GHG emission assessment methodology for YEN Zero

This document sets out the approach that ADAS is using to calculate the greenhouse gas (GHG) emissions for each field in YEN Zero. There are three types of emissions that this assessment will capture:

1. Embedded emissions – the emissions resulting from the production and transport (up to farm gate) of the inputs required for that field
2. On-farm energy use – the emissions resulting from on-farm fuel use for operations required for that field
3. Field emissions – the emissions resulting from the application of synthetic and organic nitrogen fertiliser and return of crop residues to the field

These are described in detail below with the key emission factors (value which converts an activity into equivalent CO_2 emissions) for embedded emissions and on-farm energy use presented in Table 2.

Embedded emissions

Embedded emissions for three categories of input are included in the assessment: seed, fertiliser, and agrochemicals.

1. Embedded emissions in seed sown (kg/ha): Seed inputs will have associated embedded emissions from their production. Average crop production emissions for seed are taken from the YEN Zero database.
2. Manufacture of fertilisers: ammonium nitrate (AN), urea, liquid urea ammonium nitrate (UAN), phosphate (P_2O_5), potash (K_2O), and lime (expressed per kg of nutrient). Note that an individual emission factor for sulphate is not available; sulphate-containing fertilisers use sulphuric acid, which is produced using waste heat from other manufacturing processes so is assumed to have no emissions. The embedded emission figures given in Table 2 are based on European production; these emissions can be higher for fertiliser produced elsewhere. These European figures will be used as default values. For urea and UAN, emissions from urea hydrolysis are included in the manufacture emissions (stated in Table 3).

   If entrants provide information on their fertilisers that enables identification of other production regions, the relevant embedded emissions for that region will be used instead. Additionally, if a fertiliser manufacturer has published an accredited carbon footprint figure, then this value will be used instead of the reference source given in Table 3. For lime applications it is assumed all products have the same manufacture emissions, therefore an emission factor for kg of product is used (Table 3). The calculated emissions for lime are divided by 4 as YEN Zero entrants are asked for quantity of lime applied in the last 4 years.

   a. Relevant accredited fertiliser manufacture C footprints used include:

      i. Those manufactured by CF Fertilisers

      ii. Those manufactured/distributed by Origin Fertilisers where C footprints can be sourced using the NUTRI-CO_2OL tool

   In this assessment, organic fertilisers (e.g., manure) are assumed to have no embedded emissions, which is consistent with other crop carbon footprinting methodologies.

3. Manufacture of agrochemicals: fungicide, herbicide, insecticide, and plant growth regulators (PGRs). The CO_2e emissions associated with the manufacture of agrochemicals is based on the number of applications made. Standard figures of kg of ai in each application of each

agrochemical type (herbicide, fungicide, PGR, and insecticide) were estimated based on data from the Defra Pesticide Usage Survey (Garthwaite et al., 2019). The statistics of weight of active ingredient (ai) and the area treated (ha) were used to calculate average kg ai/ha for each application. An emission factor was then used to convert kg of ai/ha into kg CO_2e/ha (Table 2). The emission factor for PGRs (kg CO_2e/kg ai) was assumed to be the same as herbicides as no data could be found from the pesticide manufacture reference source.

On-farm energy use

For calculating emissions from on-farm energy use, we are interested in the amount of fuel used for field operations and grain drying. Participants supplied information on these either by providing the actual fuel use, if it was measured, or by providing a list of farming operations that were conducted for each field. These operations are cultivations, sprayer and fertiliser passes, harvesting, and baling straw.

For this we are using the latest dataset from DESNZ (2018 - 2023). This includes emission factors for the use of Diesel *(average biofuel blend)*, both for its use and for the emissions associated with its extraction, refining and transportation (the *well-to-tank* emissions).

Table 1 Year-to-year emission factors for diesel use on-farm.

Year	Emission type	EF	Source	Total	Units
2018	Fuel use	2.627	DESNZ, 2018	3.245	kg CO_2e/L
	Fuel production	0.618			
2019	Fuel use	2.594	DESNZ, 2019	3.211	
	Fuel production	0.617			
2020	Fuel use	2.546	DESNZ, 2020	3.156	
	Fuel production	0.610			
2021	Fuel use	2.512	DESNZ, 2021	3.122	
	Fuel production	0.610			
2022	Fuel use	2.558	DESNZ, 2022	3.168	
	Fuel production	0.610			
2023	Fuel use	2.512	DESNZ, 2023	3.123	
	Fuel production	0.611			

Fuel provided by entrants was not used to calculate emissions from operations due to the disparity between the two methods and not all entries providing fuel use figures. Instead, the energy requirements for each field operation were used to calculate emissions from operations, listed in Table 2. Where entrants have detailed cultivation strategy as 'deep non-inversion', a sum of 'drill', 'roll', and 'disc' is used. These energy requirements are based on figures from Williams et al. (2006). Soil texture was not considered when calculating energy use; all sites were assumed to be of a loam soil. Emissions are calculated using the above emission factor assuming there are 38 MJ/l diesel.

Commented [MT1]: @Sarah Wynn Is this Williams reference still usable to date given that the energy requirements of machinery may have changed since before 2006?

If not, do you have any other recommendations for sources?

Emissions associated with grain drying are calculated based on the amount of material being dried, the starting moisture content and final moisture content. The energy required for drying crops to achieve stable storage is equivalent to 10.4 kg CO_2e/tonne of grain/% moisture loss required (Mortimer et al. 2004). These associated emissions are applied to crops which are more than 0.5% higher in moisture content compared to the standard moisture contents stated in Table 1.

Table 2 Standard moisture contents of crop products in YEN Zero for grain drying purposes.

Crop type	Standard moisture content (%)
Wheat	15
Barley	15
Oats	15
Triticale	15
Rye	15
Oilseed rape	9
Field beans	15
Combining peas	15
Linseed	9
Maize – grain	13
Forage crops	No drying required

Field emissions

When nitrogen fertiliser (either manufactured or organic) is added to the land, some of the nitrogen is lost as nitrous oxide. These emissions also occur from decomposition of crop material that remains on the field. These field emissions are a major contributor to overall emissions from agriculture, potentially contributing over half of the emissions from crop production. There are several pathways in which this nitrous oxide can be produced:

- Direct emissions of nitrous oxide from the soil following fertiliser application
- Indirect emissions of nitrous oxide from ammonia volatilisation following fertiliser application
- Indirect emissions of nitrous oxide from nitrates that are leached following fertiliser application
- Direct emissions of nitrous oxide from decomposing crop material left in the field

There are various means of calculating these emissions. Given that these field emissions are influenced by a range of factors (e.g., weather, soil type, application method) these calculations are approximations based on average data collected from UK field experiments. The approach that YEN Zero is taking is to use the newly built Environmental Benchmarking Calculation Engine (EBCE) that has been developed by ADAS for the AHDB. The EBCE calculates field emissions for a given set of field data (e.g., nitrogen fertiliser application rate, date of application, yearly rainfall). The approach that is taken aligns with that of the UK GHG Inventory (see Brown et al., 2023 and appendices for detailed methodology), which is the way that the UK quantifies GHG emissions from each sector of the economy.

For organic materials, N_2O emissions are calculated based on total N content of the material, and proportion of ammoniacal-N in the material to calculate emissions associated with volatolisation. Figures for the different manure types are sourced from RB209. N_2O emissions from crop residues are calculated using above and belowground crop nitrogen content figures from the UK GHG Inventory. Volatilisation of N_2O can be reduced by applying organic materials using trailing shoe, injection or incorporation techniques, which have been accounted for in the calculations. The global warming potential of 273 was used to convert N_2O emissions to CO_2 equivalent emissions, in line with the inventory approach.

Alongside nitrous oxide emissions, the UK GHG Inventory also includes emissions from land use change; in YEN Zero we are assuming that no land use change has occurred, and all fields have not been recently converted from pasture or woodland.

For more detail on how direct and indirect N_2O emissions are calculated in YEN Zero, please refer to the appendices.

Notes

YEN Zero makes several assumptions to simplify the data collection and analysis process. Firstly, we are not including emissions from capital items (e.g., the manufacture of tractors). Generally, these are only a very minor part of the overall farm GHG emissions. Secondly, the process does not include the allocation of emissions between co-products. Where straw is baled, this yield is not considered, and all emissions are allocated to the grain in the product carbon footprint.

Table 3 Greenhouse gas (GHG) emission factors for crop inputs and operations used to calculate GHG intensities of crop production.

Input	Default Rate Used		Reference	Emission Factor		Reference
Seed	N/A			0.0661 - 0.73	kg CO_2e/kg	Average YEN Zero emissions (2021-2022)
Pesticide manufacture						
Herbicide	0.452	kg ai/ha	Garthwaite (2020)	8.985	kg CO_2e/kg	Green (1987)
Insecticide	0.050			25.134		
Fungicide	0.294			6.009		
Growth Regulator	0.481			8.985		
Fertiliser manufacture						
Ammonium nitrate	N/A			3.40	kg CO_2e/kg of nutrient	Brentrup et al. (2018)
Urea				1.91 (+1.6)[a]		
UAN				2.60 (+0.8)[a]		
CAN				3.52		
P_2O_5				0.38		
K_2O				0.42		
Lime				0.07	kg CO_2e/kg of product	
Operations						
Ploughing	1350	MJ/ha	Williams et al. (2006)	0.082-0.085	kg CO_2e/MJ	DESNZ (2018 - 2023)
Power harrow	913					
Drill	280					
Roll	248					
Disc	784					
Shallow min till	784					
Strip tillage	578					
Direct drill	372					
Sprayer	114					
Fertiliser spreader	105					
Lime spreading	336					
Combine harvest – straw chopped	1134					
Combine harvest – w/o straw chopped	1096					
Grain carting	399					
Grain drying	N/A			10.4	kg CO_2e/t/%	Mortimer et al. (2004)
Baling	N/A			16	kg CO_2e/ha	John Nix (2021)
Fuel				3.12 – 3.25	kg CO_2e/l	DESNZ (2018 - 2023)

[a]Emissions from urea hydrolysis included in manufacture emissions

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Appendix

Calculating direct and indirect N_2O emissions from N fertiliser applications

Direct and indirect emissions associated with the application of nitrogen (N) fertilisers were calculated using IPCC 2019 (IPCC, 2019) Tier 2 methodology, implementing UK-specific emissions factors and parameters where available. This UK-specific data is sourced from the UK GHG inventory (Brown et al., 2023). Total direct N_2O emissions following N application were calculated using equations derived from Brown et al. (2023), which are specific to the UK environment. The relationship between N applied (N) and N_2O -N emissions is scaled by annual rainfall (R) for AN based fertiliser. Long term rainfall data from the last 10 years for each MORECS square within the UK was used for each YEN Zero entrant, using the entrant's postcode to determine their location. Weather data was sourced from DTN.

For urea and UAN there is no inclusion of rainfall in the calculation of N_2O, due to a lack of experimental evidence. The direct N_2O-N kg/ha emissions from N fertiliser are calculated net of baseline emissions, calculated from Equations 1 and 2 without N fertiliser, and are converted to N_2O from the proportion N in N_2O (44/28).

Equation 1 (Ammonium Nitrate):

=1*(1.019709*EXP((0.57 + 0.3962 *(R)/1000 -0.0001942 *N + 0.003248 *(R)/1000 *N) *1) - 1.6297212)

Equation 2 (Urea and UAN):

=1*(1.01107 * EXP((0.8404 + 0.001518 *N)*1) - 1.6297212)

Indirect N_2O emissions from volatilisation and leaching were calculated using the UK GHG inventory (Brown et al., 2023) and IPCC emission factors (IPCC, 2019). The fraction of N applied volatilised to ammonia and subsequently deposited was assumed to be 0.0153 for AN, 0.1103 for urea and 0.055 for UAN (Brown et al., 2023), with emissions of 0.014 kg N_2O/kg N volatilised (IPCC, 2019). The fraction of N leached is assumed to be 0.24 and applies to all fertiliser and crop residue N inputs, with emissions from leached N of 0.011 kg N_2O-N/kg N (IPCC, 2019).

Commented [MT2]: This needs to be really clear

Commented [MT3]: Wet climate

For scenarios where a nitrification or urease inhibitor was used the reduction in emissions did not go down to a product level. For nitrification inhibitors a blanket reduction of 43.8% of direct N_2O emissions was used based on previous research, for all N fertiliser forms (Misselbrook et al., 2014; Yang et al., 2016). The influence of urease inhibitors was derived from UK field experiments which measured ammonia emissions from N fertiliser applications with the inhibitor Agrotain (NT26; Chadwick et al., 2005). A percentage reduction in indirect N_2O emissions from volatilisation of 70% was used for urea N forms, and 44% for UAN.

Calculating N_2O emissions from crop residues

Direct N_2O emissions from crop residues were calculated using crop specific figures from the inventory (Brown et al., 2023), which included:

- Dry matter (DM) harvest index (HI) values (the HI value for forage crops was assumed to 1)
- The ratio of below-ground residues to above-ground biomass
- Nitrogen content in above and below ground residues
- The above ground residue retained if residues are removed

Crop yield was used to calculate the amount of residues produced by each crop, the calculation used to determine residue quantities is listed below along with calculations of quantities of N within the residue.

Equation 3, calculating above ground residue DM

a) Dry matter yield; Y_dm

= Yield * ((100 – crop moisture %)/100)

b) Above ground residue DM; Residue_AG_dm

= Y_dm * ((1-HI)/HI)

Equation 4, calculating below ground residue DM; Residue_BG_dm

= (Y_dm + Residue_AG_dm) * BG_to_AG_ratio

Equation 5, calculating N content in above and belowground residue

= (Residue_AG_dm * AG_N_content_residues) + (Residue_BG_dm * BG_N_content_residues)

Equation 6, calculating residue N if residues are removed from the field

= (AG_N * proportion_AG_residue_retained) + BG_N

For maize, beans and pea crops the IPCC approach is used to calculate N_2O emissions from crop residues. This uses the below calculation to determine above ground residue quantities:

Equation 7, IPCC approach to calculate aboveground residue N content

a) Residue_AG_dm

= (IPCC_Slope * Y_dm) + IPCC_intercept

b) AG_N

= Residue_AG_dm * AG_N_content_residues

Commented [CB4]: Should add in below ground element

Where the slope and intercept values for maize are 1.03 and 0.61 respectively, and the slope and intercept values for beans and peas are 1.13 and 0.85 respectively.

These figures were converted to N_2O using the same method as above after applying an emission factor of 0.01 derived from IPCC Tier 2 methodology (IPCC, 2019). The emissions associated with baling the straw (sourced from John Nix, 2021; Table 2) are also considered when residues are removed.

Commented [MT5]: @Sarah Wynn did you pick up the newest John Nix from Boxworth the other week?

Commented [SW6R5]: Yes - what value would you like from it?

Commented [MT7R5]: @Sarah Wynn please could you have a look and see if there is anything in there about straw baling emissions? Table 2 above uses John Nix (2021), which indicates about 16 kg CO2e/ha - if not then we could probably keep using this figure!

Calculating direct and indirect N_2O emissions from organic materials and manures

Direct N_2O emissions from organic materials and manure are calculated by multiplying the total N in the material applied by an emission factor specific to each organic material, sourced from the inventory (Brown et al., 2023). Total N is calculated by multiplying quantity of material applied (t or m^3/ha) by the total N content of the material (kg/m^3), sourced from RB209 look up tables.

Indirect N_2O emissions from volatilisation and leaching were calculated using the UK GHG inventory (Brown et al., 2023) and IPCC emission factors (IPCC, 2019). The fraction of N leached from organic materials is assumed to be 0.24, with emissions from leached N of 0.011 kg N_2O-N/kg N (IPCC, 2019). The fraction of N applied volatilised to ammonia and subsequently deposited is calculated by adding together the direct NO-N and NH_3-N emissions and multiplying by IPCC EF_4. The equation for this is detailed below.

Equation 8, Indirect N_2O emissions from volatilisation from organic materials

= ((Direct N_2O emissions * 0.4) + ((rate of manure applied (t or m^3/ha) * total ammonium N (kg/m3)) * direct NH_3 EF)) * IPCC EF_4

Commented [MT8]: Where is this coming from?

Where total ammonium N in each manure type is sourced from MANNER-NPK, NH_3-N emission factors sourced from the inventory (Brown et al., 2023) and the IPCC EF_4 is 0.014 for wet climates.