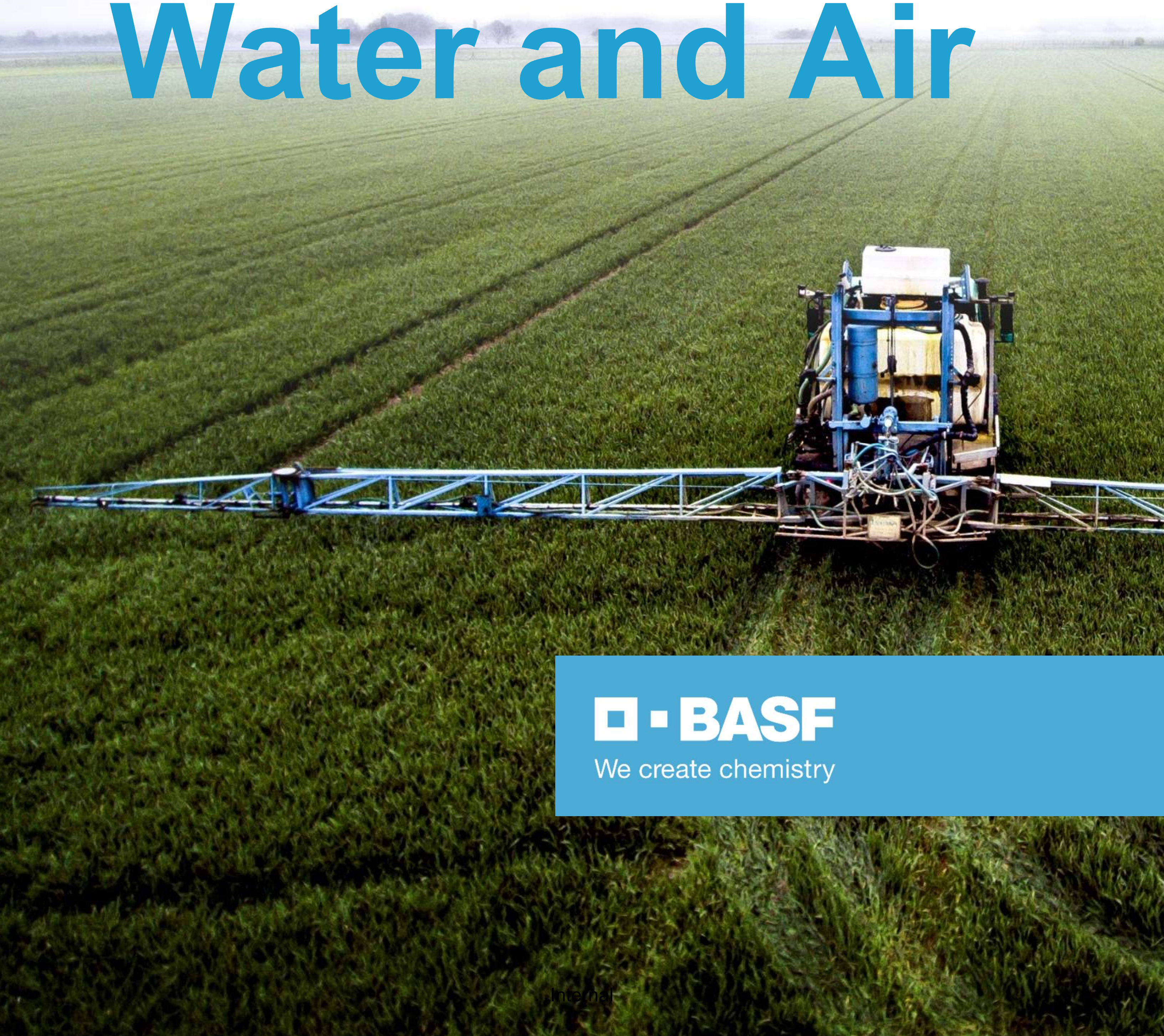
Emissions into Soil, Water and Air



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Farming practices cause various emissions into the environment (soil, water and air). These are modelled in AgBalance® to calculate the contribution of the applied inputs (e.g. fertilizer) and farming practices to the different environmental impact categories (e.g. climate change). In particular, emissions of heavy metals, crop protection agents, nitrogen and phosphorus-based compounds and other substances are assessed in the AgBalance® Model.

Emissions arising in upstream processes, such as electricity generation, production of fertilizers, etc., are modelled with the corresponding regional datasets. As for emissions occurring in the foreground system, these are modelled using an approach with global applicability or differentiated according to region or climatic conditions, depending on the data availability.

1. Heavy metal emissions to soil and water

The input of heavy metals to agricultural soil can lead to the pollution of the soil and potential toxicity concerns. There is also a tendency of heavy metals to accumulate in the agricultural soil, as annual heavy metal input values are much higher than the respective output values (Scheffer & Schachtschabel, 2010). Also, heavy metals contained in the soil are emitted to surface water by means of soil erosion (Scheffer & Schachtschabel, 2010).

The average heavy metal emissions resulting from the application of the organic and mineral fertilizers are based on their applied amounts and their heavy metal content[1]. For simplification reasons, the heavy metal emissions from fertilizers are assumed to be completely emitted to the agricultural soil and not to be taken up by the plant.

As for the emissions of each heavy metal from soil erosion into surface water, these are calculated by multiplying the corresponding heavy metal content of the soil with 20% of the amount of eroded soil, assuming that 20% of the eroded soil ends up in surface water (Prasuhn, 2006). Compared to the relocation of heavy metals through soil erosion, the losses through leaching processes are negligibly small and are therefore not considered in the model (Scheffer & Schachtschabel, 2010).

[1] Sources of heavy metal content in fertilizers obtained from (Dittrich & Klose, 2008), (Kördel, et al., 2007) and (Washington State Department of Agriculture, 2009)

The heavy metal emissions modelled in the AgBalance® Model resulting from fertilizer application and soil erosion are depicted in Table 1.

Table 1 Heavy metal soil and water emissions and respective sources in the AgBalance® Model

Emission Source	**Organic and Mineral Fertilizer Application**	**Soil Erosion**
Heavy Metal Element	As	As
	Cd	Cd
	Co a)	Co
	Cr	Cr
	Cu	Cu
	Hg	Hg
	Ni	Ni
	Pb	Pb
	Sb a)	Sb
	Ti	Ti a)
	U	U a)
	Zn	Zn
Compartment Endpoint	Soil	Water
Standard Calculation Method	Assumption 100% emitted into soil	(Prasuhn, 2006)
Reference:	(Washington State Department of Agriculture, 2009) (Kördel, et al., 2007) (Dittrich & Klose, 2008)	(Tóth, Hermann, Szatmári, & Pásztor, 2016)

Legend: a) Emissions of the heavy metal to the compartment endpoint are not considered

The average heavy metal emissions resulting from the application of the organic and mineral fertilizers is taken from (Dittrich & Klose, 2008) and (Washington State Department of Agriculture, 2009). These are equivalent to the heavy metal content in fertilizers. For simplification reasons, the heavy metal emissions from fertilizers are assumed to be completely emitted to the agricultural soil and not to be taken up by the plant.

The emissions of each heavy metal from soil erosion into surface water are then calculated by multiplying the corresponding heavy metal content of the soil[2] with 20% of the amount of eroded soil, assuming that 20% of the eroded soil ends up in surface water (Prasuhn, 2006). In contrast to the relocation of heavy metals with soil erosion, the losses through leaching processes are not considered in the model, as they are negligibly small (Scheffer & Schachtschabel, 2010). Heavy metal emissions occurring in upstream processes (e.g. fertilizer production, diesel production, etc.) are considered in the model, embedded in the corresponding LCI datasets used in the AgBalance® Model.

2. Crop protection agent emissions to soil, water and air

The emissions of plant protection agents to soil, water and air are assessed in terms of their toxicity potential in the AgBalance® Model. Three options for the emission distribution into environmental compartments are implemented, with option 1 as default:

1. An approach recommended by (European Commission, 2017), consisting of 90% emissions into soil, 1% into surface water and 9% of the active ingredient into the air. Chemical fate or adhesion on crop parts are also not considered.

[2]Sources of heavy metal content in soil obtained from (Tóth, Hermann, Szatmári, & Pásztor, 2016)

2. A novel method comprising a specific set of mass fractions determining the distribution of CPAs to environmental compartments. These factors can be entered to the AgBalance® Model when literature values relevant for the sustainability analysis are available.
3. An approach considered by ecoinvent (Nemecek & Kägi, 2007). This implies a complete (100%) emission of the active ingredient to soil. Chemical fate or adhesion on crop parts are also not considered.

Once the emissions of crop protection agents have been assigned to the different compartments (soil, air and water) using the emission factors, the USEtox® characterization factors (CF) of release version 2.12 are used in the AgBalance® Model. This method evaluates the toxicity of the plant protection agent emissions, which simulates the fate of plant protection agents and other substances in air, water and soil (Rosenbaum, et al., 2008).

3. Nitrogen and phosphorus emissions to water

For the summary of methodological approaches to model nitrogen and phosphorus water emissions see Table 2.

Table 2 Nitrogen and Phosphorus water emissions

Emission sources	Region	Climatic and geographic influence	References
NO_3^-			
Organic and mineral fertilizer	E	Specific climatic factors such as precipitation plus soil characteristics are taken into account	(Brentrup, Kürsters, Lammel, & Kuhlmann, 2000)
Organic and mineral fertilizer Soil mineral nitrogen	G	Specific climatic factors such as precipitation plus soil characteristics are taken into account	(Nemecek, Schnetzer, & Reinhard, 2014)
Organic and mineral fertilizer Soil mineral nitrogen Nitrogen from irrigation Nitrogen from precipitation Nitrogen in legumes Nitrogen from excretions of draft animals used for field work	E/G (simplified approach)	Wet or dry climates according to climatic zone, precipitation and evapotranspiration	(IPCC 2019)
P			
Mineral and organic fertilizer Phosphate fertilizer	E/G	Specific factors like site topography and land use taken into account	(Prasuhn, 2006)

The regional differentiation is implemented for the calculation of nitrogen water emissions in the AgBalance® Model. For the European region (E), the method implemented in the model is based on (Brentrup, Kürsters, Lammel, & Kuhlmann, 2000). The global approach (G) for nitrogen water emissions is modelled according to (Nemecek, Schnetzer, & Reinhard, 2014). The simplified factor-based methodology (E/G) proposed by IPCC (IPCC, 2019) is also available in the model, in case no specific input data considering e.g. soil composition, topography, etc. is available. For the description of the above-mentioned methodologies see Table 3.

Table 3 Nitrogen water emissions modelled in the AgBalance® Model

Region	Method description	Reference
E	The method applicable for the northern hemisphere locations (hydrologic summer from April 1st to September 30th) is based on (Brentrup, Kürsters, Lammel, & Kuhlmann, 2000), which takes soil and climate conditions into account. The method is implemented in the AgBalance® Model to determine the nitrate emissions of European region. The leaching rate is calculated using precipitation and soil field capacity parameters for predefined soils, according to the German soil classification system (see also section **Fehler! Verweisquelle konnte nicht gefunden werden.**), based on the soil water exchange rate that is assumed to correlate with the amount of nitrate lost to groundwater. The leaching rate represents the N losses by leaching and runoff for regions where the total amount of precipitation, minus the potential evaporation in the same time period, is higher than the soil water holding capacity, or where irrigation is employed.	(Brentrup, Kürsters, Lammel, & Kuhlmann, 2000)
G	The method is recommended for sustainability analyses of farming practices in non-European regions, it consists of an adaptation of a formula developed by (de Willigen, 2000) and it calculates the leaching of NO3-N with a regression model that includes precipitation, irrigation, soil clay content, rooting depth, nitrogen supply through fertilizers, nitrogen in soil organic matter and nitrogen uptake by the crop. In the case of soil clay content, if primary data is not available, the Harmonized World Soil Database provides information of dominant soil in the location of the analysis (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). As for the rooting depth of the crop, external literature data can be used, for example, the values from the publication of (Fan, McConkey, Wang, & Janzen, 2016).	(Nemecek, Schnetzer, & Reinhard, 2014)
E/G	This method can be used when required data (e.g. mineral N in soil, monthly precipitation rates) is not available for the above-mentioned methods. The simplified method is the factor-based approach with a steady leaching rate of 0,24 kg NO3-N / kg N applied from mineral and organic nitrogen fertilizer (IPCC, 2019), but also for nitrogen from natural sources, such as mineral nitrogen in soil, nitrogen deposition and natural occurring legumes, and nitrogen from excretion of draft animals. This factor is applicable for wet climates only (see also 4), whereas in dry climate the factor is set to zero, according to (IPCC, 2019).	(IPCC, 2019)

For **phosphorus** emissions to water, the (Prasuhn, 2006) methodology was chosen as a standard method. It considers the emissions via leaching, drainage, erosion and run-off.

- Leaching to groundwater: P losses through leaching to groundwater depend on several factors according to (Prasuhn, 2006). Following this approach, in the AgBalance® Model
  - the type of land use can be selected and thereby the corresponding initial P-value in kg P/ha,
  - the soil-factor (including soil permeability, type of soil, soil compaction) is set to 1 (equivalent to no classification),
  - the P-fertilization-factor is calculated according to (Prasuhn, 2006)
  - the P-test-factor is also set to 1 (no value).

For the explanation of the different P-factors see (Prasuhn, 2006). Generally spoken, the amount of leaching phosphorus increases with P-fertilization. Contrary to nitrates, Phosphorus is strongly adsorbed to soil particles and as a result less mobile (Prasuhn, 2006). Hence, leaching process has a relatively small contribution on the total P-losses (Prasuhn, 2006).

- Losses to surface water due to drainage systems, erosion and run-off: Most important factors in terms of P-losses through run-off are the type of land use and fertilization (especially fertilization with liquid manure). In the AgBalance® Model, the P-losses through run-off are estimated as follows:
  - The type of land use can be selected in the model and thereby the corresponding initial P-value in kg P/ha
  - The soil-factor (including soil permeability, type of soil, soil compaction) is also set to 1 (equivalent to no classification)
  - For the topography parameter, the default for the gradient value is set to 3% but can be adjusted accordingly. The values for length and form of slope, as well as for water influx and water outlet and distance to discharger are set to 1, since the relevant data is usually not available.
  - The P-fertilizer factor is calculated according to (Prasuhn, 2006)
  - The P-test-factor is also set to 1.

In order to determine the P-losses into surface water through soil erosion according to (Prasuhn, 2006), following factors are taken into account:

- The total amount of soil erosion in t/(ha·year)
- The fraction of eroded soil that ends in surface water, equivalent to 20%
- An average phosphorus content of 950 mg P/kg in soil (default value)
- An enrichment factor of the eroded soil of 1,86.

The estimation of P-losses through drainage to surface water is similar to the calculation of P-losses through leaching, described in the paragraph above. However, an additional drainage factor (value=6) is included in the calculation to account for the increased P-losses. The drainage system factor is only considered if a drainage exists on the field, if not, the value is set to zero. However, the amount of P-losses through leaching can decrease in fields with drainage systems, as comparatively more phosphorus is lost through macropores with the drained water. It is recommended to account for a reduction from 50% to 75% of the estimated value of leached P (Prasuhn, 2019) in fields with drainage. In the AgBalance® Model, a reduction of 50% is assumed as a generic value as this constitutes a worst-case scenario.

4. Nitrogen-based air emissions: NO_x, N_2O and NH_3

Table 4 shows the main nitrogen-based air emissions calculated in the AgBalance® Model, according to their emission sources.

Table 4 Nitrogen-based air emissions with the corresponding emission source modelled in the AgBalance® Model

Emission source	NO_x	N_2O	NH_3
Organic fertilizer	X	X	X
Mineral fertilizer	X	X	X
Above and below ground residues		X	
Soil mineral nitrogen	X	X	X
Nitrogen in legumes	X	X	X
Nitrogen from irrigation	X	X	X
Nitrogen from precipitation	X	X	X
Nitrogen from excretions from draft animals	X	X	X
Diesel combustion in a tractor	X	X	X
Diesel combustion in an irrigation pump	X	X	X
Biomass combustion	X	X	X
Nitrogen oxides NO_x		X[a)]	
Ammonia NH_3		X[a)]	
Nitrate (NO_3^-)		X[a)]	

Legend: [a)] Indirect N_2O emissions

Regarding the applied methods, the most important reference for nitrogen-based air emissions is the Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change (IPCC).

For calculations of emissions in Europe and the UNECE geographical area, the European Monitoring Evaluation Programme (EMEP) and European Environment Agency (EEA) support the preparation of national emission inventories with the joint EMEP/EEA air pollutant emission inventory guidebook

(EMEP/EEA, 2016). Also, a study of (Stehfest & Bouwman, 2006), that determined empirical relationships between measurements of NO and driving factors to model annual emissions, is used to estimate global and regional NOx emissions.

Furthermore, methodological approaches are available for nitrogen-based air emissions (NOx, N2O and NH3 emissions) from diesel combustion in a tractor and irrigation pump, biomass combustion, as well as from other sources such as above and below ground residues.

More details on the applied methods for the calculation of NOx, N2O and NH3 emissions from each source are found in Table 5.

Table 5 Nitrogen-based air emissions: applied methods and emission sources

Emission sources	Region	Climate	Formulas and factors	Reference
Nitrogen oxide NO_x				
Organic and mineral fertilizer	E[a)]	-	0,011 kg NO_x-N / kg N (cropland)	(Stehfest & Bouwman, 2006)
Organic and mineral fertilizer	G[b)]	-	0,012 kg NO_x-N / kg N (cropland)	(Stehfest & Bouwman, 2006)
Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation Nitrogen from excretions from draft animals	E	-	0,011 kg NOx-N / kg N (cropland) assumed as mineral and organic fertilizer from Bouwman 2006	Assumed from (Stehfest & Bouwman, 2006)
Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation Nitrogen from excretions from draft animals	G	-	0,012 kg NOx-N / kg N (cropland) assumed as mineral and organic fertilizer from Bouwman 2006	Assumed from (Stehfest & Bouwman, 2006)
Diesel combustion in a tractor	E/G	-	$(77,488-42,963*Umin-21,451*power-3,352*Umin^2+22,886*Umin*power+6,362*power^2)/1000$ kg NOx/kg diesel Umin: share of nominal engine speed [-] (ts assumption= 0,5) power: share of nominal power [-] (ts assumption= 0,5)	(Rinaldi & Stadtler, 2002)
Diesel combustion in an irrigation pump	E/G	-	0,0713 kg NO_x/kg diesel	"Irrigation pump generic" dataset (Sphera Solutions, Inc., 2018)
Biomass combustion	G	-	(Ncont*100*9,5-0,49)/1000 kg NOx/kg biomass Ncont- N content of combusted biomass (fresh mass) [kg/kg]	"Biomass combustion (field)" dataset based on (Battye & Battye, 2002) (Sphera Solutions, Inc., 2018)
Nitrous oxide N_2O (direct)				
Mineral fertilizer	E/G	Wet[c)] Dry[c)] Aggregated	0,016 kg N_2O-N/kg N 0,005 kg N_2O-N/kg N 0,01 kg N_2O-N/kg N	(IPCC, 2019)
Organic fertilizer Above and below ground residues Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation	E/G	Wet Dry Aggregated	0,006 kg N_2O-N/kg N 0,005 kg N_2O-N/kg N 0,01 kg N_2O-N/kg N	(IPCC, 2019)
Nitrogen from excretions of draft animals	E/G	Wet Dry	0,006 kg N_2O-N/kg N 0,002 kg N_2O-N/kg N	(IPCC, 2019)

		Aggregated	0,004 kg N_2O-N/kg N	
Diesel combustion in an agricultural tractor	E/G	-	0,0002325 kg N_2O/kg diesel	Assumption from "diesel, burned in agricultural machinery" Ecoinvent 3.4
Diesel combustion in an irrigation pump	E/G	-	0,000256 kg N_2O/kg diesel	"Irrigation pump generic" dataset (Sphera Solutions, Inc., 2018)

Emission sources	Region	Climate	Formulas and factors	Reference
Nitrous oxide N_2O (indirect)				
Nitrogen oxides NO_x	E/G	Wet	0,014 kg of the volatilized nitrogen in nitrogen oxides (NO_x-N)	(IPCC, 2019)
		Dry	0,005 kg of the volatilized nitrogen in nitrogen oxides (NO_x-N)	
		Aggregated	0,01 kg of the volatilized nitrogen in nitrogen oxides (NO_x-N)	
Ammonia NH_3	E/G	Wet	0,014 kg of the volatilized nitrogen in ammonia (NH_3-N)	
		Dry	0,005 kg of the volatilized nitrogen in ammonia (NH_3-N)	
		Aggregated	0,01 kg of the volatilized nitrogen in ammonia (NH_3-N)	
Nitrate (NO_3^-)	E/G		0,011 kg of the leached nitrogen (NO_3-N)	
Ammonia NH_3				
Mineral fertilizer	E	Climatic differentiation	Factors are available for the following fertilizers: anhydrous ammonia, ammonium sulphate, ammonium sulphate urea, ammonium nitrate, ammonia solution, calcium ammonium nitrate, calcium nitrate, di-ammonium phosphate, mono-ammonium phosphate, urea, urea ammonium nitrate and NPK mixtures differentiated according fertilizer type, soil pH and climate	(EMEP/EEA, 2016)
Mineral fertilizer	G		0,11 kg NH_3-N /kg N[d)]	(IPCC, 2019)
Organic fertilizer Nitrogen from excretions of draft animals	E/G	-	0,21 kg NH_3-N / kg N	(IPCC, 2019)
Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation	E/G	-	Assumed as 0,11 kg NH_3-N / kg N (emission factor for mineral fertilizers from IPCC 2019)	Assumed as (IPCC, 2019)
Biomass combustion	E/G	-	(961-984*CE)/1000*0,014 [kg NH_3/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average of forest and grass combustion efficiencies	"Biomass combustion (field)" dataset based on (Battye & Battye, 2002) (Sphera Solutions, Inc., 2018)

Legend:

a) E: European region
b) G: Global
c) For the definition of wet and dry climate see (IPCC, 2019).
d) The emission factor as stated in the (IPCC, 2019) consists of an emission factor for both NH_3 and NOx, per kg applied N. In AgBalance®, it is assumed that this factor is applicable to calculate NH_3 emissions, while the NO_x emissions are calculated separately based on (Stehfest & Bouwman, 2006).

5. Other air emissions

Following other air emissions are reflected in the AgBalance® Model:

- Non-methane volatile organic compounds (NMVOC),
- Particulate matter ($PM_{2,5}$ and PM_{10}),
- Carbon dioxide (CO_2),
- Methane (CH_4),
- Halogenated hydrocarbons,
- Sulfur dioxide (SO_2) and
- Benzo{a} pyrene.

Different methodologies were applied to model other air emissions in the AgBalance® Model. The diesel combustion in tractor was modeled according to (Rinaldi & Stadtler, 2002) and Sphera predefined datasets (Sphera Solutions, Inc., 2018). Diesel combustion in irrigation pump as an emission source is modelled using a Sphera predefined dataset (Sphera Solutions, Inc., 2018). The application of carbonates to soil in the form of lime, e.g. calcic limestone (CaCO3), or dolomite (CaMg(CO3)2), causes CO2 emissions due to the dissolution of carbonate limes into CO2 and H2O. Emission factors and formulas to account for the CO2 emissions from carbonate limes, follow the procedure from chapter 11, volume 4 of IPCC (IPCC, 2006). Data on lime fertilizer composition is taken from literature ((Landwirtschaftskammer Nordrhein-Westfalen, 2012), (Fischer, 2012)). The bicarbonate formed in the soil from urea application leads also to CO2 emissions, which are calculated according to chapter 11, volume 4 of IPCC (IPCC, 2006). Emissions generated during biomass combustion were modeled according to a Sphera dataset, which is based on (Battye & Battye, 2002). Methane (CH4) emissions from draft animals were modelled according to the methodology in the (IPCC, 2019). Finally, methane (CH4) emissions from flooding during rice cultivation are considered according to the method presented in chapter 5, volume 4 of (IPCC, 2006).

Table 6 shows the main “other air emissions” modelled, according to their emission sources. For detailed summary of the chosen methodological approaches and references see **Table 7**.

Table 6 Other air emissions with the corresponding emission source modelled in the AgBalance® Model

Emission source	NMVOC	$PM_{2,5}$ PM_{10}	CO	CO_2	CH_4	Halogenated hydrocarbons	SO_2	Benzo{a} pyrene
Diesel combustion in tractor	X	X	X	X	X		X	X
Diesel combustion in irrigation pump	X	X	X	X	X		X	
Agricultural products (mainly harvesting)	X	X						
Biomass combustion	X	X	X	X	X	X	X	X
Urea fertilizer application				X				
Limestone application				X				
Dolomite fertilizer application				X				
Calcium ammonium nitrate fertilizer application				X				
Urea ammonium nitrate fertilizer application				X				
Draft animals (net energy, enteric fermentation and pasture/grazing)					X			
Rice flooding					X			

Table 4 Emissions factors for other air emissions (European region)

Substance	Emission source	Factor	Reference
NMVOC	Diesel combustion in tractor	((22,432-43,165*Umin-11,93*power+ 26,628*Umin2+2,06*Umin*power+6,505*power2)/ 1000) [in kg NMVOC/kg diesel] Umin: share of nominal engine speed [-] (ts assumption= 0,5) power: share of nominal power [-] (ts assumption= 0,5)	(Rinaldi & Stadtler, 2002)
	Diesel combustion in irrigation pump	0,00192 [kg NMVOC/kg diesel]	(Sphera Solutions, Inc., 2018)
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Agricultural products	0,86 [kg NMVOC/ha]	(EMEP/EEA, 2016)
	Biomass combustion	(961-984*CE)/1000*combusted biomass*0,085 [kg NMVOC/ha] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies combusted biomass amount in [kg/ha]	(Battye & Battye, 2002)
$PM_{2,5}$ PM_{10}	Diesel combustion in tractor	0,003 [kg $PM_{2,5}$/ kg diesel]	(Sphera Solutions, Inc., 2018)
	Diesel combustion in irrigation pump	0,003*diesel [kg $PM_{2,5}$/kg diesel]	(Sphera Solutions, Inc., 2018)
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Natural sources: harvesting and soil cultivation	1,5 kg/ha [kg PM_{10}/ha] 0,06 kg/ha [kg $PM_{2,5}$/ha]	(EMEP/EEA, 2016)
	Biomass combustion	(67,4-66,8*CE)/1000 [kg $PM_{2,5}$/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies Combusted biomass amount in fresh matter	(Battye & Battye, 2002)
CO	Diesel combustion in tractor	((55,923-140,688*Umin+16,603*power+102,643* Umin*Umin67,597*Umin*power+44,545* power* power)/1000) Umin: share of nominal engine speed [-] (ts assumption= 0,5) power: share of nominal power [-] (ts assumption= 0,5)	(Rinaldi & Stadtler, 2002)
	Diesel combustion in irrigation pump	0,0192*diesel [kg CO/ha] diesel: amount of diesel [kg/ha]	(Sphera Solutions, Inc., 2018)
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets
	Biomass combustion	(961-984*CE)/1000 [kg CO/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies Combusted biomass amount in fresh matter	(Battye & Battye, 2002)

Substance	Emission source	Factor	Reference
CO_2	Diesel combustion in tractor	3,17 [kg CO_2/kg diesel]	(Statistics Norway, 2019)
	Diesel combustion in irrigation pump	3,14 [kg CO_2/kg diesel]	(Sphera Solutions, Inc., 2018)
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets
	Urea fertilizer application	0,2*44/12 [kg CO_2/kg applied urea fertilizer]	(IPCC, 2006)
	Limestone application	0,12*44/12 [kg CO_2/kg applied limestone]	(IPCC, 2006)
	Dolomite fertilizer application	0,13*44/12 [kg CO_2/kg applied dolomite]	(IPCC, 2006)
	Calcium ammonium nitrate fertilizer application	(0,12/0,56)*0,12*44/12 [kg CO_2/kg applied CAN fertilizer]	Assumption of ASE. Conversion of CaO content to CaCO3 content using molecular mass. Amount of CaCO3 in calcium ammonium nitrate (CAN) is multiplied by emission factor of 12%, also used for limestone, equivalent to the carbon content of the CaCO3 according to (IPCC, 2006). CaO content of fertilizer from (YARA GmbH & Co. KG, 2018)
	Urea ammonium nitrate fertilizer application	(0,15/0,46)*0,2*44/12 [kg CO_2/kg applied UAN fertilizer]	ASE. Conversion of nitrogen content in the form of urea in urea ammonium nitrate (UAN) into amount of urea, using the content of nitrogen of urea fertilizers (46%). Amount of urea in urea ammonium nitrate is multiplied by emission factor of 20%, also used for urea, equivalent to the carbon content of urea according to IPCC. N content of fertilizer from (Fritsch, 2012)
	Biomass combustion	CE*carbon content[a)]*44/12 [kg CO_2/kg combusted biomass] CE: combustion efficiency [-],0,92 (ts assumption as average) carbon content: carbon content of biomass in fresh matter [kg C/kg biomass], default value: 0,54[a)]	(Battye & Battye, 2002)
CH_4	Diesel combustion in tractor	0,000012 [kg CH_4/kg diesel]	(Statistics Norway, 2019)
	Diesel combustion in irrigation pump	0,000214 [kg CH_4/kg diesel]	(Sphera Solutions, Inc., 2018)
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets
	Draft animals (net energy, enteric fermentation and pasture/grazing)	7% of feed energy converted to methane Valid for cattle and buffalo with a diet consisting on more than 75% forage, from table 10.12 in chapter 10, volume 4 of IPCC	(IPCC, 2019)
	Rice flooding	Specific factors depending on water regimes, organic amendment and cultivation periods.	(IPCC, 2006)
	Biomass combustion	(42,7-43,2*0,92)/1000 [kg CH_4/kg combusted biomass] combusted biomass amount in fresh matter	(Battye & Battye, 2002)
Halogenated hydrocarbons	Biomass combustion	0,000053 [kg $CHCl_3$/kg combusted biomass]	(Battye & Battye, 2002)

Substance	Emission source	Factor	Reference
SO_2	Diesel combustion in tractor	0,0000156 [kg SO_2/kg diesel]	(Statistics Norway, 2019)
	Diesel combustion in irrigation pump	0,00005 [kg SO_2/kg diesel]	(Sphera Solutions, Inc., 2018)
	Fertilizer production	Fertilizer specific	Emissions modelled with the corresponding dataset
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Biomass combustion	0,001 [kg SO_2/kg combusted biomass] Combusted biomass amount in fresh matter	(Battye & Battye, 2002)
Benzo{a}pyrene	Diesel combustion in tractor	150*42,7*0,835/(1E-12) [kg benzo{a}pyrene/kg diesel]	(Sphera Solutions, Inc., 2018)
	Fertilizer production	Fertilizer specific	Emissions modelled with the corresponding dataset
	Electricity production	Country specific electricity grid mix	Emissions modelled with the corresponding dataset
	Biomass combustion	(67,4-66,8*CE/1000)*1,4E-5 [kg benzo{a} pyrene/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies Combusted biomass amount in fresh matter	(Battye & Battye, 2002)

a) If biomass combustion is part of the goal and scope of the sustainability analysis, the amount of burned biomass, its carbon (C) content and nitrogen (N) content have to be inserted into the model. If the C content is not available, a default value of 54% C (as a % of fresh matter) can be used (Battye & Battye, 2002). However, the N content varies depending on the biomass

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