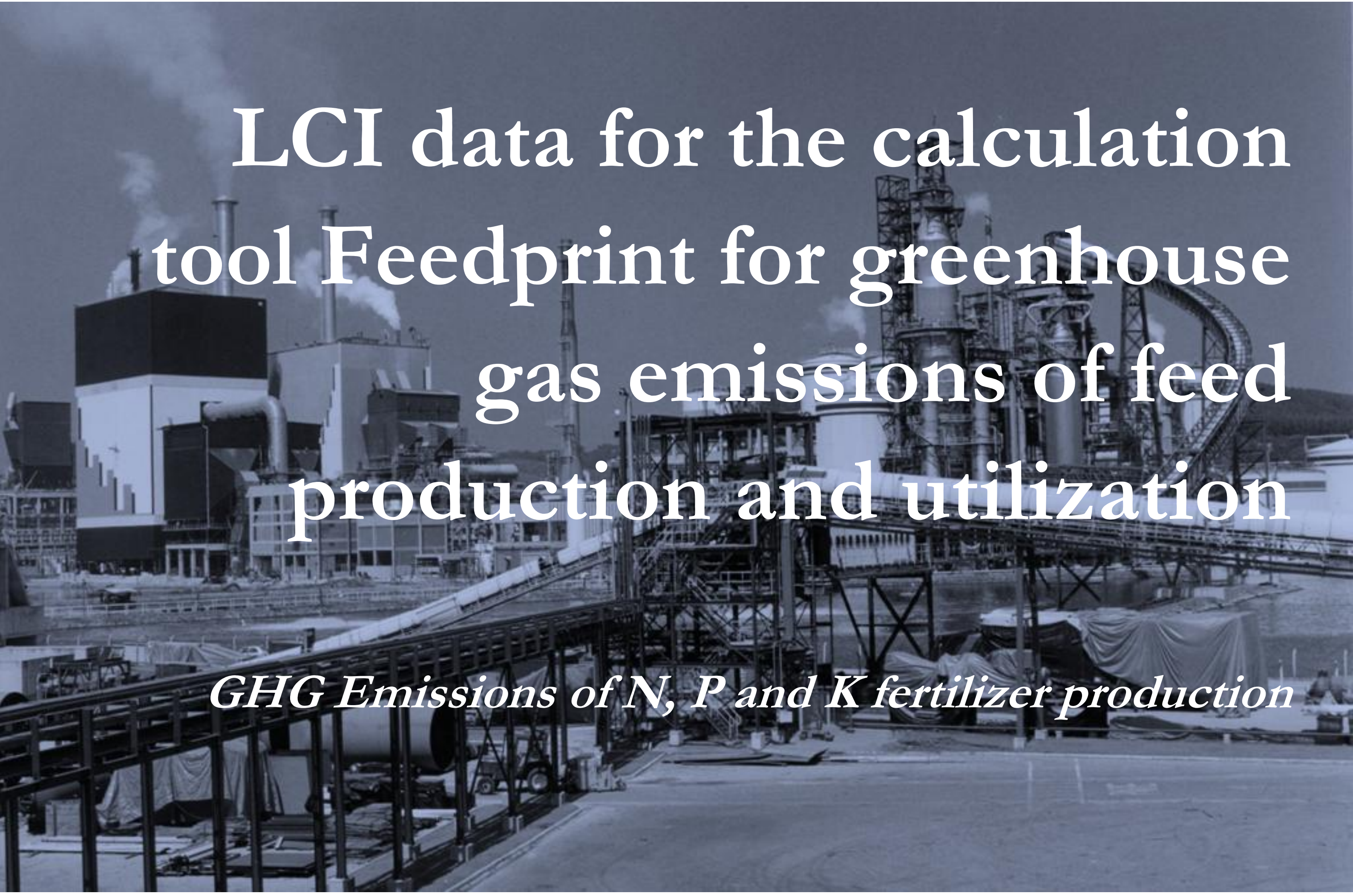

LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization

GHG Emissions of N, P and K fertilizer production

A. Kool
M. Marinussen
H. Blonk

Blonk Consultants

November, 2012

Blonk Consultants
Gravin Beatrixstraat 34
2805 PJ Gouda
the Netherlands
Telephone: 0031 (0)182 579970
Email: info@blonkconsultants.nl
Internet: www.blonkconsultants.nl

Blonk Consultants helps companies, governments and civil society organisations put sustainability into practice. Our team of dedicated consultants works closely with our clients to deliver clear and practical advice based on sound, independent research. To ensure optimal outcomes we take an integrated approach that encompasses the whole production chain.

LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization

GHG Emissions of N, P and K fertilizer production

A. Kool
M. Marinussen
H. Blonk

Blonk Consultants

November, 2012

blonk›consultants‹

Contents

1 Regional approach

Synthetic fertilizers are used in crop cultivation to provide the essential nutrients Nitrogen (N), Phosphorus (P) and Potassium (K). Also nutrients as Magnesium (Mg), Sulphur (S) and trace elements as Selenium (Se) are applied through synthetic fertilizer to optimize crop growth. By far, N, P and K fertilizers are applied the most of all fertilizers and therefore we will focus on the production and application of these fertilizers.

The manufacturing and use of fertilizers differ between regions in the world. Therefore, six global regions are defined to calculate regional specific carbon footprints for fertilizer production and use in:

1. West Europe
2. East Europe (including Russia)
3. South America
4. North America
5. Asia
6. Australia

In Chapter 2 the carbon footprints of fertilizer production is examined. There are differences in the raw materials that are used in the different global regions and there are differences in the energy use. Both affect the carbon footprint, hence the production of N, P and K fertilizers leads to regional specific GHG emissions. In Chapter 2 the carbon footprints of the production of a number of N, P and K fertilizers are calculated. These regional specific carbon footprints will be used to calculate the contribution of fertilizer production to the carbon footprint of fertilizer applications.

In Chapter 3, we estimated the share of each type in each region, using data from the International Fertilizer Association and calculated the associated carbon footprint assuming that farmers in each global region use the fertilizers that are produced in that global region.

2 Production of synthetic fertilizers

The greenhouse gas emissions and primary energy use for synthetic fertilizer production is calculated from cradle to gate of the fertilizer plant.

Ammonia and nitric acid are raw materials for many nitrogen containing fertilizers. The phosphate in fertilizers originates mostly from phosphate rock and/or phosphoric acid. Potassium components are potassium sulphate and potassium chloride which are products of mining.
The compound fertilizers (NPK, NP, PK etc) are blends of different N-, P- and or K containing components.

Natural gas is the main raw material for ammonia production and also the main fuel for ammonia, nitric acid and fertilizer production. The impact on greenhouse gas emissions and fossil energy depletion of the entire life cycle of natural gas is taken into account.

In 2.1 the use fossil fuels in fertilizer production is examined.

In the following section the production of ammonia and nitric acid as raw materials for many fertilizers is explained. The fuels used, energy efficiencies and emissions for certain production stages differ between regions in the world. We distinguish 6 global regions to calculate specific impacts for fertilizers.

2.1 Fossil fuels as feed and fuel for fertilizer production

2.1.1 Natural gas

Natural gas is the main raw material for ammonia production with approximately 80% of world ammonia capacity being produced from natural gas (EFMA, 2000a and Patyk, 1996). Recent figures of the IEA (2007) confirm that in 2005 natural gas is the main raw material for ammonia production, however in some regions other fuels are used to a much larger extent. In China 80% and in India and 50% of the ammonia production is based on other fossil fuels such as oil and coal. China and India represent a significant part in global ammonia production, 30% and 8% respectively. The production in the other regions (62% of global production) is based for 98% on natural gas (IEA 2007).

The production and transportation of natural gas causes losses. EcoInvent (2010) reports a big difference between countries. In the United Kingdom and the Netherlands the extra CO_2 eq emissions due to leakages and energy costs for transportation are the least with an emission of 2 and 3 kg CO_2 eq per GJ respectively, whereas in Eastern and Southern European countries like Greece, Hungary and Finland this emission amounts up to 23 kg CO_2 eq/GJ. In Russia this is as high as 25.3 kg CO_2 eq/GJ. This means that for the latter countries the emission factor of natural gas combustion (56.1 kg CO_2 eq/GJ) must be raised with 40%-45% to include the emissions during production and transportation. For those countries with the lowest extra emissions the correction is about 3.5 % - 5.5%. EcoInvent (2010) reports that the average European gas mix contains a significant share of Russian gas (34%). The additional GHG emissions due to production, transport and leakage of natural gas in Europe are 11.4 kg CO_2 eq/GJ or 20.3% of the emissions due to burning gas.
For Western Europe we use 20% as an average additional greenhouse gas emission above the emissions factor for combustion of gas. As a minimum and maximum 5% and 45% are used, based on figures for Russian gas and gas in the UK and the Netherlands respectively.
For gas usage in Russia and Central Europe we use 45% as an average additional greenhouse gas emission above the emissions factor for combustion. As a minimum and maximum 35% and 55% is assumed.

For China and India no figures are found for additional emissions due to gas production and transportation. Assuming that the efficiency and losses will be in between of those in Europe and Russia we assume an average of 35% with a minimum of 15% and a maximum of 50%.
For North America no recent figures were found. A dated source mentions that in 1992 the average gas leakage in the USA was 1.4 % of the amount transported through pipelines (Campbell *et al*, 1996).
The weighted average additional greenhouse gas emission is 30%, with a minimum of 14% and a maximum of 49%.

EcoInvent (2010) reports an average additional energy use for the production of gas of 18%. This figure varies between less than 1% for the UK and up to 35% for Austria and Hungary. We assume that the additional energy use is the same as the share for additional greenhouse gasses.

Table 1. Additional greenhouse gas emissions and energy use for production, transport and leakage of natural gas expressed as percentage of the greenhouse gas emissions of combustion.

	Avg	min	Max
Western Europe	20%	5%	45%
North America	20%	5%	45%
Russia + Central Europe	45%	35%	55%
China + India	35%	15%	50%
Rest of the world	20%	5%	45%
World average	30%	14%	49%

2.1.2 Oil and coal

In China and India oil and coal are used as feed and fuel for ammonia production. The additional greenhouse gas emissions for coal mining and transport in China above the emissions from burning coal are 36% (EcoInvent, 2010). In Europe this figure varies between 5% and 15%. For China and India we assume an average additional greenhouse gas emission and energy use of 35% for coal and oil, with a minimum of 15% and a maximum of 50%. For other countries we assume an average of 10% with a minimum of 5% and a maximum of 15%.

2.2 Ammonia production

Worldwide the ammonia production is largely based on modifications of the Haber-Bosch process. NH_3 is synthesized from a 3:1 volume mixture of hydrogen and nitrogen at elevated temperature and pressure in the presence of an iron catalyst. All the nitrogen used is obtained from the air and the hydrogen may be obtained by one of the following processes:

a) steam reforming of natural gas or other light hydrocarbons (Natural Gas Liquids, Liquefied Petroleum Gas or Naphtha).
b) partial oxidation of heavy fuel oil or coal.

About 85% of global ammonia production is based on steam reforming concepts using natural gas (EFMA 2000a).

The production of ammonia is a very energy demanding process. Referring to 4 studies done in 1998 – 2000, Wood and Cowie (2004) conclude that the energy use of the steam reforming process is about 25-35 GJ/ton ammonia.

The production of ammonia is exothermic and generates a net export of steam. Production plants differ in the way this steam may be utilized or exported. Also authors of LCA publications deal differently with this co-production. For instance Davis and Haglund (1999) considered the steam production to replace the combustion of fossil fuels elsewhere in the life cycle, whereas Alghren *et al.* (2008) applies economic allocation for the process resulting in the co-products N-fertilizer and electricity. Ahlgren *et al* (2008) shows that applying system expansion will reduce the carbon footprint for Ammonium Nitrate with 3% compared to economic allocation.

Based on a benchmark study for 66 ammonia plants worldwide representing operation in 2002/2003, Williams and Al-Ansari (2007) estimated an average energy use of 36.9 GJ/t NH_3.The variation in energy use is large with a lower limit of about 27.6 GJ/t NH_3 for the most efficient plants recently build according to the Best Available Techniques and an upper limit of about 50 GJ/t NH_3 for the less efficient plants (Williams and Al-Ansari (2007) and Lako (2009)). According to the EFMA, the average energy use of ammonia production in Europe is about 34.7 GJ/t NH_3 (Haas & Van Dijk, 2010).
Kongshaug (1998) mentions an average net energy consumption for European ammonia production of 39 GJ/t N- NH_3 or 32.1 GJ/t NH_3. According to Kongshaug (1998) a modern ammonia plant at those days consumes 34.5 GJ/t N- NH_3, including a 'credit' of 3 GJ/t N- NH_3 for steam export. So, the gross energy use is 32.1 GJ/t N- NH_3. He did not mention how big the credit for steam export in the average European figure of 32.1 GJ/t NH_3 is. At the end of 1960's ammonia production consumed about 48 GJ/t N- NH_3 (Kongshaug, 1998). Early ammonia plants based on oil or coal as fuel could even consume up to 50 – 60 GJ/t N- NH_3. After the oil crises in the 1970's the energy efficiency improved with about 30%.
In 2008 the International Fertilizer Association (IFA) performed a benchmarking survey among 93 ammonia plants located in 33 countries, representing approximately one quarter (40 million tons) of the global ammonia production. From this survey an average global energy use of 36.6 GJ/t NH_3 is reported (IFA 2009), with a minimum of 27 and a maximum of almost 60 GJ/t NH_3.

Table 2: The share of different fossil fuels used as feed and fuel for ammonia production and the energy efficiency of ammonia production in different global regions (IEA 2007)

	gas	oil	coal	GJ/t NH_3
Western Europe	100%			35.0
North America	100%			37.9
Russia + Central Europe	98.9%	1.1%		40.7
China + India	26.5%	18.7%	54.7%	47.6
Rest of the world	100%			36.4
World average	70.7 %	8.2%	21.0%	41.5

IEA (2007) gives an overview of the ammonia production in 2005 and summarizes the energy efficiency for different global regions. From this overview it can be concluded that in most regions ammonia is produced based on natural gas (Table 2). Except China and India where oil and coal together have a share of 80% and 50%.
In China and India the energy intensity per ton ammonia produced is higher: 48.8 GJ/ton NH_3 for China and 43.3 GJ/t NH_3 for India, which is high in comparison with natural gas based European plants (35 GJ/t NH_3) or North American plants (37.9 GJ/t NH_3).). China is the largest producer of ammonia with 30% of global production and India produces another 8% of global production.

Table 3: The energy input for production of ammonia

Region	**Values**				**unit**	**Ref**
	applied	**sources**	**min**	**max**		
World average	41.5	36.9	27.6	53	GJ/t NH_3	a
		36.6	27.0	58.2	GJ/t NH_3	d
		41.5	28.0		GJ/t NH_3	e
Europe	35.0	34.7			GJ/t NH_3	b
		32.1	28.4		GJ/t NH_3	c
		35.0	28.0		GJ/t NH_3	e
Russia + Central Europe	40.7	40.7			GJ/t NH_3	e
North America	37.9	37.9	28.0		GJ/t NH_3	e

China and India	47.6	47.6		GJ/t NH_3	e
Rest of the world	36.4	36.4		GJ/t NH_3	

References: a= Williams and Al-Ansari, 2007; b = EFMA *in* Haas & van Dijk (2010); c = Kongshaug, 1998; d = IFA 2009 and e = IEA 2007

The figures of energy use for the production of ammonia are summarized in Table 2. For Europe we choose to work with the most recent values. The figure of 35 GJ/t NH_3 from IEA (2007) is in line with the 34.7 GJ/t NH_3 mentioned by the EFMA in Haas & Van Dijk (2010) higher than 32.1 GJ/t NH_3 as reported by Kongshaug (1998).

The greenhouse gas emissions and energy use from cradle (production or mining fossil fuel) to gate of ammonia plant can be calculated combining the energy use figures and additional greenhouse gas emissions and energy use per MJ fuel used, see Table.4.

Table 4: The greenhouse gas emissions and energy use from cradle (production or mining fossil fuel) to gate of ammonia production in different global regions.

	ton CO_2 eq/ton NH_3	**MJ/ton NH_3**
	average	average
Western Europe	2.34	41.6
North America	2.55	45.5
Russia + Central Europe	3.31	58.9
China + India	5.21	64.3
Rest of the world	2.45	43.7
World average	3.45	52.8

The CO_2 emission for the average European ammonia production is 1.82 ton CO_2 eq/t NH_3 (Kongshaug, 1998). From a worldwide survey, Williams and Al-Ansari (2007) calculate a global average emission of 2.07 ton CO_2 eq/t NH_3. Haas & Van Dijk refer to a CO_2 emission from European ammonia production of 1.95 ton CO_2-eq./ton NH_3. (Table 5).

It is clear that including the additional emissions for production and transport of fossil fuels results in a significant increase of the impact of ammonia produced. For Western Europe the 20% additional greenhouse gasses per MJ natural gas used increases the greenhouse gas impact of ammonia with also 20%. Besides that a distinction in global regions using different fossil fuel mixes and different ammonia production efficiencies results in a more specific insight in impacts per ton ammonia produced.

Table 5: The GHG emissions for production of ammonia

region	**Values**				**unit**	**Ref**
	applied	**sources**	**min**	**max**		
World average		2.07	1.5	3.1	t CO_2 eq./t NH_3	a
Europe		1.95			t CO_2 eq./t NH_3	b
		1.82	1.65		t CO_2 eq./t NH_3	c

References: a = Williams and Al-Ansari, 2007 b = *in* Haas & van Dijk (2010); c = Kongshaug, 1998

2.2.1 Nitric Acid

All nitric acid production is based on the same basic chemical reactions. Oxidation of ammonia with air followed by oxidation of the intermediate nitric oxide leads to the production of nitrogen dioxide. This is added to water which results to nitric acid (Wood & Cowie, 2004). One of the co-product of oxidation of ammonia is nitrous oxide (N_2O) which has a relatively high GWP of 298 (IPCC; Forster ea, 2007)_F). The reaction from ammonia to nitric acid is exothermic (heat releasing) and contributes to a considerable net steam export, which may be considered an energy and emissions 'credit' in GHG accounting.

The amount of N_2O emitted depends on combustion conditions (pressure, temperatures), catalyst composition, burner design (EFMA 2000b) and emissions abatement technologies . In Table 6, IPCC default values are listed.

Table 6: IPCC default (kg N_2O */ t* HNO_3*) factors for* N_2O *emission from nitric acid production (IPCC 2006)*

	Pressure	avg	min	Max
Low pressure	1	5	4.5	5.5
Medium pressure	4-8	7	5.6	8.4
High pressure	8-14	9	5.4	12.6

Non-Selective Catalytic Reduction (NSCR), a typical tail gas treatment in the USA and Canada, may reduce N_2O emissions by 80-90% (IPCC 2006) and a nitric acid manufacturer in Norway developed a N_2O abatement process leading to a 70-85% reduction of N_2O emissions (Kongshaug 1998). Despite their advantages, an estimated 80% of the nitric acid plants worldwide do not apply NSCR technology (IPCC 2006).

In Table 7, N_2O emissions of nitric acid plants in different global regions are listed. According to Zwiers *et al* (2009) most plants in Europe synthesize nitric acid by the medium pressure technique with average emissions of 6 – 8 kg N_2O per ton HNO_3. Using modern technology N_2O emissions can be highly reduced. The Best Available Techniques (BAT) realizes emissions of only 1.8 kg N_2O per ton HNO_3 (Kongshaug 1998) or 1.85 kg N_2O per ton HNO_3 Haas & Van Dijk (2010). The Dutch manufacturer OCI AGRO claims that it reduces the N_2O emission of their nitric acid plant to zero (OCI AGRO, 2008).

EC 2007 summarizes several sources (from 2000 – 2004) concerning nitric acid production and comes to an average N_2O emission of 7 kg N_2O per ton HNO_3 with a minimum of 0.01 kg N_2O per ton HNO_3 and a maximum max 21.6 kg N_2O per ton HNO_3.
According to Kongshaug (1998) the average European N_2O emission at nitrc acid production is 0.03 ton N_2O / ton N- HNO_3, or 6.7 kg N_2O per ton HNO_3.

CDM projects in developing countries as Brazil, India, China, Philippines average of 49 plants: 8.9 kg N_2O / t HNO_3 (EPA 2010). In US 9 is used.

The EFMA average N_2O emission in 2007 was 4.6 kg N_2O /ton HNO_3 (Haas & Van Dijk, 2010).

Table 7: The dinitrous oxide emissions of nitric acid production

region	Values				unit	Ref
	applied	sources	min	max		
World, low pressure		5	4.5	5.5	kg N_2O /t HNO_3	f
World, medium pressure		7	5.6	8.4	kg N_2O /t HNO_3	f
World, high pressure		9	5.4	12.6	kg N_2O /t HNO_3	f
Developing countries		8.9	4	19	kg N_2O /t HNO_3	g
Europe (EFMA)		4.6			kg N_2O /t HNO_3	b
		7	6	8	kg N_2O /t HNO_3	h
		7	0.01	21.6	kg N_2O /t HNO_3	i
		6.7	1.8		kg N_2O /t HNO_3	c
North America, USA		9			kg N_2O /t HNO_3	e

References: a Williams and Al-Ansari, 2007; b EFMA *in* Haas & van Dijk (2010); c Kongshaug, 1998; d IFA 2009; e IEA 2007; f IPCC 2006 default value in Guidelines for National GHG Inventories; g EPA 2010; h Zwiers *et al*, 2009; i EC 2007

The nitric acid production process is exothermic meaning that in theory heat/steam can be exported. In practice only a share of the nitric plants manage to export steam. Kongshaug (1998) mentions that European nitric acid plants on average export 1.6 GJ/t HNO_3. Based on a benchmark study among nitric acid producers (PDC 2008) Yara summarizes that on average no energy is exported from nitric acid production, with a maximum of 0.6 GJ/t HNO_3 (Jenssen, 2010).
Lako (2009) also refers to a benchmark performed by PDC among nitric acid plants. It is not clear whether this is the same source as used by Jenssen (2010). Both sources are not public available. Lako (2009) concludes after a worldwide benchmark among 83 nitric acid producers that only 46% of the nitric acid plants realized a net energy export. The energy export in this benchmark study varied from 1.83 (export) to minus 3.8 (import) GJ /t HNO_3.
Based on the above mentioned sources we assume no energy export (and no energy use) for average nitric acid production in Europe and in the rest of the world. For all global regions we assume as minimum the figure of 1.83 GJ/t HNO_3 energy export and as maximum an energy use of 3.8 GJ/t HNO_3.
In Table 8, the chosen ranges of N_2O emissions are listed.

The impact of nitric acid production on greenhouse gas emissions and energy use is calculated by combining the figures of N_2O emissions, energy use/export and ammonia production. Ammonia is used as raw material for nitric acid production. From one mole ammonia, one mole nitric acid is formed. In practice this process does not have 100% efficiency. Kongshaug (1998) states that the efficiency of ammonia used for nitric acid formation is 94%. This is in the range of 93% - 95% mentioned by EC (2007). Using an efficiency of 94% 270 kg ammonia is used to synthesize 1 ton nitric acid. In the calculations we applied 94% as average efficiency, 93% as maximum and 95% as minimum.

The greenhouse gas emissions per ton nitric acid varies between 2.8 t CO_2 eq./t nitric acid for Europe, North America and rest of the world to 3.6 for China and India.

Table 8: The average, minimum and maximum dinitrous oxide emissions at nitric acid production

Global region	average	minimum	maximum
Western Europe	7	0.01	12
North America	7	1.85	12
Russia + Central Europe	7	4	19
China + India	7	4	19
Rest of the world	7	4	19
World average	7	0.01	19

2.2.2 Phosphate and other fertilizer components

The phosphate in P-fertilizers originates from mined phosphate rock and/or synthetically produced phosphoric acid. The energy required for mining phosphate rock depends on the accessibility of the ore and varies between 0.3 and 2.8 GJ/ton. Modern phosphoric acid plants generate energy for export where older plants are still net energy users (see Table 9) requires energy. The production of sulphuric acid (used as S-source in fertilizers) generates a net energy production.

The potassium fertilizers Potassium Chloride and Potassium Sulphate are mined, whereas Potassium Sulphate can also be synthesized. In this synthetic production the most efficient techniques are net energy exporters

Table 9: The energy input (GJ/t product) for production of phosphate and other fertilizer components (Kongshaug 1998)

	average	Minimum	maximum
phosphate rock	0.3	Not mentioned	2.8
phosphoric acid	0.5	-14.8	6.2
Sulphuric acid	- 3.0	- 6.0	-1.0
Muriate of Potash (potassium chloride)	3	1.5	6
Sulphate of Potash (potassium sulphate)	1.4	-0.7	2
Inert additives (limestone, dolomite)	0.8	Not mentioned	Not mentioned

2.2.3 Composition of fertilizers

The amount of raw materials per fertilizer type and the energy used for production of 1 ton fertilizer are summarized in Tables 10 to 12. These data are based on Kongshaug (1998).

Table 10: The amount of raw materials and energy needed to produce 1 ton of N-fertilizer

Raw material	**unit**	**Urea**	**Nitrogen solutions (liquid UAN)**	**Anhydrous Ammonia**	**Ammonium Nitrate**	**Calcium Ammonium Nitrate**	**Ammonium Sulphate**
Ammonia	kg/t	567		1000	219		255
Nitric Acid	kg/t				812		
Urea	kg/t		348				
Ammonium Nitrate	kg/t		457			756	
Dolomite	kg/t					244	
Sulphuric acid	kg/t						590
energy	GJ/t	4.14	0.13		0.7 (0.15-1.4)		

Table 11: The amount of raw materials and energy needed to produce 1 ton of P and K-fertilizer

Raw material	**unit**	**Triple Super Phosphate**	**Single Super Phosphate**	**Ground rock**	**Potassium chloride**	**Potassium sulphate**
phosphate rock	kg/t	144		1000		
phosphoric acid	kg/t	336	210			
Sulphuric acid	kg/t		367.5			
Muriate of Potash	kg/t				1000	
Sulphate of Potash	kg/t					1000
energy	GJ/t	2	1.4			

Table 12: The amount raw materials and energy needed to produce 1 ton of Compound-fertilizer

Raw material	**unit**	**Mono-Ammonium Phosphate (MAP)**	**Di-Ammonium Phosphate (DAP)**	**NPK compound**	**NPK compound**	**NK compound**	**PK**
Ammonia	kg/t	134	219				
Nitric Acid	kg/t					630	
phosphoric acid	kg/t	520	460				
Muriate of Potash	kg/t			250	250	730	370
Mono-Ammonium Phosphate (MAP)	kg/t			144			
Di-Ammonium Phosphate (DAP)	kg/t			163			
Urea					330		
Ammonium Nitrate	kg/t			330			
Triple Super Phosphate					310		460
inert	kg/t			110	110		180
energy	GJ/t	0.9				6	

2.3 Carbon footprint fertilizers

With the information described in 2.1 and 2.2 the carbon footprint for different types of fertilizer per global region can be calculated. The results of these calculations are summarized in the Tables 17 to 19. There are big differences between different types of fertilizer and between different regions. In Europe the carbon footprint per kg N varies from 2.14 for ammonium sulphate to 8.03 for CAN. And the carbon footprint for urea varies from 3.49 in Europe to 7.41 in China and India.

Table 13: The calculated carbon footprint (cradle to gate) for the most used N-fertilizers produced in different global regions compared with figures from literature (in kg CO_2*eq/per kg N) (Minimum and maximum values between brackets)*

Global region	**Urea**	**Nitrogen solutions (liquid UAN)**	**Anhydrous Ammonia**	**Ammonium Nitrate**	**Calcium Ammonium Nitrate**	**Ammonium Sulphate**
Calculated values:						
World average	5.00 (4.41 - 5.63)	7.27 (2.65 – 16.75)	4.21 (3.27 – 5.29)	9.47 (6.60– 14.14)	9.51 (6.65 – 14.18)	3.33 (0.94 – 6.23)
Western Europe	3.49 (3.06 – 3.88)	5.77 (2.11 – 10.38)	2.85 (2.19 – 3.44)	7.99 (5.25 – 10.04)	8.03 (5.29 – 10.08)	2.14 (0.75 – 4.67)
Russia + central Europe	4.82 (4.41 - 5.36)	7.08 (4.51 – 14.11)	4.04 (3.44 – 4.98)	9.28 (7.94 – 13.89)	9.33 (7.98 – 13.93)	3.18 (1.37 – 5.84)
North America	3.75 (3.29 – 4.17)	6.04 (2.74 – 12.79)	3.11 (2.40 – 3.75)	8.27 (6.15 – 12.76)	8.31 (6.18 – 12.79)	2.40 (0.75 – 4.67)
China + India	7.41 (6.64 – 8.34)	9.65 (5.23 – 17.12)	6.36 (5.16 – 7.98)	11.80 (10.18 – 16.71)	11.86 (10.24–16.77)	5.20 (1.69 – 8.17)
Rest of world	3.63 (3.18 – 4.18)	5.91 (3.49 – 13.62)	2.99 (2.30 – 3.89)	8.14 (6.77 – 12.73)	8.18 (6.80 – 12.76)	2.28 (0.75 – 5.46)
Literature:						
World average: Williams & Al-Ansari (2007)			2.07			
W. Europe: EFMA (2008)	1.6	2.74		6.1	6.25	
W. Europe: Kongshaug (1998)	2.9	4.1	1.82	6.8	6.87	1.62
W. Europe: Davis & Haglund (1999)	4.0	5.76		7.3	7.48	

Table 14: The calculated carbon footprint (cradle to gate) for the most used P- and K-fertilizers produced in different global regions compared to figures from literature (in kg CO_2*eq/per kg* P_2O_5 *or* K_2O*) (Minimum and maximum values between brackets)*

Global region	**Triple Super Phosphate**	**Single Super Phosphate**	**Ground rock**	**Potassium chloride**	**Potassium sulphate**
	Per kg P_2O_5	Per kg P_2O_5	Per kg P_2O_5	Per kg K_2O	Per kg K_2O
World average	0.45 (-0.05 - 0.63)	0.16 (-0.83 – 0.56)	0.23 (0.02 – 0.26)	0.69 (0.48 – 0.85)	0.23 (0.06 – 0.28)
Western Europe	0.36 (-0.04 – 0.52)	0.13 (-0.67 – 0.47)	0.19 (0.02 – 0.23)	0.56 (0.39 – 0.71)	0.19 (0.05 – 0.23)
Russia + central Europe	0.44 (-0.04 – 0.61)	0.16 (-0.80 – 0.53)	0.23 (0.02 – 0.24)	0.68 (0.49 – 0.82)	0.23 (0.16 -0.28)
North America	0.36 (-0.04 – 0.52)	0.13 (-0.67 – 0.47)	0.19 (0.02 – 0.23)	0.56 (0.39 – 0.71)	0.19 (0.05 – 0.23)
China + India	0.59 (-0.07 – 0.83)	0.21 (-1.10 – 0.74)	0.31 (0.03 – 0.34)	0.91 (0.62 – 1.12)	0.31 (0.08 – 0.37)
Rest of world	0.36 (-0.04 – 0.52)	0.13 (-0.67 – 0.47)	0.19 (0.02 – 0.23)	0.56 (0.39 – 0.71)	0.19 (0.05 – 0.23)
Literature:					
World average:					

Global region	Triple Super Phosphate	Single Super Phosphate	Ground rock	Potassium chloride	Potassium sulphate
Williams & Al-Ansari (2007)					
W. Europe: EFMA (2008)	0.73			0.6	
W. Europe: Kongshaug (1998)	0.35	0.095		0.57	
W. Europe: Davis & Haglund (1999)	1.08	1.05			

Table 15. The calculated carbon footprint (cradle to gate) for the most used compound fertilizers produced in different global regions compared to figures from literature (in kg CO_2 *eq/per kg N or* P_2O_5*) (Minimum and maximum values between brackets)*

Global region	Mono-Ammonium Phosphate (MAP)	Di-Ammonium Phosphate (DAP)	NPK compound (based on AN, AP and MOP)	NPK compound (based on Urea, TSP & MOP)	NK compound (based on nitric acid and MOP)	PK
	Per kg N	Per kg N	Per kg N	Per kg N	Per kg N	Per kg P_2O_5
World average	4.75 (1.21 – 6.42)	4.52 (2.39 – 5.67)	9.12 (7.57 – 11.14)	6.19 (5.54 – 6.68)	19.6 (14.1 – 28.4)	1.19 (0.84 – 1.37)
Western Europe	3.29 (0.47 – 4.52)	3.10 1.43 – 3.90)	7.47 (6.06 – 8.44)	4.45 (3.94 – 4.80)	17.1 (11.7 – 21.1)	0.97 (0.67 – 1.13)
Russia + central Europe	4.57 (1.27 – 6.14)	4.34 (2.42 – 5.41)	8.92 (7.97- 10.89)	5.98 (5.44 – 6.41)	19.3 (16.7 – 27.9)	1.17 (0.83 – 1.33)
North America	3.55 (0.71 – 4.80)	3.36 (1.66 – 4.19)	7.75 (6.57 -9.64)	4.71 (4.19 – 5.08)	17.3 (13.2 – 26.1)	0.97 (0.67 – 1.13)
China + India	7.06 (2.42 – 9.37)	6.76 (3.97 – 8.38)	11.75 (10.50 – 13.96)	8.98 (8.11 – 9.67)	23.7 (20.5 – 32.8)	1.57 (1.09 – 1.80)
Rest of world	3.42 (0.60 – 4.81)	3.24 (1.55 – 4.20)	7.62 (6.72 – 9.57)	4.59 (4.08 – 5.02)	17.2 (14.5 – 26.0)	0.97 (0.67 – 1.13)
Literature:						
World average: Williams & Al-Ansari (2007)						
W. Europe: EFMA (2008)		3.89				
W. Europe: Kongshaug (1998)	2.82	2.56	6.47	2.27	14.1	0.91

The production of fertilizers where nitric acid is involved, causes also emission of dinitrous oxide. The share of N_2O emissions in the carbon footprint of these fertilizers is summarized in Table 16 and varies on a global scale between one third and half. For fertilizers not mentioned in Table 16, the share of N_2O in the carbon footprint is negligible.

Table 16: Share of N_2O *in tot greenhouse gas emission (in* CO_2eq*) per ton N for N-fertilizers partly based on nitric acid*

Global region	Nitrogen solutions (liquid UAN)	Ammonium Nitrate	Calcium Ammonium Nitrate (CAN)	NPK compound (based on AN, AP and MOP)	NK compound (based on nitric acid and MOP)
World average	33%	51%	51%	40%	48%
Western Europe	42%	61%	60%	48%	55%
East Europe+ Russia	34%	52%	52%	41%	49%
South America	41%	59%	59%	47%	55%
North America	40%	58%	58%	47%	54%
Asia	25%	41%	41%	31%	40%
Australia	41%	59%	59%	47%	55%

3 Use of synthetic fertilizers

Regarding the use of synthetic fertilizers in crops that are relevant for the production of vegetable feed raw materials, we distinguish 5 global regions: Europe, North America (mainly USA), South America (mainly Argentina and Brazil), Asia (mainly Indonesia, Malaysia and Philippines) and Oceania (mainly Australia (Table 17). Almost 75% of the world wide produced nitrogen fertilizer is used in Europe and North America. Almost 40% of the world wide produced phosphorus and potassium fertilizers are used in Argentina and Brazil (IFA, 2011).

Table 17: The worldwide use of N, P, K fertilizers (in 1000 tonnes nutrient) in 2008 (based on IFA 2011)

Global region	**N**	**P**	**K**
Europe (West and Central Europe)	9946 (33%)	1913 (17%)	2155 (19%)
South America: Argentina and Brazil	3388 (11%)	4055 (37%	4420 (38%)
North America: USA and Canada	12189 (41%)	3471 (32%)	2981 (26%)
Asia: Indonesia, Malaysia and Philippines	3689 (12%)	706 (6%	1769 (15%)
Oceania: Australia	835 (3%)	818 (8%)	215 (2%)
Global	30047 (100%)	10963 (100%)	11540 (100%)

In the Tables 18, 19 and 20 the share of different N, P and K fertilizers are listed.

3.1 N-fertilizer use

The most used N-fertilizer is urea (31% of all global applied N-fertilizer is urea) (Table 18). Between the regions there are distinct differences in use of N-fertilizer. In Europe relative less urea is used in favour of Calcium Ammonium Nitrate (CAN), Ammonium Nitrate (AN) and NPK compounds. In South America, Asia and Australia the share of urea in N-fertilizer use is 50-75%. In North America the use of Ammonia (or anhydrous ammonia) and Nitrogen solutions is relatively high.

Table 18: The share of different N-fertilizers in total N-fertilizer use as average for the five global regions and for the individual regions, figures are average for 2004 - 2008 (based on IFA 2011).

Global region	**Urea**	**Nitrogen solutions**	**NPK compound**	**Anhydrous Ammonia (direct)**	**AN**	**CAN**	**AP**	**AS**
Global average	31%	14%	12%	12%	9%	8%	5%	5%
West Europe	18%	11%	19%	0.1%	18%	24%	2%	3%
East Europe (incl Russia)	19%	5%	11%	0%	56%	1%	5%	4%
South America	52%	4%	7%	0%	9%	1%	14%	12%
North America	23%	24%	10%	28%	3%	0.1%	6%	3%
Asia	78%	0%	8%	0%	0.1%	0%	1%	11%
Australia	55%	7%	6%	6%	0.1%	1%	19%	7%

CAN = Calcium Ammonium Nitrate, AN = Ammonium Nitrate, AP = Ammonium Phosphate, AS = Ammonium Sulphate

3.2 P-fertilizer use

Most of the phosphate in fertilizer is applied as compound fertilizer; Ammonium Phosphate and NPK compound represent together almost three quarters of phosphate fertilizer use in the five selected regions (Table 19). The share of Triple and Single Phosphate is 20%. In Western Europe relatively more NPK en PK compound is used as P-fertilizer, whereas in North America more Ammonium Phosphate is used (two thirds of tot P-fertilizer use). In South America Triple and Single Superphosphate represents almost half of the P-fertilizer use. The share of Ammonium phosphate is almost half. In Asia the share of TSP (39%) and Ground rock is relatively high.

Table 19: The share of different P-fertilizers in total P-fertilizer use as average for the five global regions and for the individual regions, figures are average for 2004 - 2008 (based on IFA 2011).

Global region	AP	NPK compound	TSP	SSP	Other NP	PK compound	Ground rock
Global average	45%	26%	11%	9%	3%	2%	2%
West Europe	22%	52%	8%	1%	4%	10%	0%
East Europe (incl Russia)	56%	31%	0%	0%	7%	0%	6%
South America	46%	3%	21%	26%	0%	0%	3%
North America	63%	27%	0	0%	6%	0%	0%
Asia	10%	30%	39%	1%	6%	0%	14%
Australia	64%	31%	5%	0%	0%	0%	0%

TSP = Triple superphosphate, SSP = Single superphosphate

3.3 K-fertilizer use

Potassium Chloride (also called 'Muriate of Potash') has the highest share (two third) in total potassium application through fertilizer (Table 20). NPK compound represents a quarter in the total K-fertilizer use in the five selected regions. This partitioning is the same for North America. In Europe more NPK compound is used compared to Potassium Chloride. In South America almost all K is applied as Potassium Chloride (97%) but there is a big difference between Brazil and Argentina in K-fertilizer use. In Argentina only half of the K is applied as Potassium Chloride whereas in Brazil this share is 98%. In Argentina more compounds (NPK and NK) are used and more Potassium Sulphate is used.

Table 20: The share of different K-fertilizers in total K-fertilizer use as average for the five global regions and for the individual regions, figures are average for 2004 - 2008 (based on IFA 2011).

Global region	Potassium chloride	NPK compound	Potassium sulphate	PK compound	NK compound
Global average	68%	26%	2%	2%	1%
West Europe	29%	55%	4%	10%	0%
East Europe (incl Russia)	56%	43%	1%	0%	0%
South America	97%	1%	1%	0%	1%
Argentina	47%	13%	15%	0%	25%
North America	67%	26%	4%	0%	1%
Asia	77%	22%	1%	0%	0%
Australia	18%	68%	11%	0%	2%

3.4 Carbon footprint of average fertilizer use

Using the average mix of fertilizer use (Tables 18, 19 and 20) and the carbon footprint of each fertilizer (Table 13, 14 and 15) a regional emission factor for applying N, P and K fertilizer can be calculated (Table 21).

It is assumed that the carbon footprint of lime application is the same for each region. In most cases diesel is used as fuel, sometimes natural gas. The energy use is estimated 0.8 GJ/ton (Kongshaug, 1998). The CO_2 emission is 0.074 kg CO_2 eq/kg lime when the fuel is diesel and 0.054 kg CO_2 eq/kg lime when the fuel is natural gas. The upper limit is set to 0.089 kg CO_2 eq/kg lime, adding 20% to the average due to inefficient diesel use.

Table 21: The carbon footprint of the average N, P_2O_5 and K_2O fertilizer use in different global regions. Best estimates, followed by the lower and upper limits between brackets (CO_2 eq/kg fertilizer)

Global region	**N-fertilizer**	**P_2O_5 fertilizer**	K_2O **fertilizer**	**Lime**
	Per kg N	*Per kg* P_2O_5	*Per kg* K_2O	*Per kg Lime*
Global average	5.66 (3.42 – 8.43)	1.36 (0.14 - 2.15)	1.23 (0.36 -1.91)	0.074 (0.054 – 0.089)
Western Europe	5.62 (3.05 – 7.27)	1.47 (-0.29 – 2.49)	1.36 (-0.21 – 2.31)	0.074 (0.054 – 0.089)
Eastern Europe (incl Russia)	6.87 (5.61 – 7.24)	1.57 (0.42 – 2.44)	1.45 (0.41 – 2.34)	0.074 (0.054 – 0.089)
South America	3.53 2.53 – 4.47)	0.54 (-0.06 – 0.85)	0.61[a] (0.40 – 0.83)	0.074 (0.054 – 0.089)
North America	4.00 (2.32 – 5.06)	1.29 (0.12 – 2.11)	1.02 (0.21 – 1.71)	0.074 (0.054 – 0.089)
Asia	6.92 (5.56 – 8.26)	1.66 (0.41 – 2.52)	1.47 (0.71 – 2.07)	0.074 (0.054 – 0.089)
Australia	3.06 (2.16 – 4.45)	1.14 (0.09 – 1.97)	1.63 (-0.06 – 3.22)	0.074 (0.054 – 0.089)

[a] In Argentina the weighted carbon footprint of K_2O fertilizer use is 1.67 due to the relatively high use of NK compound (Table 20).

4 References

Ahlgren, S., A. Baky, S. Bernesson, A. Nordberg, O. Norén and P.A. Hansson 2008. *Ammonium nitrate fertiliser production based on biomass. Environmental effects from a life cycle perspective.* In: Bioresource Technology, volume 99 (2008), pag. 8034 – 8041.

Brentrup F & Pallière C (2008) *GHG emissions and energy efficiency in European nitrogen fertilizer production and use.* International Fertiliser Society, proceedings 639, pp 28.

Campbell, L.M., M.V. Campbell and D.L. Epperson 1996. *Methane emissions from the natural gas industry, volume 9: underground pipelines.* For Gas Research Institute (GRI) and U.S. Environmental Protection Agency (EPA) by Radian International LLC, Austin.

Davis, J. and & C. Haglund 1999. *Life Cycle Inventory (LCI) of Fertiliser Production: Fertiliser Products Used in Sweden and Western Europe.* SIK-report No. 654. Gothenburg, Sweden.

EC 2007 ???

Ecoinvent 2010. Ecoinvent versie 2.2. Swiss Centre for L:ife Cycle Inventories

EFMA 2000a. Production of Ammonia,Booklet No. 1 of 8. Best Available techniques for Pollution Prevention and Control in the European Fertilizer Industry. European Fertilizer Manufacturers' Association, Brussels.

EFMA 2000b. Production of Nitric Acid, Booklet No. 2 of 8. Best Available techniques for Pollution Prevention and Control in the European Fertilizer Industry. European Fertilizer Manufacturers' Association, Brussels.

Elsayed, M. A., Matthews, R. and Mortimer, N. D. 2003. *Carbon and Energy Balances for a Range of Biofuels Options.* Report by Resources Research Unit, Sheffield Hallam University for DTI Sustainable Energy Programmes.

EPA 2010. *Available and emerging technologies for reducing greenhouse gas emissions from the nitric acid production industry.* Sector Policies and Programs Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, North Carolina.

European Commission (2007) *Reference document on Best Available Techniques for the manufacture of large volume inorganic chemicals- ammonia, acids and fertilisers. Integrated Pollution Prevention and Control IPPC Directive.* With summary in Dutch.

Haas, M.J.G. de & T.A. van Dijk 2010 *Inventarisatie klimaatvriendelijke kunstmest.* Nutriënten management instituut NMI, Wageningen.

IEA 2007. *Tracking Industrial Energy Efficiency and* CO_2 *Emissions*

IFA 2009. *Energy Efficiency and* CO_2 *Emissions in Ammonia Production 2008-2009 Summary Report.* International Fertilizer Association, Paris.

IFA, 2011 *Statistical information on fertilizer use from International Fertilizer Association* . Obtained from: www.fertilizer.org/ifa.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories 2006. Volume 3 Industrial Processes and Product Use, Chapter 3: Chemical Industry Emissions.

Jenssen, T.K. 2010. *Calculation of Carbon Footprint of Fertilizer Production.* Yara HESQ. Downloaded from: http://www.yara.com

Kongshaug, G. 1998. *Energy consumption and greenhouse gas emissions in fertilizer production.* Proceedings on IFA Technical Conference1998, Marrakech, Morocco.

Lako P, 2009.*Energy conservation potential of the nitrogen fertiliser industry*. Rapport ECN-E-09-11. Pp 42.

Lauriente, D. 2008 *Nitrogen Solutions* downloaded from www.sriconsulting.com

OCI-AGRO, 2008 *VNCI rewards top performance of Agro* Downloaded from www.ociagro.com

Patyk, A. 1996. Balance of Energy Consumption and Emissions of Fertilizer Production and Supply. Reprints from the International Conference of Life Cycle Assessment in Agriculture, Food and Non-Food Agro-Industry and Forestry: Achievements and Prospects, Brussels, Belgium, 4-5 April 1996.

PDC 2008. *Benchmarking of Energy Efficiency of Nitric Acid Plants*, Process Design Center, the Netherlands, June 2008

Williams, G. & F. Al-Ansari 2007 IFA Benchmarking of Global Energy Efficiency in Ammonia Production. Workshop on Energy Efficiency and CO_2 Reduction Prospects in Ammonia Production, IN: IFA Technical Committee Meeting, 12-14 March Ho Chi Minh City, Vietnam.

Wood, S. and A. Cowie 2004. *A review of greenhouse gas emission factors for fertilizer production*. Cooperative Research Centre for Greenhouse Accounting.

Zwiers R, Van Balken JAM, Härmälä EYE, Pallière & Cryans MC (2009) EU climate policy and emission trading: challenges for the European fertiliser industry. International Fertiliser Society, proceedings 643. pp18.