Carbon footprint analysis of mineral fertilizer production in Europe and other world regions

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Frank Brentrup
Yara International

Antoine Hoxha
fertilizers europe

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Frank Brentrup[1,*], Antoine Hoxha[2], Bjarne Christensen[3]
[1] Yara International ASA, Research Centre Hanninghof, D-48249 Duelmen, Germany
[2] Fertilizers Europe, Av. E Van Nieuwenhuyse 6, B 1160 Brussels, Belgium
[3] ChemTechnic Consulting, Virumgade 49 A, DK-2830 Virum, Denmark

[*] Corresponding author: Email: *frank.brentrup@yara.com*

ABSTRACT

The production and use of mineral fertilizers contributes significantly to the carbon footprint of agricultural crops and crop-based food products. In arable crops such as winter wheat the share of nitrogen (N) fertilizer-related GHG emissions can be as high as 80%. The contribution of emissions from the production of mineral fertilizers is often as important as fertilizer-induced emissions from agricultural soils.

It is therefore important to use appropriate and up-to-date emission data for fertilizer production, which represent the actual technology and efficiency of manufacturing of specific fertilizer grades. Objective of this study is to provide up-to-date carbon footprint data for the main fertilizer products produced in selected world regions.

The association of the European fertilizer producers "Fertilizers Europe" has developed a carbon footprint calculator (CFC) for fertilizer production. This tool has been employed to derive reference values for the main mineral fertilizers produced in Europe and other relevant fertilizer-producing regions of the world. The European data are reported by all members in a regular survey to Fertilizers Europe and are representative for the year 2011. Reported data include energy consumption in ammonia synthesis (Haber-Bosch) and N_2O emissions from nitric acid production, as well as expert-validated data for other sources of CO_2 (e.g. energy consumption for urea synthesis and granulation). The non-European figures are based on an expert evaluation by Integer Research Ltd. of ammonia and nitric acid production in 2011, while for all other emission sources the European values were used.

The Fertilizers Europe CFC follows general LCA and carbon footprint rules. It covers all main sources of GHG emissions and has been reviewed by DNV GL to verify its completeness and correct calculations.

This paper explains the methodology applied in the calculation of the carbon footprint values. In addition the results will be presented per fertilizer product and production region. We suggest that these data should be used in carbon footprint studies as reference values for fertilizer production in different world regions with the technology baseline 2011.

Keywords: fertilizer production, product carbon footprint, GHG emissions

1. Introduction

Agriculture is responsible for 10 to 12% of the total global greenhouse gas (GHG) emissions (Smith et al., 2007) and the overall level of GHG emissions from agriculture is expected to grow further as agricultural production needs to expand in order to keep pace with increasing demand for food, feed, fiber and bioenergy. The production and use of mineral fertilizers is required to provide sufficient plant nutrients for sustainable food production. At the same time it also contributes significantly to the carbon footprint of agricultural crops and crop-based food products. The share of the global GHG emissions directly related to the production, distribution and use of fertilizers is estimated at between 2 and 3% (IFA, 2009). In arable crop production such as winter wheat the share of nitrogen (N) fertilizer-related GHG emissions can be as high as 80% (Brentrup et al., 2004; Skowroñska & Filipek, 2014). The contribution of emissions released during the production of mineral fertilizers is in most studies as important as the fertilizer-induced emissions from agricultural soils.

Information about production of mineral fertilizers used in major global life-cycle assessment (LCA) databases (e.g. Ecoinvent) is mostly outdated and relates to studies from 1990s (Patyk & Reinhardt, 1997; Kongshaug, 1998; Davis & Haglund, 2000). Since then production technologies have improved substantially mainly in terms of nitrous oxide (N_2O) emission control during nitric acid production, which is an intermediate product of nitrate-containing nitrogen fertilizers (EFMA, 2000a; Brentrup & Palliere, 2008). But also energy efficiency in particular in ammonia synthesis has improved over time (EFMA, 2000b; Jenssen & Kongshaug, 2003; Brentrup & Palliere, 2008).

It is therefore important to use appropriate and up-to-date emission factors for fertilizer production. The objective of this study is to provide up-to-date carbon footprint data for the main fertilizer products produced in important fertilizer-producing regions.

2. Methods

The association of the European fertilizer producers "Fertilizers Europe" has developed a carbon footprint calculator (CFC) for fertilizer production. The CFC is available for free use to anyone on simple request to Fertilizers Europe (www.fertilizerseurope.com). This tool has been employed to derive reference values for the main mineral fertilizers produced in Europe and other relevant fertilizer-producing regions of the world. The European data are based on primary data reported by all members in a regular survey to Fertilizers Europe. The data are representative for the year 2011. Reported data include energy consumption in ammonia synthesis (Haber-Bosch) and N_2O emissions from nitric acid production, as well as expert-validated data for other sources of CO_2 (e.g. energy consumption for urea synthesis and granulation of final products). The non-European figures are based on an expert evaluation by Integer Research Ltd. (2014) of ammonia and nitric acid production in 2011, while for all other emission sources the European default values were used. The reference data for Europe and other world regions will be regularly updated and published.

The CFC is a cradle-to-factory-gate calculator based on the principles developed by Kongshaug (1998). This means that the emission factors of the final products (expressed as kg CO_2-equivalent/kg fertilizer product) are calculated stepwise in building blocks that represent the actual steps in the production process. The building blocks include importation of raw materials, production of intermediates and the finishing process combining the materials into a final product (Fig. 1). All building blocks are characterized by emission factors and energy consumption values. The CFC takes into account all emissions with global warming potential (GWP), i.e. N_2O, CO_2 and CH_4. Using the GWP conversion factors (IPCC, 2007) N_2O and CH_4 emissions are converted to CO_2-equivalents (CO_2e). The CFC contains built-in default values for important fertilizer-producing world regions (EU, Russia, China and US) for the reference year 2011, but the user can also insert own individual values in order to calculate the carbon footprint of specific own-produced fertilizer products (Christensen et al., 2014).

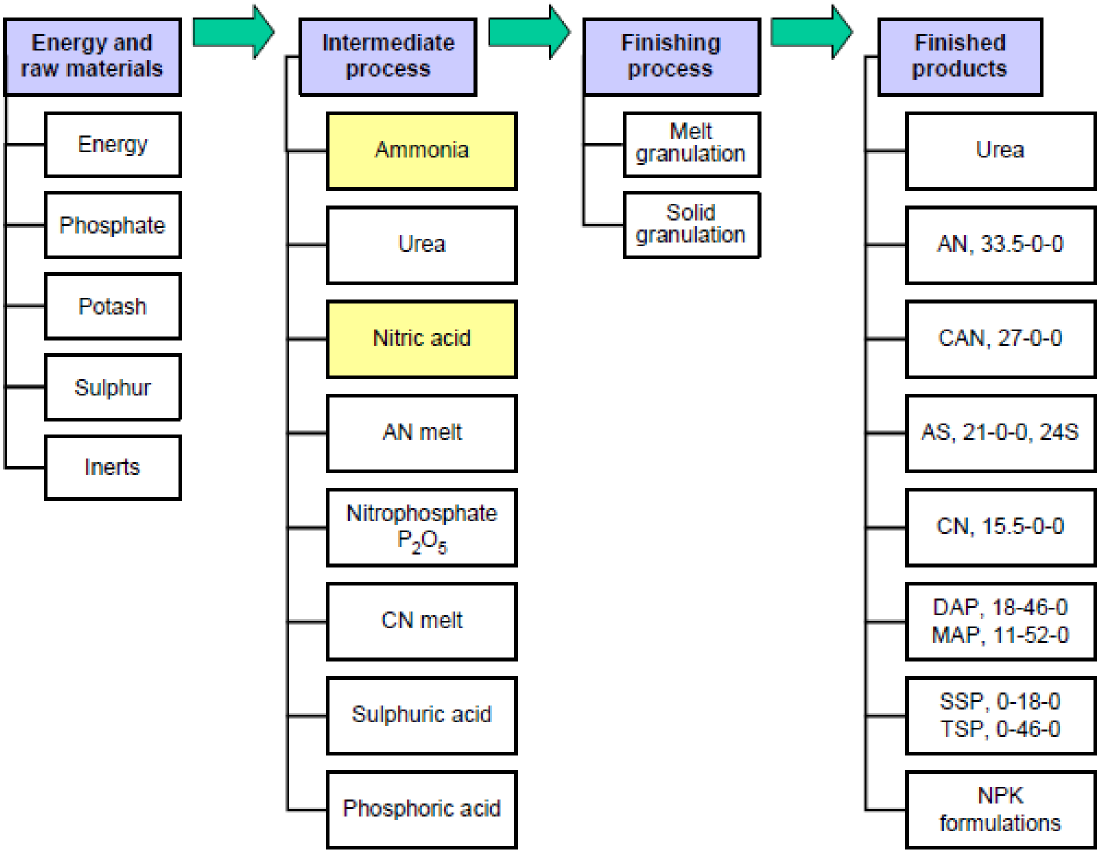

Figure 1: The building blocks used in the CFC for fertilizer production. Intermediates contributing to the majority of emissions are marked yellow (Christensen et al., 2014).

The Fertilizers Europe CFC follows the lines of the general LCA and carbon footprinting rules (ISO 14040/14067), but is not completely compliant with established standards such as PAS 2050 or Carbon Trust. The calculation covers all main sources of GHG emissions and has been externally reviewed by DNV GL to verify its completeness and correct calculations. Tables 1 and 2 summarize selected key background information used to calculate the default reference carbon footprint values for the different world regions.

Table 1: Background information on energy, raw materials and transportation used to calculate the reference carbon footprint values

Energy data		**kg CO_2e/GJ**	
Energy source	Region	Supply [a]	Use [b]
Natural gas	Europe	10.6	56.1
Natural gas	Russia	13.1	56.1
Natural gas	USA	20.8	56.1
Natural gas	China	12.9	56.1
Liquid petroleum gas (LPG)	Europe	16.3	63.1
Heavy fuel oil	Europe	10.6	77.4
High viscosity residue	Europe	0.0	80.7
Coal (bituminous)	Europe	10.7	94.6
Coal (bituminous)	China	10.5	94.6
Electricity	Europe	34.1	97.8
Electricity	Russia	45.8	121.4
Electricity	USA	47.0	139.7
Electricity	China	54.5	212.2
Electricity (coal-based)	Europe	26.8	238.9
Steam from natural gas (93% efficiency)	Europe	11.4	60.3
Steam from natural gas (93% efficiency)	Russia	14.1	60.3
Steam from natural gas (93% efficiency)	USA	22.3	60.3
Steam from natural gas (93% efficiency)	China	13.9	60.3
Steam from LPG (93% efficiency)	Europe	17.5	67.8
Steam from oil (93% efficiency)	Europe	11.4	83.2
Steam from coal (90% efficiency)	Europe	11.9	105.1
Raw material data [c]		**kg CO_2e/t**	
Type of raw material		Supply	
Phosphate rock (sedimentary, 4% CO2)		47.7	
Phosphate rock (sedimentary, 6% CO2)		67.7	
Phosphate rock (igneous, 2% CO2)		89.7	
Phosphate rock (igneous, 4% CO2)		109.7	
Potassium chloride (Muriate of potash/MOP)		232.2	
Potassium sulphate (Sulphate of potash/SOP)		108.4	
Dolomite (ground)		61.9	
Limestone (ground)		61.9	
Transport data [d]		**kg CO_2e/t*km**	
Means of transport			
Deep sea vessel		5	
Coastal shipping		16	
Barge		31	
Rail		22	
Truck		62	

[a] Data from GaBi database (PE International, 2013)

[b] Data for fossil fuels and steam from IPCC (2006), for electricity from IEA (2012)

[c] Data for raw materials based on Jenssen & Kongshaug (2003), validated by Fertilizers Europe Technical Committee (personal communication, 2014)

[d] Data for transport from McKinnon & Piecyk (2011)

Table 2: Reference values for the energy input required for ammonia and nitric acid production and direct emissions of nitrous oxide (N_2O).

Product	**Region**	**Energy input**				**Direct emissions**
		Feedstock & fuel		Electricity [a]	Steam [a]	N_2O
		Type	GJ/t product	GJ/t product	GJ/t product	kg/t product
Ammonia	Europe	Natural gas	34.7	0.79	-1.37	0
Ammonia	Russia	Natural gas	40.5	0	0	0
Ammonia	USA	Natural gas	35.7	0	0	0
Ammonia	China	Natural gas	42.2	0	0	0
Ammonia	China	Coal	54.0	0	0	0
Nitric acid	Europe	-	0	0.3	-1.75	0.87
Nitric acid	Russia	-	0	0.3	-1.75	7.40
Nitric acid	USA	-	0	0.3	-1.75	6.00
Nitric acid	China	-	0	0.3	-1.75	5.70

[a] Assumptions by Integer Research Ltd (2014):
For non-European ammonia no steam generation and zero electricity consumption were assumed.
For non-European nitric acid the steam and electricity data from Europe were assumed.

3. Results & discussion

Table 3 shows the carbon footprint (CFP) values for the main mineral fertilizer products. The new European reference values are also included in the on-farm GHG calculation tool "Cool Farm Tool" and the regional values will be added soon (www.coolfarmtool.org).

Table 3: Reference carbon footprint (CFP) values for main mineral fertilizer products from different regions (reference year 2011)

Fertilizer product		**Nutrient content**	**CFP at plant gate (kg CO_2e/kg product)**			
			Europe	**Russia** [c]	**USA** [c]	**China** [c]
Ammonium nitrate	AN	33.5% N	1.18	2.85	2.52	3.47
Calcium ammonium nitrate	CAN	27% N	1.00	2.35	2.08	2.86
Ammonium nitrosulphate	ANS	26% N, 14% S	0.82	1.58	1.44	2.22
Calcium nitrate [a]	CN	15.5% N	0.67	2.03	1.76	2.20
Ammonium sulphate	AS	21% N, 24% S	0.57	0.71	0.69	1.36
Di-ammonium phosphate	DAP	18% N, 46% P_2O_5	0.64	0.81	0.73	1.33
Urea [b]	Urea	46% N	0.89	1.18	1.18	2.51
Urea ammonium nitrate [b]	UAN	30% N	0.81	1.65	1.50	2.37
NPK 15-15-15	NPK	15% N, 15% P_2O_5, 15% K_2O	0.73	1.40	1.27	1.73
Triple superphosphate	TSP	48% P_2O_5	0.18	0.25	0.19	0.26
Muriate of potash	MOP	60% K_2O	0.23	0.23	0.23	0.23

[a] CN is assumed to be produced as co-product from NPK production via nitro-phosphate route (EFMA, 2000c)
[b] Urea and UAN contain CO_2, which will be released shortly upon application to soil (0.73 kg CO_2/kg urea and 0.25 kg CO_2/kg UAN). This amount is not included in the plant gate CFP.
[c] For Russia, USA and China specific values were used for energy supply, energy consumption for ammonia production and N_2O emissions from nitric acid production. All other values are equal to Europe. Specific assumption for China: 80% of ammonia production is based on hard coal; remainder on natural gas (IFA, 2009).

Figure 2 documents the improvements in fertilizer production which are particularly obvious when comparing the CFP of nitrate-containing products produced in Europe as shown for the example of calcium ammonium nitrate (CAN), which contains 50% nitrogen as nitrate. Values such as that from Ecoinvent (2002) represent European production technology of the 1990ties or earlier (Patyk & Reinhardt, 1997; Kongshaug, 1998). At that time nitric acid, which is the precursor of nitrate-N in mineral fertilizer, was produced without any abatement technology for N_2O emissions occurring at significant rates during the nitric acid production process (see also Table 2). The first Fertilizers Europe reference value for CAN represents production technology in 2006 (Brentrup & Palliere, 2008) and shows already some improvement due to partly installation of N_2O abatement catalysts in European nitric acid plants. Today, practically all European nitric acid plants are equipped with this technology, which led to an average reduction of N_2O emissions by 80-90% as compared to the pre-abatement time.

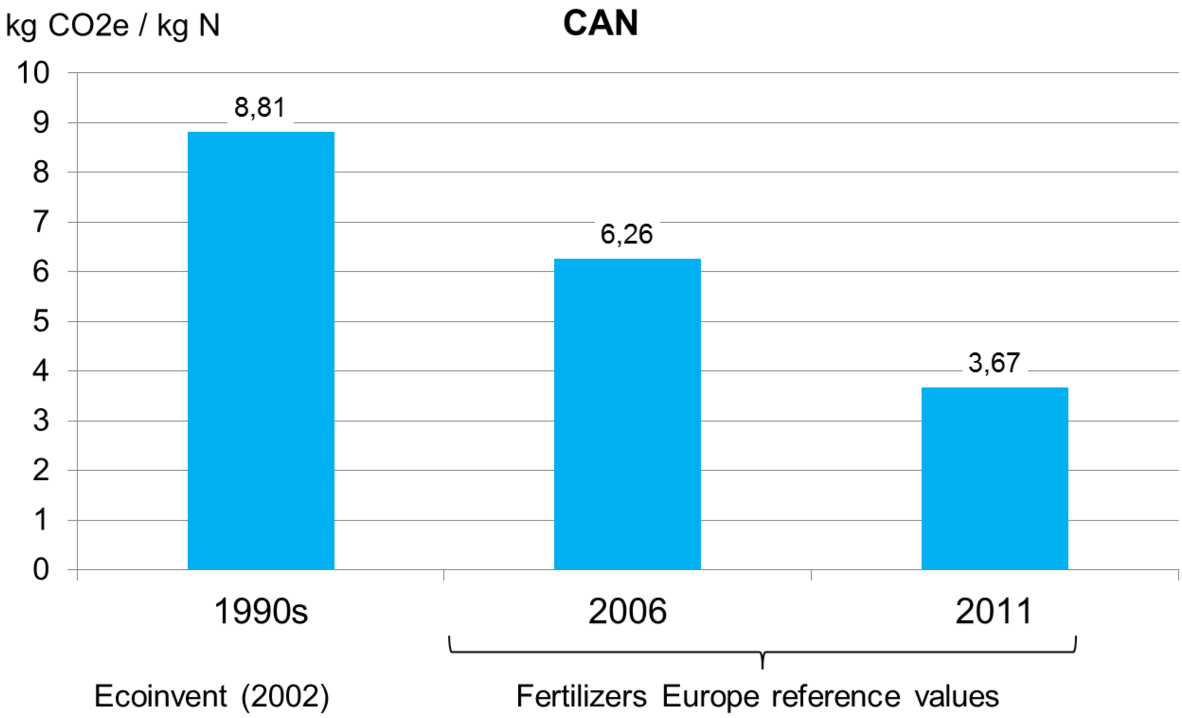

Figure 2: Development of carbon footprint values for Calcium ammonium nitrate (CAN) production in Europe from the 1990s until 2011

In order to compare the production carbon footprint of different fertilizer products the values need to be related to the same functional unit, which is in the case of nitrogen fertilizers one kg of N. Figure 3 compares three different products (AN, Urea, UAN) that contain only N as a plant nutrient and are therefore directly comparable without any allocation that would be required for multi-nutrient products. The graph shows that European production of all three products results in the lowest CFP among the production regions compared. The European values for AN, Urea and UAN are very close to each other at around 3.5 kg CO_2e/kg N. The CO_2 released during the hydrolysis of urea after application to soil is included in this comparison because it is in principle only a delayed emission of CO_2 that has been previously used in the factory to produce urea from ammonia. The same amount of CO_2 needed to synthesize urea will be emitted after application in the field. This is also valid for the urea part in UAN (50% urea, 50% ammonium nitrate).

The differences between the production regions are more obvious for nitrate-containing products than for urea. However, the differences are not only related to the existence and efficiency of N_2O abatement in nitric acid, but also strongly influenced by the source of fossil fuels used for the production of ammonia. China's ammonia production is still dominantly based on coal (IFA, 2009; Zhang, 2013) and this is the reason for the high CFP values for all three N fertilizers. N_2O emissions from nitric acid production in China is even lower than in the US and Russia (Table 2), but this does not compensate for the higher CO_2 emissions from coal-based ammonia production. The reason for lower N_2O emissions in China is the Clean Development Mechanism (CDM) under the Kyoto Protocol of the United Nations (IPCC, 2007), which supports certain emission reduction projects in particular in countries not included in the Annex I of the Kyoto Protocol (e.g. transition and developing countries). Russia and USA show low CFP of urea indicating high energy efficiency, but higher values for AN and UAN due to missing or very limited installation of N_2O abatement in nitric acid production.

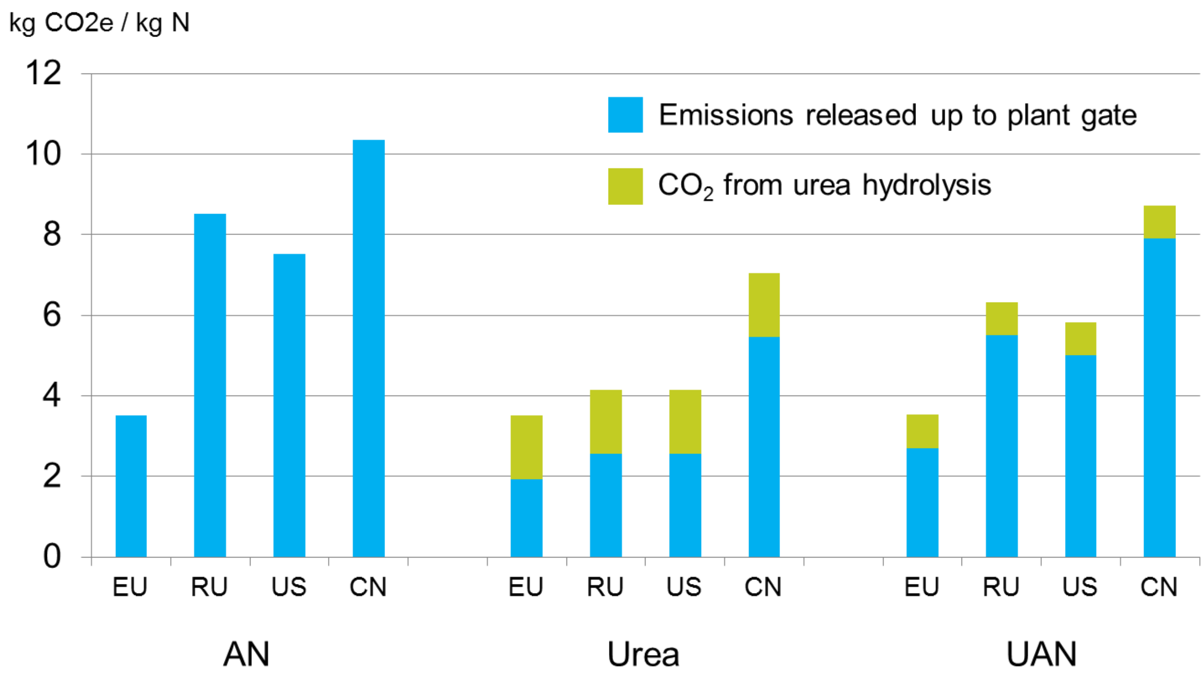

Figure 3: Carbon footprint of ammonium nitrate (AN), urea, and urea ammonium nitrate solution (UAN) expressed per kg of N and produced in different regions.

Fertilizer production is an important contributor of GHG emissions to the carbon footprint of agricultural products. When evaluating the CFP of fertilizers it is even more important to consider the complete life-cycle emissions in order to account for all additional sources of GHG emissions beyond the production step. This is mainly relevant for nitrogen fertilizers because their use in agriculture can lead to N_2O emissions via different pathways. In addition, the use of most N fertilizers acidifies the soil, which is usually compensated by application of lime releasing CO_2 after conversion in soil. Figure 4 summarizes the GHG emissions from production and application of different N fertilizers. The emissions from the use of the fertilizers were estimated using current default values for the different pathways:

(1) IPCC Tier1 emission factor for direct N_2O emissions,
(2) EMEP/EEA Tier 2 emission factors for NH_3 emissions (EEA, 2013) plus IPCC (2006) for indirect N_2O via NH_3,
(3) IPCC (2006) for indirect N_2O via NO_3,
(4) KTBL (2005) figures for lime demand together with IPCC (2006) for CO_2 from lime.

The resulting values are only rough estimates since for instance potential differences between the N products in their agronomic efficiency are not taken into account. This means that for example high losses as ammonia could lead to an additional need for N application in order to substitute for the lost nitrogen, which would then increase the CFP of this product. There is also evidence that different N forms behave differently in terms of direct N_2O emissions from soil. Applied to well drained soils without anaerobic conditions, the emission rates are often clearly lower than the default IPCC factor of 1% N_2O-N per unit N applied and the emissions usually decline with an increasing share of nitrate in the product. Poorly drained soils and high precipitation can lead to anaerobic conditions. This together with high organic soil carbon availability triggers N_2O emissions by denitrification. Under those conditions urea and ammonium based N fertilizers often show lower emissions than nitrate-containing products. However, using standard default emission factors for all pathways the overall CFP of urea is 8% higher than that of AN (see Fig. 4).

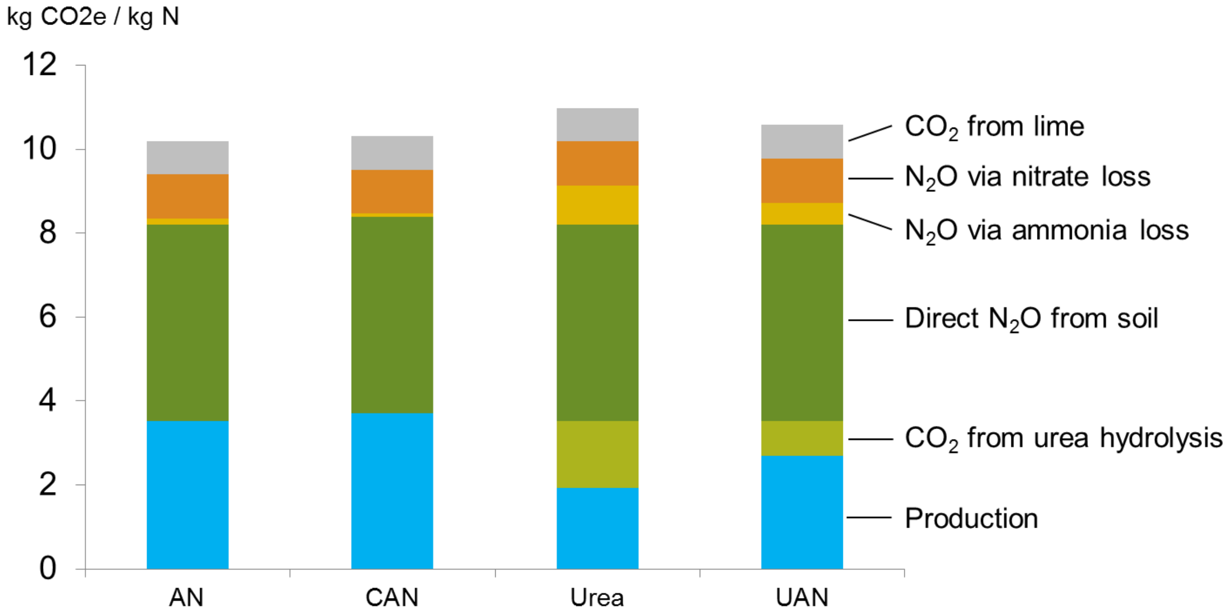

Figure 4: Carbon footprint of N fertilizer production and use based on default emission factors (for references see text).

4. Conclusions

The paper explains the methodology applied in the calculation of the carbon footprint values. The results show carbon footprint values per fertilizer product and production region (Europe, Russia, USA, and China). We suggest that these data should be used in carbon footprint studies as reference values for fertilizer production with the technology baseline 2011. The data clearly show the improvements made in Europe in particular in terms of N_2O emission reduction in nitric acid production, which is an intermediate in the production of all nitrate-containing N fertilizer products. The differences between the production regions are mainly due to two aspects, (1) absence or presence of N_2O emission control and (2) energy source (coal or gas) and efficiency in ammonia production.

For a valid conclusion about the carbon footprint of fertilizers it is necessary to include the use of the fertilizers into the analysis in order to have a complete picture along their life-cycle. Emissions from N fertilizer use on field can be even higher than of their production, in particular when improved production technology as in Europe is employed. Emissions from N fertilizer use are highly variable depending on soil and climate conditions and need to be assessed with care. The use of standard default emission factors suggests slightly higher life-cycle GHG emissions from urea as compared to ammonium nitrate.

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