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Global Availability of Phosphorus and Its Implications for Global Food Supply: An Economic Overview

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Abstract:
Being of crucial importance for agricultural production and also having experienced significant price volatility, phosphate and its future availability have drawn growing attention from both academics and the public over the last years. This paper overviews the recent literature and data on the availability of phosphorus and discusses the economic aspects of phosphate scarcity by describing major price determinants of the global phosphate market. We show that past price fluctuations of phosphate rock and phosphate fertilizers are not a reflection of physical phosphate rock depletion but rather attributable to numerous other demand- and supply-side factors. Given the current reserve estimates for phosphate rock, neither an exhaustion of global reserves nor a peak event is likely to occur within this century. However, these estimates are subject to a significant degree of uncertainty. Moreover, the global distribution of phosphate production and reserves is highly skewed and has the potential to pose a threat to food security in developing countries through factors such as the volatility of the phosphate rock price or price setting by suppliers with significant market power.

Keywords: Phosphate scarcity, peak phosphorus, global food security, phosphate market, fertilizers

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1 Introduction

Phosphorus is an essential ingredient of fertilisers, and its continuous supply constitutes the foundation of modern agriculture. Recently, phosphorus and its future availability have attracted increasing attention from both academics and the public. Triggered by massive price fluctuations on the phosphate rock market in 2007 and 2008, with price increases of more than 900%, the question arose whether this was a signal for an impending physical phosphate rock scarcity. Considering the paramount importance of phosphate rock for phosphate fertiliser production and its essential role in supplying phosphorus for today's agricultural system such a potential scarcity could be expected to have grave consequences for global food production and security. Soon after the 2007/08 price spike scientific literature emerged predicting that a supply-induced phosphate rock production peak ("peak phosphorus") would occur around the year 2033 (Cordell et al. 2009). The term "peak phosphorus" denotes a point at which the production of phosphate rock reaches its maximum due to the decreasing availability of phosphate rock deposits, declining steadily thereafter and even though demand exceeds supply (Cordell et al. 2009). Although reserve estimates since this first "peak phosphorus" prediction have risen significantly and "peak phosphorus" forecasts have adjusted accordingly (the most recent estimate now being the year 2070) (Cordell et al. 2011a) many questions remain to be answered. During the last years, there has been growing recognition of the importance of fertiliser input to increase agricultural production in developing countries, particularly in sub-Saharan Africa (Denning et al. 2009; Jayne and Rashid 2013). Therefore, a critical overview of this phosphorus problem should also provide a useful insight for global policy debates about sustainable development.

This paper overviews the recent literature and data on the availability of phosphorus and discusses the economic aspects of phosphate scarcity by describing major price determinants of the global phosphate market. We show that past price fluctuations of phosphate rock and phosphate fertilisers are not a reflection of physical phosphate rock depletion but rather attributable to numerous other demand- and supply-side factors. Given the current reserve estimates for phosphate rock, neither an exhaustion of global reserves nor a peak event is likely to occur within this century. However, these estimates are subject to a significant degree of uncertainty. Moreover, the global distribution of phosphate production and reserves is highly skewed and has the potential to pose a threat to food security in developing countries through the volatility of the phosphate rock price.

The rest of the paper is organised as follows. Section 2 outlines the essential role of phosphorus for modern agriculture as well as the exhaustible nature of phosphorus as a resource. Section 3 explains the structure of global phosphate supply and shows that phosphate rock reserves are unlikely to face depletion in the near future. Section 4 analyses basic characteristics of global phosphate demand. Section 5 explains the past price development of phosphate rock, concluding that neither historic nor recent price fluctuations can be attributed to an actual physical phosphate scarcity. Finally, the last section reasons that even with physical abundance, the global supply of phosphate still has a potential to cause problems due to factors such as the skewed geographical distribution of global reserves.

2 The Essential Role of Phosphorus for Modern Agriculture

Phosphorus (elemental symbol P) is essential for all forms of life and needed for highly important biological functions and components, such as the RNA, DNA, cell membranes and bones (Elser 2012). In the form of the molecules ATP and ADP, e.g., phosphorus is involved in the process of cellular energy metabolism and for plants it is crucial for the process of photosynthesis (Smit et al. 2009; Vaccari 2009). Whereas humans and animals satisfy their need for phosphorus via food intake plants have to take it up from the soil they are growing on. Together with nitrogen and potassium phosphorus forms the group of so called macronutrients, all of which are essential for plant life (Smil 2000) and non-substitutable (Elser 2012). Without each of these plant growth would be very limited, if possible at all[1] (Smit et al. 2009). Although all three macronutrients are naturally available in arable soils to a certain extent their quantity is often insufficient for high crop yields (Syers et al. 2011), or they only occur in forms that are not readily usable for plants, a circumstance which is especially relevant in the case of phosphorus as it is a chemically very reactive element (Roy et al. 2006). Consequently, all forms of biomass contain varying fractions of phosphorus, a fact that provides the very basis of phosphorus demand.

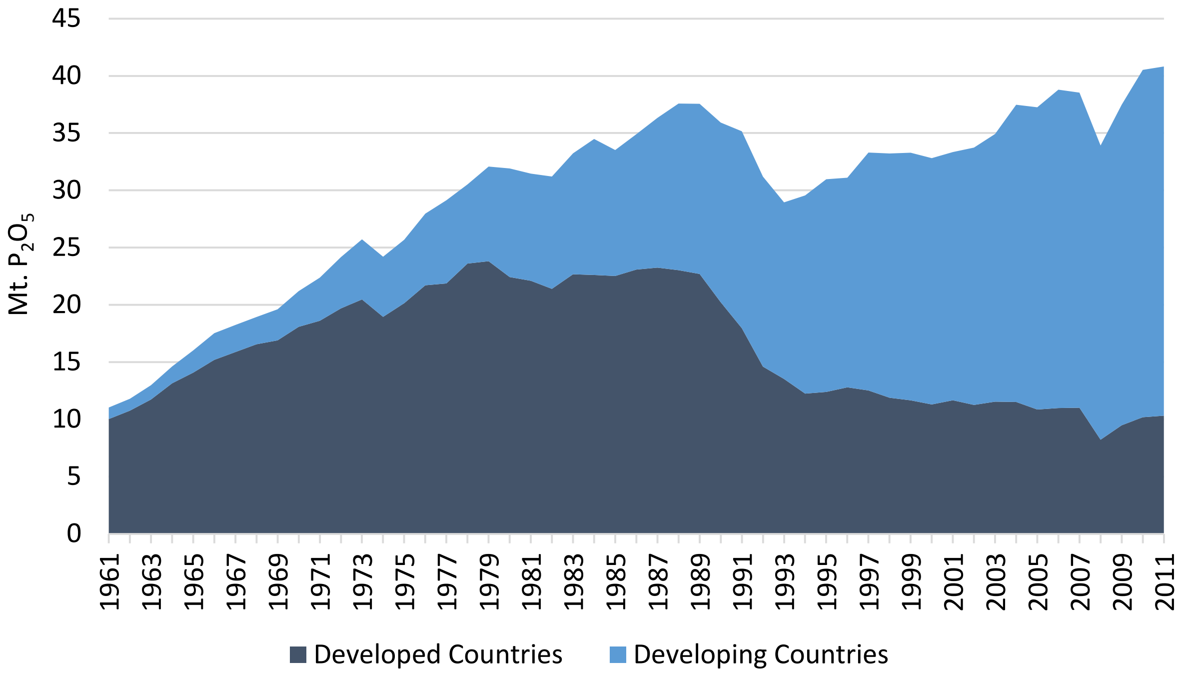
Despite not being a rare or scarce element in a geochemical sense of the word, phosphorus has been said to be one of the most crucial inputs for modern agriculture and a main driver behind last century's Green Revolution (Ashley et al. 2010). Dawson and Hilton (2011) emphasise that without the advent of phosphate fertiliser application to agricultural soils during the second half of the 19th century, the deterioration of soil fertility soon would have made human life in industrialised countries unsustainable. Today, it is common consensus that phosphorus additions guarantee high yield and high intensity agriculture and are therefore needed to ensure global food supply and security (Scholz et al. 2013a). Thus, phosphorus is not only one of the key elements allowing rapid historical and still ongoing population growth but it is also at least partly responsible for increased agricultural productivity as, e.g., reflected by a rising per capita food supply (FAOstat 2013a).

From a historical perspective, the artificial addition of phosphorus to arable land in the form of mineral phosphate fertiliser is a relatively new development, becoming widespread only after the Second World War (see figure 1). But even before that farmers were well aware of the beneficial effects of phosphorus containing materials on plant growth which made substances such as guano, bonemeal, animal manure and

[1] This also applies to the larger group of micronutrients (e.g., Cu, Fe, S), though they are needed in much lower quantities and therefore are usually sufficiently available for plants without being artificially supplied (Dawson and Hilton 2011).

human faeces frequently applied biological fertilisers (Ashley et al. 2010).

Fig. 1 ***Phosphate Fertiliser Consumption in Developed & Developing Countries***



Source: Based on IFAdata (2013d).

Nowadays, however, owing probably as much to their seemingly abundant availability as their convenient applicability (Killiches 2013), mineral phosphate fertilisers are the primary source of phosphorus input to agricultural land. The overwhelming majority of these fertilisers are, in turn, exclusively manufactured from mined phosphate rock. And it is the inherent finiteness of this natural resource that led some people to believe that "peak phosphorus" was imminent.

The need for continuous phosphorus input in agriculture can be attributed to two different rationales. On the one hand, phosphorus is removed with each harvest at a higher rate than the soil can naturally provide. Therefore, phosphorus needs to be supplied artificially in order to keep crop yields constant and the soil's phosphorus stock from getting depleted (Van Vuuren et al. 2010). On the other hand, there is a strong economic incentive for farmers to apply large quantities of phosphate fertiliser to the soil for it usually is fast-acting and, ceteris paribus, leads to higher crop yields[2] (Syers et al. 2008). Whereas some of these phosphorus inputs are returned to arable land in the form of manure and crop residues, the majority is not. Instead, various inefficiencies along the value-added chain in fertiliser and food production as well as natural soil erosion entail considerable phosphorus losses to the environment. Eventually, a significant amount of phosphorus ends up in the aquatic environment (Cordell et al. 2009). Once it has dissolved therein, phosphorus is, today as well as in the foreseeable future,

[2] However, there are limits to this rationale. For instance, phosphate fertiliser application is subject to diminishing marginal returns in terms of crop yield (Römer 2009) and above a certain threshold additional phosphorus input to soils merely results in increased run-off and leaching (Kleinman et al. 2000).

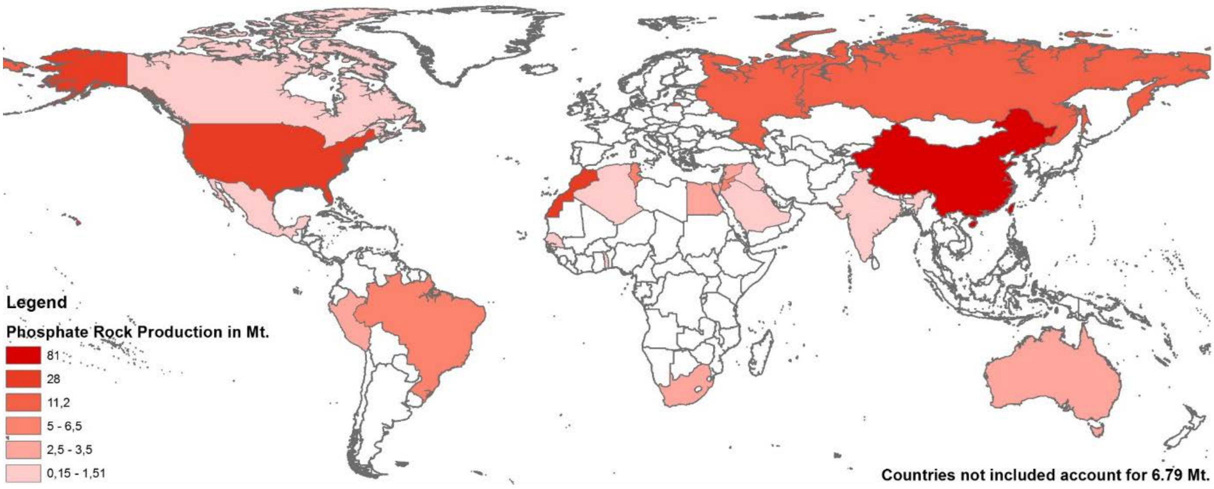
not recoverable and thus being lost permanently for human use (Smit et al. 2009). Since the natural rate of replenishment for phosphorus from the aquatic environment to the soil via tectonic uplift is estimated to range from 10 to 100 million years (Smit et al. 2009), the phosphorus cycle is a cycle only in the very long run and, unfortunately, not on a human time scale. Ultimately, it is this combination of modern agriculture's strong dependency on phosphorus, its currently highly unsustainable use and the finiteness of phosphate rock deposits that recently attracted increased scientific and public attention.

3 Global Phosphate Supply

3.1 Phosphate Rock Production

According to Jasinski (2013) global phosphate rock production amounted to 198 megatonnes (Mt.) in 2011 and was expected to increase to an overall of 210 Mt. in 2012. Starting in the 19th century, global phosphate rock production only grew slowly at first and did not show rapid growth until the end of WW II (USGS 2012). Since then however, global production has increased more than 18-fold and a recent forecast by the IFA predicts global production capacity to increase to approximately 257 Mt. by 2017 (Heffer 2013; Heffer and Prud'homme 2013). This prediction implies an average annual growth rate of 3% for the time period from 2012 to 2017 which would be moderately higher than the average annual growth rate of production between 1995 and 2011 (2.66%) (Heffer 2013; Jasinski 2013). Overall, phosphate rock production shows a clear upward trend, only interrupted by a sharp decline in production and demand from 1989 to 1994 which can be attributed to the collapse of the Soviet Union and a period of reduced demand from North America and Western Europe (al Rawashdeh and Maxwell 2011; Cordell et al. 2009).

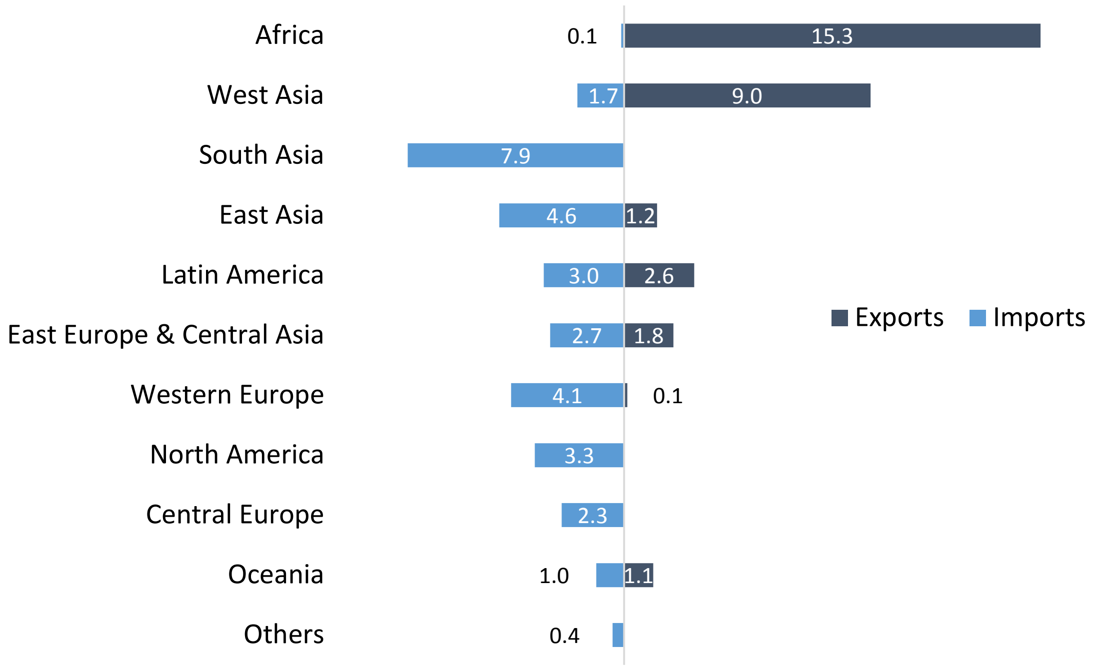
Fig. 2 Phosphate Rock Producing Countries, 2011



Source: Based on Jasinski (2013).

Except for a handful of underground mines, phosphate rock is mined in large open-pit mining operations in various regions of the world (Van Kauwenbergh 2010). Figure 2 gives an overview of major phosphate rock producing countries. In 2011, China was, by far, the world's largest producer of phosphate rock (81 Mt.), followed with a considerable gap by the U.S. (28.1 Mt.), Morocco (28 Mt.) and Russia (11.2 Mt.). Together, these four countries were responsible for nearly 75% of global phosphate rock production.

Fig. 3 ***Phosphate Rock Ex- & Imports, 2011 (Mt.)***



Source: Based on IFAdata (2013a).

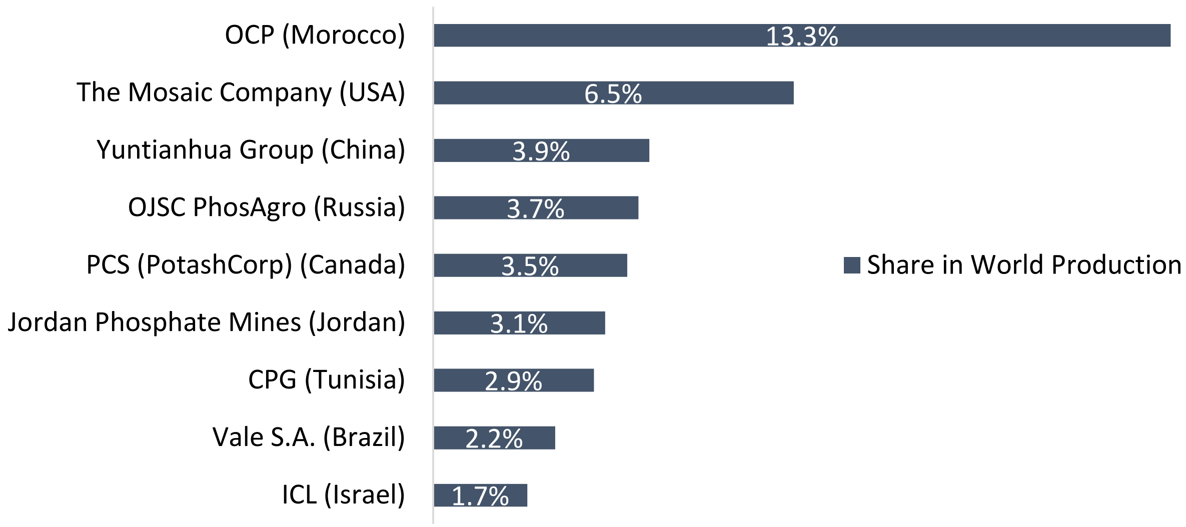
However, when looking at their shares in the world phosphate rock trade (i.e., exports) the picture changes drastically. Of 198 Mt. of phosphate rock mined in 2011, only about 31 Mt. or approximately 16% were exported (IFAdata 2013a). Thereof, 78% were exported from North African countries and countries of the Middle East such as Jordan, Syria and Egypt (IFAdata 2013a), with Morocco's government owned monopolist OCP (36.7%) clearly holding the title of being the world's largest exporter of phosphate rock (OCP 2011; PotashCorp 2011). Together with the fact that phosphate rock trade declined from 50 Mt. in the 1980's to 31 Mt. today (Mew 2011), this shows two things: First, there seems to be a trend towards vertical integration in the industry such that nowadays the majority of phosphate rock is processed directly in the country of origin[3] (IFA 2012; Van Kauwenbergh 2010). And second, although Morocco is exporting large quantities of it and certainly has a monopolistic position for some regions, the world is, at least today, in no way completely dependent upon Moroccan phosphate rock. The worldwide import shares of phosphate rock inferred from figure 3 reflect that

[3] According to Dennis (2013) 70% of phosphate fertiliser manufacturers are vertically integrated.

East and South Asia are currently the largest markets for phosphate fertilisers (FAOstat 2013b). A short analysis of downstream phosphate rock processing as well as the chapter on demand will make this point even clearer.

As could already be seen in figure 2 global phosphate rock production is rather concentrated in geographical terms. This is even truer for phosphate rock reserves, as Morocco alone is in possession of 74% of currently estimated reserves (Jasinski 2013). Especially the potentially politically unstable producing countries in North Africa and the Middle East could become the cause of significant disturbances in the availability of phosphate rock, now as well as in the future. Scholz and Wellmer (2013) compared country-level phosphate rock production and reserves to a range of other commodities and found that while production is located well within the average of concentration and supply risk, reserves are both far more concentrated and riskier in terms of supply. Examples for political instability severely affecting phosphate rock production can be found in Tunisia during the Arab Spring and in Syria today as a consequence of the ongoing civil war (de Ridder et al. 2012; Taib 2013).

Fig. 4 ***The World's Biggest Phosphate Rock Producers, 2012***



Source: Based on Dennis (2013) and ICL (2013).

In contrast to the high geographical concentration found in phosphate rock production there is a comparably moderate degree of concentration in terms of producing companies (see figure 4). This is reflected by the cumulative production share of the five biggest phosphate rock producers which hardly exceeds 30%. As a consequence, the market is described as being rather competitive with low entry barriers (al Rawashdeh and Maxwell 2011; de Groot et al. 2012). However, given Morocco's dominant export and reserve position the market might get more centred on OCP in the future. Even today OCP is sometimes described as swing producer which implies a certain degree of market and price setting power (Dennis 2013; Saywell 2013). Considering that OCP together with other, often government-controlled phosphate rock companies in North Africa and the Middle East has a very significant export share, cooperative or even collusive behaviour seems at least conceivable and has in fact been attempted before (Radetzki 2008). Further down the value added chain, fertiliser markets generally seem to be prone to show collaborative behaviour of market participants as can be seen at the examples of consortiums like Canpotex[4] and the Belarusian Potash Company[5] on the potassium and PhosChem[6] on the phosphate fertiliser market (Terazono 2013).

3.2 Downstream Processing of Phosphate Rock

While the vast majority of phosphate rock production is used either for manufacturing phosphate fertilisers (82%) or feed and food additives (8 – 9%) and, thus, is consumed for agricultural or food purposes, there is a residual fraction of 9% - 10% that is used for purely non-food related, industrial production processes (Schröder et al. 2010 based on Prud'homme 2010). For example, phosphates are used in diverse products such as soaps, detergents, ceramics, leather, flame retardants, anti-freezing and anti-corrosion agents as well as in metal, textile and rubber production (Sartorius and von Horn 2011). In stark contrast to agricultural production, where the only option for the substitution of phosphate rock would be recycled fertilisers, phosphorus (and thus phosphate rock) is in principle substitutable in all industrial uses (Sartorius/von Horn 2011). This once again emphasises the paramount importance of phosphate for food production, not only today but also in the coming decades.

After phosphate rock has been mined and cleaned it usually is beneficiated to form marketable product with an average P_2O_5 (phosphorus pentoxide) content of around 30% (USGS 2012). It then is used in various processes, each of which eventually leads to the production of a different kind of phosphate fertiliser. Amongst them, multi-nutrient fertilisers such as Mono- and Diammoniumphosphate (MAP, DAP) are the most popular, accounting together for roughly 78% of globally consumed phosphate in fertilisers in 2010 (Heffer 2013).

A central intermediate good in the phosphate market is phosphoric acid which is not only needed for the manufacturing process of MAP, DAP and TSP (Triple Superphosphate) but also provides the basis for many non-fertiliser uses of phosphate (Van Kauwenbergh 2010). In 2011, approximately 72% of worldwide produced phosphate rock was used to manufacture phosphoric acid for all purposes (IFAdata 2013a, b). Of that amount, around 90% were further processed to form phosphate fertilisers (PotashCorp 2013). As table 1 demonstrates, phosphoric acid is predominantly produced in East Asia, i.e. China, North America and (North) Africa, where together also 87% of the world's exports come from. Similar to the phosphate rock market, the cumulative mar-

[4] Canpotex consists of PotashCorp, The Mosaic Company and Agrium.

[5] Until its disbanding in July 2013, the Belarusian Potash Company was a cooperation of Uralkali and Belaruskali.

[6] Before the collaboration ended in October 2013, PhosChem was comprised of PotashCorp and the Mosaic Company.

ket share of the five companies with the biggest phosphoric acid production capacities is close to one third (29%) (PotashCorp 2013). And as in the phosphate rock market, only a comparatively small fraction of phosphoric acid is actually traded across borders, with Moroccan company OCP once again being the world's leading exporter (OCP 2013).

Table 1 Phosphate Market Statistics, 2011 (Mt. P_2O_5)

	Phosphoric Acid	Phosphate in Fertilisers			
Region	**Production**	**Production**	**Exports**	**Imports**	**Consumption**
Africa	**6.13**	**3.22**	**2.33**	**0.66**	**1.05**
East Asia	**17.61**	**18.42**	**4.15**	**1.81**	**14.06**
South Asia	**1.54**	**4.85**	**0.01**	**5.23**	**9.22**
West Asia	**1.61**	**1.59**	**0.98**	**0.35**	**1.12**
North America	**8.75**	**6.45**	**2.77**	**0.71**	**4.83**
Latin America & the Caribbean	**1.72**	**2.68**	**0.61**	**3.81**	**5.74**
Eastern Europe & Central Asia	**3.39**	**3.76**	**2.93**	**0.40**	**1.21**
Western & Central Europe	**0.88**	**1.91**	**1.11**	**1.94**	**2.37**
Oceania	**0.45**	**0.96**	**0.23**	**0.51**	**1.22**
World	**42.08**	**43.82**	**15.11**	**15.41**	**40.82**
Share of world production traded	**10.5%**	**34.2%**			

Source: IFAdata (2013b, c).

Country-specific data (IFAdata 2013c) reveal that China plays an important role on the phosphate market and not only is the world's biggest producer (39%) of phosphate fertilisers but also leading in consumption (28%) and exports (26%). Other important producing countries are, in descending order, the USA, India, Russia, Morocco and Brazil. With the exception of Morocco and Russia all of these countries (incl. China) consume the majority of their phosphate fertiliser production domestically. And while China, the USA and Russia nearly exclusively export finished fertilisers the countries of North Africa and the Middle East export large amounts of phosphate rock and phosphoric acid and only a comparably small amount of finished products. Interestingly, developing and emerging region's production of phosphoric acid showed significant, and in the case of China even rapid, growth between 2002 and 2011 while developed regions' (North America and Western/Central Europe) production declined considerably. This trend extends to fertilisers where China's and Morocco's production more than doubled and Brazil's, Russia's and India's grew by 36%, 20% and 11% respectively during this time span. In contrast to this growth in developing and emerging regions, phosphate fertiliser production in West and Central Europe declined by 34% and in North America by 19%. This shift in production reflects and anticipates changing market conditions for it is expected that developing and emerging nations are going to contribute the majority of future phosphate fertiliser demand growth (Heffer and Prud'homme 2013).

According to a recent forecast by the IFA (Heffer 2013; Heffer and Prud'homme 2013), phosphate rock mining capacities are expected to increase most in North Africa (11 Mt.), West (8 Mt.) and East Asia (8 Mt.) and Latin America (6 Mt.) within the next 4-5 years. The same forecast predicts global phosphoric acid production capacity to increase by 21% or 11 Mt. P_2O_5 as compared to 2012 of which East Asia and North Africa each will contribute 3 Mt. and Latin America and West Asia each 2 Mt. Since the main growth in processed phosphate capacity will also take place in these regions it is possible to conclude that they will at minimum retain their importance in the global phosphate market and are even more likely to increase it (Heffer 2013). Overall, phosphate production volumes and capacities can be expected to grow within the next years and the phosphate market is likely to get more centred on East and West Asia, North Africa, Latin America and maybe South Asia.

3.3 Size of Global Phosphate Reserves

In the light of the expected phosphate supply expansion a fundamental question is whether a depletion of phosphate rock reserves, accompanied by a "peak phosphorus" event, might occur any time soon.

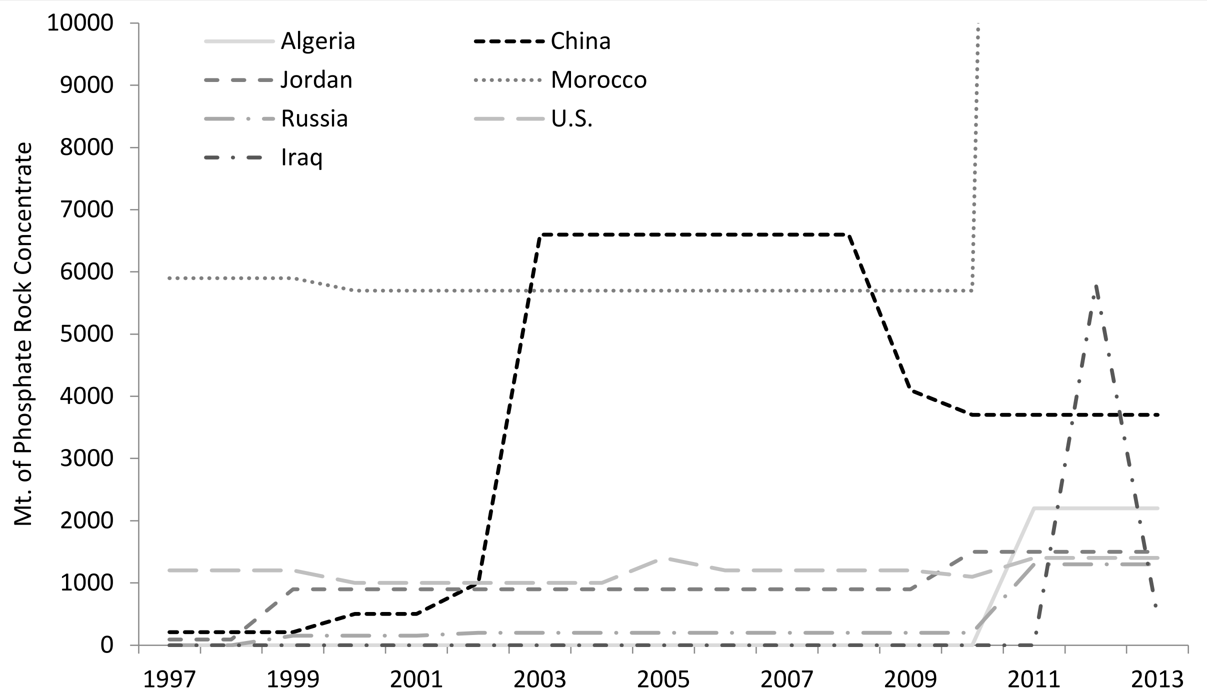
To be defined as a reserve a phosphate deposit has to meet certain minimum requirements concerning grade, quality, thickness and depth and, more importantly, has to be exploitable in an economic way at the time of determination (USGS 2009). Since market prices as well as production costs and technological innovations are dynamic and have significant influence on whether or not deposits can be deemed economic to exploit, the reserve concept itself is, by definition, dynamic (USGS 2013). Consequently, and as can be seen in figure 5, reserve estimates are frequently revised due to exploration efforts, improving technology and changes in the price of phosphate rock.

Currently, worldwide reserves are estimated at some 67 Gt. of phosphate rock (Jasinski 2013), a number that supports a static lifetime of 338 years[7] which is extraordinarily high when compared to other finite natural resources (Scholz and Wellmer 2013). Moreover, the measure of resources, i.e., phosphate rock deposits of any grade that may or may not be economically extractable at the time of determination (incl. reserves), amounts to between 290 and 460 Gt. (Jasinski 2013; Van Kauwenbergh 2010). And while both these figures are subject to considerable uncertainty and not all of the resources may eventually become economically extractable, it is likely that a significant fraction will, thereby increasing the lifetime of phosphate rock reserves. At the same time and despite the fact that until today approximately 7.25 Gt. of phosphate rock have been mined (USGS 2012) reserve estimates are increasing rather than decreasing (Scholz and Wellmer 2013). According to Radetzki (2008), a relatively stable

[7] Static lifetime = Reserves/Current Consumption. Although being a dynamic measure and therefore of very limited use for predicting the actual lifetime of a finite resource, Scholz and Wellmer (2013) argue that it still can be useful when being compared to other such figures for different resources and as early-warning indicator.

static lifetime is a common pattern on natural resource markets and largely attributable to a positive (causal) correlation between market price and exploration as well as technological innovation.

Fig. 5 ***Historical USGS Estimates for Phosphate Rock Reserves (Selected Countries, Mt.)***



Source: Rabchevsky (1997) and Jasinski (1998 – 2013).

Furthermore, mining companies often have a planning horizon of 15 – 20 years, meaning that they normally have no interest in exploring total available reserves or resources (Radetzki 2008). While this behaviour is reasonable from an economic point of view it certainly adds to the dynamics of statistics of global phosphate rock reserves and resources and the general uncertainty surrounding them.

After all, there is no indication why the classic economic rationale of the price mechanism as a measure of scarcity should not work on markets for finite natural resources. Both unexpectedly strong demand and temporary supply shortages might cause a situation of economic phosphate scarcity, indicated by an increasing price. The higher price positively affects the profitability of exploration and extraction of resource deposits and sets incentives for higher recycling rates, a more efficient utilisation and the substitution of the respective resource (BGR 2013; Scholz et al. 2013b; Wellmer and Dahlheimer 2012). For the phosphate rock market there are numerous examples for the development of recyclates as substitutes for phosphate rock based fertilisers; however, most of them are not yet economically profitable (Waida and Weinfurtner 2011; Sartorius and Tettenborn 2011). Additionally, there are at least two examples for the development of offshore phosphate rock deposits (CRP 2013; Stone 2013; NMB 2013), a circumstance that perfectly illustrates price- and technology-induced exploration. This, together with ongoing exploration investments for conventional deposits (MEG 2011), shows that the dynamics of the phosphate rock market are comparable to those of other natural resource markets.

Finally, an often found argument in favour of increasing physical phosphate rock scarcity (Cordell et al. 2009; Cornish 2010) is that of decreasing phosphate rock grade. Ostensibly, there seems to be consensus amongst phosphate rock companies that the grade of mined ore is, indeed, declining (Cordell and White 2011; Van Kauwenbergh 2010; Schröder et al. 2011; Scholz and Wellmer 2013). However, as Scholz and Wellmer (2013) exemplarily show for copper, decreasing ore grades do not necessarily coincide with increasing scarcity and prices, for innovation in mining and processing technology as well as improvements in recycling occur constantly and offset the influence of decreasing ore quality to a certain degree. The same can be expected for the phosphate (rock) market, though, in the long-run, declining ore quality might very well indicate the gradual exhaustion of easy-to-access phosphate rock deposits.

Eventually, there can be little doubt about the finiteness of phosphate rock. At the same time, however, depletion estimates based on static reserves fail to acknowledge the fundamental dynamic incorporated in this measure and thus, are somewhat arbitrary and of limited use. Without an estimate for the ultimately recoverable resource of phosphate rock all predictions regarding its depletion remain incomplete (Vaccari and Strigul 2011). Unfortunately, no such estimate is available and due to the limited planning horizon and knowledge of market participants this situation is not going to change. As a consequence, the question when phosphate rock deposits will be exhausted cannot be answered precisely. Nevertheless, both the comparably high estimates for phosphate rock reserves and resources as well as an increasing static lifetime provide evidence for the thesis that phosphate rock will not become physically scarce for a very long time. Hence, it is possible to draw a preliminary conclusion by stating that there are no alarming indications for an imminent, supply shortage induced “peak phosphorus” or an impending depletion of phosphate rock reserves.

4 Global Phosphate Demand

Up to 90% of worldwide phosphate production is utilised in agriculture in the form of feed and food additives, but mainly as phosphate fertilisers. Consequently, to understand what factors are driving phosphate demand today and in the future it is necessary to analyse what long-term trends influence phosphate fertiliser demand.

Generally speaking, phosphate fertilisers are needed to ensure a constantly high level of crop yields. These, in turn, are necessary to meet the world's food demand and provide a living for the farmer engaging in planting and harvesting the crops. Therefore, on an individual level, fertiliser use is closely connected to the classic economic rationale of yield (profit) maximisation. As mentioned before, additional application of phosphate fertiliser usually results in increasing crop yields, though with diminishing marginal returns (Römer 2009). Put differently, this means that for every combination of crop variety, farming system and soil, a characteristic critical value exists, beyond which increased phosphorus availability does not result in increasing yields. As long as this critical value is not reached, phosphorus over-application[8] can help to achieve higher yields and to raise the soil's stock of phosphorus which then can be used by crops in subsequent years (Syers et al. 2008; Roy et al. 2006). Thus, over-application of phosphate fertilisers can make sense, especially on phosphorus-deficient soils. After reaching said value, however, it is sensible to apply only as much phosphorus as is needed to maintain this critical level (Syers et al. 2008). For not only is any excess application economically unprofitable, but it can also result in increased run-off of phosphorus to the aquatic environment, thereby creating serious environmental risks (Syers et al. 2008).

Historically, phosphate fertiliser over-application was relatively common in Western Europe and North America (Scholz et al. 2013a; Syers et al. 2008). This changed with increasing phosphorus soil saturation and is also reflected by decreasing phosphate fertiliser demand in these regions (Roy et al. 2006). Developing countries and emerging nations, on the other hand, have largely phosphorus-deficient soils (Syers et al. 2008) and are therefore expected to contribute the majority of the estimated phosphate fertiliser demand growth over the next years and decades (Heffer and Prud'homme 2013). For example, East and South Asia are estimated to contribute 40% and Latin America and the Caribbean another 33% to total demand growth between 2012/13 and 2017/18. Furthermore and in accordance with this trend, Sattari et al. (2012) collected data showing a converging gap between phosphorus application (including phosphate from fertilisers and manure) and crop phosphorus uptake in Western Europe and North America, whereas it is diverging in Asia and Latin America. In a way, the data can be interpreted to show both phosphorus saturated soils as well as learning effects in the application of phosphate fertilisers and an overall tendency towards an intensified agriculture (Scholz et al. 2013b). Hence, the general need to increase soil fertility by applying phosphate fertiliser in most of Asia, Africa and Latin America is one long-term determinant of phosphate fertiliser demand growth. At the same time, however, it is reasonable to assume that once critical soil thresholds will be approached, demand will start to adjust in a similar way as could and can be seen in developed countries, thereby moderating global demand in the very long run.

While the growth trend in developing and emerging countries is obvious, it has to be stressed that phosphate fertiliser consumption in these regions is far from equally distributed. Especially China, India and Brazil consume enormous amounts of phosphate fertilisers, in absolute as well as in per hectare terms (FAOstat 2013b, c) and aggregate consumption in these regions is projected to grow further in the future. In contrast, the whole continent of Africa currently accounts for only 3.6% of world phosphate fertiliser consumption and for the most part displays a very low use of phosphate fertilisers per hectare (FAOstat 2013b, c). More importantly and in stark contrast to the other developing regions, Africa has hardly shown any growth in consumption during the last

[8] In this context, the term over-application refers to a situation where more phosphorus is applied to the soil via fertilisers than is removed by harvest, run-off and erosion.

decades and today essentially consumes as much phosphate fertilisers as in 1980 (IFAdata 2013c). Furthermore, consumption within Africa is mainly focused on North and South Africa as well as Ethiopia with fertiliser availability and accessibility being especially poor in Sub-Saharan countries (Killiches 2013). Considering the expected massive population growth in Africa (UN 2013), a boost both in agricultural productivity and fertiliser consumption seems inevitable in the long run. However, it is highly uncertain when this development might gain momentum.

While the above analysis is sufficient to explain the distribution of future phosphate fertiliser demand (and supply), the question what other influences are driving demand remains. In the short run, fertiliser demand tends to closely follow (expected[9]) agricultural commodity prices (IFA 2011). According to the IFA (2011) this also explains that during the price spike of 2007/08 the price of agricultural commodities rose first, followed by fertiliser prices and then, eventually, also by the prices of their input materials, e.g. phosphate rock (Van Kauwenbergh 2010).

In the long run, there are essentially two drivers of phosphate (fertiliser) demand. First, ongoing population growth will lead to significantly increasing global food demand. In 2050, global population is expected to reach 9.6 bn people according to the UN's medium scenario (UN 2013). Second, and in addition to a growing world population, per capita income growth in developing countries is likely to lead to shifting dietary habits; from a mostly vegetarian diet to a diet with a higher share of meat and dairy products, which, in turn, results in further increased demand for crops (IFA 2011; Cordell et al. 2009; Smit et al. 2009; Schröder et al. 2011). FAO (2009) estimates that to feed such a massive number of people food production has to increase by 70% until 2050. This required growth in crop production necessitates an expansion of agricultural land as well as an intensification of agriculture, both of which is going to increase phosphate fertiliser demand. In developing countries, which are expected to account for the overwhelming majority of population growth until 2100 (UN 2013), the split between intensification and expansion is estimated to be in the order of 80% to 20% (FAO 2009). Finally, also the demand for bioenergy, particularly biofuels, could raise demand for crops and, correspondingly, for phosphate fertilisers (IFA 2011; Rosemarin et al. 2010).

In total, Cordell et al. (2011b) estimate that the sum of the above mentioned influences might lead to growing global phosphate demand well into the 22nd century if no structural changes in phosphate use and efficiency occur. Of course, there is plenty of potential for demand reductions as a result of advancements in farmers' knowledge of fertiliser application, plants' phosphorus use efficiency and recycling of phosphorus. However, such developments and their effect on phosphate demand are hard to predict over a long period of time[10]. Eventually, this means that while there are certain demand

[9] The underlying rationale for this is that farmers have to make an investment decision on how much fertiliser they are going to buy without knowing future agricultural commodity prices. This, of course, is due to the circumstance that plants need time to grow such that there is a significant time gap between fertiliser investment, application and the final harvest.

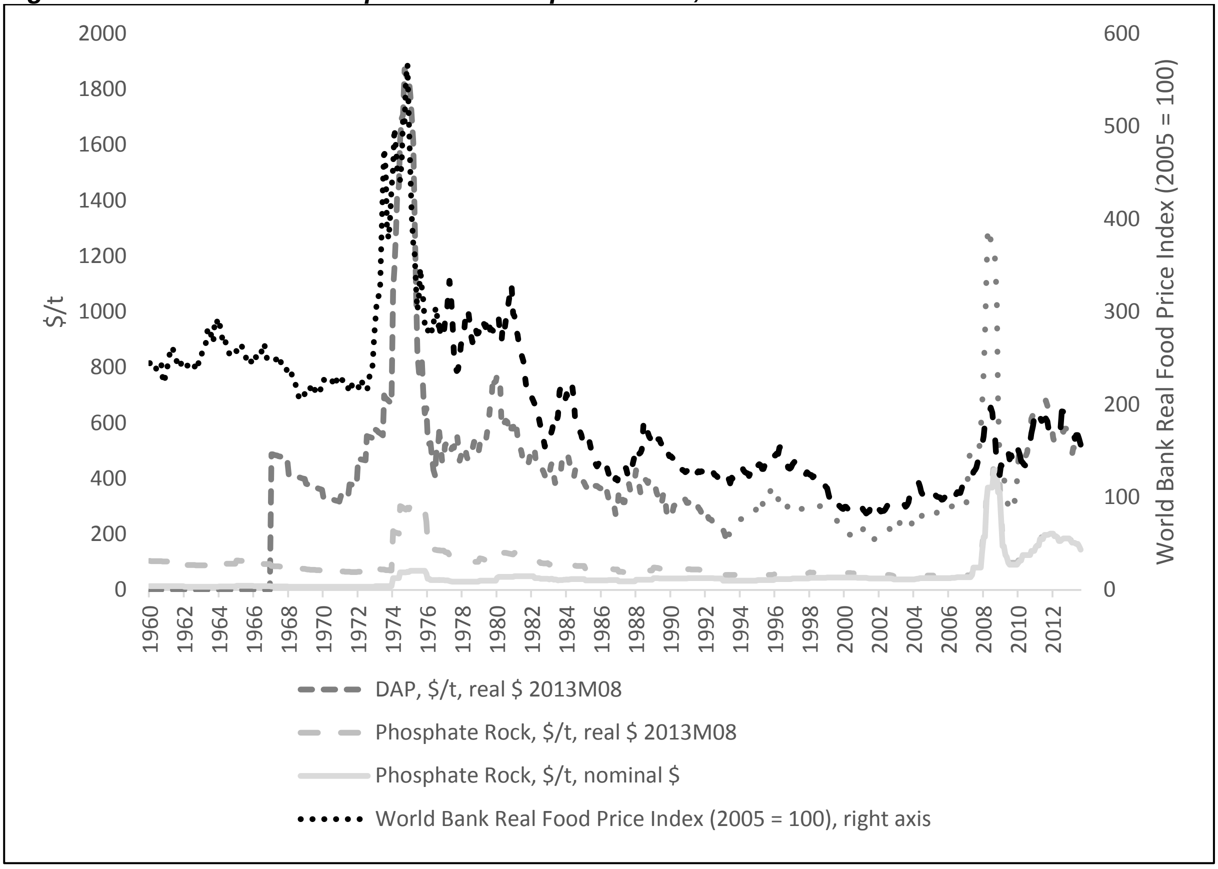
[10] See Koppelaar and Weikard (2013) and Van Vuuren et al. (2011) for long-term phosphate consumption scenarios.

increasing influences that make long-run phosphate demand growth likely, considerable uncertainty regarding potentially offsetting influences remain.

5 Past and Future Price Determinants of Phosphate Rock

As explained in the framework of a classic resource-economic model (Hotelling 1931), increasing resource prices can be a sign for a rising scarcity rent. Therefore, the sudden price surge of phosphate in the 2007-2008 period prompted some speculation whether the high prices might be a sign hinting at a shortage of phosphorus resources in the future.. But a close inspection of price trends and determinants reveals that the recent price peak is not a sign of imminent resource exhaustion. Figure 6 shows that a price peak comparable to the one in 2007/08 has occurred once before. Though not as extreme in magnitude, the 1974/75 price spike showed for the first time the volatility potential of phosphate rock as a commodity.

Fig. 6 Historic Price Development of Phosphate Rock, DAP and Food



Source: World Bank (2013a, b, c) and U.S. Bureau of Labor Statistics (2013).

In the 1974-75 period, a unique combination of supply and demand side shocks was responsible for the market's imbalance. On the one hand, two subsequent years of draughts and low crop yields all over the world, together with the high food demand of a rapidly growing world population led to high phosphate fertiliser demand (Bräuninger et al. 2013). On the other hand and allegedly influenced by the emergence of OPEC, Morocco's OCP raised its price for phosphate rock more than fourfold. In a concerted, though not necessarily coordinated effort, the government controlled phosphate rock producers in Algeria, Tunisia, Togo and Senegal as well as the American phosphate rock exporters increased their prices, too (Radetzki 2008). This informal cartel controlled nearly 70% of phosphate rock exports at the time with OCP accounting for roughly 50% (Radetzki 2008). In 1975, however, a severe recession hit the world economy and as a consequence of the ensuing battle for market shares between the individual companies the collaboration ended (Radetzki 2008). What followed was a prolonged period of constantly decreasing (real) phosphate rock prices, spanning from 1976 to mid-2007, despite rising demand. In the long-run, assuming that easy-to-access, high quality resource deposits are mined first and that ore grade is therefore indeed slowly declining, this may be a sign for competition as well as improvements in technology.

In mid-2007 the price of phosphate rock skyrocketed once again, reaching an absolute peak of $430 in August and September 2008. It then quickly reduced to about double the pre-spike level ($90/t), only to rise to a second price peak of $202 at the end of 2011 and beginning of 2012. Since then the price is declining and as of November 2013, the time this is being written, phosphate rock is listed at $108.5 (World Bank 2013a). The 2007/08 price rally can be explained by a combination of factors influencing fertiliser demand (Van Kauwenbergh 2010). First of all, high prices for agricultural commodities and food set a strong incentive for farmers to increase their crop yields by applying more fertilisers, including phosphate fertiliser (IFA 2011). While these high food prices are commonly attributed to a low world cereal stock-to-use ratio and growing demand for meat and dairy products in developing countries (Cordell et al. 2009), the high oil price can be considered another factor. For not only did it raise additional demand for biofuel crops and fertiliser but also directly affected the phosphate rock production via rising energy and transportation costs (IFA 2011).

As demonstrated in figure 6 it seems that phosphate rock prices follow food and agricultural commodity prices very closely, though they are slightly lagging. For example, during the 2007/08 price fluctuations food prices rose first, followed very quickly by fertiliser prices and then, after a month or two by the phosphate rock price (Van Kauwenbergh 2010). This behaviour could also be observed during the second price peak in 2011/12 and can be seen as evidence for the phosphate rock market being a demand-driven market (Saywell 2013). Therefore, the increasing price volatility of phosphate rock (de Groot et al. 2012) can possibly be explained by a higher volatility of food and agricultural commodity prices. Interestingly, phosphate rock prices are on the decline since early 2012 which on the one hand surely has to do with decreasing food prices. However, one additional explanation for this could be sought in differences in the planning horizons of supply and demand (Scholz et al. 2013b). In general, changes in demand may occur very quickly whereas capacity adjustments on the supply-side are limited and take time. Therefore, small demand peaks may be offset by the relatively quick expansion of mining operations at existing sites but larger adjustments require the exploration and development of new sites, a process that may take considerable time and usually involves high capital costs (Wellmer and Dahlheimer 2012). Weber and Steiner (2013) estimate that the gap between investment decision and actual phosphate rock production adds up to 3 – 5 years, though this time span can easily be longer when extensive exploration efforts have to be undertaken or comprehensive environmental regulations have to be obeyed. According to this notion market frictions are possible whenever supply capacity cannot keep up with sudden demand growth. This was likely the case during all three mentioned price peaks and is also one possible explanation why the phosphate rock price did not react as sensitive during the 2011/12 price peak as compared to 2007/08 although the food price index was of similar magnitude. The high price set a strong incentive for capacity expansions which gradually went productive in subsequent years, thereby moderating the effect of once again increasing agricultural commodity prices in 2011/12.

As a result of significant capacity expansions for both phosphate rock and phosphoric acid within the next five years the FAO (2012) expects a rising supply/demand balance surplus for phosphate. Assuming this proves correct, the phosphate (rock) market could once again see a period of stable nominal and declining real prices which is, in fact, what both the World Bank (2013d) and de Groot et al. (2012) predict whereas The Mosaic Company expects stable to slightly rising nominal prices (Saywell 2013). However, as with all price forecasts, these have to be taken with great caution for the uncertainty involved is very high.

6 Conclusion

As far as this can be said today, agriculture will always be dependent on phosphorus inputs. And at least in foreseeable future it is very likely that the prime source of phosphorus for agriculture will be mineral phosphate fertilisers and therefore, ultimately, phosphate rock. Although phosphate rock is a finite natural resource and contrary to recently published articles predicting a “peak phosphorus” event within this century, the currently available information shows no clear indications that phosphate rock deposits are facing depletion any soon. At the same time, the inherent uncertainty of such predictions needs to be emphasised.

Furthermore, a close inspection of price trends and their determinants reveals that none of the past price peaks were triggered by physical phosphate rock scarcity but instead by a combination of demand increasing factors, long capacity expansion lead times and, possibly, by an oligopolistic market structure.

But even though mineral phosphate deposits might not run out in the near future, there can be no doubt about the finiteness of this resource. Given that phosphorus as a nutrient is not substitutable in agriculture the only alternative to the use of phosphate rock-based mineral fertilisers is using phosphate recyclates. In other words, unless the phosphorus cycle is closed, essentially through complete recycling, the supply of mineral phosphate fertilisers is going to be finite. This is unlikely to be a problem within this century, yet it remains a permanent threat in the long run. A fundamental question therefore is whether the market price mechanism will provide appropriate economic incentives for phosphorus recycling early enough to prevent a peak phosphorus event and eventually a limited availability of this non-substitutable nutrient. A precautionary approach would surely include a strategy towards a more efficient use of phosphorus fertilisers and investment in recycling options.

Meanwhile, physical abundance of phosphate rock alone may not be enough to ensure a safe and stable economic supply. On the one hand, this relates to the highly skewed distribution of global phosphate rock production and reserves which may lead to a further increasing dependency of phosphate importing regions and nations on only a handful of producing countries, such as China, Morocco and Russia. On the other hand, increasingly volatile phosphate rock and fertiliser prices can pose a risk, especially to farmers in developing and emerging nations. In contrast to developed countries, the soils in developing regions are often phosphorus-deficient and therefore quite responsive to fertiliser application. Consequently, a price shock that renders phosphate fertiliser unaffordable can be assumed to have more severe effects on agricultural yields in tropical countries than in the industrialised countries of the North with phosphorus saturated soils.

In that sense, and although the “peak phosphorus” debate cannot be expected to provide a reliable depletion or peak estimate, it surely helped raise public, political and scientific awareness of a formerly barely noticed topic. As a result, inter- and transdisciplinary research networks and initiatives such as Global TraPs, the European Phosphate Platform and GPRI have been founded and the European Commission aims at publishing a Green Paper on the topic (ENEP 2013; EPP 2013; GPRI 2011; Scholz et al. 2013a).

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