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Reducing carbon emissions from fertiliser.

The potential of Laconik's technology to reduce carbon emissions from synthetic fertiliser.

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1. Introduction

Global climate change resulting from the human-induced greenhouse gas (GHG) emissions has become a constant threat for the sustainable growth of society. There is a strong desire in the world to address, avert and minimize these losses which resulted in Paris Agreement, a milestone in multilateral climate change process. It is a legally binding agreement which aims to limit global warming to 2°C below the pre-industrial levels. Given the ambitious scale of these goals, significant emission abatement is needed with each sector playing its parts. 24% of the global GHG emissions come from the agriculture making it an integral part of emission reduction strategy however the relationship between both is a double-edged sword. On one hand, FAO predicted that a 70% increase in food production is required to adequately satisfy the expected rise of human population to 10 billion by 2050 [1]. This puts the agriculture sector all over the world in a precarious position to increase their productivity drastically.

However, this substantial increase in production will comes at the cost of augmented GHG emissions. The gains in the growth of agricultural production are often accompanied with negative effects on natural resource bases including soil erosions, higher pest resistance, increased GHG emissions, nitrate pollution of water bodies and deforestation [2, 3]. IPCC (2016) predicted a substantial negative impact of climate change on agroecosystem estimating 17% decrease in global food productivity by 2050 [4]. Further, the change in climate conditions not only impact the global food supply, it'll reduce the nutrition value of the crops including wheat, rice and soybeans by 8% with lower protein and higher carbohydrates levels [1].

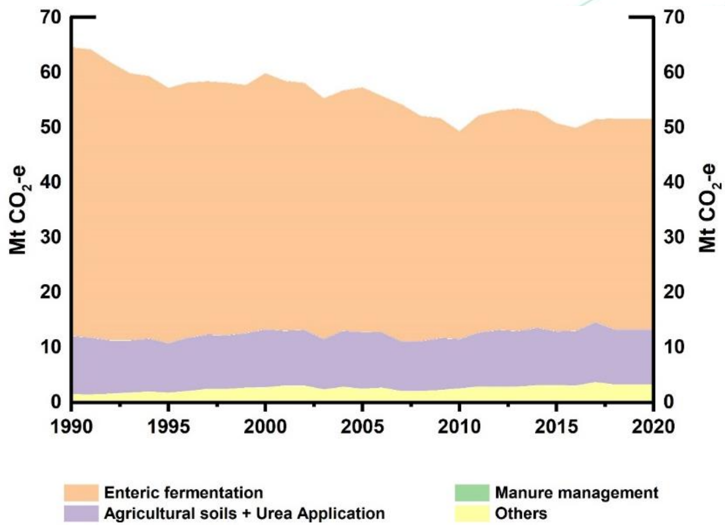

Figure 1: GHG emission distribution in Agriculture sector in Australia
Source: Department of Industry, Science, Energy and Resources (2021)

Being a strong supporter of Paris agreement, Australia has pledged to reduce it GHG emissions by 26-28% by 2030, compared to 2005 levels. Agriculture accounts for 14% of the anthropogenic GHGs emissions of the country and holds a high priority for fulfilling the Paris agreement due to the second largest source of national emissions. Department of Agriculture, Water and the Environment (ABRARES) has projected that Agriculture emissions would need to be cumulatively reduced by 23% to achieve these targets by the designated year [5]. Australian climate council has predicted a rise of 75 Mt CO_2-e (12% than 2020 levels) by 2030 due to increased agriculture activities [6]. Furthermore, Australia is ranked as 12th in the world accounting for 3% of the total agriculture trade in the world [7]. Approximately 67% of Australian agriculture production is being exported since 1990 and this increase in demand has opened doors for future growth and opportunities for Australian farmers. This increase suggests that it is very unlikely for Australia to achieve its GHG emission targets in the agriculture sector by 2030 without any drastic measures.

Figure 1 shows the current distribution of CO_2-eq agriculture emissions within Australia. It is evident that livestock emissions contribute to 70% of the agriculture GHG inventory followed by soil degradation and fertiliser application (17%) [8]. Methane (CH_4) is mostly contributed by enteric fermentation due to livestock and manure management whereas nitrous oxides (N_2O) primarily come from the use of nitrogen-based fertiliser on crops and pastures [9]. Majority of CO_2 produced from agriculture is a part of natural carbon cycle and is not counted as a part of GHG emissions [10]. Though the percentage change in overall agriculture emissions is reasonably steady over the years, the fertiliser emissions are constantly increasing with an average of 44% (shown in Figure 2).

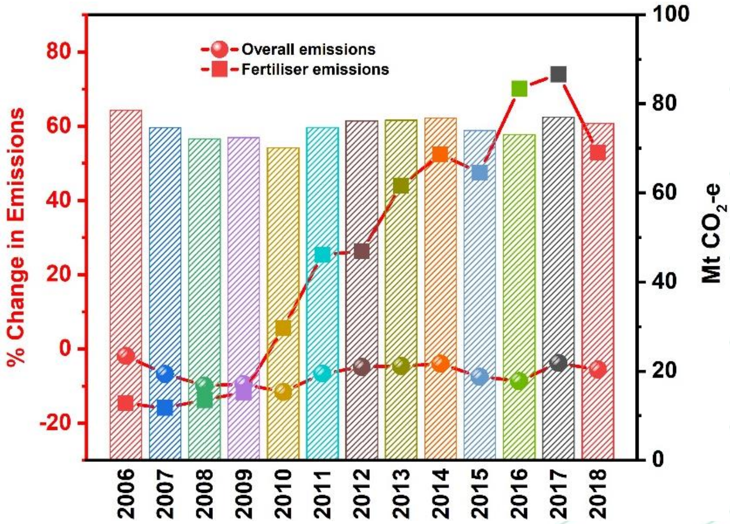

Figure 2: % Change in Agriculture Emissions with base year of 2005
Source: Department of Industry, Science, Energy and Resources (2021)

A decrease of 10% was observed in 2010 which is most likely due to reduced agriculture activity owing unfavourable seasonal conditions [11]. Despite its seemingly low contribution in total national GHG profile, its potential threat is heightened by the fact that not only it contributes to global warming, it is 310 times more potent than CO_2 and depletes ozone layer [12]. Additionally, it has an atmospheric lifespan of 110 years as compare to CO_2 which can stay in the atmosphere somewhere between 300 to 1000 years, it's reduction will have more noticeable effect in near future [13]. Moreover, soil stores three times more carbon than atmosphere and intensive fertilization erodes the soil 100 time more than it forms which leads to increasing GHG emissions and loss of over one-third arable lands till now [14]. Leaching and run-off of excessive fertilisers in the form of nitrate-N (NO_3-N) and its adverse impact of water bodies is widely reported in the literature. Therefore, reducing N_2O emissions could have a faster and significant effect on the current climate conditions.

The need to adapt new technologies and smart strategies to meet increasing food requirements while sustaining the ecosystem is profound in the current global situation [15]. Dissemination of best management practices such as holistic 4R stewardship (right source, right rate, right time, right place) help accomplish this goal. Precision technologies allows the farmers to emphasize on all the R's at the same time beyond traditional nutrient management [16]. It integrates IT, GNSS data, remote sensing and proximal data gathering to optimise the fertiliser input with maximum yield [17].

Laconik has developed a novel technology that measure the impact of fertiliser application on farm profit in diverse climatic conditions. It's VRT (Variable-rate fertiliser technology) helps address the 3R's out of four by providing farmers with precise recommendation on future fertiliser applications. Over 2019 and 2020, Laconik has conducted the largest review in Australia on the impact of in-season N fertiliser. Laconik has completed 85 replicated farm-scale trials across Australia, under diverse production environments (1-5 t/ha). The results from these trials has shown that 87% of the N applied during July and August has not translated into a grain yield increase for growers. It is counter intuitive to assume that most of that nitrogen has been lost of the environment in different forms however there is a lack of research on the GHG budgets of over-fertilization within Australia.

The aim of this study is to measure the carbon value of low, medium and improved fertiliser efficiency based on Laconik's recommendation. A life-cycle analysis with cradle to grave approach is used to realize the overall impact of its technology on the net GHG mitigation from Australian agricultural ecosystems.

2. Overview of current methodology and reporting status

IPCC developed a tier approach for reporting GHG emissions based on their methodological complexity. Tier 1 refers to basic method which uses default EFs provided by the IPCC in combination with national or international statistics. Tier 2 uses the same calculation approach as tier 1 but with a country or site-specific EFs and activity data. EFs for Tier 2 represents a higher disaggregation level based on management conditions (i.e. type of crop, fertiliser source, application method, tillage, water management etc.) and environmental factors (i.e. soil conditions, climatic changes, drainage etc.). Tier 3, however, is the most complicated and intensive method left at the discretion of national experts with stringent transparency requirements. It requires a mix of GIS-based systems for data collection, statistical models, and inventory measurement systems for accurately evaluating and reporting GHG emissions.

In 2019, IPCC has published a step-by-step approach for parameterizing and evaluating models, data integration, checklist of best management practices and examples for better guidance. Out of 191 countries participating in Paris agreement, 95% are reporting their fertiliser emissions in Tier 2, 5% in Tier 2 and United States is the only country using Tier 3 methodology by integrating Daycent, a daily-time series biogeochemical model, which provides emissions estimates for major crops grown on mineral soils. Australia is using Tier 2 approach with a country specific emission factors to report the N_2O emissions from the effect of change in management practices. An overview of protocols developed in different countries to assess the fertiliser related emission is shown in Figure 3.

Canada: The Nitrous Oxide Emission Reduction Protocol (NERP)

- Approved in 2010
- Comprehensive 4R Nitrogen Stewardship Plan i.e. Right Source, Right Rate, Right time and Right Place
- Can be applied at three levels: basic, intermediate and advanced
- Limited to on-farm reductions of nitrogen sources i.e. manure, crop resiude, fertiliser etc.
- Allow farmers to claim carbon credits
- Using a mix of Tier I/II emission factors for application rate along with reduction modifiers (RM) to assign reduction potential for remaning 3 R's

United States: Fieldprint Platform - Field to Market

- Used Tier 1 emission factors until 2011
- Methodology for both national and regional level emissions.
- 4R Nitrogen Stewardship Plan i.e. Right Source, Right Rate, Right time and Right Place
- Can be applied at three levels: basic, intermediate and advanced
- Combined with USDA's Daycent which captures emissions sensitivity to crop, land resource region, soil texture and N-applicatoon rates
- Available for corn, soyabean and wheat production
- Only country reporting Agriculture emissions in Tier 3 with reduction factor for inculcating impacts of other

Europe: Farm Carbon Calculator

- A mix of tier 1, 2 and 3 approaches
- Available for 150 crops and 10 livestock categories
- Allows to calculate farm-level, management and climate-sensitive N_2O emissions using simple data inputs like fertiliser type, rate, inhibitor, crop type, climate etc.
- Other similar calculator exists for the EUE like EU carbon calculator, Cool farm tool, CBP, EX-ACT, Swiss carbon offset program etc
- Swiss carbon offset program is specifically designed for stablised fertilisers whereas cool farm tool has a cradle to farmgate approach for fertiliser development.

Figure 3: Overview of International Bottom-Up calculation approaches for fertiliser GHG emission

Currently government of Australia has an approved methodology for crediting carbon credits under Carbon farming Initiative for reduced GHG emissions from fertiliser application in Irrigated Cotton farms. 98% of the trials performed by Laconik last years have shown a relatively stable yield with an increased rate of fertilisation. These results agree with the proposed theory behind cotton methodology developed by clean energy regulators that there is an opportunity to improve nitrogen fertiliser use efficiency. Hence, the opportunity to provide abatement by reducing on-farm fertiliser emissions according to yield potentials of farm is immense. Since the approved methodology only focuses on cotton farms, the work done by Laconik will ratify and extend that work for wheat farms.

3. Materials and Methods

3.1 Site Description

The field experiments were carried out located in the wheatbelt region of Western Australia between January 2014 and December 2015. To avoid complications, Soil Ag map (Figure 4) is used to represent the data in the study. An overview of sample sites and yield data is shown in Table 1. The climate of the region is Mediterranean with hot dry summers and wet winters. Wheat is the predominant crop of the region with a soil texture of deep sandy duplexes with an approximate PH of 5.5 (topsoil) & 4.8 (subsurface), total N – 0.1 mg/kg and soil bulk density – 1.2 g/cm^3.

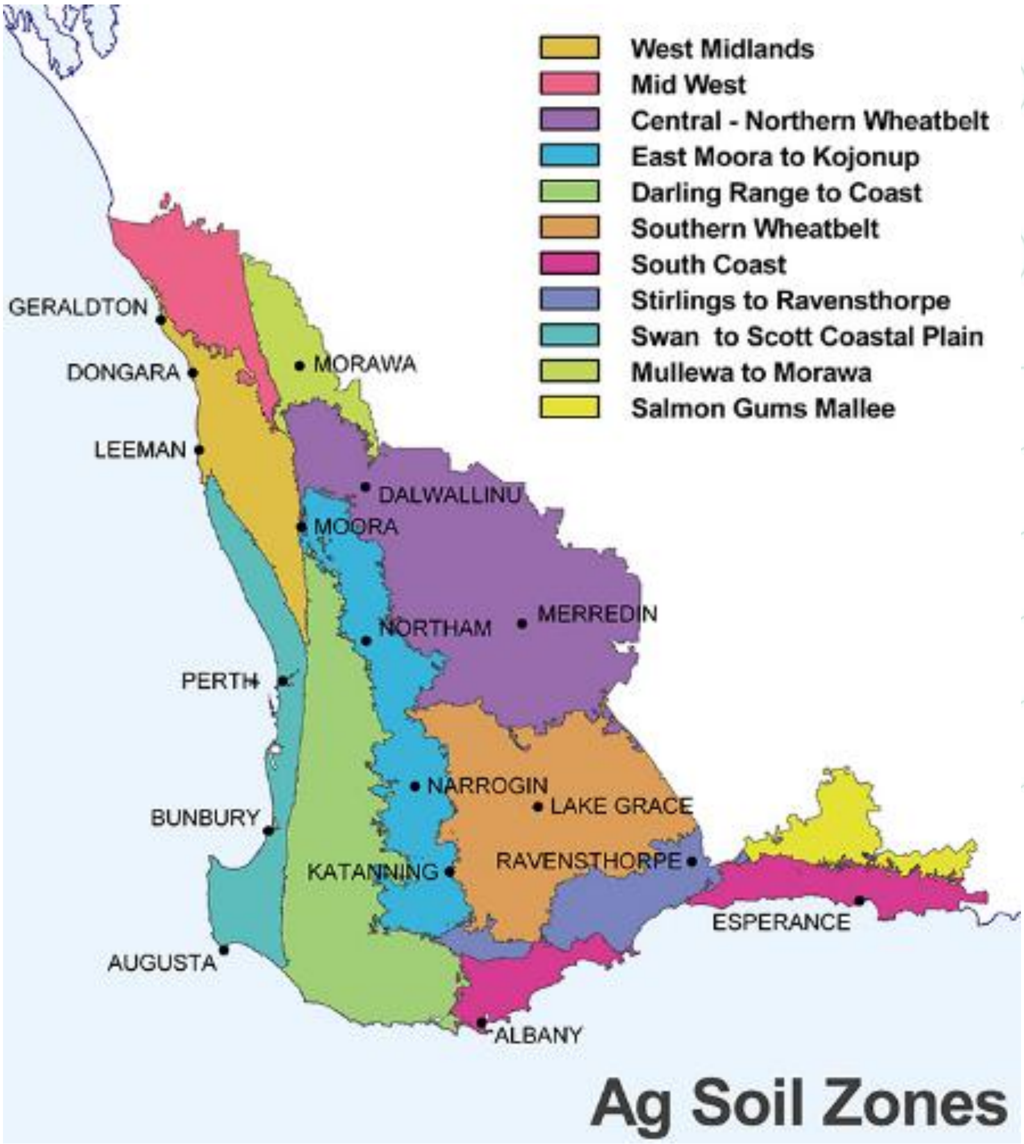

Figure 4: Site Description - Wheatbelt WA soil Ag zones

Notation Used: West Midlands: WM; Mid-West: MW; Central Wheatbelt: CWB; East Moora to Kojonup: EMK; Southern Wheatbelt: SW; Salmon Gums Mallee: SGM

The soil organic C is typically within a range 0.7-1% in the top 10cm of the soil which is comparatively low when compared with global standards. WA temperature is expected to increase of 0.5-1.3°C by 2030 irrespective of GHG emissions. An average rainfall of 344mm per annum which is expected to decline by 6% in 2030 resulting in high intensity and long duration hot spells.

Table 1: Sample site and Field data

Site/Location	Sample percentage (%)	Soil Description - Texture	longitude	latitude	PH	Rain fall (mm)	Tmin ©	Nrate (kg/ha)	Yield (t/ha)
SMG	10%	Calcareous loamy earths	149.0744	-32.2018	5.2	201	12.3	0	5.44
								50	5.68
								76	5.72
								100	6.03
								200	5.81
EMK	15%	Deep sandy and sandy earth soils	116.5799	-31.1381	5.8	331	9.6	0	1.00
								40	1.01
								80	1.06
								160	1.16
								200	1.15
CNW	45%	Deep sandy and sandy earth soils	117.0762	-31.6812	8.1	209.4	10.2	0	2.66
								40	2.64
								80	2.65
								160	2.64
								200	2.52
WM	5%	Colored sands - Grey deep sandy duplexes	115.0171	-28.4585	7.8	258	13.4	0	3.59
								40	3.55
								60	3.57
								80	3.60
								100	3.76
SW	20%	Alkaline shallow duplex	119.0786	-33.8054	5.5	257	12.3	0	2.36
								50	2.19
								100	2.22
								150	2.15
								200	2.12
MW	5%	Brown deep sand	114.8211	-28.4278	6.9	237.9	13.4	0	3.12
								30	3.07
								60	3.04
								90	3.08
								120	3.09

3.2 Experimental Design

Five in-season N fertiliser treatments were applied to a field plot based on a randomised block design with three replicates in July. The crop is completely rainfed and dependent on the water stored in the soil prior to seeding. The basal fertiliser rate was kept the same for all the farmers at 90kg of Urea. Diesel consumption data for each agronomical input is obtained through MyJohnDeere™ for individual experimental site. All other field management practices including seeding, pesticide application and harvesting are consistent with locally adopted practices. Emissions from land preparation phase are not included in the study as no-till sowing (86% - 90% of the farmers) is predominant practice is the region.

3.3 Carbon Footprint Estimation

Carbon foot of agriculture production is defined as the sum of GHG emissions and uptake, expressed as CO2-eq, in a product-based carbon footprint. A strategy like Australian National Greenhouse and Energy Reporting (NGER) scheme (2019) is used to perform the analysis.

3.3.1 System boundaries

The most important step in carbon footprint calculations is system boundary which is set as cradle to farmgate including raw material sourcing, manufacture, transportation, storage and delivery of final product (harvested wheat grain) which is consistent with the similar studies in the literature [18-21]. Though 85% of total fertiliser used in Australia is produced overseas [22], its emissions are included as a part of GHG footprint of Australian wheat production. This will show the overarching potential of optimizing fertiliser usage in Australia on an international scale (how much emissions will be reduced internationally if Australia control its fertiliser). After harvest, straw and roots are left in the field to decompose which contribute to direct and indirect emissions through nitrification and denitrification as consistent with the regional practice [23].

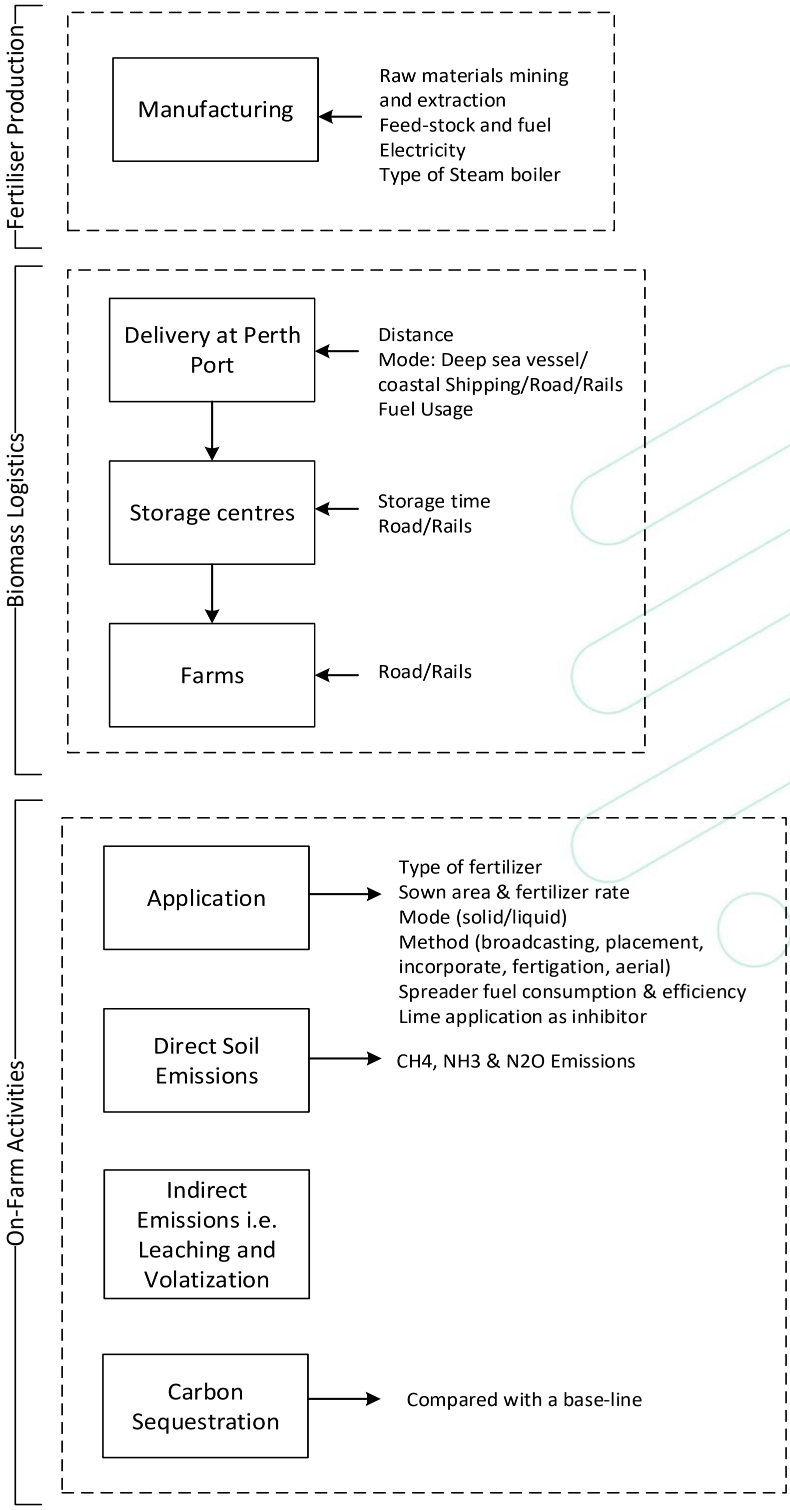

Figure 5: Methodology for Carbon Footprint Estimation

3.3.2 Pre-farm Emissions

3.3.2.1 Production Emissions

Instead of using the world average for estimating the carbon footprint of urea production as reported in the literature, a more targeted approach is devised using country specific emission factors depending on their contribution to the overall Australian fertiliser imports. For instance, 75% of the urea fertiliser employed in Australia is being imported from countries including Qatar (29%), Saudi Arabia (25%), China (21%), Indonesia (15%) and Malaysia (10%). Similarly, 52% of UAN is being exported from Russia (52%) and 42% from Estonia respectively [24]. Since the global trade statistics are available at national level, therefore same contribution is assumed for WA. Similar strategy is adopted for other potash and phosphorus fertilisers (superphosphate & potassium chloride), however It is assumed that the carbon footprint of lime application is the same for each region [25].

3.3.2.2 Transportation Emissions

Handymax or supramax bulk carrier ships with a capacity of 35,000-60,000 DWT are primarily used for carrying dry cargos like fertiliser[26]. An extensive supply chain network via roads is established throughout Australia to distribute these supplies to farmers using heavy duty freight trucks (~60 tonnes payload). An activity-based approach is used to quantify the GHG emissions using a default emission factor of 0.08 and 0.62 kg CO_2/ton-km for road and rail transport [27]. Assuming a return distance of 12000km for coastal shipping, 40km for port to storage and 200km for storage to farmer for road transportation is used to calculate GHG emissions throughout the study i.e. 0.19, 0.003 and 0.03 kg CO_2-eq/kg N respectively during fertiliser transportation. However, a detailed analysis of selecting different transportation distances with different fertiliser rate application is shown in Figure 5 for reference. It is evident that as the application rate of fertiliser increases, the difference of emissions between different transportation distances becomes apparent.

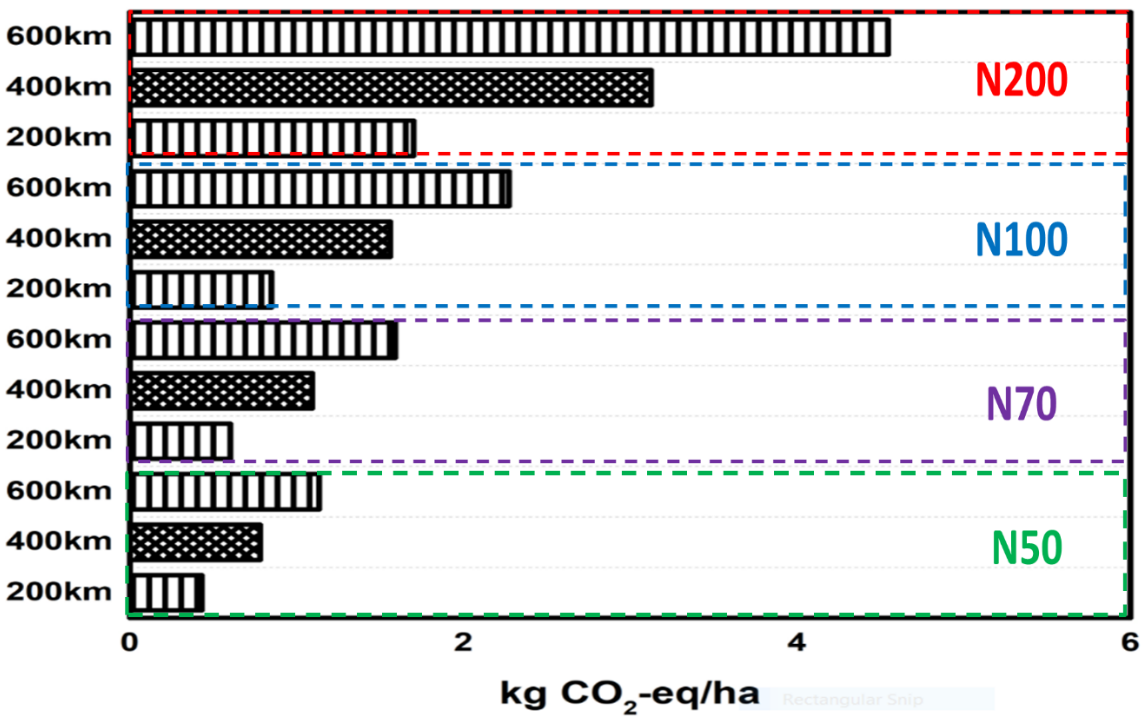

Figure 6: Comparison of emissions between different transportation distances

3.3.2.3 On-farm Emissions

Estimated GHG emissions from varying N-based fertiliser application includes emissions from i.e. direct and indirect emissions etc. The direct emissions refer to the conversion of nitrates (NO_3^-) to nitrous oxide (N_2O) because of denitrification whereas carbon present in urea also contributed to the direct carbon dioxide emissions (CO_2). Indirect emissions occur due to the volatilization of ammonium and water leaching.

A mix of CS EFs and IPCC recommendations is used in the study to estimate the direct and indirect emissions from inorganic fertilisers. These EFs derived by NIR are based on several experimental studies conducted through different programs including Nitrous Oxide Research Program (NORP) and the National Agricultural Nitrous Oxide Research Program (NANORP) [28]. The total emissions associated with fertiliser application is calculate by multiplying emission factors with their respective activity data obtained through field experiments. A conversion factor of 1.57 is employed convert elemental mass of N_2O to molecular mass and default metrics of 100 year - GWP for converting N_2O emissions into their CO_2 eq. as proposed by IPCC to ensure consistency and comparison with published data. [21, 23, 29, 30]. An overview of emission categories, their reference equations and method employed is presented in Table 1.

To determine the areas susceptible to leaching, ratio of ratio of evapotranspiration to annual precipitation (Et/P) is used. The areas with $E_t/P > 0.8$ or $E_t/P < 1$ are considered as dryland whereas leaching losses are considered for the rest [29]. Most of the wheatbelt in WA has Et/P ratio lies within leaching zone, therefore leaching and runoff losses are calculated in the study. Additional carbon emissions are calculated in case of urea application due to the loss of fixed CO_2 after it is applied to the soil. Soil carbon sequestration (SOC) was not included in the analysis as WA soil is known for its inherent low SOC and a ten-year monitoring is required to observe any significant change due to high temporal and spatial variabilities associated with it [31, 32].

Table 2: Overview of On-farm Emission Categories

Emissions Categories	GHG Source & Sink Categories	Reference Equations	Units	Emission Factor	Method Applied
Direct Emissions	Inorganic Fertilisers	$E_d = T_M F_N \, EF_d$	Gg N_2O-N/Gg N	If <600mm, 0.0021 If >600mm, 0.0085[a]	T_2, CS
	Crop Residue	$E_{cr} = 0.88 T_P EF_{cr}(R_{AG} NC_{AG} + R_{AG} R_{BG} NC_{BG})$	Gg N_2O-N/Gg N	0.014	T_2, IPCC
Indirect Emissions	Atmospheric Deposition	$E_d = T_M F_N frac_{GASF} \, EF_d$	Gg N_2O-N/Gg N	0.010	T_1, CS
	Leaching and Run-off	$E_{leach} = (T_M F_N + 0.88 T_P EF_{cr}(R_{AG} NC_{AG} + R_{AG} R_{BG} NC_{BG})) \, EF_{leach} frac_{wet} \, frac_{leach}$	Gg N_2O-N/Gg N	0.011	T_1, CS
	Lime Application	$E_{lime} = (0.9 M_{lime} fraclime / 1000)$	Mg C per Mg	0.12 – limestone 0.13 - dolomite	CS, IPCC
	Urea Application	$E_{urea} = M_{urea} EF_{urea} / 1000$	Mg CO_2C per Mg	0.2	T_1, IPCC

a. Weighted EF assuming 80 per cent of non-irrigated crops occur on low rainfall areas. Low rainfall EF = 0.0005 and high rainfall EF =
0.0085.
CS = country specific, IPCC = IPCC defaults, T_1 = Tier1, T_2 = Tier 2, T_3 = Tier3, T_M is total mass of fertiliser (Gg), F_N = fraction of N applied to the system, $frac_{wet}$ is the fraction of N available for leaching (0.223 Gg N/Gg applied), $frac_{leach} = 0.24$ (Gg N/Gg applied), $frac_{GASF} = 0.11$ (Gg N/Gg applied), $fraclime$ is the limestone fraction, M_{lime} is the mass of limestone applied to soils, T_p is the annual crop production (Gg), R_{AG} is residue: crop ratio (= 1.50); R_{BG} is below ground-residue: above-ground reside ratio (0.29); NC_{AG} and NC_{BG} is N content of above-ground and below-ground residue (0.006 & 0.010 kg N/kg-DM) respectively.

The total CO_2-eq emissions is

$$Onfarm\ \mathrm{CO_2 - eq} = (E_d + E_{cr} + E_d + E_{leach}) * \frac{44}{28} + \left((E_{lime} + E_{urea}) * \frac{44}{12}\right) * 298 \quad (1)$$

The main issue associated with NGGI methodology is the use of weighted average emission factor for all rain-fed, N-fertilised cereal crops in semi-arid regions. Li, Barton [33] developed a process-based Water and Nitrogen Management Model (WNMM) to investigate the senstivity of annual N_2O emissions in rain-fed semi-arid regions of southwestern Australia. They developed a predictive equation for estimating annual N_2O emissions with 64–74% of yearly variations using Multiple linear regression models. We used the same equation (2) to highlight the differences between NGGI Methodology and site-specific data.

$$E_{min} = 0.00096\mathrm{Nrate} + 0.0017\mathrm{Tmin} - 0.000028\mathrm{Y} + 0.000087\mathrm{P} \quad (2)$$

Where N_{rate} = nitrogen fertiliser rate (Kg N/ha), T_{min} = minimum average temperature (°C) and P = annual rainfall (mm).

Further, recommended rates of herbicide, fungicide, and insecticide are applied based on current practices as discussed above. An overview of lifecycle inventory data is presented in Table 1 on annual basis. We assumed an average emission factor for the use of pesticides because of their relatively small contribution in the overall carbon footprint although it varies based on the concertation and type of active ingredient. The common practice in WA is to mix fungicide with either fertiliser or herbicide operations, therefore separate diesel consumption isn’t considered in the study.

Farm machinery emissions are included to produce tractor and harvester used, however since the contribution of remaining infrastructure like sheds, bins etc. is assumed to very low as in consistent with studies [34-36]. Further, emissions from the packaging materials like packaging drums etc. is not included as their contribution has been determined even less than 0.001% of the total emissions [19]. An average diesel consumption data for each agronomical input i.e. sowing, spraying, harvesting is obtained through MyJohnDeere™ for experimental sites.

Table 3: Lifecycle Inventory Data

Agriculture Operation	**Lifecycle Operation**				**Agriculture Inputs**	
	Unit	**Values**		**Process**	**Application Rates**	**Units**
Pre-farm						
Manufacture						
Urea	kg CO2-eq/ kg N	4.17	Simapro; AusLCA	manufacture	Selected using Laconik Proprietary software using Precision Ag technology	kg/ha
MAP	kg CO2-eq/ kg N	4.75	Simapro; AusLCA	manufacture		
UAN	kg CO2-eq/ kg N	6.93	Simapro; AusLCA	manufacture		
Lime	kg CO2-eq/ kg lime	0.074	Simapro; AusLCA	manufacture, transportation, storage and delivery	0.5	
Wheat seeds	kg CO2-eq/ kg	0.19	Simapro; AusLCA		70	
Superphosphate	kg CO2-eq/ kg P2O5	1.14	Simapro; AusLCA		12	
Potassium Chloride	kg CO2-eq/ kg K2O	1.63	Wang et al. (2015); [37]		14	
Herbicide	kg CO2-eq/ kg of active ingredient	23.2	Brock et al. (2012) [38]		0.6	kg of active ingredient/ha
Insectides	kg CO2-eq/ kg of active ingredient	13.8	Wang et al. (2015); [37]		0.13	kg of active ingredient/ha
Fungicides	kg CO2-eq/ kg of active ingredient	13.8	Wang et al. (2015); [37]		0.1	kg of active ingredient/ha
Farm Machinery	kg CO2-eq/ t wheat	2.57	Simapro; AusLCA	embodied energy for harvester and tractors		
Diesel	kg CO2-eq/ L	0.4	Simapro; AusLCA	production and transport of diesel		
Coastal Transport of nitrogenous fertiliser						
Urea	kg CO2-eq/ kg N	0.25	Calculated	Average value for all ports	Average distance = 13000	km
UAN	kg CO2-eq/ kg N	0.37				
MAP	kg CO2-eq/ kg N	1.03				
Road Transport						

Urea	kg CO2-eq/ kg N/km	0.0001 42	Calculated	Average value	Port to storage: 40km (two-way);	km
UAN	kg CO2-eq/ kg N/km	0.0002 05			Storage to farm Distances: 200, 400, 600 km (one-way)	
MAP	kg CO2-eq/ kg N/km	2.0006 55				
Fuel Combustion						
Sowing	kg CO2-eq/ L	2.3	Simapro, AusLCA	Average value	2.8583333 33	Average Measured Value from trials (L)
Fertiliser	kg CO2-eq/ L	3.26			3.1111111 11	
Herbicide	kg CO2-eq/ L	2.71			1.024	
Harvesting	kg CO2-eq/ L	0.75			0.7349206 35	

4. Discussion

Figure 7 depicts that Urea emits higher emissions (170 kg CO_2 eq/ha) as compared to UAN (90 kg CO_2 eq/ha) and MAP (33 kg CO_2 eq/ha). Urea caused more than 50% higher ammonia emissions as compared to UAN and MAP. Whereas Table 3 highlights the percentage contribution of each sector with different N-source applications.

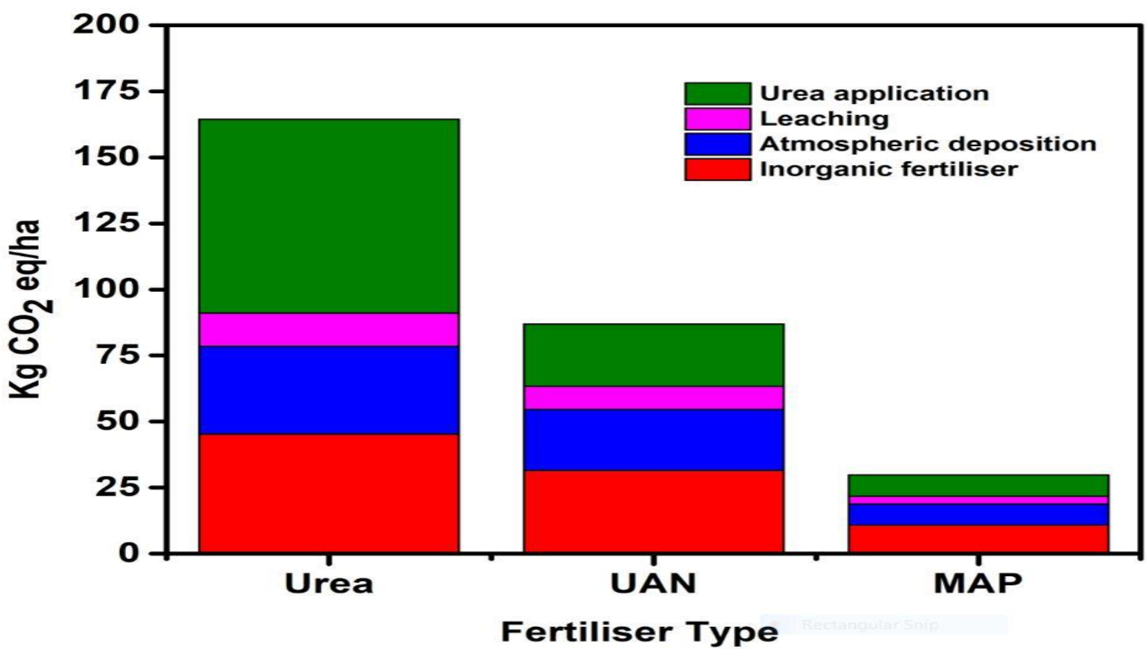

Figure 7: Comparison of on-farm emissions due to application of different fertilisers

The production and delivery of Urea, UAN and MAP contributes to 51%, 56% and 38% of the total emissions respectively. The other inputs including herbicides, insecticides etc. contributes approximately 4.2% of all emissions. The contribution of embodied energies in on-farm is as low as 1% in the overall lifecycle analysis. Similarly, from on-farm emissions, the direct and indirect nitrous emissions from different fertiliser applications contributes around 28% of the total emissions. However, these numbers are highly contingent on the use of right emission factors. Further, CO_2 emissions from the application of urea and lime dissolution contributes around 16% of the total emissions. Emissions of CO_2 during production and N_2O emissions during cultivation have a high share in the total carbon footprint. On the other hand, transportation share is very Production and nitrous emissions during cultivation have the highest share in total footprint emissions whereas transport contributed the low percentage (3-4%).

Table 4:Percentage comparison of different N-source – contribution of each sector

Emissions (%)	**N50**
Urea	
Pre-farm Emissions	55.95
On-farm Emissions	40.94
Transport	3.12
UAN	
Pre-farm Emissions	58.68
On-farm Emissions	38.30
Transport	3.02
MAP	
Pre-farm Emissions	39.72
On-farm Emissions	55.82
Transport	4.46

A comparison of impact of using NGGI approved methodology and locally adopted emission factors is done. The results indicate the use of generic emission factor grossly underestimated the emissions at lower fertiliser rate whereas overestimated the results at higher fertilisation rates. However, the locally adopted emission factors predict a smaller total emission at higher rates as compared to other. This could be attributed to increase in protein content of grain and in line with literature [37]. Hence, modified relation predicts a weak negative correlation between yield and overall nitrous emissions which matches our experimental results.

Table 5: Comparison of different methodologies

Location	Parameters	NGGI				Modified			
SMG	**Nrate (kg/ha)**	***50***	***76***	***100***	***200***	***50***	***76***	***100***	***200***
	Kg N_2O/ha	0.07	0.11	0.15	0.30	0.15	0.16	0.17	0.22
	Kg CO_2-eq/ha	22.61	34.38	45.23	90.47	46.04	49.46	52.62	65.78
EMK	**Nrate (kg/ha)**	***50***	***80***	***160***	***200***	***50***	***80***	***160***	***200***
	Kg N_2O/ha	0.07	0.12	0.24	0.30	0.11	0.13	0.16	0.18
	Kg CO_2-eq/ha	22.61	36.18	72.37	90.47	34.45	39.72	50.24	55.51
CNW	**Nrate (kg/ha)**	***50***	***80***	***160***	***200***	***50***	***80***	***160***	***200***
	Kg N_2O/ha	0.07	0.12	0.24	0.30	0.12	0.14	0.16	0.18
	Kg CO_2-eq/ha	22.61	36.18	72.37	90.47	35.64	42.22	48.80	55.38
WM	**Nrate (kg/ha)**	***50***	***60***	***80***	***100***	***50***	***60***	***80***	***100***
	Kg N_2O/ha	0.07	0.09	0.12	0.15	0.17	0.18	0.19	0.20
	Kg CO_2-eq/ha	22.61	27.14	36.18	45.23	51.79	54.42	57.05	59.69
SW	**Nrate (kg/ha)**	***50***	***100***	***150***	***200***	***50***	***100***	***150***	***200***
	Kg N_2O/ha	0.07	0.15	0.22	0.30	0.15	0.18	0.20	0.22
	Kg CO_2-eq/ha	22.61	45.23	67.85	90.47	47.52	54.10	60.68	67.26
MW	**Nrate (kg/ha)**	***50***	***100***	***150***	***200***	***50***	***100***	***150***	***200***
	Kg N_2O/ha	0.07	0.09	0.13	0.18	0.15	0.16	0.17	0.18
	Kg CO_2-eq/ha	22.61	27.14	40.71	54.28	44.88	48.83	52.78	54.09

5. Conclusion

A 70% increase in food production is required to adequately satisfy the expected rise of human population to 10 billion by 2050 [1]. This puts the agriculture sector all over the world in a precarious position to increase their productivity drastically. However, this substantial increase in production will comes at the cost of augmented GHG emissions due to increase N-fertilisation use whose importance and reliance of yield is widely documented. Since fertiliser costs represent a significant part of the variable costs of growing grain crops in the Mediterranean-type environment of Western Australia (WA), it is important to make these decisions wisely.

The results of this study estimated that only 50% of the nitrogen fertiliser growers apply is used by the crop. The remaining 50% is lost to the environment where it can become nitrous oxide (N_2O), a greenhouse gas with approximately 300 times the global warming potential of carbon dioxide. An average of 3.4 kg of CO2 is released with per kg of urea application at farm gate. The study also determined the relevant contribution of different components of production system with production and on-farm nitrous emissions having the highest contribution. The relative impact of using the right emission factors is also discussed in this context.

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