

*Anticipation Study*

NPK - will there be enough plant nutrients to feed a world of 9 billions?

REPORT

# **Supply of and access to key nutrients NPK for fertilizers for feeding the world in 2050**

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This report has been elaborated in the framework of the JRC anticipation study on NPK - will there be enough plant nutrients to feed a world of 9 billions?, which aims at reviewing the current forecasts of the supply and availability of essential macronutrients (nitrogen, phosphorus and potassium - NPK) and then assessing if the basic needs associated with food supply and an increase in consumer demand of a growing and more affluent world population will be met or jeopardized by the forecast.

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## List of abbreviations and acronyms

Bt	Billion tonnes or 10 <sup>9</sup> tonnes
CAN	Calcium Ammonium Nitrate
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organization
IAASTD	International Assessment of Agricultural Science and Technology for Development
IFA	International Fertilizer Industry Association
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
GPRI	Global Phosphorus Research Initiative
K	Potash in terms of plant nutrient (K <sub>2</sub> O)
KCL	Potassium Chloride
kt	Thousand tonnes
LNG	Liquefied natural gas
MAP	Monoammonium phosphate
MOP	Potassium Chloride (Muriate of Potash)
Mt	Million tonnes or 10 <sup>6</sup> tonnes
NEPAD	New Partnership for Africa's Development
N	Nitrogen in terms of plant nutrient
NPK	N+P <sub>2</sub> O <sub>5</sub> +K <sub>2</sub> O (Nitrogen + Phosphate + Potash)
OECD	Organisation for Economic Co-operation and Development
P	Phosphate in terms of plant nutrient (P <sub>2</sub> O <sub>5</sub> )
PR	Phosphate rock
SOP	Potassium Sulphate (Sulphate of Potash)
TSP	Triple superphosphate
SSA	Sub-Saharan Africa
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
USGS	United States Geological Survey



## 1. Introduction

Feeding a population of 9 billion people in 2050 will rely upon the availability of plant nutrients commensurate with the necessary increase in productivity, the deployment of new plant and farming technologies and the cultivation of more marginal land. Food production has increased substantially over the 20<sup>th</sup> century, partly because of fast yield growth. Smil (2011a) compares typical grain yields in 1900 with the year 2000, concluding that, with average crop yields remaining at the 1900 level, nearly four times more land would be required to obtain the crop harvest of year 2000.

Increased use of fertilizers has been a major factor explaining a significant share of yield growth. As harvested crops remove large amounts of plant nutrients (mainly nitrogen, phosphorus and potash) from the soil, fertilizers are important to replenish the soil reserves of nutrients and maintain soil fertility. Several authors claim that at least 30 to 50% of yield growth is attributable to commercial fertilizers (Heisey and Norton 2007).

At the same time that food production is escalating, agriculture is becoming more and more dependent on regular application of plant nutrients. Hence, understanding whether future availability of essential plant nutrients could jeopardize food production growth in the years to come becomes crucial.

FAO projections show that feeding a world population of 9.1 billion people in 2050 would require raising overall food production by some 70% between 2005/07 and 2050 (FAO 2009). New projections show a 100-110% increase in global food demand in 2050 compared with 2005 (Tilman et al. 2011). Fertilizer production will have to increase significantly in order to meet future fertilizer demand: between 50% and 100% in 2050 compared with 2005 depending on the food growth pathway.

The objective of this study is to review and assess the current forecasts of the supply and availability of essential macronutrients (nitrogen, phosphorus and potassium - NPK).

Sections 2 and 3 will discuss the main topics related to the supply and access to NPK fertilizers. In section 2, we will focus on the various issues related to fertilizer supply. In the case of nitrogen, since nitrogen fertilizers can be produced from nitrogen present in the atmosphere, there are no major concerns about the future availability of this nutrient; adequate supply of nitrogen fertilizers will be mostly determined by production costs. On the contrary, phosphorus and potassium fertilizers are produced from non-renewable sources, raising concerns about the future availability of these nutrients. Section 3 will deal with accessibility issues, paying particular attention to the major factors driving fertilizer prices as well as regional disparities.

In section 4 we will focus on the existing prospects for future supply and availability of fertilizers. Medium-term as well as long-term trends will be analyzed. In addition, potential NPK supply scenarios for 2050 will be assessed.

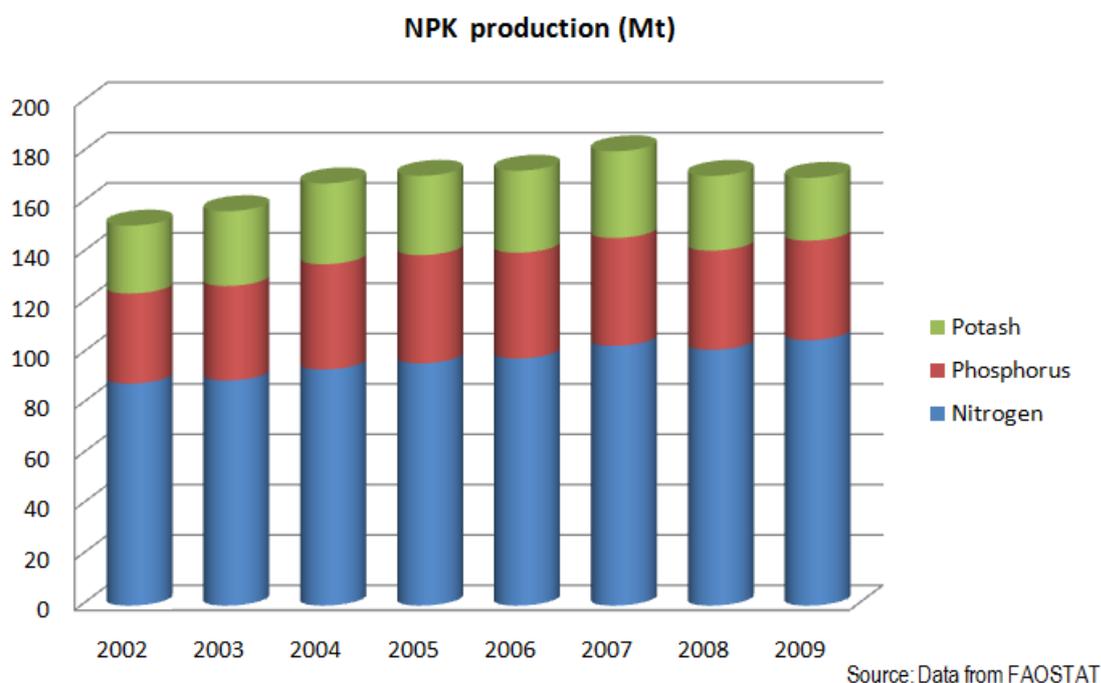
Finally, in the last section some concluding remarks will be presented.

## 2. Supply of NPK fertilizers

### 2.1. World production of fertilizers

Figure 1 shows recent fertilizer production trends at the world level. During the period 2002-2007, NPK fertilizer production has increased at an average annual rate of 3.6%. Because of the negative growth rates in 2008 and 2009, the average annual rate for the period 2002-2009 was much lower (only 1.7%). As shown in Figure 1, nitrogen is the main macronutrient produced worldwide, followed by phosphate and potash. Of total macronutrients produced over the period 2002-2009, nitrogen accounted for 58%, phosphate for 24%, and potash for the remaining 18%.

**Figure 1.** NPK fertilizer production



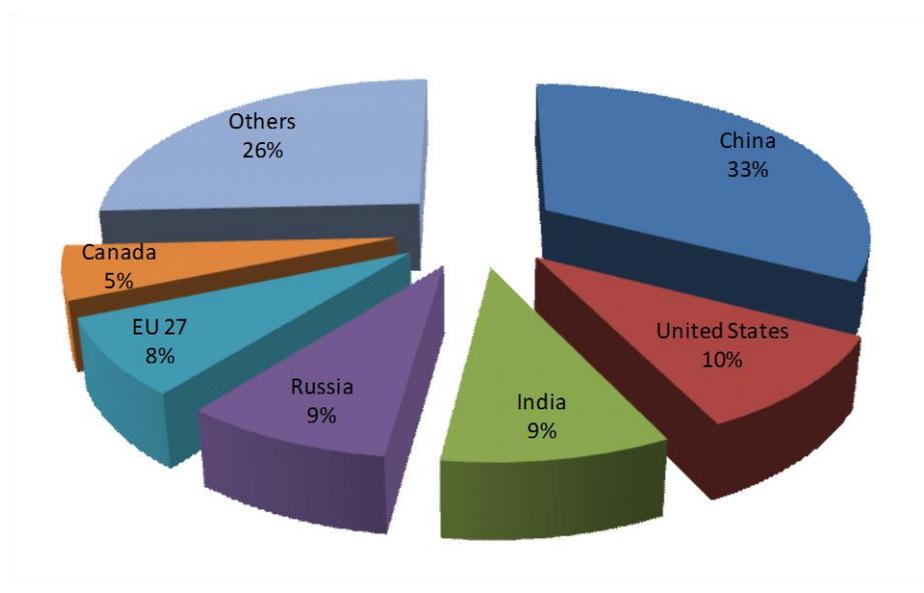
According to FAO (2010), since 2009, the global fertilizer market has moved towards stabilization, as fertilizer demand started to recover from the mid-year of 2009 in the main consuming countries. In 2009, production of phosphate and potash declined,

while production of nitrogen increased moderately. Global capacity of fertilizers increased in main exporting regions, but at modest rates compared with those of the previous years. Completion of a few projects was postponed due to a combination of soft market conditions and technical delays (FAO 2010).

The production of fertilizers is characterized by a high and increasing level of concentration. As Gregory and Bumb (2006) point out, this trend can be explained because the fertilizer industry is a capital-intensive industry with economies of scale in production and a high requirement of raw materials (particularly natural gas, phosphate rock, and potassium salts), which represent a high share of production costs.

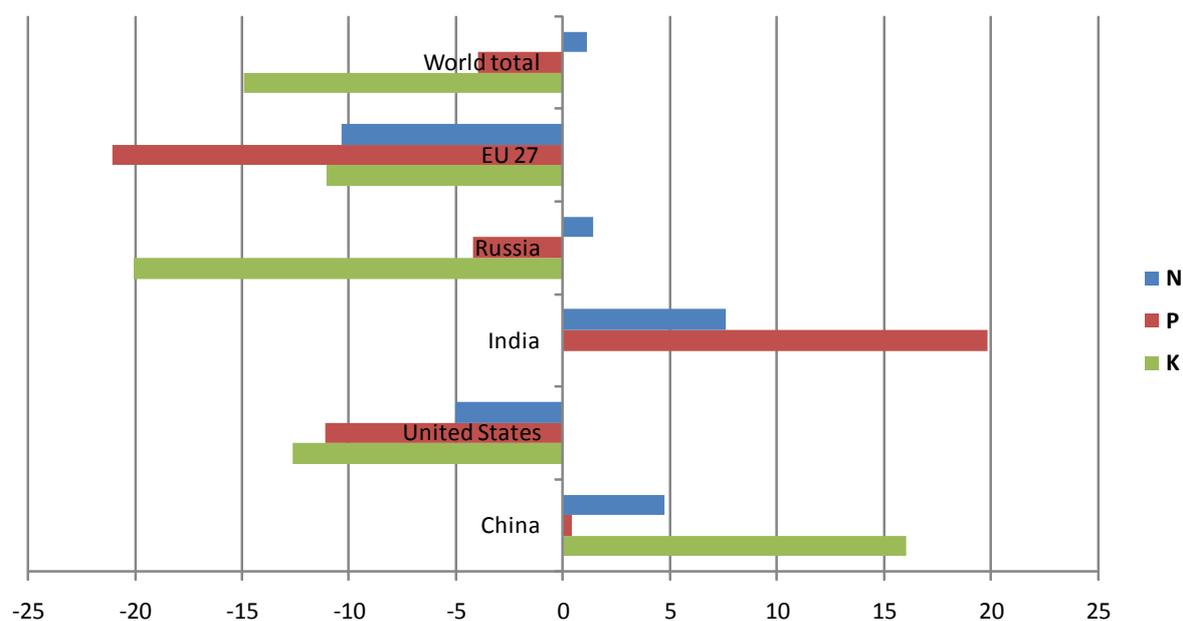
In 2009, the leading production region was China, accounting for 33% of global production. Other countries with a significant share of total world fertilizer production were the United States (10%), India (9%) and the Russian Federation (9%).

**Figure 2.** Main fertilizer producing regions in 2009



Source: Data from FAOSTAT

In the last decade, favourable expectations on food demand growth resulted in increased fertilizer supply and capacity. Nevertheless, in recent years, the fertilizer sector has experienced price tensions similar to those experienced in the energy and food commodities markets. As Figure 3 shows, potash and then phosphorus fertilizers were most affected by the economic slowdown in 2008 and 2009. The crisis did not affect all world regions similarly: decrease in NPK production took place mostly in the EU, Russia and the US, while other leading regions such as India and China expanded production.

**Figure 3.** Annual average change in fertilizer production in the period 2007-2009

Source: Data from FAOSTAT

In this regard, it is important to keep in mind that, to a large extent, the costs of fertilizers are influenced by energy costs.

On the one hand, commercial fertilizer production is a very energy-intensive process. About 74% of total energy used to produce fertilizers comes from natural gas. Natural gas is the main input used to produce ammonia, which, in turn, is the main input to produce nitrogen fertilizers. Increases in natural gas prices translate into higher production costs for ammonia.

On the other hand, transportation costs are a major factor determining fertilizers' prices. Fertilizers are one of the most highly traded commodities in the world. Each year around 30 Mt of fertilizers are transported across the globe (IFA 2006). Not surprisingly transport costs are a significant share of total costs of supplying fertilizers.

Fertilizer prices are expected to remain high. The expected long-term rise in fossil energy prices will increase the cost of supplying fertilizers. Rising energy costs would increase both the cost of producing fertilizers and the cost of delivering to the farmers.

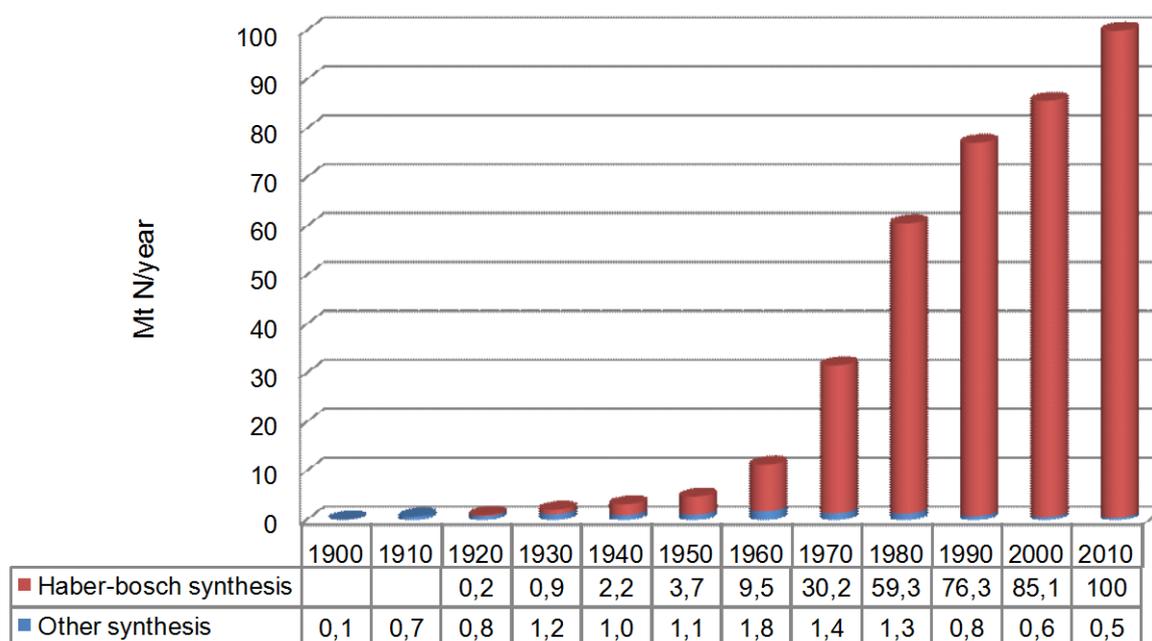
## 2.2. Nitrogen fertilizer production

Nitrogen is very abundant in the atmosphere. Some plants (legumes mainly) can recover nitrogen directly from the atmosphere or from the soil (nitrogen biofixation).

Nitrogen is commercially recovered from the atmosphere as ammonia (produced by combining nitrogen from the atmosphere with hydrogen from natural gas). Ammonia is the main feedstock for other nitrogen compounds used as fertilizers, such as urea, ammonium nitrate and ammonium sulphate.

Haber-Bosch synthesis of ammonia made it possible to mass-produce synthetic nitrogen fertilizers (Smil 2011b), its global output rising rapidly since the 1960s. Soon, China became, and remains, the largest user as well as the largest producer of synthetic nitrogen (FAO 2011). The wide use of nitrogen fertilizers has been one of the major drivers of yield growth in various world regions.

**Figure 4.** World production of synthetic nitrogen fertilizers 1900-2010 (Mt N/year)



Source: Data from Smil (2011b)

According to Smil (2011b), synthetic N fertilizers provide just over half of the nutrient received by crops worldwide, the rest coming mostly from natural and managed biofixation (leguminous crops), organic recycling (manures and crop residues) and atmospheric deposition. Smil (2011b) argues that without the use of nitrogen fertilizers we could not secure enough food for the prevailing diets of nearly 45% of the current world's population.

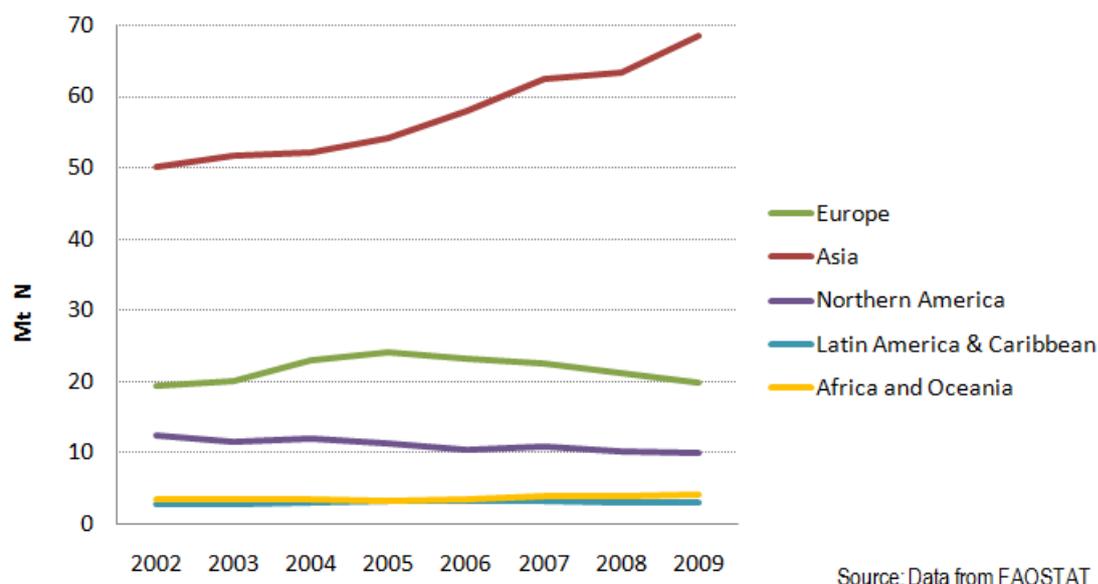
Nitrogen application rates increased steadily since the 1960s, mainly because of low fertilizer prices and the quest for higher crop yields. Yet, significant disparities exist at the regional level. While typical fertilizer application rates are below the recommended levels in sub-Saharan Africa (Goulding et al. 2008), in other parts of the world high application levels along with low efficiencies lead to notable nitrogen losses (Eickhout et al. 2006, Bowman et al. 2009). Nitrogen use efficiencies in major EU agricultures range from just 38% in France and the Netherlands to 42% in Germany and 44% in Italy (Oenema *et al.* 2009). In China's paddy fields typical losses are still higher: even with optimized applications they can exceed 70% and with traditional applications they can be more than 80% (Fan *et al.* 2007).

The trend towards higher nitrogen application rates is changing nowadays, mainly because of higher fertilizer prices and rising concerns about environmental impacts of farming intensification practices. While industrial production of nitrogen fertilizer will still be essential to sustain a continuously increasing food production in the future, alternatives to reduce dependence upon mineral fertilizers while protecting the environment are getting more and more attention. Among these potential sources of nitrogen, we highlight:

- Nitrogen biofixation, presently restricted to the legumes by their symbiotic relationship with the Rhizobium bacteria, which settle in the root nodules of the plants.
- Recycling of animal manure and human excreta, which has large potential to substitute fertilizer use (Bouwman et al. 2009), even though the current availability of animal manure for application in agriculture is limited due to spatial separation of intensive livestock and crop production (Janssen and Oenema 2008).
- Adoption of more efficient fertilizer technologies, through better management options that could help to increase the efficiency of on-farm use of N.

Looking at the regional dimension of nitrogen supply, whereas production of nitrogen fertilizers is widely distributed throughout the world, production levels highly differ across regions (Figure 5).

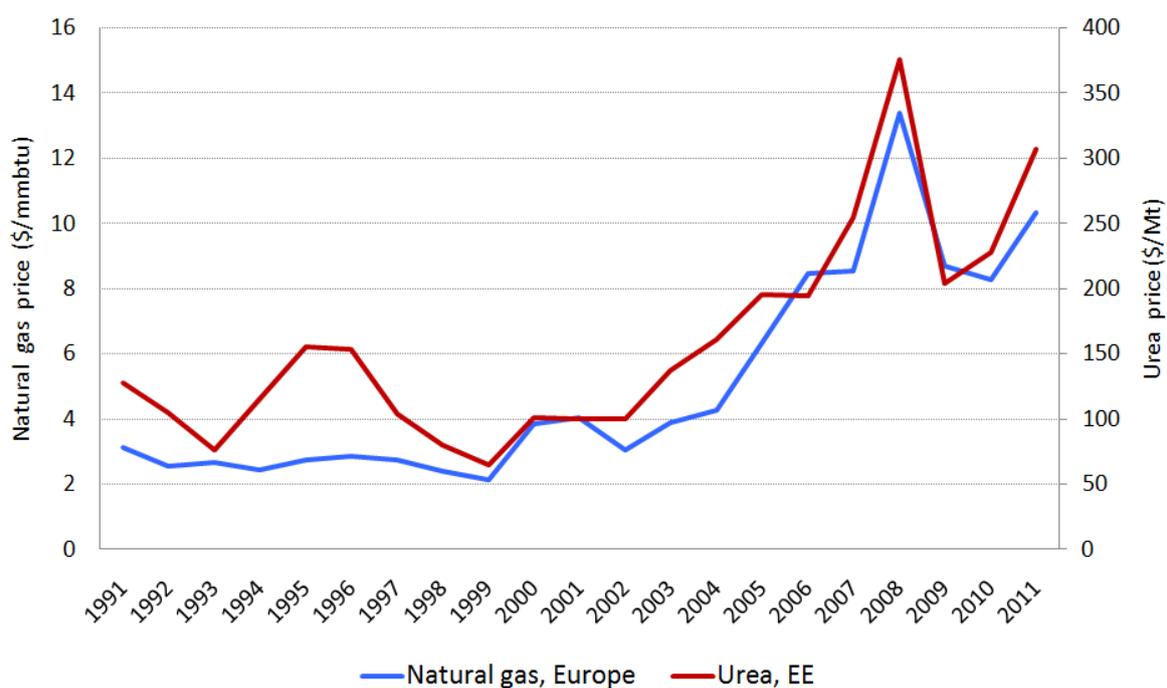
Over the past 10 years, global nitrogen production capacity has grown by approximately two million tonnes per year. The majority of recent nitrogen capacity additions have been in Asia and Latin America. Future additions will likely be built in regions with abundant supplies of low-cost natural gas. No new gas-based nitrogen facilities have been built in North America and Western Europe for the past 10 years because of the relatively high cost of natural gas.

**Figure 5.** Regional production of N fertilizer (Mt)

Almost all N fertilizer is derived initially from anhydrous ammonia ( $\text{NH}_3$ ), which is produced by reacting atmospheric  $\text{N}_2$  with  $\text{H}_2$  from natural gas. While unreactive  $\text{N}_2$  in the atmosphere is effectively limitless, supplies of energy and feedstock sources for ammonia production are not. Methane coming from natural gas is currently the most efficient hydrogen feedstock (Dawson and Hilton 2011). Actually, the cost of natural gas accounts for 70 to 90% of the production costs of ammonia.

Increased efficiency in ammonia production allowed N fertilizer prices to fall until the 1990s. Smil (2008) reports that the energy for manufacturing ammonia using the best available technology declined from 80 GJ per tonne of ammonia in 1950, to 50 GJ/tonne in 1980, and about 40 GJ/tonne in 2000. According to Fischer et al. (2011), as the major efficiency gains have already been made, it is likely that the price of N fertilizer will rise in line with energy prices.

Actually, during the last decades, N fertilizer prices have closely tracked energy prices, with 1 tonne of urea (46 percent N) costing about 40 times as much as 1 GJ of natural gas (The Economist 2011). As long as natural gas continues to be the main feedstock used in ammonia production, it seems very likely that N fertilizer prices will move in line with natural gas prices. A scenario of rising natural gas prices, along with taxation of fertilizer use in many countries to prevent pollution, will lead to significant increases in fertilizer prices. A way to face increasing N prices will be to enhance nitrogen use efficiency, documented to be very low in a number of studies (Bowman et al. 2009).

**Figure 6.** Real prices of urea (Eastern Europe, bulk) and natural gas in Europe

Source: World Bank Databases (constant 2000\$), accessed November 2011

The high dependence of N fertilizer production on energy costs and availability raises concerns about N supply security.

Globally, natural-gas reserves are huge<sup>1</sup> and rapid development of non conventional production (mainly shale gas production) has further contributed to reserve expansion. In the United States, as a result of the deregulation of the natural-gas market, shale-gas production has increased sharply in the last years, currently accounting for roughly one quarter of US natural gas. In the recently published “World Energy Outlook”, the International Energy Agency develops a scenario called the “Golden age of gas”, forecasting a steep growth in world production until 2035.

Nevertheless, the development of shale-gas reserves beyond US is still at an early stage. Awareness about potential environmental impacts (mainly water pollution) has led to a moratorium on shale-gas exploration in some countries (France). In the EU, Poland might have the largest shale-gas reserves.

To the extent that the shale-gas production is further developed, more natural gas will become available (both in terms of quantity and diversity of suppliers) and a downward pressure on natural gas prices is to be expected. Alternatively, if development of shale-gas production is curtailed because of environmental or safety

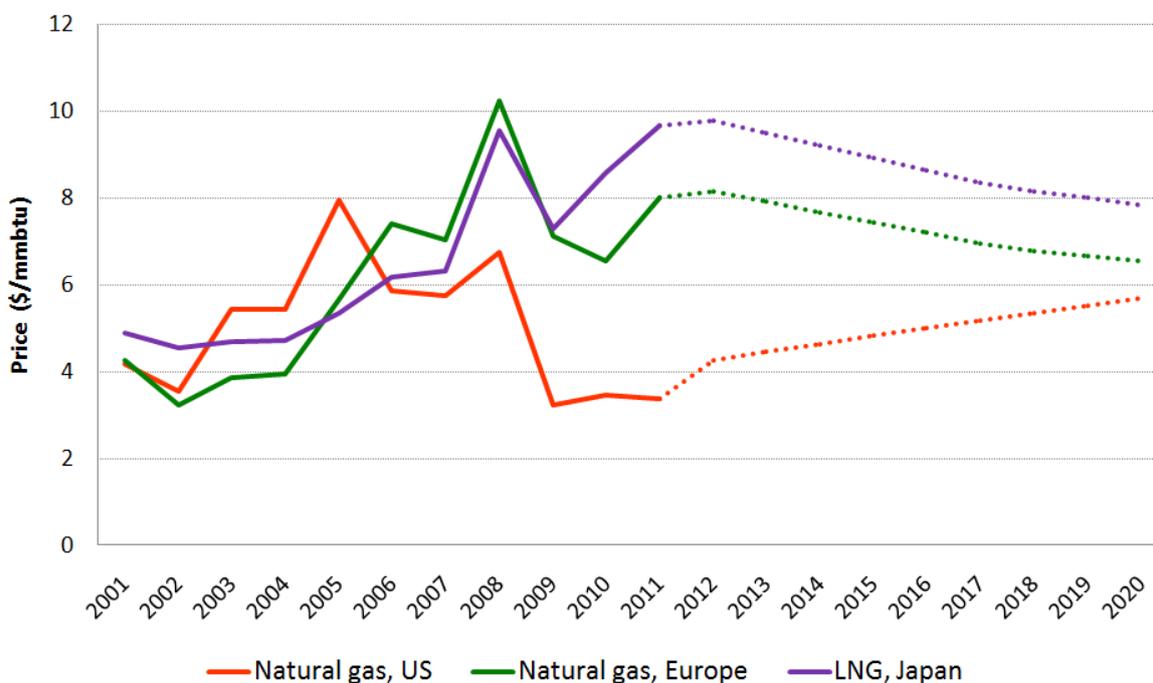
<sup>1</sup> If all the known reserves of natural gas ( $171 \times 10^{12}$  m<sup>3</sup> (European Commission 2010)) were used for the production of N fertilizer, at the current rate of production, these reserves will last approx. 1000 years.

concerns, gas supplies will be more limited and natural gas prices would be expected to move upwards.

Globally, three natural-gas markets with varied prices can be distinguished (North America, Europe and Asia). In deregulated North America, with a competitive market and plenty of shale-gas to augment conventional supplies, prices are low. In Asia, where gas is largely traded using a system of long-term contracts tied to the price of oil, prices are high. Europe sits in between (The Economist 2011).

Natural gas prices are projected to stabilize over the long-run according to the World Bank (2011).

**Figure 7.** World price of natural gas in constant 2000\$ (data and projections to 2020)



Source: World Bank Databases (data 2001-2010) and World Bank 2011 (projections 2011-2020)

In addition, alternative technical solutions to produce ammonia are foreseen. Even if today natural gas remains the most cost-efficient source of hydrogen to produce ammonia and it is difficult to envisage other systems competitive enough to replace it, in a scenario of rising natural gas prices, the development of alternative processes can be anticipated (Dawson and Hilton 2011). Bartels and Pate show that significant research is being done on the generation of hydrogen from alternative sources (nuclear power, solar energy, wind energy).

Therefore, it seems that N supply security is not jeopardized, at least in terms of N production possibilities. Still, N security in terms on accessibility at affordable prices

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will most likely be a major concern in many world regions, as we will comment later on in the section devoted to NPK access.

The latest data and projections on N fertilizer markets show that increase in N capacity is closely related to natural-gas market developments. No new gas-based nitrogen facilities have been built in North America and Western Europe for the past 10 years because of the relatively high cost of natural gas. Additional gas-based nitrogen facilities will likely be built in regions with abundant supplies of low-cost natural gas.

### 2.3. Phosphate fertilizer production

Today nearly all phosphorus fertilizers are produced from phosphate rock (PR), a non-renewable resource. Mining of PR for use in fertilizers began in the XIX century and boosted from the 1950s. Before large-scale mining of PR, agriculture had largely relied on natural soil reservoirs of phosphorus and the application of animal-based fertilizers (manure, bones, guano).

Phosphate rock is generally extracted with surface mining techniques, and most of it is used for fertilizer production (82% of total P<sub>2</sub>O<sub>5</sub> production is used for fertilizer production and 18% for industrial uses according to Prud'homme 2010). Among the most common P fertilizers produced, we distinguish:

- ✧ Diammonium phosphate (DAP): the most widely used P fertilizer in the world.
- ✧ Monoammonium phosphate (MAP): broadly used source of P and N.
- ✧ Triple superphosphate (TSP): one of the first widely used P fertilizers.

Commercial production of P fertilizer from phosphate rock increased rapidly over the second half of the XXth century, raising concerns about potential resource depletion. Actually, since phosphate-rich rocks are non-renewable on human timescales and there is no substitute for phosphorus in agriculture, phosphorus must be viewed and managed as a non-renewable non-substitutable resource.

Several studies have alerted about the risk of reaching a “peak phosphorus production” and subsequently, of entering an era of phosphorus scarcity. This issue is, however, highly controversial, and has originated a number of disagreeing studies.

The first discrepancy comes from the precise definition of PR reserves and resources. In this study, wherever possible, we will adopt the terminology used by IFDC (2010):

- ✧ Reserves: Phosphate rock that can be economically produced at the time of the determination to make suitable products, reported as tons of concentrate.

- 
- ✧ Resources: Phosphate rock of any grade that may be produced at some time in the future, including reserves.

IFDC (2010) highlights that the concept of reserves is not static and, therefore, the world reserves is a dynamic figure.

Estimating the PR reserves and resources is extremely complex, partly because of the inherent uncertainty with respect to future technological developments as well as the likelihood of discovering additional resources. In the case of P resources, some authors argue that estimates are somewhat more uncertain due to strategic reporting by different stakeholders (Gilbert 2009).

Limited information on world PR reserves and resources is available in the conventional scientific literature. Only one source, the United States Geological Survey (USGS), publishes PR reserve estimates on a regular basis. Furthermore, the methodology used to estimate current and future availability is quite opaque. Several authors call attention to the relatively low information available on P resources compared to other resources such as energy, and stress that more substantive effort is needed to collect/make available data on phosphorus sources (Gilbert 2009, Van Vuuren et al. 2009, Van Kauwenbergh 2010).

No matter how much PR will be available, it is a non-renewable resource and concerns about its possible depletion started long ago. Already in the 1970s, Emigh (1972) reported that phosphorus could be depleted before the end of the 21st century. Numerous studies followed, presenting very divergent findings. While some studies pointed out that reserves will last for many hundreds of years (Brinck 1977), a number of studies concluded that phosphorus resources (phosphate rock reserves) will be depleted in the very near future (Herring and Fantel 2003, Steen 1998).

During the last decade, there have been a number of studies concerning a looming scarcity of PR. Déry and Anderson (2007) predicted a rapid decline in P consumption due to the depletion of P resources already in the coming decades (the so-called peak phosphorus hypothesis). Other authors reached similar conclusions, indicating that the PR reserves will be exhausted in the next century with a peak in P production occurring in 2033-2034 (Rosemarin 2004, Cordell et al. 2009, Vaccari 2009).

In a recent IFDC report, Van Kauwenbergh (2010) reviews the literature on PR reserves and PR depletion, pointing out that, although most studies on phosphorus depletion rely on USGS data for PR reserve estimates, they seem to fail in recognising the dynamic nature of reserves. Van Kauwenbergh (2010) revises upwards previous estimates and concludes that there is no indication that a "peak phosphorus" event will occur in 20-25 years.

The exhaustive review by Van Kauwenbergh (2010) provides more details on global P reserves and shows much larger world reserves than previously estimated. Based on this reserve estimate, at current rates of production, PR reserves to produce P fertilizer will last for 300-400 years.

The upward revision in PR reserve estimates by IFDC is mainly due to revised figures for Morocco. As it is showed in Table 1, in 2011 USGS has also revised the PR reserves for Morocco and other African countries (USGS 2011), presenting now figures in line of those obtained by IFDC, and even slightly higher.

**Table 1.** World Phosphate Rock production and reserves (Mt)

	USGS					IFDC	
	Mine Production			Reserves		Reserves	Resources
	2008	2009	2010	2010	2011	2010	2010
United States	30.2	26.4	26.1	1100	1400	1800	49000
Algeria	--	1.8	2.0	--	2200	--	--
Australia	2.8	2.8	2.8	82	82	82	3500
Brazil	6.2	6.4	5.5	260	340	400	2800
Canada	1.0	0.7	0.7	15	5	5	130
China	50.7	60.2	65.0	3700	3700	3700	16800
Egypt	3.0	5.0	5.0	100	100	51	3400
Israel	3.1	2.7	3.0	180	180	220	1600
Jordan	6.3	5.3	6.0	1500	1500	900	1800
Morocco	25.0	23.0	26.0	5700	50000	51000	170000
Russia	10.4	10.0	10.0	200	1300	500	4300
Senegal	0.7	0.7	0.7	80	180	50	250
South Africa	2.3	2.2	2.3	1500	1500	230	7700
Syria	3.2	2.5	2.8	100	1800	250	2000
Togo	0.8	0.9	0.8	60	60	34	1000
Tunisia	8.0	7.4	7.6	100	100	85	1200
Other countries	7.4	8.6	9.5	950	620	600	22000
<b>World total</b>	<b>161.0</b>	<b>166.0</b>	<b>176.0</b>	<b>16000</b>	<b>65000</b>	<b>60000</b>	<b>290000</b>

Source: Data from USGS (2010 and 2011) and IFDC (2010)

Estimates of PR reserves are plagued with uncertainty and, therefore, it remains unclear how much reliance should be placed on these new figures. Furthermore, some authors argue that PR reserves remain subject to significant constraints as the economic viability of mining low-value ores and the willingness of communities in some jurisdictions, such as in Florida, to allow mining in future at all (Dawson and Hilton 2011).

In response to the IFDC report, the Global Phosphorus Research Initiative (GPRI 2010) argues that, while the timeline may vary, the fundamental problem of phosphorus scarcity would not change. Moreover, the GPRI - co-founded by Dana Cordell and at the forefront of recent debate on phosphorus availability - points out that the IFDC report assumes a constant rate of production of 160 Mt PR per year to

give the 300-400 years timeline, and this constant production assumption is fairly unrealistic for a long-term forecast.

Actually, the last point is not unimportant. Assuming a constant production rate, around 11% of the current PR reserves will be depleted by 2050. We compared the PR depletion estimates from Van Kauwenbergh with several alternative scenarios implying an increasing trend of P fertilizer production. As shown in Table 2, to duplicate P fertilizer production in 2050, PR extraction should increase annually at a rate of 1.75%, implying the depletion of around 16% of the current PR reserves by 2050.

**Table 2.** Depletion of PR reserves in several 2050 scenarios

	Increase in P production in 2050 compared to 2010			
	0% increase	50% increase	70% increase	100% increase
PR production (2010)	160	160	160	160
PR production (2050)	160	240	272	320
Annual extraction rate increase (%)	0.00	1.02	1.34	1.75
PR depletion by 2050 (Mt)	6560	8094	8668	9478
PR depletion by 2050 (% 2010 reserves)	10.9	13.5	14.4	15.8

Source: Own calculations

Over a longer period, the difference between a constant production rate and an increasing one is more obvious. While assuming a constant rate, only 24% of current PR reserves will be depleted by 2100, assuming an increasing rate of 1.75% per year will imply depletion of around 59% of current PR reserves by 2100. However, these calculations need to be handled with caution. Firstly, because a 1.75% increasing extraction rate per year until 2100 will multiply by five the current P fertilizer production and this is a fairly unrealistic projection. Secondly, because the PR reserve is dynamic, as the IFDC report highlights and, with PR resources accounting for 290000 Mt, it is very likely that PR reserves will increase over time.

Nevertheless, from the perspective of long-term food security, even a perspective of 300-400 years into the future is very short. Sooner or later the supply will become scarce, calling for P resource management policy initiatives. Policies encouraging a more efficient fertilizer use should be investigated. Recycling and reuse of P resources are other relevant options which should be taken into consideration (Dawson and Hilton 2011).

Looking now at the regional dimension, PR reserves are far from being equally distributed across the world. According to IFDC (2010), top 5 countries are Morocco, China, United States, Jordan and Russia. The last update from USGS (2011) points at Morocco, China, Algeria and Syria as major reserves holders.

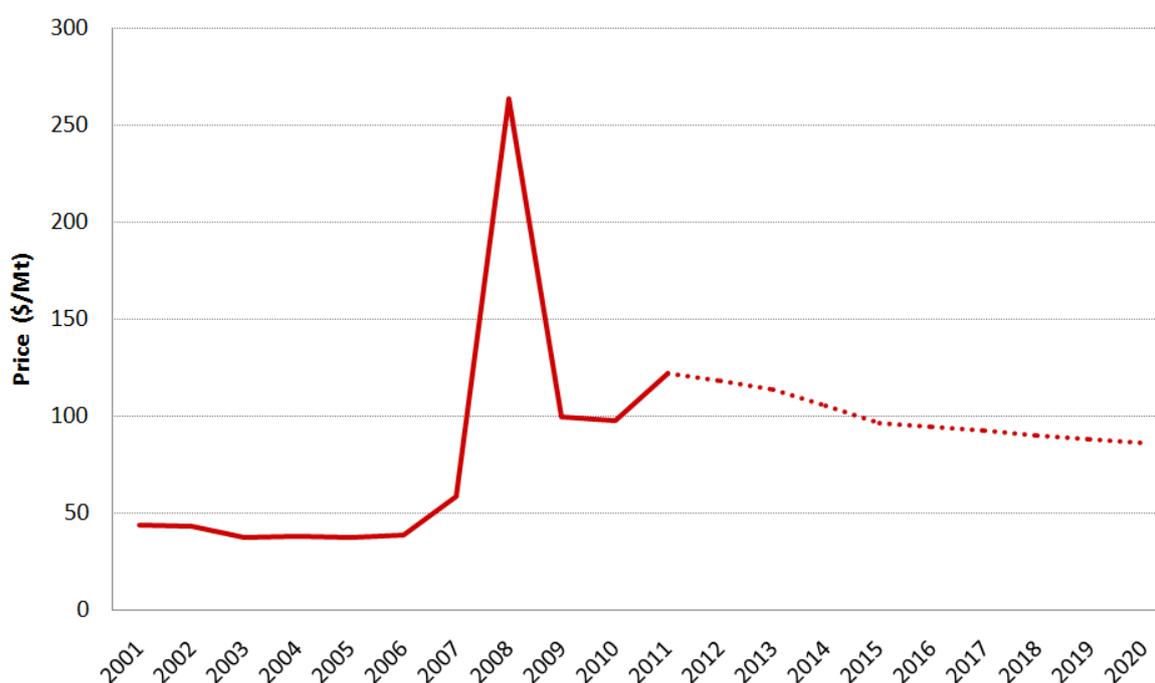
Despite the fact that reserve figures differ between IFDC and USGS sources, Morocco alone control more than 75% of all PR reserves and together with China controls more than 80% of total stock. Even if new mines were recently opened in other countries such as Australia and Saudi Arabia, the geopolitical implications of this supply concentration on the global market are significant and might contribute to global fertilizer market insecurity.

According to Van Kauwenbergh (2010), a collaborative effort by phosphate rock producers, government agencies, international organizations and academia will be required to make a more complete and accurate estimate of world phosphate rock reserves and resources.

Furthermore, as P fertilizer is a critical nutrient for food production and only a handful of countries control PR reserves, some international action would be needed to secure fertilizer access.

There has been a fundamental upward shift in the value of phosphate resources and hence phosphate fertilizers. This is partly a function of high concentration in the phosphate rock /phosphoric acid industries, particularly in the export markets.

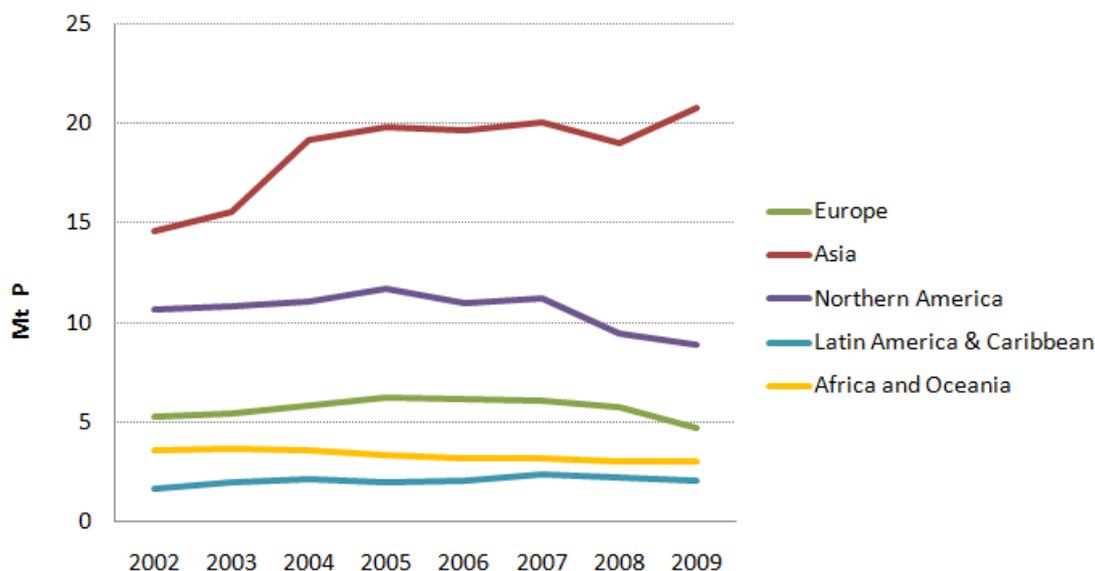
**Figure 8.** World price of Phosphate Rock (data and projections to 2020)



Source: World Bank Databases (data 2001-2010) and World Bank 2011 (projections 2011-2020)

Regarding P fertilizer production, notable regional differences also exist. Asia produces more than half of total P fertilizer, showing an increasing trend over time.

**Figure 9.** Regional production of P fertilizer



Source: Data from FAOSTAT

From a sustainability and food security perspective, the global P cycle as well as environmental concerns need to be taken into account. Paradoxically, at the same time that phosphate reserves are increasingly limited, excessive application of P fertilizers is polluting the environment.

Apart from pollution problems associated to use of P fertilizers (eutrophication), which could be alleviated through the implementation of best management practices (BMPs) in order to minimize P runoff from fields, the production of P fertilizers also implies significant environmental impacts.

Some studies point out that there has been a continuous decrease in world phosphate rock quality as reserves of high-grade and high-quality phosphate rock are being depleted. Improved technologies both allow for increasing recovery rates and for mining lower grade PR ores.

Commercial PR varies in grade from over 37% P<sub>2</sub>O<sub>5</sub> to less than 25% P<sub>2</sub>O<sub>5</sub>. In general, lower P<sub>2</sub>O<sub>5</sub> content means higher impurities content. In order to produce DAP at the worldwide accepted commercial grade (18-46-0), phosphoric acid with a suitable low impurities content must be used. Van Kauwenbergh (2010) reports that, in the past years, it has been difficult to ammoniate phosphoric acid produced from Florida PR to commercial DAP grade because the impurity level in Florida has

reached a level where impurities reduce the possibility of combining P with ammonia. As a result, ammonia nitrate or urea was added in the processing.

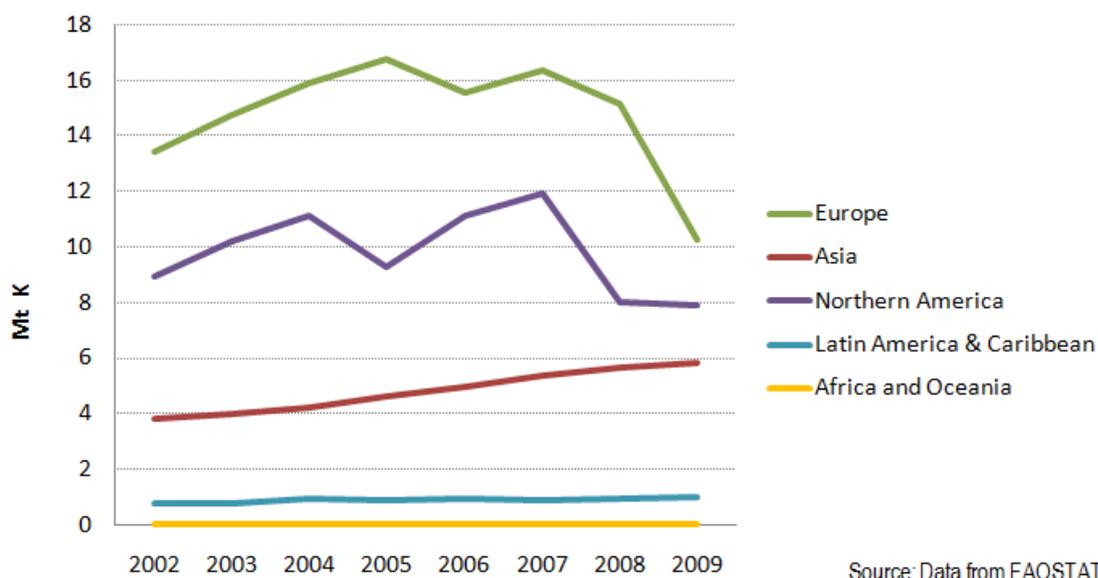
Growing concerns about negative environmental impacts of fertilizer use and the resulting alteration of the global nutrient cycle have been at the origin of efforts to recover phosphorus from human and animal waste.

The potential for phosphate recycling and reuse seems to be very high. A number of pilot and commercial plants are recovering P from human waste in Austria, the Netherlands and Germany. Cordell et al. (2009) argue that, while small-scale trials on P recovery from human and animal excreta exist, commercialization and implementation on a global scale could take decades to develop.

## 2.4. Potash fertilizer production

Potassium has many important functions in plant growth (regulating plant water relations, activating enzymes, and promoting protein formation). Potassium is found in potash, a term that includes various mined and manufactured salts. All commercial potash deposits come from marine sources (ancient seas that are now buried, salt water brines). As larger potash deposits are very deep under the earth's surface, potash recovery requires complex and expensive mining techniques.

**Figure 10.** Regional production of K fertilizer



Potassium fertilizer is mined from underground deposits in many parts of the world. Canada is the largest producer of potash fertilizer, followed by Belarus, Russia, and China. A few naturally occurring surface-water brines (such as the Great Salt Lake in

Utah and the Dead Sea bordering Jordan and Israel) contain sufficient K to make potash extraction feasible. Solar evaporation is used to concentrate the salts, which are washed to separate the K salts from the sodium salt.

While potassium is mined from non-renewable sources, global reserves are estimated to be high in relation to current needs. U.S. Geological Survey estimates global K<sub>2</sub>O reserves at 18 Bt, 8.3 Bt considered commercially exploitable. The world has an estimated 250 Bt of known K<sub>2</sub>O resources (USGS 2011).

At current levels of production (around 33 Mt K<sub>2</sub>O per year) and with current/planned capacity, the industry can easily meet future demand for P fertilizer (Prud'Homme 2008). The current reserves (8.3 Bt) are sufficient to supply potash for 250 years and another 250 would be added if we consider the reserve base (18 Bt). Taking into account the known resources, there will be enough potash to meet demand to thousands of years.

Main concerns about K fertilizer availability are related to the market structure of the market. Canada, Russia and Belarus control most of the global supply of potash. These countries have a strong influence in setting the potash price in global markets. Furthermore, global potash trade is largely controlled by a few companies. An export association controls potash exports in Russia, and the same happens in USA (Phosphate Chemical Export Association) and in Canada (CANPOTEX).

As opposed to nitrogen and phosphorus fertilizers, potassium fertilizer has no significant impacts on environmental quality.

### **3. Access to NPK fertilizers**

#### **3.1. Regional disparities in NPK production**

Tables 2 to 4 show the regional distribution of NPK production. Of the three nutrients, N is the one being widely produced. Even so, production is concentrated in a few countries: China, followed by India, the United States and the Russian Federation are the leading N producers. Within the EU, Poland, Netherlands and Germany are the main N fertilizer producers.

**Table 3.** Regional production of N fertilizer

	2002		2009	
	(Mt)	(% share)	(Mt)	(% share)
China	27.609	31.27	38.777	36.73
India	10.392	11.77	12.047	11.41
United States of America	9.387	10.63	7.685	7.28
Russian Federation	5.968	6.76	7.404	7.01
Indonesia	1.975	2.24	3.591	3.40
Egypt	1.558	1.76	2.724	2.58
Pakistan	2.192	2.48	2.586	2.45
Canada	3.088	3.50	2.205	2.09
Ukraine	2.239	2.54	2.066	1.96
Saudi Arabia	1.290	1.46	1.591	1.51
Poland	1.035	1.17	1.546	1.46
Netherlands	1.478	1.67	1.455	1.38
Other countries	20.075	22.74	21.905	20.75
<b>World total</b>	<b>88.284</b>	<b>100.00</b>	<b>105.581</b>	<b>100.00</b>
EU 15	6.482	7.34	4.910	4.65
EU 12	3.341	3.78	3.926	3.72

Source: FAOSTAT

The production of P fertilizer is concentrated in a handful of countries. Similarly as for N fertilizer, China, India, the United States and the Russian Federation are the main producing regions. Very little P fertilizer is produced in the EU, mainly in Poland and Lithuania.

**Table 4.** Regional production of P fertilizer

	2002		2009	
	(Mt)	(% share)	(Mt)	(% share)
China	7.791	21.77	14.035	35.48
United States of America	10.392	29.04	8.656	21.88
India	3.802	10.62	3.885	9.82
Russian Federation	2.513	7.02	2.575	6.51
Brazil	1.490	4.16	1.813	4.58
Morocco	1.148	3.21	1.054	2.66
Tunisia	0.968	2.71	0.855	2.16
Australia	0.637	1.78	0.550	1.39
Lithuania	0.344	0.96	0.427	1.08
Turkey	0.311	0.87	0.416	1.05
Pakistan	0.111	0.31	0.359	0.91
Republic of Korea	0.323	0.90	0.309	0.78
Other countries	5.959	16.65	4.627	11.69
<b>World total</b>	<b>35.790</b>	<b>100.00</b>	<b>39.561</b>	<b>100.00</b>
EU 15	1.299	3.63	0.730	1.84
EU 12	1.007	2.81	0.859	2.17

Source: FAOSTAT

Very few countries produce K fertilizer. The major producer is Canada, followed by the Russian Federation, China and Belarus. In the EU, K fertilizer is mostly produced in Germany, Spain and the United Kingdom.

**Table 5.** Regional production of K fertilizer

	2002		2009	
	(Mt)	(% share)	(Mt)	(% share)
Canada	8.134	30.09	7.037	28.18
Russian Federation	5.080	18.79	4.651	18.63
China	0.754	2.79	2.715	10.87
Belarus	3.812	14.10	2.461	9.86
Germany	3.201	11.84	2.300	9.21
Israel	1.918	7.10	2.000	8.01
Jordan	1.174	4.34	1.100	4.41
United States of America	0.823	3.04	0.840	3.36
Chile	0.409	1.51	0.600	2.40
Spain	0.407	1.51	0.417	1.67
Brazil	0.364	1.35	0.416	1.66
United Kingdom	0.784	2.90	0.400	1.60
Other countries	0.170	0.63	0.034	0.14
<b>World total</b>	<b>27.030</b>	<b>100.00</b>	<b>24.971</b>	<b>100.00</b>
EU 15	4.522	16.73	3.117	12.48
EU 12	0.000	0.00	0.000	0.00

Source: FAOSTAT

### 3.2. Structure of the fertilizer markets

In general, fertilizer markets are characterized by atomized fertilizer demand and concentrated fertilizer supply. NPK supply concentration puts upward pressure on fertilizer prices and contributes to global fertilizer market insecurity.

Most countries increasingly trade fertilizers and fertilizer raw materials, with imports meeting about 44 percent of world fertilizer demand in 2000 (FAO 2002). Therefore, the international trade is an important part of the fertilizer business and export and import measures of major fertilizer traders may affect fertilizers prices worldwide.

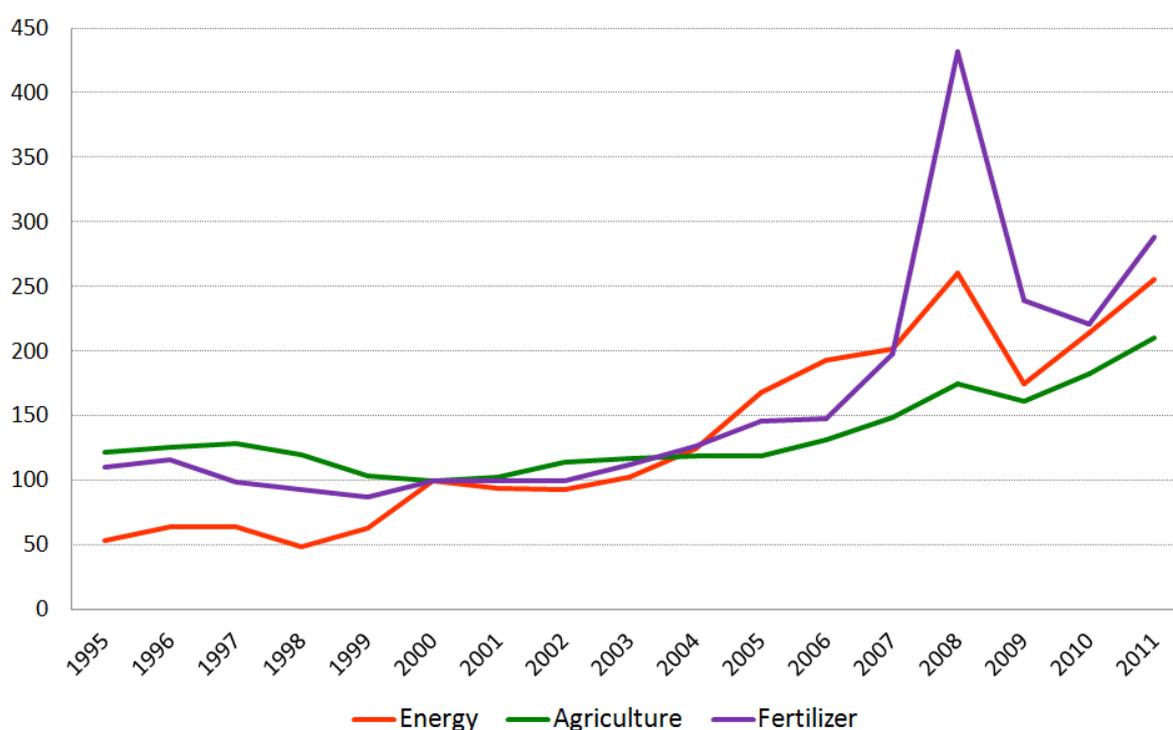
In April 2008, anticipating short supplies of fertilizers, China announced a special export tariff on fertilizers of 100% to protect internal agriculture. This measure increased export tariff rates for urea, DAP and MAP to 135%, thereby restricting supply to the international markets. Although only a few countries have continued to maintain export restriction measures for fertilizers since 2008, China's export tariffs on DAP and urea were being maintained in 2011. Since China contributes to more than 20% of global DAP and urea trade, these measures significantly influence global fertilizers markets.

### 3.3. Fertilizer prices

Increased global demand for fertilizer has played a significant role in recent price trends, putting upward pressure on fertilizer prices.

Natural gas is the main feedstock for producing anhydrous ammonia, which is the source of nearly all the N fertilizer produced in the world. The cost of natural gas accounts for 70 to 90 percent of the production cost of ammonia. Thus, with natural gas prices increasing significantly since 2000, prices of urea fertilizer rose by more than 90% in real terms between 2000 and 2005.

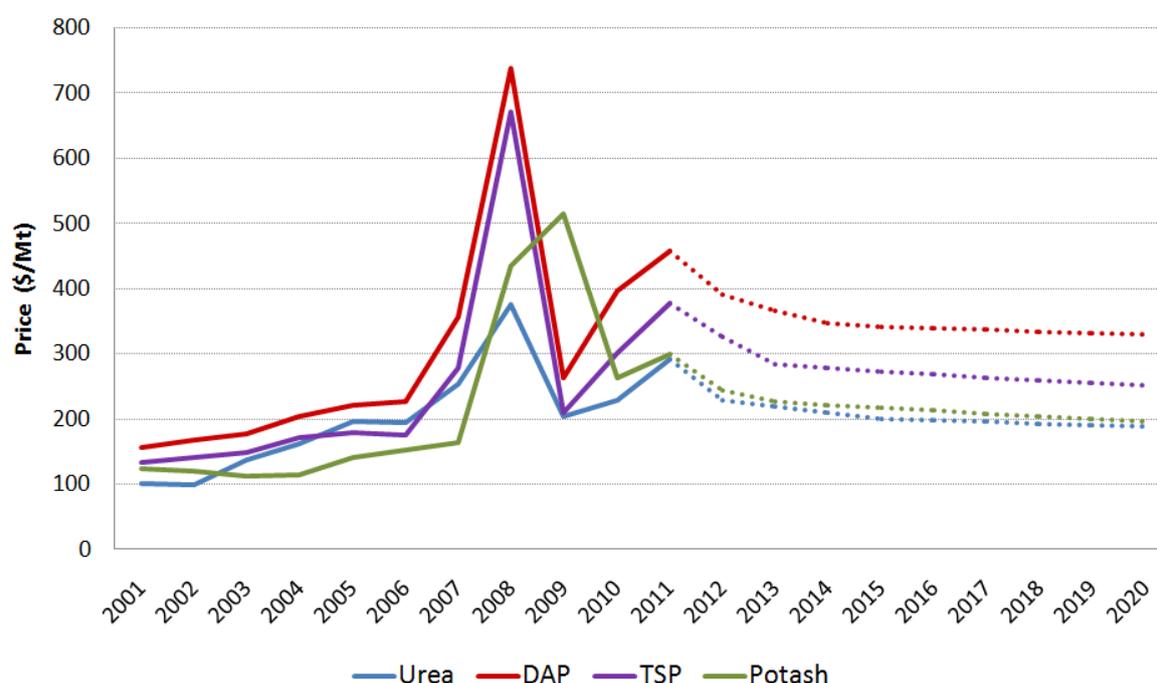
**Figure 11.** Commodity price indices (constant US\$, 2000=100)



Source: World Bank Databases, accessed November 2011

Since 2000, significantly higher costs for major production inputs like ammonia and sulphur have also put upward pressure on the prices of the major phosphate fertilizer materials like DAP and MAP.

Potash is produced in only 12 countries and then traded worldwide. Potash production costs are, therefore, highly dependent of energy prices.

**Figure 12.** World fertilizer prices (data and projections to 2020)

Source: World Bank Databases (data 2001-2010) and World Bank 2011 (projections 2011-2020)

Fertilizer markets, like other commodity markets, have been affected by the economic slowdown. To a great extent, the production costs of most fertilizers are influenced by energy costs, particularly with regard to the use of natural gas. Upward fluctuations in energy prices in 2008 increased fertilizer production costs as well as shipping costs. Average prices paid by farmers for the major fertilizer nutrients reached the highest levels in 2008 (Figure 10) and decreased from 2009, although they remain well above pre-crisis levels.

According to IFA, aggregate world fertilizer demand in 2008/09 is estimated to be down by 5 percent compared with the previous year: from 168 to 160 Mt of nutrients. Nitrogen is least affected, because drastic reductions in N fertilizer application rates have immediate negative consequences for yield; this is not the case with P and K fertilizers. Drops in consumption have been registered in all regions except Africa, South Asia and EECA (in these latter two regions farmers benefit from strong government support for increased fertilizer use). The most significant drops in volume are in Western and Central Europe, North America and Latin America (FAO 2009).

Phosphate prices moved substantially higher in 2008, due to a combination of factors pushing phosphate prices higher: relatively low carryover stocks in 2006, restriction of Chinese exports of DAP/MAP, and feedback loop whereby higher downstream prices promoted higher raw material prices and vice versa. High concentration in the

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phosphate rock industry, particularly in the export market, helped to enable prices to move higher.

Between 2003 and 2008, nominal energy and metal prices increased by 230 percent, food and precious metal prices doubled, and fertilizer prices increased fourfold. Although most prices have declined sharply since their mid-2008 peak, they are still considerably higher than their 2003 levels (World Bank 2009).

Only a few countries have continued to maintain export measures for fertilizers and raw materials since 2008. In 2011, China's export tariffs on DAP and urea were being maintained, but the periods of high tariffs have been extended compared to previous years. These measures may impact available supply in international markets, in view of China's contribution of 26 per cent and 20 per cent of global DAP and urea trade, respectively, in 2010.

Farmers are hurt by high fertilizer prices in terms of both the profitability of fertilizer use and the affordability of its purchase. Fertilizer price increases generally decrease farm incomes and fertilizer profitability, unless cost increases from higher fertilizer prices are more than offset by revenue increases from higher crop prices. Proportional increases in international fertilizer prices over 2008-2009 have been higher than price increases for food commodities.

### **3.4. Factors hampering access to NPK fertilizers in sub-Saharan Africa**

While the negative environmental consequences of fertilizer use and production require action in many countries such as China, where the overuse of fertilizers is damaging the environment, in some developing countries the problem is not excessive, but insufficient fertilizer use. In 2002, for instance, fertilizer consumption was only 13 kg per ha in sub-Saharan Africa, compared to 73 kg in the Middle East and North Africa and 190 kg in East Asia and the Pacific (FAO 2009). Crop yields have grown little in sub-Saharan Africa in recent decades and large and economically exploitable yield gaps remain in this area.

There are many reasons why agricultural productivity is low in this region, including lack of access to information, extension services and technical skills. High transaction costs make fertilizers more expensive in Africa than anywhere else in the world and low fertilizer use explains a large part of the lagging productivity growth in sub-Saharan Africa (IFDC 2006).

To some extent, the low use of mineral fertilizers in Africa is due to the specificities of the fertilizer markets in this region (Morris et al. 2007). Many local factors hamper access to NPK fertilizers in SSA, including weakness of infrastructures, lacking

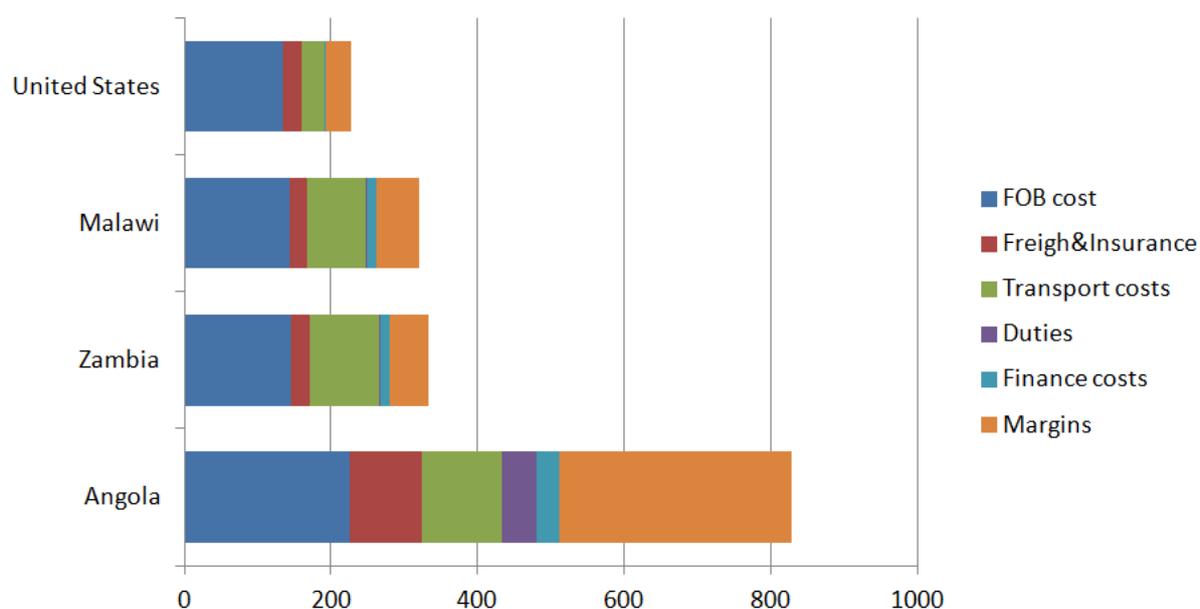
distribution networks, low trade volume, limited market information and limited access to finance.

Furthermore, given the considerable dependence of sub-Saharan Africa on imported fertilizers, increased market concentration in international markets is also a crucial force driving fertilizer prices up. Hernandez and Torero (2010) have carried out a study to formally examine the relationship between fertilizer prices and market structure. The results of the study indicate that the fertilizer industry is a highly concentrated market with high and increasing levels of trade. The top five countries control more than 50 percent of the world's production capacity for the main nitrogen, phosphate, and potash fertilizers. The results also prove that fertilizer prices are higher in more concentrated markets because of the apparently greater market power enjoyed by firms.

Ironically, the African continent is simultaneously the world's largest exporter of PR and the continent with the largest food shortage (FAO 2006). This highlights the importance of NPK accessibility, in addition to physical (and political) scarcity.

Several authors have analyzed NPK price divergence between industrialized countries and sub-Saharan Africa, showing that non-production costs contribute to more than 50% of farm-gate price in some African countries (Gregory and Bumb 2006, Morris et al. 2007). Fresco (2003) points out that the average sub-Saharan farmer pays 2-6 times more for fertilizers than the average European farmer, due to higher transport and delivery costs.

**Figure 13.** Comparison of farm-gate fertilizer prices (dollar/tonne)



Source: Data from Gregory and Bumb (2006)

Several countries have reintroduced input subsidies to promote the adoption of fertilizers and stimulate the development of input markets (World Bank 2007), but high fiscal costs and the displacement of commercial sales threaten their long-run sustainability and effectiveness.

Improving access to NPK fertilizers in SSA requires policies aimed at creating robust distribution networks, promoting retail outlets, and facilitating the transfer of technology and knowledge for efficient fertilizer use. Lower dependence upon external sources could be achieved through improved management practices as well as use of organic fertilizer sources (crop residues, manure and human waste).

## **4. Meeting future fertilizer demand**

### **4.1. Global fertilizer outlooks**

Fertilizer supply is commonly absent in global agricultural outlooks. This is the case both for medium-term projections of global food markets (OECD/FAO 2011) and long-term futures for agriculture (Alexandratos 2011). As a matter of fact, while future scenarios for food production take into account the available resource base for certain fixed inputs (land resources, irrigation water), fertilizers are usually considered as variable inputs with unlimited supply. Therefore, agri-food outlooks fail to recognize the role of fertilizer availability in food production growth.

Some specific projections for fertilizers exist, however. Focusing first at the medium-term horizon, different international institutions analyze future trends for fertilizer supply. The most comprehensive medium-term fertilizer outlook is elaborated annually by FAO, in cooperation with various international fertilizer associations. FAO provides five-year prospects of world and regional fertilizer demand, supply and potential balance, which are reviewed by a Working Group of Fertilizer Organizations. The last outlook has been published recently and provides projections for the period 2011-2015 (FAO 2011).

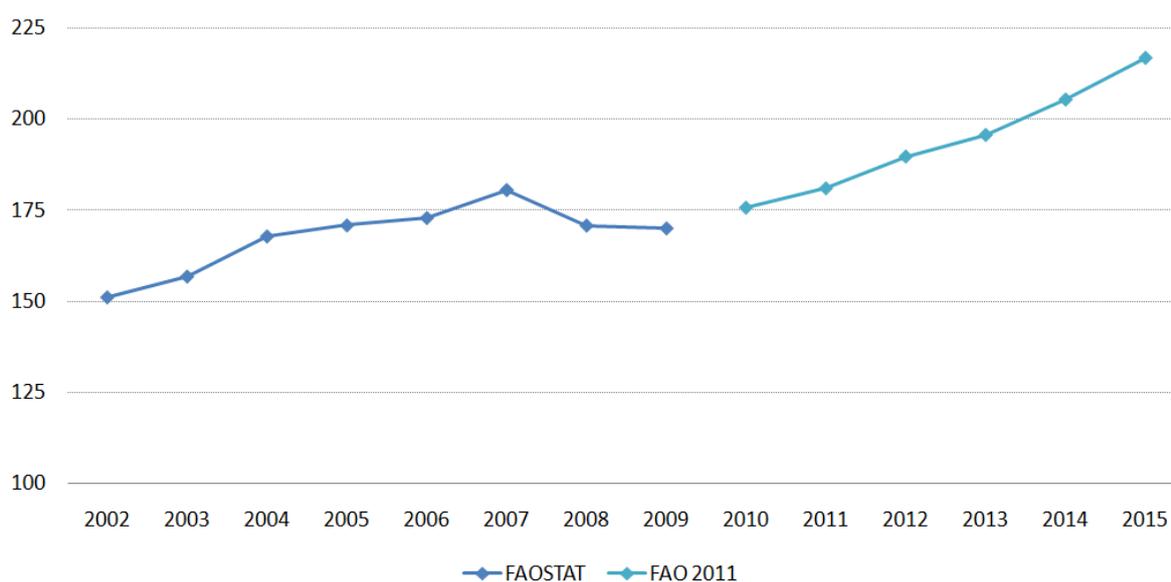
Whereas these projections help to understand future trends for fertilizer supply and demand, what is driving the projections remains unclear. In the case of fertilizer demand, estimates are based on future scenarios for food and agricultural production (i.e. OECD/FAO 2011). The supply projections, on the contrary, seem to be mostly based on expert knowledge and, since the assumptions underlying the projections are not made explicit and the methodology used is poorly documented, assessing the results is not straightforward.

In October 2006, the FAO/Fertilizer Organizations Working Group adopted a new protocol for the preparation of nutrient supply/demand balances based on the work of

the IFA Production and International Trade Committee in 2005/06. The main objectives of the revised protocol were to take into account the resilient surplus between production and consumption and to update the parameters used for the computation of supply and losses (FAO 2010).

Figure 14 shows data on global NPK production for the period 2002-2009 and medium-term projections for 2010-2015. These recently published medium-term projections (FAO 2011) seem quite optimistic. In effect, whereas the annual average NPK production growth in the period 2002-2007 has been only 1.7%, the assumed growth rate for the period 2010-2015 averages 4.3%.

**Figure 14.** Actual and projected global NPK supply



Source: Data from FAOSTAT (2002-2009) and FAO 2011 (2010-2015); own calculations (2015-2050)

Looking now at long-term projections for fertilizer supply, no systematic study has been found in the literature. Some institutions such as FAO and IFPRI provide long-term outlooks for food and agriculture (Conforti 2011, Msangi and Rosegrant 2011, Nelson et al. 2010, Rosegrant et al. 2001) and some studies on fertilizers demand are available, mostly based on projections for food demand (Tenkorang and Lowenberg-DeBoer 2008). Nevertheless, projections for fertilizers supply are lacking. Long-term studies on the availability of resources to feed a growing population focus on land and water resources (Bruinsma 2011), neglecting the rising concerns about potential fertilizer scarcity.

One of the few studies on long-term fertilizer scenarios is the one from Van Vuuren et al. (2010). In this study, the authors present trend estimates of available resources and future P fertilizer demand until 2100 considering several potential scenarios.

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They conclude that rapid depletion of extractable PR is not very likely; in worst-case scenarios about 40-60% of the current reserves would be extracted by 2100.

Van Vuuren et al. (2010) also point out that even partial phosphorus depletion may be relevant for agricultural production as production costs for fertilizers will very likely increase. Furthermore, a consequence of the depletion of high-grade PR will be the decline in P content and the increasing concentration of heavy metals. At present, the lack of information on heavy metal content in current reserves makes it hard to analyze the environmental impacts of exploiting low-grade ores but, with increasing exploitation rates, environmental concerns will undoubtedly become increasingly important.

#### **4.2. Anticipating future developments of fertilizer supply**

As we have pointed out in the previous section, long-term trends for fertilizer production are not easily available. Future fertilizer supply will be driven by:

- Expectations on future fertilizer demand, foreseen as quite positive.
- Energy prices, expected to remain high and having a strong influence in NPK production costs.
- Government policies, which influence market conditions and investment patterns. Particularly, trade measures such as export taxes affect NPK availability in international markets.
- Environmental regulations in some countries, influencing investment in new capacity as they increase compliance costs.

Hereafter, we will investigate the potential of the fertilizer industry to accommodate fertilizer supply to foreseen changes in demand.

Global food production is projected to increase by 70% between 2005/07 and 2050 (100% according to recent projections). Growth in food production will require more fertilizer application, but not necessarily at the same rate of expansion. Farmers in Europe and North America are increasingly succeeding in achieving higher yields with similar or lower fertilizer applications through the adoption of improved production technology that is cost-effective and knowledge-intensive. A similar development may emerge in particular in South Asia and East Asia as agricultural commercialization progresses (FAO 2008).

According to FAO projections, fertilizer use (nutrients NPK) is foreseen to increase at an annual average rate of 1% globally (from 138 Mt in 1997/99 to 188 Mt in 2030). This significant slowdown in the growth of fertilizer use as compared with the past (e.g. 3.7% for 1989-99) reflects the expected continuing deceleration in agricultural

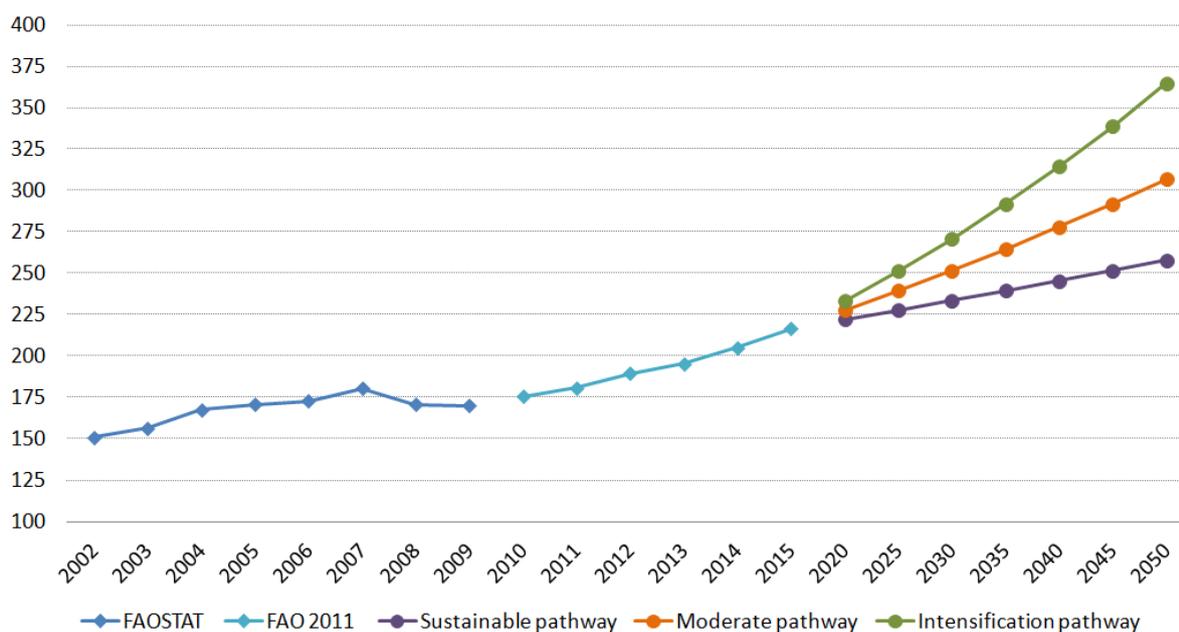
production growth, the relatively high levels of application already attained in several countries, and the expected increase in fertilizer use efficiency, partly induced by environmental concerns (Bruinsma 2003).

Long-term projections for fertilizer demand reflect very different futures. In a recent study, fertilizer demand is projected to double by 2050 (Tilman et al. 2011). Unlike this study, other authors find fertilizer demand growing at much more moderate rates (Bouwman et al. 2009).

Taking into account projected trends in global fertilizer demand for 2050, we will investigate under which conditions the fertilizer industry will be capable of meeting future demand. Three alternative demand growth scenarios have been retained:

- a) Sustainable pathway: fertilizer consumption is assumed to increase by 50% between 2005/07 and 2050 (NPK growth rate lower than food production growth rate, meaning that more efficient fertilizer use and fertilizer recycling will largely contribute to food production expansion)
- b) Moderate intensification in developing countries: fertilizer consumption is assumed to increase by 70% (increase in food production will be partly achieved through land expansion and production intensification in developing countries).
- c) Intensification pathway: fertilizer consumption is assumed to double by 2050 (NPK growth rate similar to food production growth rate).

These scenarios will result in quite different average rates for fertilizer production. To estimate these rates, the medium-term fertilizer supply projections (see Figure 14) will be taken as a starting point. These medium-term projections have been generated by an international expert panel and show a quite optimistic near future. As shown in Figure 15, required NPK production rates from 2015 on will be lower than previous rates even in the intensification pathway. In the sustainable pathway, we assume an average annual production growth of 0.5%, while in the moderate and intensification pathways the growth rates will be 1.0% and 1.5% respectively.

**Figure 15.** Long-term projections for global NPK supply

Source: Data from FAOSTAT (2002-2009) and FAO 2011 (2010-2015); own calculations (2015-2050)

## 5. Concluding remarks

Increased use of fertilizers has been a major factor explaining productivity growth since the 1960s, driving up food production. Or, as food production has increased, agriculture has become more dependent on regular application of commercial fertilizers. Furthermore, to sustain the further world population, more fertilizers will be required, raising concerns about future availability of NPK nutrients and potential resource scarcity.

This report reviews the available forecasts on NPK supply and access, to assess whether the future availability of essential NPK nutrients could jeopardize food production growth in the years to come.

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