HOW SENSITIVE IS THE CALCULATED CLIMATE CHANGE IMPACT OF COTTON PRODUCTION IN NORTH-WEST NEW SOUTH WALES TO FERTILISER-RELATED N_2O EMISSIONS VALUES?

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ABSTRACT

With the evolution of approaches used to calculate the climate change (CC) impact of cotton production in Australia, there has been a transition from the application of global (IPCC) default emissions values (EVs) for the fertiliser-related N_2O to more localised values. In the study reported here, we used Life Cycle Assessment (LCA) to estimate the climate change impact of cotton production in North West New South Wales (NSW), and tested the sensitivity of applying global versus Australian and/or available region-specific fertiliser-related N_2O EVs. The life-cycle stages included in the analysis were pre-farm, on-farm and post-farm.

We calculated the CC impact of the functional unit (i.e. one tonne of cotton lint) for a cradle-to-port basis as 1687 kg CO_2e if the region-specific fertiliser-related N_2O EVs were applied, and 1950 kg CO_2e if global average emission values were applied. This represents a 15.6% greater level of impact under the global-average scenario. We also tested the sensitivity of applying global fertiliser-related N_2O EVs versus the Australian and regional values at the 'within farm boundaries' system and, in addition, within the processes involving the use of fertiliser on farm. The impacts were 30.3% higher when the global EVs were applied instead of the North West NSW values, for the 'within farm boundaries' system. This demonstrates the importance of applying country-specific values, in an Australian context. When fertiliser-related N_2O EVs for Queensland were applied instead of those for North West NSW, we observed a low sensitivity of the results to the specific regional fertiliser-related N_2O EVs. This is mainly attributed to the fact that the majority of the EVs that we used to calculate the CC impacts of these regions were the same. As fertiliser-related N_2O emissions are an important contributor of the cradle-to-port CC impact of cotton production in Australia (~20% for North West NSW), further research about the breadth of regional variation is recommended.

Keywords: Cotton, N fertiliser, climate change impact, greenhouse gas emissions (GHG), Life Cycle Assessment (LCA), N_2O emissions, emissions factors, IPCC default values

1. INTRODUCTION

The increasing global population demands more agricultural products including food, feed, and fibre. An enhanced agricultural production is achievable through different approaches such as minimising crops disease, a better soil health management, and providing more soil nutrition. The latter could be achieved through the application of synthesis nitrogen (N) fertilisers. A draw back associated with the application of N fertilisers is the emissions of nitrous oxide (N_2O), which has the global warming potential of 298 times more than carbon dioxide (CO_2). The N_2O emissions from the application of N fertilisers along with the N_2O emissions from other sources (e.g. the decomposition of agricultural residues) make the agricultural sector one of the main N_2O emission sources. The extent to which the agricultural sector contributes to the global N_2O emissions is uncertain. Some consider agriculture accountable for about 60% of the total global N_2O emissions [1] and some consider it to make an even greater contribution, about 80% [2].

Nitrous oxide (N_2O) emissions from N fertilisers are an important and often challenging aspect of agricultural emissions-related Life Cycle Assessment (LCA) studies. Fertiliser N_2O emissions are often a substantial contributor to the total GHG emissions in agricultural LCA studies [3, 4]. The calculation of fertiliser N_2O emissions is also regarded as a challenging task, as the emissions occur through both direct and indirect pathways. Direct N_2O emissions primarily occur via denitrification in soil from synthetic N fertilisers. Indirect N_2O emissions can occur from runoff and leaching of N, from the volatilised N from the agricultural production systems that is deposited from the atmosphere.

The calculation of both direct and indirect fertiliser N_2O emissions requires the use of emissions values (EVs) for several specific emissions factors (e.g. the amount of the direct atmospheric N_2O emissions per kg of applied N fertilisers) and some partitioning factors (e.g. the fraction of the applied N fertiliser which is lost through leaching/runoff compared to that retained within the system boundary). The types of EVs required for calculating the direct and indirect N_2O emissions from the applied synthetic fertilisers in a cropping system are shown in Fig.1.

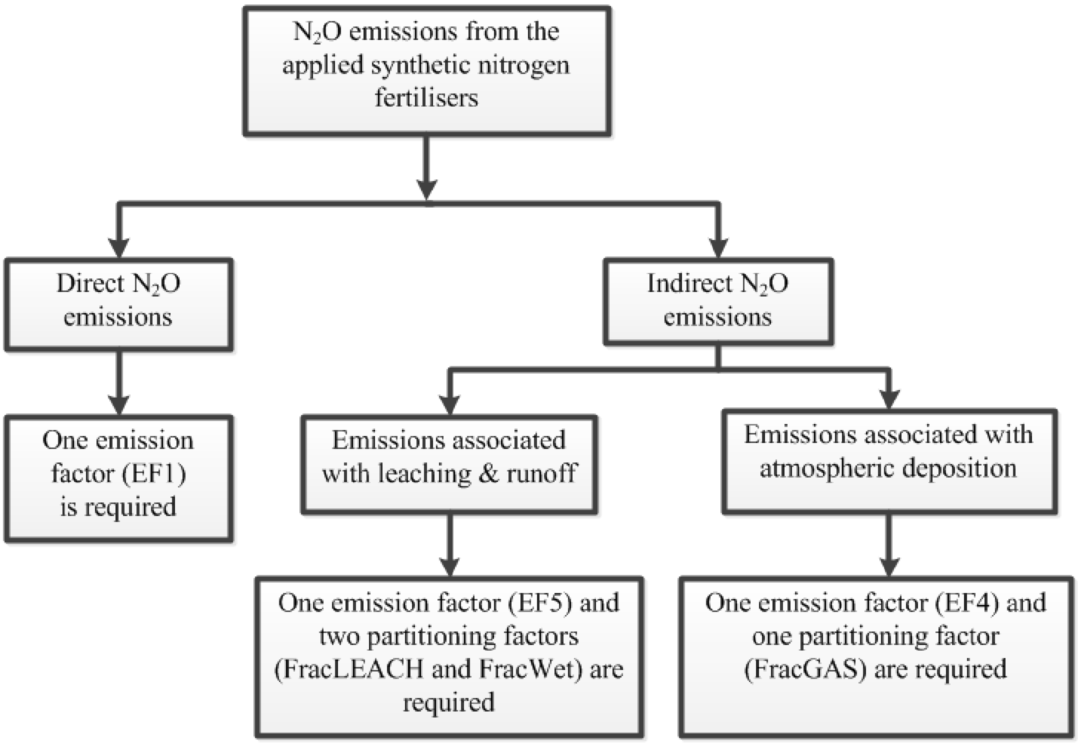

Fig.1: Emissions values required to calculate the direct and indirect N_2O emissions from synthetic fertilisers

In the absence of regionally-specific EVs, the values provided by the Intergovernmental Panel on Climate Change [5] are often used. Research conducted in Australia has led to the estimation of the Australian-specific EVs (Table 1).

Table 1: Description of fertiliser-related N_2O EVs and their values for continuous irrigated cotton systems [5-9]

Emission value	Description	Value			
		IPCC	Australia	North West NSW	QLD
EF1	kg N_2O -N (N_2O as N) is produced per kg of input synthetic N fertiliser	0.01	0.0055	0.0063	0.0063
EF4	kg N–N_2O per kg (NH_3–N + NOx–N) volatilised	0.01	0.0055	0.0063	0.0063
EF5	kg N_2O -N per kg of N that is lost through leaching and runoff	0.0075	0.0075 (IPCC default)	0.0075 (IPCC default)	0.0075 (IPCC default)
FracGAS	a constant mass fraction of the applied synthetic N fertilisers that volatilises soon after the application/deposition of fertilisers	0.1	0.1 (IPCC default)	0.1 (IPCC default)	0.1 (IPCC default)
FracLEACH	fraction of total mass of synthetic fertiliser lost by leaching and runoff	0.3	0.12	0.12	0.12
FracWet	fraction of fertiliser N available for leaching and runoff	1.0	0.845	0.932	0.713

The values presented for EF1 and EF4 are based on the average synthetic N application rate of 246 kg per ha for Australia [8] and 255 kg N per ha for North West NSW and QLD. Other values are currently considered to be independent of the applied N rate. The IPCC EVs are sourced from IPCC [5] apart from the value considered for FracWet. In the absence of any IPCC value for FracWet, we consider that the value is similar to the value applied for North West NSW. The EVs for Australia, North West NSW, and Queensland (QLD) are sourced from the relevant government publications [8-10] apart from the FracLEACH values for Australia, North West NSW and QLD where these values were calculated based on the research conducted by McHugh, Bhattarai [6] and Ringrose-Voase and Nadelko [7]. It should be noted that no Australian-specific values for FracGAS and EF5 have been estimated to date. The IPCC default values for FracGAS and EF5 are used by the Australian Government in the Australian National Inventory Report [8].

The values presented in Table 1 are for continuous irrigated cotton systems, whereas our assessment is based on the mixed production of irrigated (~94% of the total cotton) and rainfed cotton (~6% of the total cotton). For continuous rainfed crop systems, FracLEACH is considered to be zero [11]. In the absence of any study that has measured EF5 and FracGAS for the rainfed cotton systems, we consider these values similar to those of the irrigated cotton systems (the values presented in Table 1). The values for EF1 and EF4 for the rainfed cotton systems have not been estimated yet; we consider these values to be 0.003 kg N2O-N per kg of input synthetic N fertiliser. We have calculated the figure (i.e. 0.003) based on the synthetic N application rate of 50 kg per ha for the rainfed cotton systems and by using the equation relating EF1 and EF4 to the N application rate in cotton systems [9]. We acknowledge that the equation is for the irrigated cotton systems not the rainfed systems; however, we consider this proxy appropriate as rainfed cotton contributes to a small fraction (~6%) of the total mass of the produced cotton in North West NSW.

2. METHODS

We apply the Life Cycle Assessment (LCA) method to quantify the life-cycle climate change (CC) impact of cotton production in North West NSW, adopting the four-step procedure outlined in ISO 14040:2006 [12]. The functional unit of the LCA study is 1 tonne of cotton fibre (lint) at an export port, given that approximately 99% of the cotton grown in Australia is exported [13]. The system boundaries 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). In this paper we test the sensitivity of the results to the applied fertiliser N_2O emissions factors for three different systems (or system scenarios). These systems are shown in Fig.2. The first system (cradle-to-port) is the system with the boundaries specified with the outset solid lines, the second system (within farm boundaries) is the system with the boundaries specified with the dashed lines, and the third system (fertiliser use) is the system with the dotted lines.

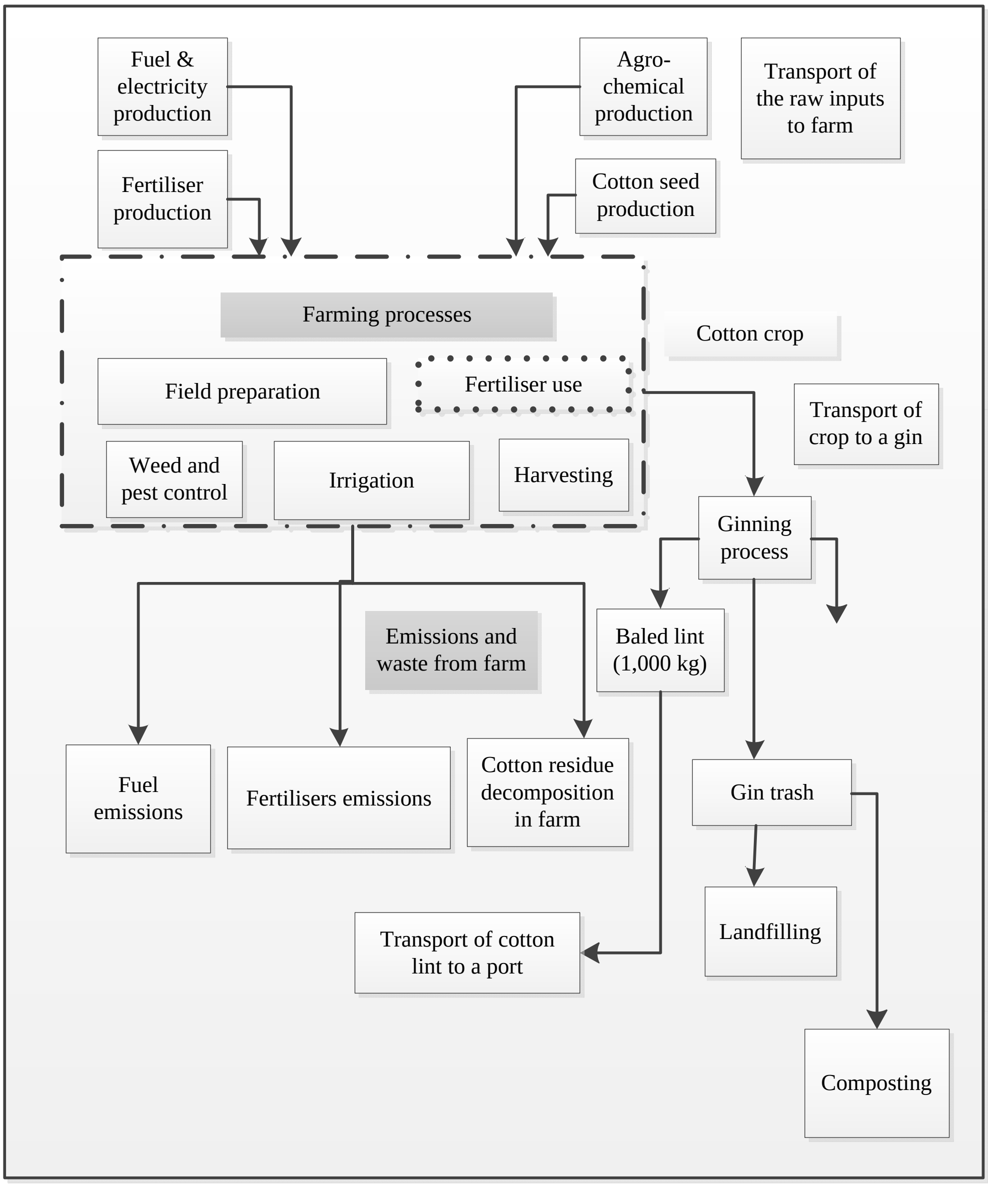

Fig.2: System boundaries of the LCA study

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 and validated by experts' opinion from the industry. The background data (e.g. fertiliser production) were accessed from different sources including the Australian life-cycle inventory databases for Australian agriculture [14], and AusLCI database. The inventory for the foreground data and the key modelling assumptions are provided in Appendix A. We performed all impact assessment calculations by using SimaPro 8.0.3.

We applied the Australian Impact Method (Australian Indicator Set V3) to interpret LCA inventory results but did not calculate carbon dioxide absorbed by cotton from air during its growth and the carbon dioxide released from the decomposition of cotton waste residues in the field, for consistency with the Australian National Inventory Report (NIR) [8]. We calculate the potential life-cycle climate change by multiplying the total emissions of the various greenhouse gases by their respective global warming potentials (GWPs), then adding the global warming equivalencies for the various GHGs. The GWPs are based on the GWP values provided by the UNFCCC [15] for a 100-year timeframe. The N_2O emissions associated with the decomposition of cotton residues are included in the assessment for the both irrigated and rainfed cotton systems.

We allocate the climate change impact of the cotton production system between the co-products (i.e. cotton lint and cottonseed) in proportion to the economic values of the products. We allocate 86% of the impacts to cotton lint and 14% of the impacts to cotton seed. This is consistent with the allocation used in similar studies [16, 17]. The figures are based on our best estimate of the region's average price (2010-2014) 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 this paper, we exclude sensitivity testing of other variables, such as crop yield, irrigation practices and disposal of gin trash. We also exclude sensitivity testing associated with the spreading of the total CC impacts over cotton lint and seed based on the system expansion approach. These factors are covered in related publications that are currently in preparation. The inclusion of inputs and outputs in our assessment is based on mass and energy. We exclude any elementary flows representing less than approximately 1% of the cumulative mass flows or representing less than approximately 1% of the cumulative energy flows.

3. RESULTS

Our results indicate that the calculated CC impact, on a cradle-to-port basis, is 1687 kg CO_2e per 1 tonne of cotton lint at port. The relative contributions of the CC impact of the individual processes to the total calculated CC impacts are shown in Fig. 3. As indicated in Fig. 3, fertiliser N_2O emissions are important contributor of the cradle-to-port CC impact of cotton production in North West NSW, contributing to around 20 % of the total CC impact. These include the CC impact from direct N_2O emissions (16.3%), the indirect N_2O emissions associated with atmospheric deposition (1.5%) and leaching and runoff (2.2%).

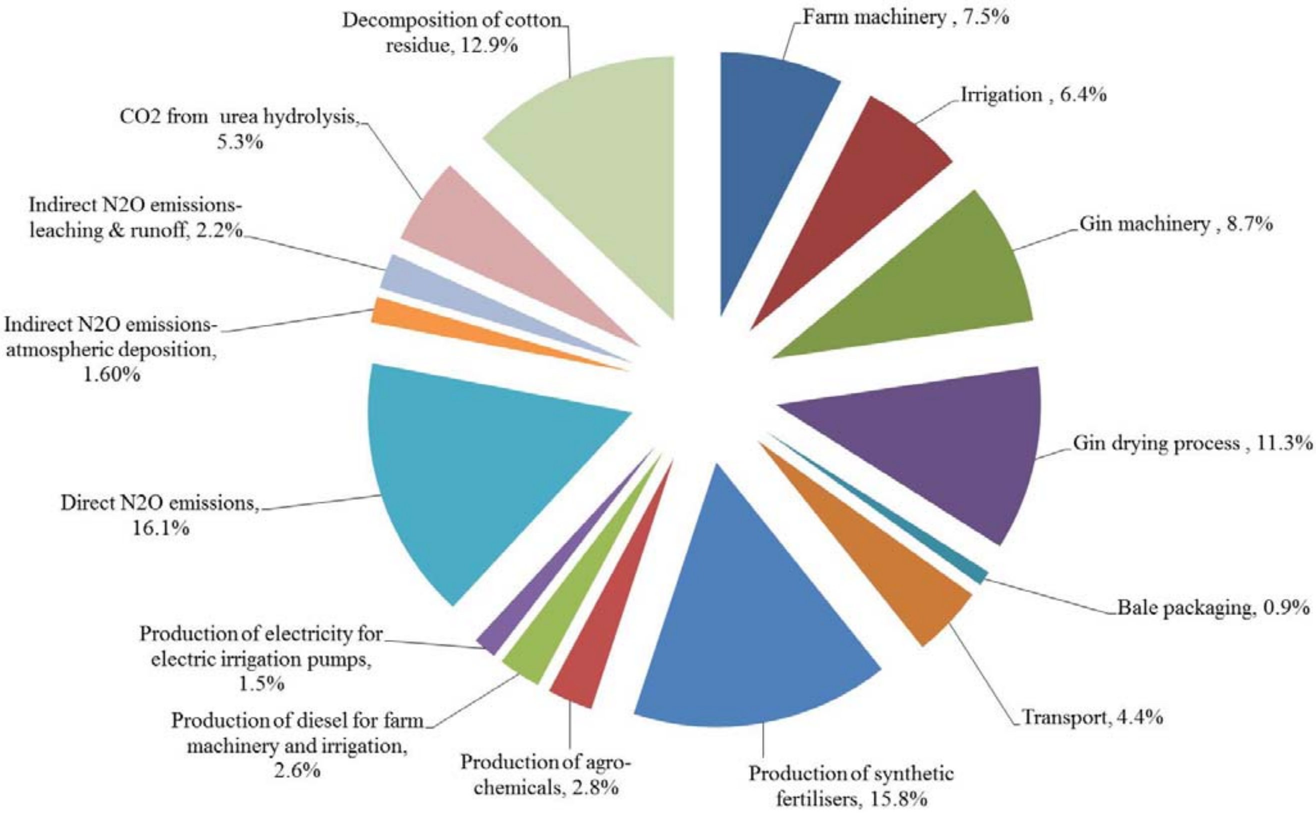

Fig. 3: The relative contribution of the CC impact of the processes to the total CC impact of cotton production in North West NSW for the cradle-to-port system scenario

The potential CC impact of cotton lint production for the different system scenarios and under the different fertiliser N_2O EVs are presented in Table 2. The table also provides the percent difference between the CC impact calculated for the functional unit based on the EVs of North West NSW and the CC impact calculated by using the alternative EVs. These values are presented in the parentheses. The positive (+) sign implies less CC impact for North West NSW and the negative (-) sign implies more CC impact for North West NSW.

Table 2: The CC impact of cotton production for the different system scenarios and under the different fertiliser-related N_2O EVs

LCA System-boundaries	Climate change impact of cotton lint produced in North West NSW as kg CO_2e/tonne cotton lint			
	Using the IPCC emissions values	Using the Australia emissions values	Using the North West NSW emissions values	Using the Queensland emissions values
Cradle-to-port	1950 (+15.6%)	1666 (-1.2%)	1687	1679 (-0.5%)
Within farm boundaries	1143 (+30.3%)	855 (-2.5%)	877	868 (-1.0%)
Fertiliser use only	689 (+61%)	405 (-5.0%)	427	418 (-2.0%)

4. DISCUSSION

We found the CC impact of cotton production in North West NSW to be sensitive to the applied fertiliser-related N_2O EVs. The results indicate that by expanding the system boundaries from 'fertiliser use only' to 'within farm boundaries' and 'cradle-to-port', the sensitivity of the CC impact results to the applied N_2O emissions values is reduced. This is attributed to the fact that by expanding the system boundaries, the CC impacts associated with the fertiliser N2O emissions (a constant value) are divided by a greater amount of the CC impact results.

With regards to the sensitivity of the results to the national and regional fertiliser N_2O EVs, the results of the present paper show small reductions (between 1.2% to 5.0%) in the CC impact of the LCA systems in North West NSW if the fertiliser N_2O EVs of North West NSW are replaced with the Australian average EVs. With regards to the regional comparison of the results between North West NSW and QLD, the present paper shows a small reduction in (between 0.5% to 2.0%) in the CC impacts of the LCA systems in North West NSW if the fertilisers N_2O EVs of North West NSW are replaced with the QLD average EVs. However, it is important to note that two of the applied emissions factors (EF1 and EF4) for North West NSW and QLD are the same because the current estimations of these factors are based on the nitrogen (N) application rate only, and not based on other factors such as climate, temperature, soil type. As such, the values that we used for EF1 and EF4 may be subject to change in the future when other regional variations (e.g. soil types) are included in the calculations of EF1 and EF4.

As fertiliser N_2O emissions are important contributor of the cradle-to-port CC impacts of cotton production in Australia (~20% for North West NSW), further information about the breadth of regional variation is recommended.

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Appendix A

Table A. 1: Inventory data per one hectare of land used per year for both rainfed and irrigated cotton production in north-west New South Wales

Parameter	Irrigated cotton	Rainfed cotton	Unit	Note
	Quantity	Quantity		
Outputs				
Cotton lint yield	10.5	5	bale/ha	Based on the average yield 2011 to 2014, 1 bale=227 kg
Cotton lint total mass	2384	1135	kg/ha	Total mass of cotton lint produced in one hectare
Seed/lint ratio	1.17	1.17	-	Based on the production of 42 kg cotton lint, 49 kg cotton seed, and 9 kg of gin trash per 100 kg of gin output
Cotton seed total mass	2789	1328	kg/ha	Based on the cotton seed to the cotton lint ratio of 1.17
Crop yield	5172	2460	kg/ha	Total mass of products (cotton lint and cotton seed)
Farm inputs				
Raw cotton seed for cotton planting	13	13	kg/ha	Average quantity
Irrigation water	7.7	0.0	ML/ha	Total water used from both surface water (e.g. rivers, dams) and groundwater
Diesel for machinery	122.1	103.3	L/ha	Total diesel used for all farming practices from planting to harvesting (irrigation excluded)
Diesel for irrigation pumps	99.5	0.0	L/ha	Total diesel used for water pumping from surface water and groundwater
Electricity for irrigation pumps	58.5	0.0	kWh/ha	Total electricity used for water pumping from surface water (e.g. rivers) and groundwater
Urea	315.0	96.0	kg/ha	Total mass of the product not the active ingredient
Ammonia	120.0	0.0	kg/ha	Total mass of the product not the active ingredient
Mono ammonium phosphate (MAP)	113.0	57.0	kg/ha	Total mass of the product not the active ingredient
Herbicides	6.6	6.6	kg/ha	Total mass of the product not the active ingredient
Growth regulator	1.59	1.59	kg/ha	Total mass of the product not the active ingredient
Insecticides	0.83	0.83	kg/ha	Total mass of the product not the active ingredient
Transport distance	500	500	km	Average distance between farms and the raw materials suppliers
Gin inputs				
Electricity for the ginning machinery	33.5	33.5	kWh/bale	Average of the actual data from two major ginning plants in the region
LPG for seed cotton drying	2.1	2.1	L/bale	Average of the actual data from two major ginning plants in the region
Packaging plastics	1	1	kg/bale	Average weight of bale plastic (from PET) packaging
Transport distance	50	50	km	Average distance between farms and the gin plant (road freight)
Transport distance	550	550	km	Average distance between the gin plant and an export port (rail freight)
Filed-related emissions to air				
Direct N_2O emissions from N fertilisers	2.4	0.47	kg/ha	Calculated based on the Australian NIR 2013 guidelines [8]

Indirect N_2O emissions from N fertilisers through leaching & runoff	0.33	0	kg/ha	Calculated based on the Australian NIR 2013 guidelines and the data from Ringrose-Voase and Nadelko [7] and McHugh, Bhattarai [6] to estimate the mass fraction of N lost through leaching and runoff (FracLEACH). No leaching and runoff for rainfed (dryland) crop (cotton) as per Eder, Blöschl [11].
Indirect N_2O emissions from N fertilisers through atmospheric deposition	0.25	0.05	kg/ha	Calculated based on the Australian NIR 2013 guidelines [8]
Emissions of CO_2 that was fixed in Urea	231	70.4	kg/ha	Calculated based on the Australian NIR 2013 guidelines [8]
Emissions of N_2O from cotton residue decomposition in the filed	1.8	0.86	kg/ha	Calculated based on the Australian NIR 2013 guidelines [8]
Gin trash generation and treatment				
Gin trash/lint ratio	0.21	0.21	-	Based on the production of 42 kg cotton lint, 49 kg cotton seed, and 9 kg of gin trash per 100 kg of gin output
Gin trash total mass	511	238	kg/ha	Based on the gin trash to cotton lint ratio of 0.21
Gin trash composting	383.2	178.5	kg/ha	Based on the average composting rate of 75%, as per the information obtained from some selected ginning plants, the LCI inventory data for windrow composting systems of solid wastes sourced from NSW EPA [18] but the diesel consumption in the inventory excluded for waste shredding as gin trash contains small particles
Gin trash landfill disposal	127.8	59.5	kg/ha	The AusLCI database for the landfill disposal of garden and green wastes is used as a proxy
Transport distance between gin and landfill	50	50	km	The average distance between the gin plant and the local landfill site

Table A. 2: Key modelling assumptions

Modelling assumption	Value	Unit	Note
Irrigation water			
Fraction of the irrigation water sourced from surface water (e.g. rivers)	0.8	-	Best estimate based on the ratio between surface water and groundwater used by the NSW farms in 2012-2013 [19]
Fraction of the irrigation water sourced from groundwater	0.2	-	Best estimate based on the ratio between surface water and groundwater used by the NSW farms in 2012-2013 [19]
Fraction of the irrigation water pumped by diesel pumps	0.85	-	Best estimate based on the average ratio between diesel and electricity used in the Australian cotton farms [20]
Fraction of the irrigation water pumped by electric pumps	0.15	-	Best estimate based on the average ratio between diesel and electricity used in the Australian cotton farms [20]
Average total dynamic head (TDH) for water pumped from surface water	8	m	Best estimate based on the information provided by Welke [21]
Average total dynamic head (TDH) for water pumped from groundwater	35	m	Best estimate from the average groundwater depth (m) for the selected regions provided in NSW Water [22] and NSW Water [23]
Production of irrigated cotton			
Fraction of the used cotton land for irrigated cotton production	0.88	-	Based on the information in ABS [19]
Mass fraction of irrigated cotton to the total mass of the harvested cotton	0.96	-	Based on the information in ABS [19], it is consistent with the national average figures in Cotton Australia [13] and Cotton Australia [24]