between 11.4 – 25.1 °C. The soil is free draining sandy soil overlying poor draining clay (Biswas et al., (2008). In the IST framework, as different data layers and attribute data sets are geo-referenced, just by "clicking" on the yellow circle users would be able to display the full features of the target study area in terms of its exact location, size, soil type, rainfall, crops grown, management practices applied etc.

Figure 2. Geographic location of the baseline study paddock.

For this paddock Biswas et al., (2008) quantified CO_2, N_2O and CH_4 emissions associated with per tonne of wheat produced at the [5]pre-farm, [6]on-farm stages and [7]post-farm stages of production. In testing the IST framework only the pre-farm and on-farm stages were considered (Figure 3). In the pre-farm stage the production of inputs (fertiliser, pesticides etc.), transportation of inputs and manufacture of farm machinery were quantified. In the on-farm stage, land preparation, the use of farm machinery and paddock emissions were studied (Biswas et al. 2008) (Figure 2a-b). The goal and scope for this project was the reduction of the carbon footprint resulting from the WA grain industry and was limited to pre-farm and on-farm (cradle to gate) activities. The system boundary was determined to be a specific paddock in the agricultural region of Cunderdin, Western Australia (WA), as referred to above. For the baseline study, the functional unit (e.g. GHG emissions from 1 tonne of wheat production from 0.37 ha) was fixed and the corresponding factors of production and data requirements (i.e. chemicals, energy, emissions etc.) decided on (Biswas et al., 2008).

Figure 3. Life cycle inventory diagram showing the inputs and outputs for the pre-farm and on-farm stages.

In compiling and calculating the inventory the relevant emission factors were mostly obtained from the Australian Life Cycle Inventory database for the production of chemical inputs such as pesticides and fertilisers. As no emission factor was available for super-phosphate it was generated by obtaining required information from the phosphate manufacturer. A USA input-output database was used to assess the GHGs from the manufacture of farm machinery and the Australian LCA database was used for farm machinery operation (Biswas et al., 2008). The CO_2, N_2O and CH_4 emissions of inputs and

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[5] Pre-farm includes all processes, such as soil preparation, chemical production, machinery production, chemical applications etc. required up to the sowing of the seed

[6] On-farm includes all emissions resulting from the growing of the crops as well as the use of required machinery for chemical applications and harvesting

[7] The post-farm stage includes emissions resulting after the harvesting of the crop for e.g. from electricity required for storage purposes

outputs were converted to CO_2 equivalents (CO_2-e) by multiplying the measured value with the current conversion factors, (1 for CO_2, 25 for CH_4 and 298 for N_2O) (CC, 2013; IPCC, 2007a). These CO_2-e values of all inputs and outputs were then summed to determine the resulting carbon footprint. These CO_2–e values of inputs and outputs enabled the identification of ‘hotspots’ or inputs or outputs causing the significant emissions.

Associated literature review (Biswas 2011; Chadwick et al., 2011; Hansen et al., 2006), presented two options that could be used to reduce GHG emissions from the baseline study. Option 1 included the use of organic fertiliser in the pre-farm stage, whereas option 2 involved crop rotation methods in the on-farm stage. Both of these options were applied for validating the workability of the IST framework.

Option 1 applied *input substitution,* i.e. the substitution of urea with organic fertilizer such as pig manure containing an equivalent amount of nitrogen. Data on GHG emissions during the anaerobic production of the pig manure were extracted from Hansen et al., (2006) and Chadwick et al., (2011). This data were applied to the baseline study with the underlying assumption that the pig manure produced is in close proximity to the paddock in question, the manure was distributed on the land using the same machinery used for fertiliser spreading and wheat yield was assumed to be the same as in the baseline scenario.

Option 2 considered wheat rotation with legumes (lupins) which is regarded worldwide as an established source of enhancing nitrogen in the soil (Shah et al, 2003; Biswas et al, 2011), termed a *good housekeeping* CP strategy (Biswas et al. 2011). The sowing of wheat after lupins harvest allows for the reduced application of urea fertilizer (Shah et al., 2003). For the baseline study, research reported by Bowden and Burgess, (1993) was used for assessing this mitigation strategy. It was assumed that the lupins yield on the paddock was

1.2 t/ha and the residual organic nitrogen from the lupin totalled 46 kg N/ha, thus for the following year the urea fertilizer usage could be reduced by 15.84%.

Using the geo-referenced location from the baseline study, the calculated values from both Option 1 and Option 2 were separately integrated into the RS and GIS based database. This allowed for the mapping of the carbon footprints of both options thus generating three datasets (baseline study, option 1 and option 2). These three datasets allowed the comparative analyses of all three options using the same consolidated output method.

3. Results

As to date there are no results available for the DAFWA-collaborated study, only the results for the validation of the IST framework, using a hypothetical example (integrated with a case study), are presented here.

The results obtained in the baseline study are tabulated in Table 1. These results show that most of the GHG emissions were generated in the pre-farm stage (134.34 kg CO_2-e vs 133.51 kg CO_2-e). In this stage the production and supply of urea was identified as a 'hotspot' (it has the highest overall GHG emissions) i.e. 37.48 % of the total GHG emissions and 74.73 % of the pre-farm GHG emissions. In order to reduce these GHG emissions the use of urea fertilizer required further investigation. In the on-farm stage, the CO_2 emissions from the paddock soil were due to urea hydrolysis and amounted to the highest of the on-farm emissions i.e.81 kg CO_2-e or 60.67 %. The examination of alternative mitigation measures which focused on the reduction of GHGs generated from the use of urea was therefore required.

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

Using input substitution the use of pig manure as fertiliser was considered for option 1 as expounded upon previously. Table 2 presents the results obtained when urea is substituted with pig manure in the same farming practice as the baseline study. Overall the results show that there is an insignificant change in the total CO_2-e when urea is substituted with pig manure, 267.84 kg CO2-e vs 67.81 kg CO2-e. However on closer inspection there is a reduction of 44.61 kg CO2-e in the pre-farm stage and an increase of 44.56 kg CO2-e in the on-farm stage.

Table 2. Calculated carbon footprint resulting from the use of mitigation strategies – option 1, product substitution

In option 2 the use of lupins as a crop rotation was considered, this allowed for the reduction in the application of urea. The results (Table 3) reveal an overall GHG emissions decrease of 5.38 % when compared to the baseline study. In this scenario the GHGs from the on-farm stage decreased from 133.51 kg CO2-e to 119.93 kg CO2-e (10.17 %) and in the pre-farm stage from 134.34 kg CO2-e to 133.50 kg CO2-e (0.63 %).

Table 3. Calculated carbon footprint resulting from the use of mitigation strategies – option 2, crop rotation

The results from all three options were entered into the IST for the generation of the output as depicted in Figures 4-5, and as discussed above. In Figures 4 a-c graphs are generated to facilitate the identification of the hotspots. In Figure 4a the CO_2 emissions from chemicals (production and supply) accounts for 50 % of the total emissions or 99.3 kg CO_2-e. Figure 4b portrays the emissions from option 1 in which manure replaces urea. It can be seen that the N_2O emissions from the paddocks is the highest in this scenario (52.4 kg CO_2-e or 57 %). In option 2, using a lupin-wheat rotation to reduce the use of urea, 99.3 kg CO_2-e for CO_2 emissions for chemical production and use is generated (52 %).

Figure 4. IST framework database output

The final figure (Figure 5) generated by the IST illustrates the pre-farm, on-farm stages and total CO_2-e emission values for all three options on one axis for comparison purposes. In this figure it is clear that in the pre-farm stage Option 1 has the least emissions (90 kg CO_2-e), in the on-farm stage Option 2 emits the least GHGs (120 kg CO_2-e) and overall the total GHG emissions for option 2 is the lowest (253 kg CO_2-e).

Figure 5. Comparative GHG output for the pre-farm, on-farm and total emissions

4. Discussions

The following discussion is based on the results obtained during the validation of the IST framework using the hypothetical example. As this study has not been carried out with the intention to explain the reasons behind the change in results, no explanation is given as to why there is a change in the emissions. The discussions focus on the workability of the IST framework.

The hypothetical testing of the IST framework, using a case study and calculated results from other projects, shows the successful integration of RS, GIS and SLCA with CP as mitigation measures. Figures 3a and 3b respectively show the location and shape of the paddock in question. Further multi-layer data manipulation of these figures could, for example, highlight unique characteristics of the study area. These characteristics could include amongst others soil type, management practices adapted, crop sequence used and/or the rainfall/temperature gradient for the study area.

The graphical output in the IST framework (Figures 4 a-c and Figure 5) was generated by clicking on the yellow circle in Figure 2b. The graphs highlighted in Figures 4-5 are based on the calculated results presented in Tables 1-3.

In each of the Figures 4 a-c the bar graph presents the GHG emissions for the baseline study, option 1 and option 2 by source (machinery, chemical (includes agro-chemicals and fertilisers), paddock and diesel emissions) and GHG emissions (CO_2, N_2O and CH_4). The baseline study results (Figure 4a) revealed that, the production of chemicals (including fertilisers) resulted in the highest emission of CO_2 as CO_2-e (99.3 kg CO_2-e). Option 1 (Figure 4b), showed N_2O emissions originating from the paddock as the hotspot (152.4 kg CO_2-e) whereas option 2 (Figure 4c), revealed chemical (including fertilisers) associated CO_2 emissions (99.3 kg CO_2-e) as the highest. When examining the baseline study (Table 1) it was observed that the CO_2 emissions accounted for 77.2 % of the total GHG emissions. It was also apparent that by altering one aspect in the production line it could change the consequent emissions of the individual GHGs. For example, by substituting N-fertilizer with an organic fertiliser the GHG paddock emissions may increase, but the GHG emissions from the other input agrochemicals decrease. Alternatively, by using crop sequencing methods (option 2) GHG chemical emissions may increase but GHG emissions from the paddock decrease.

Each emission category is also depicted as a part of a pie graph in Figures 4a-c. In each graph the CO_2-e are summed across all categories and shows GHG percentage contribution. By presenting the data as a pie graph the user is able to recognise the emission category with the most GHGs at a glance. For the baseline study the emissions arising from chemical production was the highest (50 %). For option 1 the paddock emissions resulted in 57 % of the total emissions and in option 2, the overall emissions from the production of chemicals (which includes fertilisers) was also the highest (52 %).

The analytical view of the bar graphs in Figure 4, reveal that the IST framework is a tool that can assist with the identification of the hotspots at micro (paddock) level and highlights the impact of alternative mitigation measures applied in reducing GHG emissions.

In Figure 5, nine resultant bars are grouped into the two stages namely pre-farm and on-farm GHG emissions and the third set of bars represents the sum of the GHG emissions from these two stages as CO_2-e. Analysis of the first set of bars (pre-farm) reveals that the highest GHG emissions are attributed to option 2 in the baseline study. As Option 1 generates the least GHG emissions the user could conclude that using pig-manure in the pre-farm stage would aid with the reduction of GHGs. The second set of bars represents the on-farm stage, with the highest emissions generated when pig manure is used and the least GHG emissions resulting from the use of a crop rotation system. As these results appear to be contradictory, the third set of results could be considered as they illustrate the sum of all of the stages. In this scenario the user could deduce that if crop rotation systems were used to produce the same amount of wheat, on the same area of land, as in the baseline study, the GHG emissions could be reduced by 9.4% (12 kg CO_2-e)

For this hypothetical example it can thus be concluded that by using the IST an alternative mitigation method could be selected. In this scenario it is apparent that if an alternative mitigation method was to be considered for the baseline study agricultural practice, that option 2 should be preferred over option 1.

5. Conclusions and recommendations

The introduction of Clean Energy Act 2011 and the CFI precipitates a need for the development of tools designed to assess mitigation measures in Agriculture. In this study an IST framework has been presented in which RS, GIS and SLCA are integrated to highlight carbon footprint hotspots and as a means for identifying the underlying contributing factors. The key feature of the proposed framework is its ability to be applied on a micro scale (paddock and/or farm level). This enables individual property holders to make a strategic decision to evaluate their farming activities thereby facilitating with the alteration of farming practices to reduce GHG emissions.

Theoretically, the IST framework has been developed to integrate environmental management tools to generate output which summarises various scenarios. It offers an alternative tool that can assist farmers with the identification of the hotspots at micro and macro level and shows that if mitigation measures are identified and applied, it could aid the farmer in reducing GHG emissions. Moreover when the data is broken down into smaller categories (e.g. chemical emissions, machinery emissions etc.) and the corresponding layers are generated for each of these categories, it could eventually even aid with the identification of other aspects (such as individual contribution to GHGs, eutrophication and other impacts) at a paddock level to larger scales. Other advantages include multi-layer data manipulation, for example the study area can be highlighted as per its unique characteristics such as mapping by soil type, management practices adapted, crop sequence used and/or the rainfall/temperature gradient in which the study area falls

Considering the current carbon-constrained economy, the framework has been developed to address only carbon footprint modelling, but has the potential to include other relevant impacts identified during the SLCA. These impacts could include aspects such as water scarcity, land use changes etc., and may also be applied to other primary industries sectors such as livestock and horticulture. It is envisaged that in future, the proposed IST framework may encourage the development of PC, PDA or iPhone based automated tools. Furthermore, future research could improve this framework by incorporating an economic analysis for determining the cost-effective GHG mitigations strategies.

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

Baseline	**Greenhouse gases**			**kg CO2-e***			**Total**
Stages	**CO2**	**N20**	**CH4**	**CO2**	**N2O**	**CH4**	**kg CO2-e**
	(kg)	**(kg)**	**(kg)**		**kg CO2-e**		
Pre-farm							
Farm Machinery Production	0.93	5E-05	1E-04	0.93	0.01	3E-03	0.95
Production and supply of urea	79.25	0.05	0.25	79.25	14.90	6.25	100.40
Production and supply of superphosphate	2.93			2.93			2.93
Production and supply of pesticide	17.15	0.04	0.04	17.14	11.92	1.00	30.06
Subtotal	***100.26***	***0.09***	***0.29***	***100.25***	***26.83***	***7.25***	***134.34***
On-farm							
N2O emissions from paddock (Barton et al. 2007)		0.09			26.82		26.82
CO2 emissions from paddock (IPCC 2006)	81.00			81.00			81.00
Diesel supply and utilization for spraying ferilizer	4.65	1E-04	6E-04	4.65	0.03	0.02	4.69
Diesel supply and utilization for spraying herbicide	2.32	5E-05	3E-04	2.32	0.01	0.01	2.34
Diesel supply and utilization for spraying seeds	9.24	2E-04	1E-03	9.24	0.06	0.03	9.32
Diesel supply and utilization for harvesting	9.24	2E-04	1E-03	9.24	0.06	0.03	9.32
Subtotal	***106.45***	***0.09***	***3E-03***	***106.45***	***26.98***	***0.07***	***133.51***
Grand Totals	**206.71**	**0.18**	**0.29**	**206.70**	**53.82**	**7.33**	**267.84**

*kg CO2-e : carbon dioxide equivalent

Source: adapted from Biswas et al, 2008

Table 2. Calculated carbon footprint resulting from the use of mitigation strategies – option 1, product substitution

Option 1	**Greenhouse gases**			**kg CO_2 equ-**			**Total**
Stages	**CO_2**	**N_20**	**CH_4**	**CO_2**	**N_2O**	**CH_4**	**kg CO2 equ-**
	(kg)	**(kg)**	**(kg)**		**kg CO2 eq-**		
Pre-farm							
Farm Machinery Production	0.93	5E-05	1E-04	0.93	0.01	3E-03	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			2.93			2.93
Production and supply of pesticide	17.15	0.04	0.04	17.14	11.92	1.00	30.06
Subtotal	***43.92***	***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
Diesel supply and utilization for spreading manure	4.65	1E-04	6E-04	4.64	0.03	0.02	4.68
Diesel supply and utilization for spraying herbicide	2.32	5E-05	3E-04	2.31	0.01	0.01	2.33
Diesel supply and utilization for spraying seeds	9.24	2E-04	1E-03	9.23	0.06	0.03	9.31
Diesel supply and utilization for harvesting	9.24	2E-04	1E-03	9.23	0.06	0.03	9.31
Subtotal	***25.45***	***0.51***	***3E-03***	***25.41***	***152.59***	***0.07***	***178.07***
Grand Totals	**69.37**	**0.60**	**0.79**	**69.32**	**178.74**	**19.75**	**267.81**

*kg CO2-e : carbon dioxide equivalent

Table 3. Calculated carbon footprint resulting from the use of mitigation strategies – option 2, crop rotation

Option 2	**Greenhouse gases**			**kg CO_2 equ-**			**Total**
Stages	**CO_2**	**N_20**	**CH_4**	**CO_2**	**N_2O**	**CH_4**	**kg CO2 equ-**
	(kg)	**(kg)**	**(kg)**		**kg CO2 eq-**		
Pre-farm							
Farm Machinery Production	0.93	5E-05	1E-04	0.93	0.01	3E-03	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			2.93			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			26.82		26.82
CO_2 emissions from paddock (IPCC 2006)	68.17			68.17			68.17
Diesel supply and utilization for spraying ferilizer	3.91	8E-05	5E-04	3.91	0.03	0.01	3.95
Diesel supply and utilization for spraying herbicide	2.32	5E-05	3E-04	2.32	0.01	0.01	2.34
Diesel supply and utilization for spraying seeds	9.24	2E-04	1E-03	9.24	0.06	0.03	9.32
Diesel supply and utilization for harvesting	9.24	2E-04	1E-03	9.24	0.06	0.03	9.32
Subtotal	***92.88***	***0.09***	***3E-03***	***92.88***	***26.98***	***0.07***	***119.93***
Grand Totals	**180.59**	**0.18**	**0.25**	**193.13**	**53.96**	**6.33**	**253.43**

*kg CO2-e : carbon dioxide equivalent

Figure 1. Flow diagram showing Integrated Spatial Technology Approach

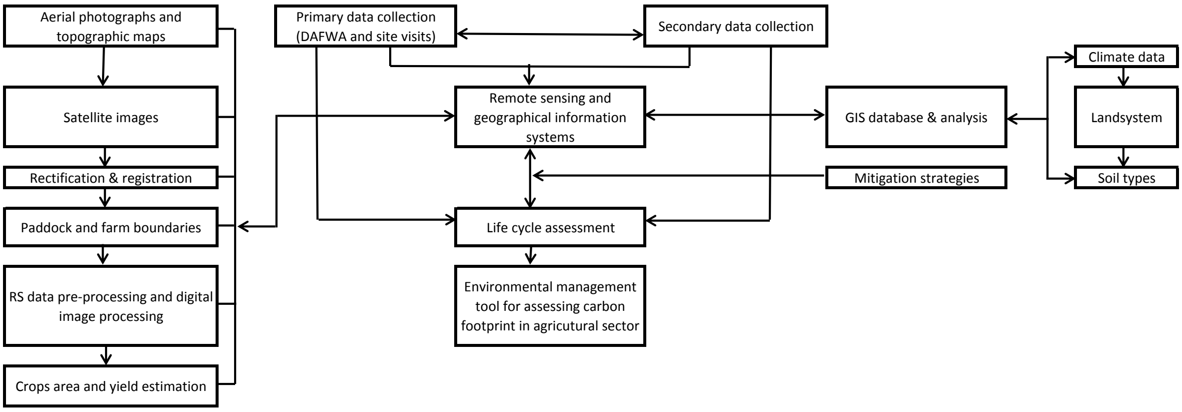
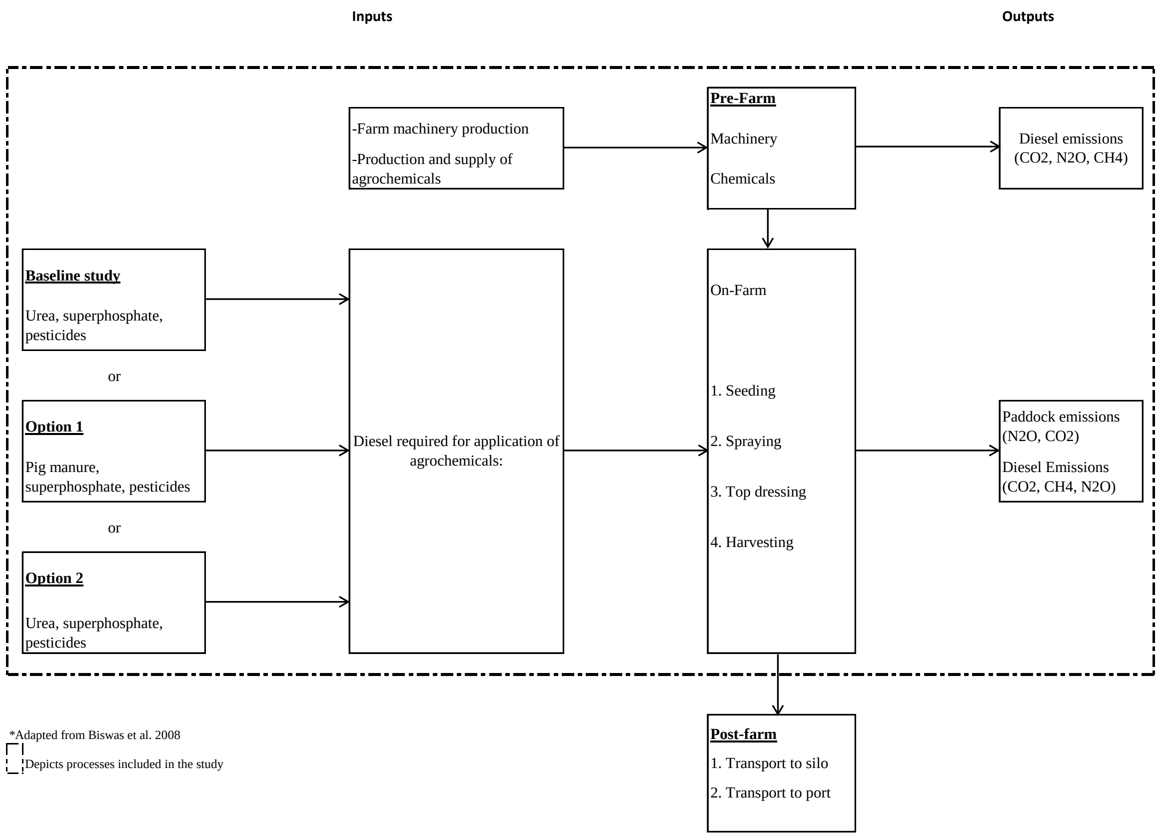


Figure 2. Geographic location of the baseline study paddock.

a) Geographic location of the base line study area in Western Australia.

b) Exact location of the paddock used for the baseline study.

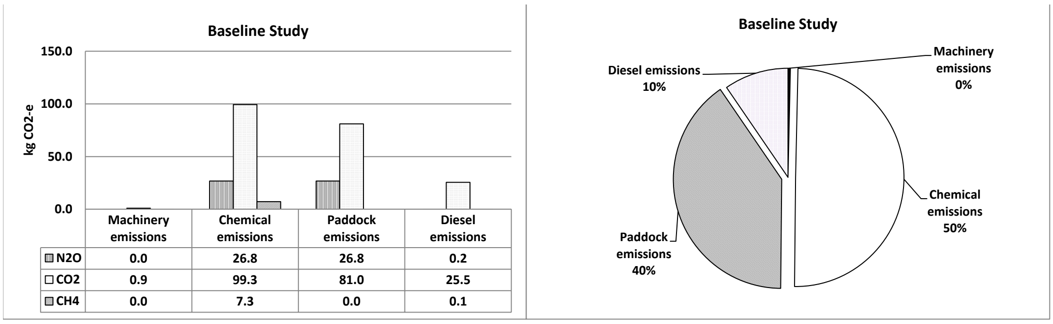
Figure 3. Life cycle inventory diagram showing the inputs and outputs for the pre-farm and on-farm stages.



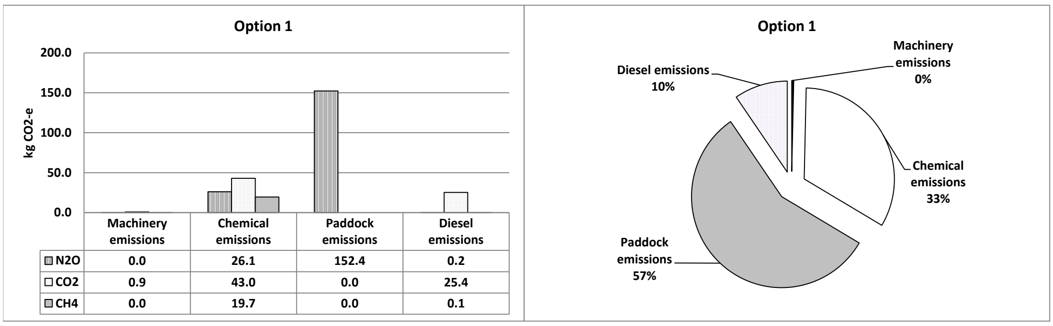
*Adapted from Biswas et al. 2008

Depicts processes included in the study

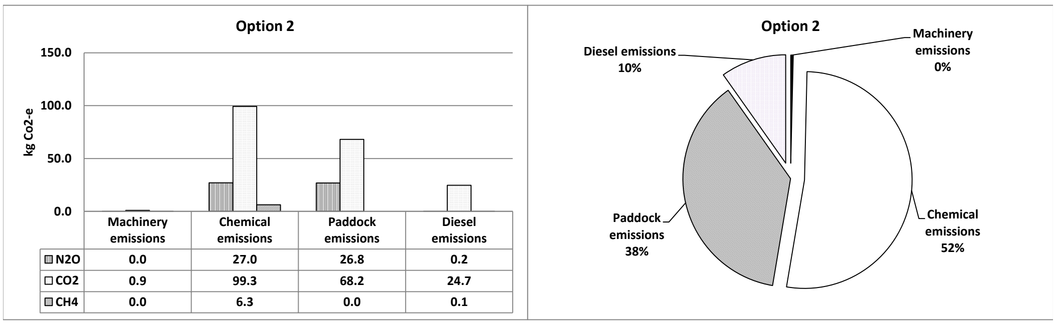
Figure 4. IST framework database output



a) Carbon footprint of baseline study



b) Carbon footprint of mitigation option 1



c) Carbon footprint of mitigation option 2

Figure 5. Comparative GHG output for the pre-farm, on-farm and total emissions