CONSEQUENTIAL LCA IN COTTON PRODUCTION SYSTEMS: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

We consider the cotton production system of North West New South Wales (NSW) in Australia as a reference system and the climate change (CC) impact of that system as a reference impact indicator to discuss the opportunities and challenges associated with the application of Consequential Life Cycle Assessment (CLCA) in cotton systems. In addition, the present paper aims to open debate among the research community about CLCA in cotton production systems. We researched primary consequences of displacing animal feed and seed oil (canola seed) without considering the secondary consequences of further downstream displacements associated with the co-products of cotton seed crushing (i.e. cottonseed meal, cottonseed hull, and cotton linter). This will depend upon further development of models that capture the various primary and secondary consequences. For the treatment of the co-products of the system, we apply both the consequential (system expansion) approach and the attributional approaches.

Our results indicate that the calculated CC impacts associated with the functional unit (i.e. 1000 kg cotton lint produced in North West NSW and transported to an export port) are sensitive to the applied co-product treatment approaches. The applied system expansion approach calculated the impacts in the range of 1288 kg CO_2e to 1552 kg CO_2e for four different system expansion scenarios. The CC impacts based on the attributional approaches of mass allocation and economic allocation were calculated as 770 kg CO_2e and 1687 kg CO_2e respectively.

The main opportunity associated with the application of CLCA in cotton systems is the ability through CLCA to identify and measure the potential consequence of cotton seed production on other production systems in the economy and to relate these consequences to cotton lint. The main challenges associated with CLCA are the lack of universally accepted methods to identify the products that are most affected by cotton systems (the sensitive products) and measure the extent to which those products are affected by cotton production.

Keywords: Cotton, climate change impacts, greenhouse gas emissions (GHG), life cycle assessment (LCA), system expansion, consequential LCA, allocation

1. INTRODUCTION

Agricultural production systems often generate two or more products. In Life Cycle Assessment (LCA) studies, the treatment of co-products, or the distribution of the overall inputs (resources) and outputs (emissions) between co-products, is an important and often controversial subject. The treatment of co-products, one the most controversial issues in the development of the methodology for LCA [1], has been addressed in ISO 14044:2006 Standard [2]. The most preferred approach in the hierarchy outlined by this Standard is to divide the involved processes into two or more sub-processes and to collect the input and output data related to these sub-processes.

The next preferred approach is the system expansion approach, which is based on expanding the system under study to include the additional functions related to the co-products. The system expansion approach takes into account the consequence of co-production on other production systems in the economy. For this reason, LCA studies based on the system expansion approach are often referred as Consequential Life Cycle Assessment (CLCA) studies [3, 4]. The so called attributional LCA (ALCA) is often applied to studies dealing with relatively contained (in terms of system boundaries) products or systems [3], or as a basis from which CLCA studies can be developed.

As for some systems such as milk production [5] and seafood production [6], it is not practical in the cotton systems to divide the processes involved in cotton production systems (e.g. irrigation) into two or more sub-processes to collect the input and output data related to the sub-processes. As such, according to ISO 14044:2006, the system expansion approach is recommended. However, little is known about the application of the system expansion approach in cotton production systems, perhaps due to the challenges that appear when these systems are expanded. The present paper explores these challenges along with a view to some opportunities associated with the application of consequential LCA in these systems. To facilitate the discussion, we consider the cotton production system in North West New South Wales (NSW) as a reference system and calculate the impact indicator of climate change (CC) of that system based on the system expansion approach and via the attributional approaches of mass allocation and economic allocation.

We acknowledge that the consequential modelling in some LCA studies comprises consideration of the marginal sources or technologies (e.g. fertilisers produced from the marginal sources or irrigation water supplied by the desalination technologies) [7]. The applied CLCA in the present paper excludes any LCA modelling based on the consideration of marginal sources or technologies as we were unable to find evidence of current or proposed future applications of marginal sources or technologies that are likely to lead to this type of consequential modelling.

2. METHODS

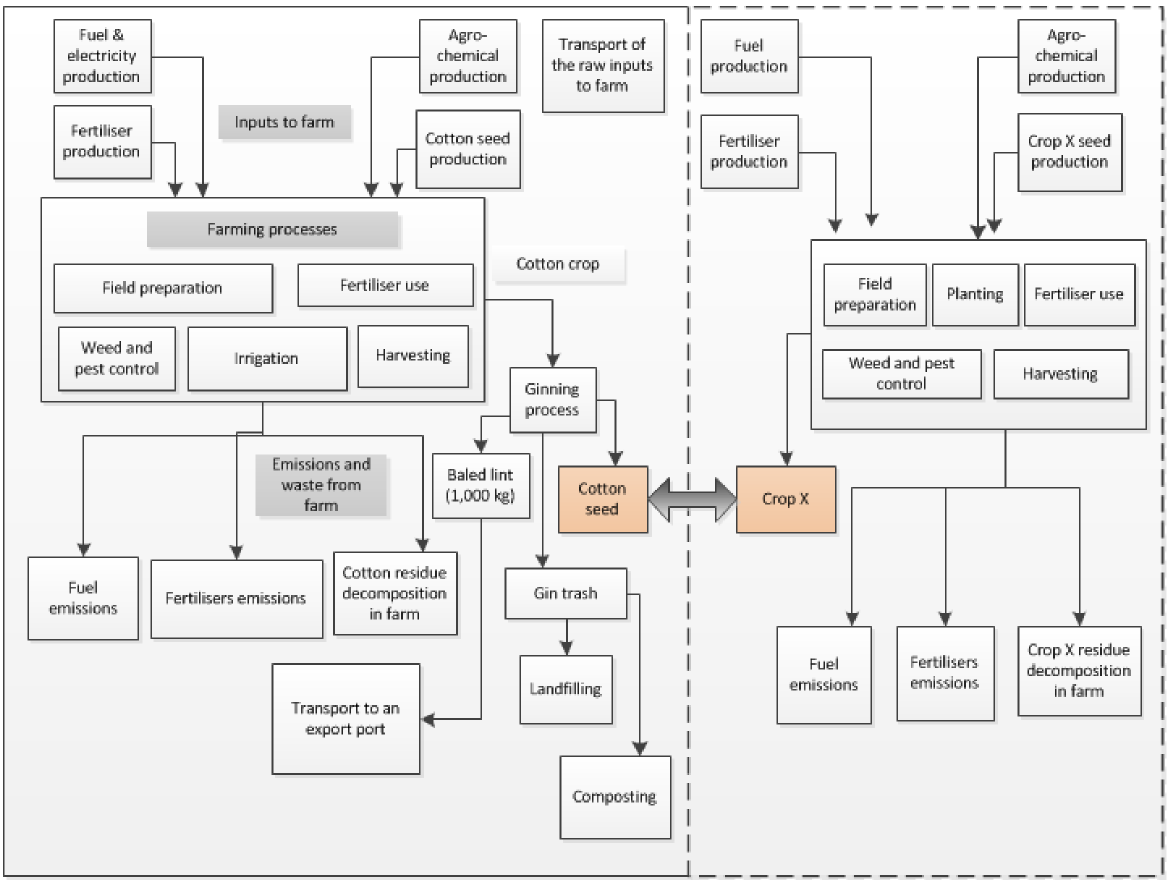
We conducted an (LCA) to quantify life-cycle climate change (CC) impact of cotton production in North West NSW, adopting the four-step procedure outlined in ISO 14040:2006 [8]. The functional unit of the LCA study is the production of 1 tonne cotton fibre (lint) and its transport to an export port, given that approximately 99% of the cotton grown in Australia is exported [9]. The system boundary of the LCA study includes the processes involved in the pre-farm stage (i.e. the production of raw materials and their transport to farm), the on-farm stage, and the post-farm stage (i.e. cotton ginning and the transport of cotton lint to an export port).

The foreground data included that from questionnaires sent to some ginning plants, interviews conducted with some cotton farmers, gross margin data, industry surveys and case study research. Data were also validated by obtaining expert opinion from industry representatives. The background data (e.g. fertiliser production) were accessed from the different sources including the Australian life-cycle inventory[10], AusLCI database [11], and the Ecoinvent database [12]. We perform all impact assessment calculations using SimaPro 8.0.3 [13]. The inclusion of inputs and outputs in our assessment is based on mass and energy. To ensure that all relevant environmental impacts were represented in the study, we have excluded only those flows that had less than 1% of the cumulative mass or energy of all the inputs and outputs of the LCI model, provided the environmental relevance of the excluded flow is not a concern. An example is the exclusion of the CC impact associated with the manufacturing of small quantity of packaging glues that are used in a cotton ginning plant. In this example, we regarded the CC impact associated with the production of use of the applied packaging glue to be less than 1% of the total life-cycle CC impact of the product.

We apply the Australian Impact Method (Australian Indicator Set V3) to interpret the LCA inventory results but exclude carbon dioxide absorbed by cotton from air during its growth and the carbon dioxide released from the decomposition of cotton residues in the field (i.e. biogenic CO_2). We calculate the potential life-cycle climate change by multiplying the total emissions of the various greenhouse gases by their respective global warming potential (GWPs) (http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf), then adding the global warming equivalencies for the various GHGs for a 100-year timeframe.

With regard to the treatment of the co-products, in the mass allocation approach, we allocate the total impacts of the cotton system not only to cotton lint and cotton seed, but also to cotton gin trash. We allocate the total impacts of the system in proportional to the relative mass output of the co-products form a typical ginning plant in North West NSW (42% cotton lint, 49% cotton seed, and 9% gin trash). As there is no recognised economic value for gin trash, during economic allocation we distribute the total CC impacts of the cotton system between cotton lint and cotton seed, on the basis of, cotton lint contributing 86% of the income from one ha of cotton land and cotton seed contributing to 14% of the total income. The figures are based on the average price (2011-2014) of $470 per bale of cotton lint (227kg cotton lint) and $300 kg per tonne of cotton seed. While the prices of both cotton lint and cotton seed in some years might be more or less than the prices considered in the present paper, we consider that the changes would not considerably change the economic allocation figures used in the study.

In the system expansion approach, we apply the approach developed by Weidema [1]. The four-step method includes four decision rules that facilitate the identification of independent co-products (the co-products which determine the production volume of a production system) and the dependent co-product. The method is also useful in identifying and measuring the potential consequence of co-products of a system on other production systems in the economy. Cotton seed, the dependent co-product is used as animal feed[1] and as seed oil. As such, the production of cotton seed affects the animal feed and seed oil production systems. The animal feed production systems are varied including those for grain-based (e.g. wheat, feed barley) animal feed. The production systems for seed oil products are also varied, including those for canola production. The system boundary for the cotton production system under study (solids lines) and those for the expanded system (dashed lines) are shown in Figure 1.



*Please refer to Table 1 for the information related to crop X

Figure 1: System boundaries of the reference system (solid lines) and its expanded systems (dashed lines)

In the present paper, we limit our assessment to identifying and measuring the consequences of cotton production on grain-based animal feed namely wheat and barley, and on the production of canola seed. We regard this as a reasonable approach given that we aim to explore the challenges and opportunities of expanding cotton production systems. Whilst there are other potential flows on effects, this substitution provides sufficient rigour to underpin this methodological exploration.

[1] There are some recommendations for the maximum daily use of cotton seed as animal feed for different animals (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/96008/white-cottonseed-a-supplementary-feed.pdf)

Another important aspect of the system expansion approach in cotton systems is to determine the displacement ratio or the amounts of wheat and feed barley (animal feeds) and canola seed (seed oil) that are displaced by one additional kg of cotton seed. The value of any animal feed depends mainly on the concentration of Metabolised Energy (ME) and Crude Protein (CP) in the dry matter (DM) of that feed [14, 15]. As such, to determine the displacement ratio between cotton seed and wheat or barley, it is important to ensure that after displacement, cotton seed provides exactly the same amount of ME and CP that were previously provided by wheat or barley. Often, the balance between the ME and CP between two animal feeds is achieved through the inclusion of a third animal feed into the animal feed. In the present paper, we consider sorghum and lupins as the agents to balance ME and CP. In addition to ME and CP, the Oil Content (OC) of cotton seed and canola seed also contributes to the estimation of the displacement ratio. As such, to estimate the displacement ratios for the animal feed systems, we simultaneously balance the two animal feed systems of cotton seed and wheat (or barley) based on their ME and CP contents. Likewise, to estimate the displacement ratios for the seed oil systems, we simultaneously balance the two seed oil systems of cotton seed and canola seed, based on their ME, CP, and OC contents. We consider sorghum and lupins as plausible substitutes but purely to facilitate the ME, CP, and/or OC of the systems. Data related to ME and CP of the products are available in NSW DPI [14] and data for ME, CP, and OC of canola seed are available in Weightman, Patrick Garland [16]. We considered several different substitutions including a system which displaces urea that is currently added to stock feed mixes. Urea is commonly added in small quantities as a means of increasing crude protein. However, we are currently exploring the relative toxicity to livestock of cotton seed versus urea before progressing this analysis.

3. RESULTS

We followed the decision-tree presented by Weidema [1] to calculate the CC impacts of cotton lint based on the system expansion approach. The dependent co-product of the system under study (i.e. cotton seed) is considered to displace other products and be fully used. As such, according to the decision tree [1], we follow Rule 1 and Rule 2 of the procedure developed by Weidema [1]. These rules require ascribing all of the impact of the cotton production system to cotton lint but credit the lint for avoided GHG emissions associated with the production of those products that are displaced by cotton seed.

The exact portion of the total produced cotton seed that is used as seed oil is unknown for North West NSW. However, in another Australian cotton growing region of Central Queensland, around 90% of the produced cotton seed is used as animal feed [17]. Given the existence of a large seed oil crushing plant in North West NSW (in Narrabri) [17], it is more likely that more cotton seed is crushed in North West NSW than in Central Queensland. However, as the actual figure is unknown, we assume that similar to Central Queensland, 90% of the total cotton seed are used as animal feed and the remainder is crushed for cottonseed oil extraction. The CC impact results are presented in Table 1. We challenge the assumption regarding the fraction of cotton seed used as animal feed in a sensitivity analysis study in which we assigned different values for the considered fraction. The results of the sensitivity analysis are presented in Table 2.

Table 1: Climate change impact of the functional unit under different system expansion scenarios

System expansion scenario	Animal feed systems		Seed oils systems		Climate change impact (kg CO_2e/t lint)
	Product displaced by cotton seed	Product balancing CP and ME	Product displaced by cotton seed	Products balancing OC, CP, and ME	
Scenario 1	Wheat	Sorghum	Canola seed	Sorghum and lupins	1288
Scenario 2	Wheat	Lupins	Canola seed	Sorghum and lupins	1524
Scenario 3	Barley	Sorghum	Canola seed	Sorghum and lupins	1399
Scenario 4	Barley	Lupins	Canola seed	Sorghum and lupins	1552

Table 2: Results of the sensitivity analysis study

System expansion scenario	Climate change impact (kg CO_2e/t lint)					
	Fraction of the total produced cotton seed used as animal feed					
	1.0	0.8	0.6	0.4	0.2	0.0
Scenario 1	1272	1305	1339	1372	1405	1439
Scenario 2	1534	1515	1496	1477	1458	1439
Scenario 3	1395	1404	1413	1421	1430	1439
Scenario 4	1566	1539	1512	1485	1459	1439

The CC impact of the functional unit based on the mass allocation and economic allocation approaches was 770 and 1687 kg CO_2e respectively.

4. DISCUSSION

Our results indicate that the calculated CC impacts associated with the functional unit are sensitive to the applied co-product treatment approaches, especially when mass and economic allocations are compared. When the system expansion approach is applied, calculated impacts range from 1288 kg CO_2e to 1552 kg CO_2e for four different system expansion scenarios. The differences among the impacts of the system expansion scenarios can be related to the different products that were employed to balance the CP, ME, and OC between the cotton systems and the affected systems. The sensitivity analysis revealed that the results are also sensitive to the fraction of the total produced cotton seed in the region that is used as animal feed. In Scenario 1 and Scenario 3, the CC impact increased when a lower fraction of the total cotton seed was used as animal feed, whereas in Scenario 2 and Scenario 4 the trend was reverse. As such, when an additional unit of cotton seed displaces other products used in animal feed in North West NSW, this does not necessarily lead to a reduction in the CC impact of cotton lint.

We argue that the mass allocation approach is not an appropriate approach for the treatment of co-products in cotton systems as the majority of the CC impacts are shifted towards cotton seed which is not the primary product of these systems. So, uncertainty about whether to attribute emissions to gin trash becomes only a minor consideration. The differences between the CC impacts calculated by the economic allocation and those calculated for the system expansion scenarios (Table 1) are greater for Scenario 1 and Scenario 3 than for Scenario 2 and Scenario 4. The most substantial difference in the CC impact is between the economic allocation approach and Scenario 1 (23.6% lower for Scenario 1).

In this study, we researched the primary consequences of displacing animal feed and seed oils by cotton seed without considering the secondary consequences of further downstream displacements associated with the co-products of cotton seed crushing (i.e. cottonseed meal, cottonseed hull, and cotton linter). This will depend upon further development of models that capture the various primary and secondary consequences. We intend for the present paper to open debate among the research community about consequential LCA in cotton production systems.

The main opportunity associated with the application of CLCA in cotton systems is the ability to identify and measure the consequence of additional cotton crop production on other production systems in the economy and to relate these consequences to the CC impacts of cotton lint. The main challenges associated with CLCA are the lack of the universally accepted methods to identify the products that are most affected by additional cotton production) and to measure the extent to which those products are affected by cotton production.

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