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PERSPECTIVE

The governance gap surrounding phosphorus

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Abstract There are gaps in the governance of phosphorus (P) across the value chain components (from "mine to fork"), within the monitoring and regulation of these components, and surrounding the role of stakeholders in the process. As a result the intrinsic objectives of a governance system for P are not well formulated and yet to be implemented. Phosphorus is a mineral and is produced and marketed much like other minerals. But since P is also an essential element in our food systems, critical for all forms of life and very dispersed in different products, it requires special attention concerning data collaboration especially regarding rock phosphate (RP) commercial reserves and potential resources. Policy leadership in this area is lacking and the world has no independent source of data or a governance system set up to provide independent monitoring of the knowledge and resource base. The science of P governance benefits from a review of how other minerals have been governed but also by taking a multi-level governance perspective to unpack the complexities. This study reviews key interacting factors affecting the need for governance including common perceptions surrounding P and fertilizers among producers and consumers, the highly skewed distribution of the global resource, the absence of the UN system in monitoring availability and consumption of RP resulting in uncertainty about the size of the commercial reserves, and the inefficiencies in various steps in the phosphate value chain from "mine to fork". The paper provides an overview of governance opportunities including the realms of mining, agriculture and waste management, the respective parameters worth monitoring and regulating, the stakeholders involved and the associated objectives of the resulting improved governance. It provides some suggestions for policy priorities and a staged process of steps to achieve progress.

Keywords Phosphorus · Governance · Geopolitics · Reserves

Introduction

This study questions how P could remain a low global governance priority knowing that it is an essential dietary element that limits the productivity of ecosystems and that exists as commercial reserves in mainly one country in the world, Morocco (USGS 2015). That the UN has no structure in place to monitor and regulate RP extraction suggests that a serious gap exists. Phosphorus prices rose 800 % in 2008 but at the ensuing UN Food Security Summits (FAO 2009) neither P nor other fertilizers were mentioned as issues of concern. Whereas most African smallholder farmers cannot afford today's chemical fertilizers to

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improve the quality of their nutrient-deficient soils (Simons et al. 2014), heavy agriculture subsidies in the North have engrained a common perception that fertilizers are practically limitless and hence food should remain cheap. Contributing to this is the fact that we subsidize agriculture in the EU with 0.8 billion Euros per week (http://ec.europa.eu/agriculture/cap-funding/budget/mff-2014-2020/mff-figures-and-cap_en.pdf). The geopolitics surrounding P dependency on only a few countries is not being adequately addressed. That the EU recently put RP on the EU list of critical raw materials (EC 2014) is a first indication of serious concern. Losses and inefficiencies along the P value chain are significant (Schröder et al. 2010; Withers et al. 2015b) and it will take decades of technological and governance innovation to improve system components. As Brown (2003) coined it, the present way we use P is like driving a car at top speed down the highway with no fuel indicator on the dashboard, and we will do nothing until we first run out of gas. This calls for a concerted effort to develop the global and regional governance of this essential and valuable resource.

This paper outlines and justifies why governance of P as a critical resource is necessary to ensure more efficient use and secure future P supply. We present some suggestions for policy priorities within the mining, agriculture and waste management sectors and a staged process involving the UN for implementation.

The current state of play

Phosphorus is not a well understood element. It is confusing for non-experts to hear that P is an essential element found in all forms of life, a key component of food and dairy products, but at the same time it can be a water pollutant that causes toxic algal blooms and that it can also be a key component in explosive incendiary devices, pesticides and long-life rechargeable batteries. It is also not well known that P is one of the key elements in agricultural fertilizer and that nutrient-poor soils have low levels of available phosphate (www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053254.pdf). It is also very poorly appreciated that the P we use in chemical fertilizers comes mainly from sedimentary marine deposits and 70–80 % of P is lost from "mine to fork" (Schröder et al. 2010). It is even less well known that P is a non-renewable fossil resource like oil with 75 % of the current available commercial reserves found in one country, Morocco/Western Sahara and the following 20 % in just eight countries including China, Algeria, Syria, South Africa, Russia, Jordan, US and Australia (USGS 2015). Governance of P thus can span the gamut of a food security question, one of defense and terrorism, batteries for electric vehicles and water pollution from local, regional to global scales. So when a discussion on governance of P is initiated, little or no response is quite normal on the part of the media, the informed public, policy-makers, industrialists, global leaders and the UN. Also clouding things further, fertilizers are seen by most consumers as something ubiquitous without limits. Indeed the production of ammonia using the Haber–Bosch method which extracts nitrogen from the atmosphere using methane (natural gas) as the hydrogen source has given us the impression of limitless resources. The foundation of the green revolution and the fact that we have enough food to feed at least 6 of the 7.2 billion people on the planet lies in the assumption that chemical fertilizers have had no practical limits at least for the rich part of the world. This has engendered "lock-in" or path-dependent behavior among stakeholders including producers and consumers (Foxon 2008).

As the world's population continues to grow with an increasing number enjoying improved living standards and changing diets, the global demand for P fertilizers is bound to continuously increase. Whether and when this global demand will surpass supply is subject to debate, but one thing is certain the availability of low cost, high quality rock is decreasing (Schröder et al. 2010) and it appears that the market has been permanently disrupted since 2008 creating "scarcity pricing" (Elser et al. 2014). Even the work on planetary boundaries from 2010 including the recent 2015 update does not venture into the resource side of fertilizers (Steffen et al. 2015). The latter work declares that we have exceeded the safe operating space for N and P on the basis of runoff and loading rates to aquatic systems but the obvious question about the practical and commercial limits to the extraction of these resources remains a glaring omission. Knowledge about more efficient farming methods to make use of less P and reduce losses are being further developed and fertilizer use is reducing in the rich countries (Sharpley et al. 2015). However, governance questions surrounding P and fertilizers and where they come from have not created much attention yet both internationally and locally. In addition, the current governance arrangements are poorly coordinated and do not sufficiently address issues connected with the mismanagement of P within the global food system which is characterized by imbalances in terms of fertilizer costs and availability (high and low respectively, in the developing world) (Simons et al. 2014) and food production and consumption patterns (high in the rich countries). International and national policies or guidelines are still to be put in place to ensure long-term availability and accessibility of P for food production in all countries.

In addition, P is a food mineral that is actually managed in the same way as any other non-food mineral, and should not be left entirely for market forces to steer. To address this particular governance challenge would need some form of institutional change to overcome paths that have become “locked-in”. Institutions enable coordination, cooperation, and information exchange among stakeholders (Ostrom 1990). Institutions also provide principles, practices, and opportunities that actors use creatively as they innovate within constraints (Campbell 2004). Path dependence occurs when previous choices often are relevant to current action and organizations may be locked into an existing choice, as taking a new alternative could require new investments and efforts (Pierson 2000). Institutional change can occur in several different ways. North (1990) argues that institutional change naturally occurs incrementally rather than in a discontinuous manner. According to Campbell (2004), this change could either be evolutionary (slow, step wise, continuous change, prone to inertia) which results from the process of path dependence, or revolutionary (rapid and profound discontinuous). Pierson (2004) suggests that when institutions have been in place for a long time, most changes become incremental or evolutionary. Work remains to be done in mapping out exactly how P governance is occurring today, where the gaps are and what elements are needed to ensure a more sustainable path.

Phosphorus governance from a multi-level perspective

Unpacking the governance questions surrounding P reveals a wide array of complex issues at diverse scales including access to data on proven commercial rock reserves, data from exploratory activities, control over exploitation and trade, the role of national and multi-national industries, the role of sovereign governments and regional country partners, and the role of multi-lateral UN and financial organizations. Leadership, coordination and cooperation on these questions has been lacking within the EU until recent years and when it comes to managing RP reserves, leadership remains lacking within the UN system. In particular stakeholder co-ordination is conspicuously absent in terms of the lack of institutional oversight of the issue of P scarcity (Cordell 2010). Within industry, transparency regarding prospecting, potential reserves and commercial reserves is lacking, partly because this is how the mining industry is set up. There is no reliable and independent source of data when it comes to RP reserves. The USGS publishes monthly updates and remains the sole source of data affecting global data governance (http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/).

The governance issues surrounding P management within the global food system are complex, non-linear and predominantly driven by markets. As a result, there are numerous uncertainties, externalities and risks in terms of long-term P sustainability and food security. This necessitates new forms of governance involving steering from the top, commitment, actions, decisions, shared responsibilities and coordination between stakeholders at different territorial levels—supranational, national, regional, and local, enmeshed in territorially overarching policy networks (Marks 1993). Governance must operate at multiple scales in order to capture variations in the territorial reach of policy externalities (Marks and Hooghe 2000). Since externalities arising from the provision of public goods vary immensely from planet-wide to local, as it is in the case of P extraction and use, so should the scale of governance which must be multi-level to internalize externalities. “Scale” refers to spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and “level” refers to the units of analysis that are located at different positions on the scale (Gibson et al. 2000).

Multi-level governance (MLG) is ‘a system of continuous negotiation among nested government at several territorial tiers’ (Marks 1993: 392). There are both vertical and horizontal dimensions of MLG. “Multi-level” refers to the increased interdependence of governments operating at different territorial levels, while "governance" refers to the increasing interdependence between governments and non-governmental actors at various territorial levels (Bache and Flinders 2004). The MLG concept considers policy and decision-making processes involving the simultaneous mobilization of public authorities at different jurisdictional levels as well as that of dispersing power horizontally and vertically to the private sector, NGOs and social movements, and are useful in explaining complex governance patterns (Hooghe and Marks 2001). There are two types of MLG, Type 1 and Type 2 which represent alternative responses to fundamental problems of coordination within governance regimes such as those within the current global P governance regime (Hooghe and Marks 2003). Simply put, in Type 1 MLG, authority is relatively stable and analysis is focused on individual governments rather than on specific policies. Whereas in Type 2 MLG, jurisdictions are flexible responding to specific demands for change in policies (Bache and Flinders 2004).

Phosphorus governance fits mainly into a Type 2 MLG system since it is dominated by a multitude of factors also requiring iterative policy processes affected by the needs of the different stakeholders. The need to map out these processes thus calls for using MLG as an analytical framework.

Progress in recent years on the governance of phosphorus

When Rosemarin (2004) wrote one of the first exploratory papers on global P reserves in the Indian CSE journal Down to Earth, the question of inefficient use and possible global shortages had not been until then properly described. In 2008 when oil prices per barrel exceeded 140 USD, RP world prices increased by 800 % in just a few months. Since then there has been an increased interest in knowing more about the absence of sustainable practices, the low efficiency along the value chain and possible peak behavior in supply (Cordell 2010; Rosemarin et al. 2009; Schröder et al. 2010; Vaccari 2011; de Ridder et al. 2012; Wyant et al. 2013; Butusov and Jernelöv 2013; Schipper 2014; Withers et al. 2015a). Critical needs surrounding P governance, however, remains a new subject. In 2009 there was discussion surrounding the possible threat of peak P (Cordell 2010) and a reaction to this in 2010 (IFDC 2010) attempted to redefine the data on commercial reserves particularly for Morocco. This so far has been the most significant change in data governance in modern time for P and has significantly altered the global outlook on commercial reserves (Fig. 1). This was followed up by activities within the EU creating the European Sustainable Phosphorus Platform (www.phosphorusplatform.eu), an EU green paper (unpublished) by DG Environment, two key EU conferences in 2013 and 2015, several national nutrient platforms in Europe (the Netherlands, Germany, Flanders) and North America (North America Partnership for Phosphorus Sustainability) promoting reuse of P from waste streams and manure and as of recent, RP has been placed on the EU list of critical raw materials by DG Enterprise (EC 2014). This is an example of Type 2 MLG wherein task-specific governance structures such as the nutrient platforms emerge, often self-organized, to cope with locally specific common pool resource problems within common property regimes (Ostrom 1990; Keohane and Ostrom 1995). Common pool resource is a general term used to refer to a wide diversity of resources where it is hard to exclude people from them but once they are in and extract or use the resources this creates compromises among other users (Ostrom 1990).

Notwithstanding, at the international level there is still absence of authoritative coordination setting standards and norms. A glaring absence in the process of improving governance of RP is that of the UN, where no sign of leadership has developed other than some weak signals from UNEP in their 2011 Year Report (UNEP 2011) and inclusion of P into the committee Global Partnership on Nutrient Management which has had nitrogen as its central concern (UNEP 2010).

Reserves, resources, prices and demand outlooks

Status of phosphate rock reserves, resources and geographic distribution

Phosphate *reserves* are defined as geological deposits containing phosphate (RP) that can be economically extracted. Commerciality is determined by both market and technological capacities so this is a changing and dynamic process. Geopolitical factors also contribute to whether a certain deposit is

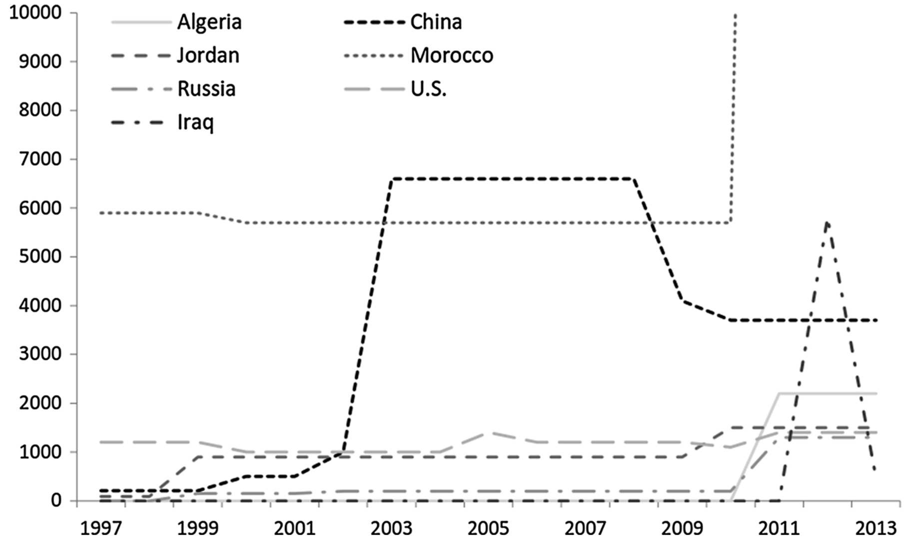

Fig. 1 Historical trend in USGS estimates for phosphate rock reserves in megatons (Heckenmüller et al. 2014)

commercially competitive. Phosphate *resources* go beyond the commercial reserves and include PR that could become commercially viable in the future (Van Kauwenbergh et al. 2013). The longevity of the availability of the reserves has been coined "reserves lifetime" and is estimated by dividing the known reserves by the current annual consumption. This estimate is influenced by a number of factors which include: type of deposit, distribution of reserves according to deposit size, costs, price level, intensity of exploration, and development of technology (Wellmer and Becker-Platen 2013).

The debate on the estimated global PR reserves has attracted much attention during the last decade. Several authors have presented different scenarios for the depletion of PR reserves. One of the most influential is that of Cordell et al. (2009) who first suggested that global PR reserves will run out in 30–40 years. A more specific estimate is presented by Wellmer and Becker-Platen (2013) who reported that the PR reserve lifetime was 81 years. In 2010, the USGS estimate for global PR reserves was 16 billion tons. The IFDC (2010) estimate of global commercial PR reserves was much higher at 60 billion tons. IFDC's method of PR reserve estimation included review of industry and government reports, statistics, scientific literature and presentations (Van Kauwenbergh et al. 2013). The main source for this change was a reinterpretation of the data for Morocco which was given 50 billion tons of commercial RP from what was originally identified as a potential base reserve. In 2011, USGS followed up with major revisions to its PR estimates and reported a revised global figure of 65 billion tons, four times higher than what was previously reported. The IFDC report and the USGS response to it was not followed by the media but had a major impact on dampening the debate on peak P and stimulating large investments in Morocco as well as other locations in the world. The only reaction to the IFDC report was a critical assessment by Edixhoven et al. (2014) which questions fundamentally the validity of the IFDC assessment.

Indeed the USGS data when projected over a few decades provides, to say the least, a picture of instability in the system of defining what is and what is not a commercial resource (Fig. 1). The data for China, Morocco, Algeria and Iraq have all taken abrupt and massive jumps. These can be seen as indicators of a lack of international governance on how these data are to be scrutinized and published. In the latest USGS report (Table 1) the present known global commercial PR reserves are concentrated mainly in a few countries. Morocco and Western Sahara alone has 74 % of world PR reserves and six countries together hold 90 % of the reserves. With this as background, the observed absence of an authoritative coordinator such as the UN as a governing body in this question seems all more apparent and this will become even more obvious as the geopolitics of RP become more complicated over the years ahead.

Table 1 The top 12 country sources of commercial phosphate rock reserves and the percentage of world reserves held (USGS 2015)

	'000 t	%	Accumulated%
Morocco and Western Sahara	50,000,000	74.2	74.2
China	3,700,000	5.5	79.7
Algeria	2,200,000	3.3	82.9
Syria	1,800,000	2.7	85.6
South Africa	1,500,000	2.2	87.8
Jordan	1,300,000	1.9	89.7
Russia	1,300,000	1.9	91.7
United States	1,100,000	1.6	93.3
Australia	1,030,000	1.5	94.8
Peru	820,000	1.2	96.0
Egypt	715,000	1.1	97.1
Iraq	430,000	0.6	97.7

Price variation of rock phosphate

The phosphatic fertilizer market is dominated by key companies such as Yara International ASA (Norway), Agrium Inc. (Canada), Coromandel International Ltd. (India), Potash Corp., of Saskatchewan (Canada), CF Industries Holdings Inc. (US), Eurochem (Russia), OCP (Morocco), Mosaic (US), ICL (Israel), and Phosagro (Russia). In 2012, the global P fertilizer market generated a value of 96.5 billion USD and was projected to grow at a compound annual growth rate (CAGR) of 2.4 % by 2018. The market was led by superphosphate with the fastest growing CAGR and market share (www.agprofessional.com/news/Phosphate-fertilizers-market-Forecasts-to-2018-257395551.html).

Geopolitics has a direct and indirect impact on P market prices. The two significant hikes in 1974 and 2008 (Fig. 2) occurred in connection with increases in oil prices. The large short-term price hike of 800 % in 2008 resulted in a long-term higher price level which has remained running at about 300 % the 2005 levels. That the levels remained high has been classified by Elser et al. (2014) as "scarcity pricing" or an indication of long-term disruption of the phosphate market. There were several contributing factors that could have contributed to the rapid increase in price during 2008. For example there was an upswing in biofuel prices and since sulfuric acid (derived mainly from oil refineries) is a key ingredient in the production of phosphoric acid, its price was a significant determinant as well (Rosemarin et al. 2009). Other factors were that China imposed an export embargo in 2008, the presence of cartel activity among various producers, political instability in Northern Africa, and preferential free trade agreements between large users and Morocco e.g. US, India and EU. Following the spike in prices in 2008, the UN (FAO) held three global summits on food security but the words fertilizer nor P cannot be found at all in the declaration (FAO 2009). These meetings reinforced that 70 % more food will need to be produced by 2050 to meet the demand from nine billion people and that the World Food Program needed increased backing. The need to manage fertilizers and global P limitations were not discussed. Here again the absence of the UN on the question of RP governance was apparent.

Phosphate fertilizer supply and demand

Mined P is mainly consumed as fertilizer. The global demand for fertilizers during the 1940s–1960s led to a large increase in nitrogen, P and potassium production to fuel the green revolution and the demand and use of these fertilizers are continuously increasing. According to FAO (2015), the total fertilizer nutrient ($N + P_2O_5 + K_2O$) consumption is estimated to increase by 2.3 % per year, and it is expected to reach 200.5 million tons by the end of 2018. Phosphate fertilizer demand is growing at the rate of about 2.2 % per year, dominated by East Asia, South Asia and Latin America (Fig. 3) and it will reach 46.6 million tons as P_2O_5 by 2018 (FAO 2015). Phosphate fertilizers will be primarily driven by high consumption levels in developing and large populous countries such as India, China, Brazil, Indonesia, Mexico, and

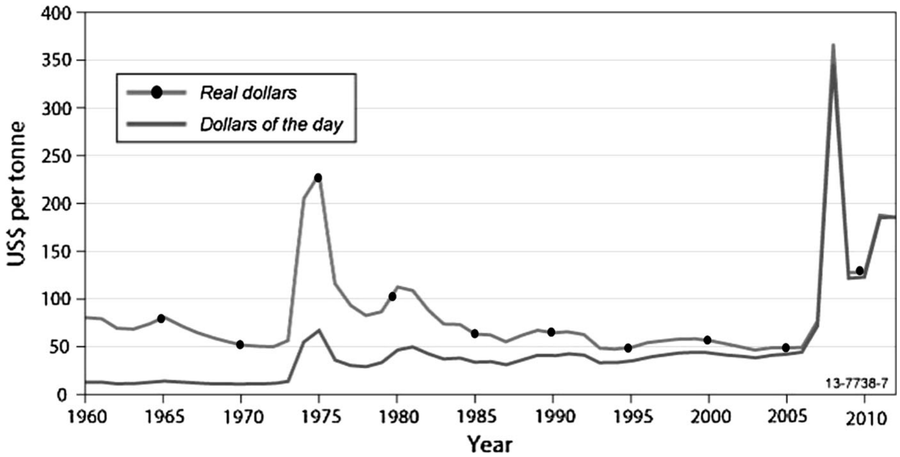

Fig. 2 Price variation of phosphate rock from 1960 to 2012. "Real dollars" refer to 2012 dollar values and thus correct for inflation while "dollars of the day" are nominal and refer to the value for the specific year (http://www.australianminesatlas.gov.au/aimr/commodity/phosphate.html)

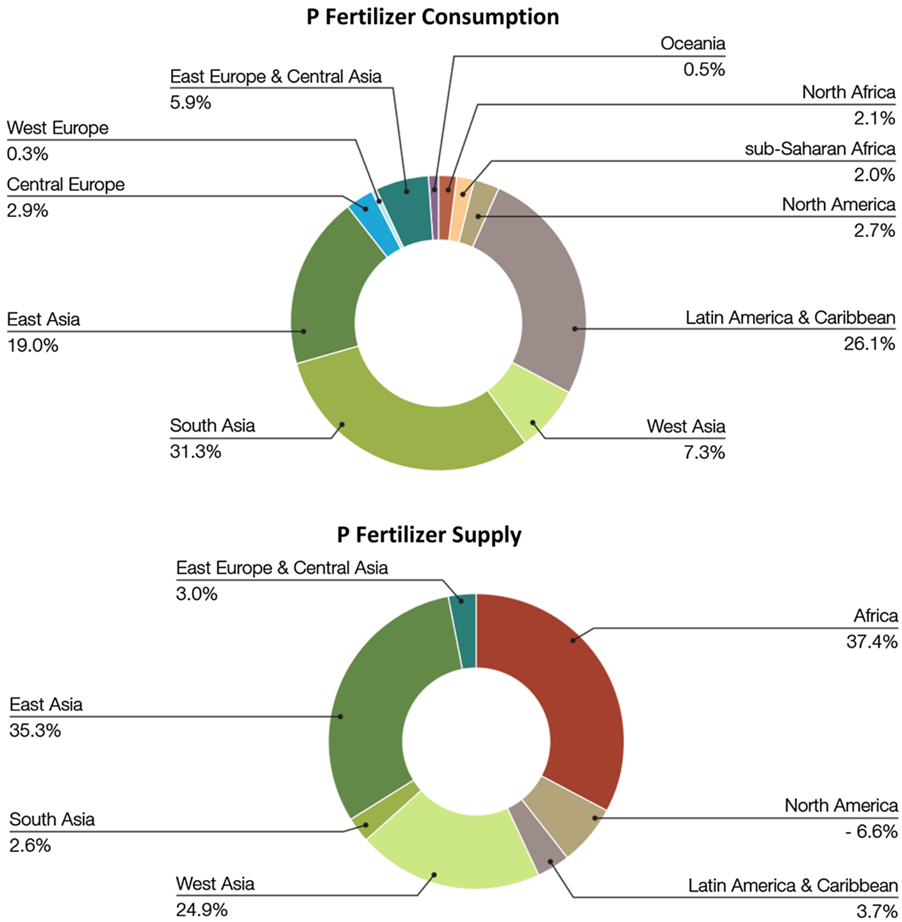

Fig. 3 Regional and sub-regional share of world increase in phosphate fertilizer supply and consumption from 2014 to 2018 (FAO 2015)

Argentina due to greater food requirements. Also increasing milk and meat consumption in the world has necessitated larger feed volume that in turn has increased the demand for forage production. Responding to this demand is the supply picture (Fig. 3). By 2018 the supply capacity will reach 61.5 million tons as P_2O_5. This increase will be provided mainly by Morocco, China and Saudi Arabia. The actual supply will reach about 52.2 million tons as P_2O_5. China is at present the world's largest RP producer followed by the US. There are currently very significant investments in Morocco which will make them the world's largest producer in a few years' time. There is a clear mismatch in terms of the countries that are the main consumers and those that are the main producers. Again, this is even more reason for more transparent and sustainable global P governance to prevent the geopolitical perils that are most likely to occur as a result of the monopoly of this non-renewable resource by just a few countries. In order to develop a more sustainable and equitable use of these limited resources the world would benefit from a more sophisticated governance system.

Learning from governance frameworks for other minerals

A look at how mineral policies have evolved

It is important to put RP into perspective by examining how other key minerals are being governed. The focus of mineral policies has evolved continuously since the pre-industrial period. It is important to understand this background in order to identify what sorts of policy options could exist surrounding the RP question. That P is a mineral intimately linked to food security makes it an exceptional case. But this has yet to be reflected in how we manage this limited resource. Shields and Šolar (2006) present the expansion of the scope of concern demonstrated by the changed thinking about mineral supply over the past 100 years. Moving along the gradient from the pre-industrial era to industrialization, the late and post-industrial era and beyond, the focus respectively has shifted from access to/availability of deposits, to economic markets, to workers' rights and protection, to environmental protection, to social impacts and finally to resource distribution equity. During the nineteenth century, there was a perception especially among economists that increased capital and technological progress would prevent natural resources from slowing down the world's economic growth. On the other hand, conservationists were of the view that increasing consumption of natural resources would reduce the productive capability of future generations but did not propose ways of achieving intergenerational equity through the reallocation of resources (Barnett and Morse 1963). In 1972, Meadows et al. suggested that the mode of behavior of the world economy at that time was one of overshoot and collapse due to the fact that it was driven by positive feedback loops for both population and industrial capital. They stressed that collapse would occur because the rapidly increasing scarcity of agricultural land and minerals would lead to an increase in prices and hence cause conflicts over access to resources. This would in turn lead to societal conflicts and socio-economic collapse before the resources even ran out. Hotelling (1931), pointed out that the exhaustion of mineral reserves will be delayed until substitutes are found for either the mineral or for the products using the mineral. Other authors such as Cole et al. (1973) and Beckerman (1974) from the engineering field suggested that global systems are rigid and mechanistic rather than flexible and adaptable. They argued that technological advance would make possible the substitution of produced goods for natural resources in such a way that productivity of capital is maintained and growth continues even when natural resources are depleted. Similarly, Radetzki (1992) argued that deposits that are presently uneconomical to extract may become economic in the future due to technical advances in mining and metallurgy. How P aligns itself with the above theories is still evolving. Business models have changed considerably and even for P there is increasing evidence of a fundamental shift in industry attitudes to production, welfare and fair marketing on a needs basis (Withers et al. 2015b). The mining industry is starting to take a more sustainable approach to P but wider stakeholder participation is needed to achieve Type 2 MLG.

The principle of sustainability extends to mineral production and management, which Solar et al. (2009) refer to as a sustainable supply mix (SSM). This places the concern of access to mineral resources into a sustainability context and that products containing minerals can be reused and recycled but this has economic and environmental implications. A shift to SSM requires that the mineral policies are reconsidered, revised or extended. This process is just commencing for phosphate through the identification of commercially viable residues in the rock extraction processes, fertilizer manufacturer and use, manure, crop residues, food processing and sewage/sludge systems. Indeed these are the focus for the nutrient platforms and participating industries and researchers referred to above and advanced stewardship along the value chain has been called for (Withers et al. 2015a).

How other minerals are governed

The following provides some examples of how other minerals are being dealt with in order to strive after more sustainable governance. All of the following provide solutions that have relevance to the challenge surrounding the more sustainable use of P. The EU raw materials initiative (RMI) identifies materials that are being threatened by risk to adequate supply and on that basis require improved reuse policies and techniques or even substitution to alternatives (EC 2014) (see "EU raw materials initiative" section for more details). The UNEP International Resource Panel (IRP) has been set up to break the link between economic growth and environmental degradation (UNEP 2012) and has produced several groundbreaking assessments within the water, mineral and energy sectors. The Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development (IGF), the EU–US–Japan agreement on developing substitutes, recycling and raw material and product efficiency, and the IEA global energy cooperation all have in common the striving after policies towards more sustainable use of raw materials.

There are also existing models designed to increase data transparency and enhance collaboration. These include the Joint Organizations Data Initiative (JODI) of the International Energy Forum (IEF) which is a contribution to transparency on the oil and gas markets, the Extractive Industries Transparency Initiative (EITI), the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas and the World Gold Council. So there are established mechanisms that could help provide guidance as we further develop appropriate systems for cooperation around P.

There are also independent UN study groups that exchange knowledge aimed at achieving greater consensus on important key minerals. These create market transparency by providing data on production, consumption, trade, and prices and national policies e.g. environmental legislation. These groups exist for lead and zinc (ILZSG), copper (ICSG) and nickel (INSG). So there are some possible solutions for RP based on the above experiences.

EU raw materials initiative

In 2008, the European Commission launched the RMI, which expresses the need for an integrated policy response at EU level to ensure sufficient access to raw materials at fair and undistorted prices. The EU List of Critical Raw Materials (EC 2014) which is produced by DG Enterprise is based on economic importance of the resource, the supply risk and also the need/possibility for substitution or reuse. It is a governance tool within the EU to promote improved stewardship of important materials that can influence the economy and growth strategies. Phosphate rock as of 2014 is now included in the list of 20 Critical Raw Materials (http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm). Of the ca 20 materials listed, RP is the only one directly linked to food systems. This is a clear signal from the EU that there is concern about the security of RP supply and that reuse capacity is insufficient to provide adequate supplies for fertilizer and feed. Improved management and governance mechanisms are called for and will receive more attention now.

Governance of phosphorus

The phosphorus value chain

In comparison to current governance frameworks for other raw materials and minerals P represents the first instance where we have an essential nutritional element being managed like any other mineral. For the P value chain to be better governed in a more integrated and sustainable fashion requires inclusion of several linked components (Schröder et al. 2010). These include the mined RP (apatite), sulfuric acid (five parts H_2SO_4 give three parts H_3PO_4 in the wet phosphoric acid extraction process following RP beneficiation), the manufacturing of P fertilizer products (MAP, DAP, TSP), the use of fertilizers in agriculture and the production and processing of food—in turn including the soil, crops, animal feed, manure, and agriculture residues and finally human waste flows (solid and liquid). Few countries possess both sulfuric acid and RP thus requiring trade and equity agreements. Sulfuric acid contributes significantly to the market price of phosphoric acid. Current production is 180 Mt, about four times the amount of phosphoric acid produced (http://www.potashcorp.com/industry_overview/2011/nutrients/43/). Sulfuric acid is produced as a byproduct in oil refineries and thus follows the price of oil. The geopolitics of RP are thus further complicated by the geopolitics and pricing of oil.

Also soil is a significant factor in determining the relative requirements of P as a fertilizer. Soil fertility varies in part due to differences in retention of P (ISRIC 2012). Higher levels of retention or sorption render phosphate unavailable to plants, thus increasing the need for P fertilizer additions in order to produce significant yields. This further complicates the geopolitical mix not least because of the large variation in soil tests to assess soil fertility in different countries and the resulting large disparity in the amounts of fertilizer recommended between countries (Jordan-Meille et al. 2012).

Wellmer and Becker-Platen (2013) stress that future options for P sustainability should include improved fertilizer technology, precision farming and improved recycling of wastes such as manure. The following policies contributing to sustainable use of P are relevant to the governance requirements: improvement in the efficiency in mining and extraction; improved fertilizer use and technology; less consumption of meat and dairy products; improved recycling of food production wastes, sludge, manure, struvite, polonite, etc. and economic instruments and even flexible fees where large users pay higher tariffs than smaller users (something that utilities might consider as well).

The need for change

Based on the above dissertation, a blueprint for change at various fronts is called for and new policy arrangements are needed to provide a more stable and sustainable governance structure for RP and its associated value chain. This is a call for a concerted effort to develop the global and regional governance of this finite resource and the way it is used. Access to independent data on RP commercial and potential reserves needs to be developed. Independent sources of data need to be fostered along with monitoring and reporting capacity. When it comes to management of P, a mapping of governance power and relative degree of interest among various stakeholders like the UN, EU, regional trading blocks, the mining and chemical fertilizer industry, governments, farmer's organisations and consumers is necessary to clarify where the gaps and weaknesses exist. These stakeholders must be able to exert effective influence rather than being mere participants in policy processes. The difference between MLG and multi-level participation is significant (Bache and Flinders 2004) and the latter is characterized by greater involvement of new stakeholders with them being unable to exert effective influence in policy processes. Thus it is important to focus on how the mobilization and participation of new stakeholders in particular affect policy outcomes such as increased general awareness about global phosphate limitations, the need for increased efficiency along the entire value chain, knowledge about future accessibility to affordable phosphate and necessary institutional change required to improve governance.

Table 2 provides a list of components each requiring attention within a framework of improved governance at different levels in order to create greater efficiency of use and reuse of P. It is based on the value chain and major flows of P and common MFAs (e.g. Ott and Rechberger 2012) and takes a stakeholder approach to the various sectors including mining, extraction and fertilizer production, agriculture and consumers. Key questions guiding such an approach are: who are the key stakeholders? What role do they play? What is their stake? What are their priorities and preferences? In all cases monitoring with the purpose to increase efficiency, reduce losses and increase reuse will improve knowledge and lead to opportunities for improvement. Indeed the activities at national and regional levels of late within the EU and the European Sustainable Phosphorus Platform (http://phosphorusplatform.eu) which is a representation of Type 2 MLG, have led to similar national knowledge and action platforms and a wealth of spin-off activities are occurring within industry and the research sectors to close the nutrient loop. Furthermore a stewardship framework is proposed to improve efficiency within a five-tiered or 5R programme (Withers et al. 2015a). This framework also represents Type 2 MLG as it involves a wide range of public and private actors from different sectors to address a specific policy problem. The stewardship

Table 2 Elements to be mapped within a framework of improved governance including parameters to be monitored and better regulated, the key stakeholders involved and the objective of the improved governance

Components	Product/parameter to be monitored, regulated and better governed	Key stakeholders	Object of improved governance
Mining and extraction			
Prospecting and mining of RP	RP	Mining industry, national geological surveys, national governments, EU, UN authorities	Improve access to data on base resources and commercial reserves
Beneficiation of RP	RP concentrate	Mining industry, national regulators	Increase efficiency of beneficiation, decreases in product losses
P extraction	Sulfuric acid and phosphoric acid	Mining and chemical fertilizer industries, regulators	Increase efficiency of extraction, decrease losses and ensure acceptable level of trace substances
Fertilizer production and distribution	MAP, DAP, TSP, APP	Chemical fertilizer industry, regulators	Improve efficiency as fertiliser; improve availability to all countries
Agriculture			
Soil application of fertilizer	Residual soil P; fertilizer regime to supply crop requirements	Farmers, national and regional regulators	Improve efficiency and use less fertilizer
Crop uptake	Crop choices for optimal yields and uptake	Farmers and farmer associations	Improve uptake and decrease losses
Harvesting and storage	Crop harvesting, drying and storage techniques and transportation logistics	Farmers and farmer associations	Reduce losses in harvesting storage and transportation
Food and fodder processing and storage	Processing technology and storage methods	Food and fodder industry, farmers, national regulators	Reduce waste and losses
Market distribution	Packaging, transportation and storage	Food processing, packaging transportation, wholesalers and distribution industry	Reduce waste and losses; design to reduce consumption losses
Consumption, waste flows and reuse			
Human food	P content in and amounts of food consumed and wasted	Consumers, consumer organizations, food wholesalers and distribution chains, regulators	Reduce consumption losses and waste; source separate for reuse in biogas production and compost
Solid waste	P content in source separated organic material and unconsumed food	Consumers, municipal utilities, regulators	Reduce waste and increase reuse of composted organic material in agriculture
Municipal sewage	P content in sludge and wastewater	Consumers, municipal utilities, regulators	Reduce waste and increase reuse through extraction from wastewater and use of treated sludge in agriculture
Agriculture residues	P content in silo digestate, perennial cuttings, straw and other residues	Farmers, farmer organizations, regulators	Reduce waste and to encourage reuse
Animal manure	P content and amounts of fodder consumed and manure produced	Farmers, farmer organizations, regulators	Reduce consumption losses and waste; reuse from wastewater and manure

framework involves re-aligning P inputs to necessary requirements, reduction of P losses in runoff and erosion, recycling P by integrating crop and livestock systems, recovering P in wastes and improving manure transportability, and redefining the basic levels of P in the food chain by also modifying diets. All these together will help identify and deliver a range of integrated, cost-effective, and feasible technological innovations to improve P use efficiency to reduce a country or region's dependence on P imports. Part and parcel to this are novel approaches at examining and improving parts of the global P cycle that are particularly at present inefficient (Withers et al. 2015b) making use of so-called green engineering or clean technology approaches. These will be especially important in making use of agriculture residues and other waste flows from society. A further decision-making framework (Cordell 2010) to guide most effective and sustainable P investment strategies in regions or countries exemplifies that implementation requires political will, and in many cases investment by public or private stakeholders.

In addition to such developments, incentives will need to be developed and even taxes and penalties will need to be used when wasteful practices continue. The net effects will be higher product extraction from rock and better use of fertilizers, decreases in losses and increased reuse of agriculture residues such as manure, silo digestate, straw and cuttings. On the consumer side it will mean reduced food consumption and waste and increased reuse from the respective waste streams. Table 2 is therefore the basis to a more extensive mapping exercise that could be taken on as a first step at the supranational governance level by a UN agency such as the UNEP IRP which has carried out similar tasks for other materials (UNEP 2012). This could be an entry point for global governance of RP into the UN system and could then lead to the stages that are outlined below that could lead to a global policy convention on P.

In terms of next steps in an advanced governance cycle of targeted policies leading to a global convention, an action plan with several linked stages is thus suggested. The fact that the world has produced a carbon convention (the climate change convention) without very much connection to either nitrogen, P or potassium is telling in the narrow way we tackle and rally around particular policy problems related to critical materials and both natural and anthropomorphic chemical cycles. A P convention needn't mimic the climate change nor the biodiversity or dry lands conventions. It should develop itself on the basis of policy requirements in order to ensure increased sustainability and food security as the world speeds towards its predicted peak population of 9.6 billion by 2050 (UN 2013).

The action plan on P governance would take on the following steps:

1. The UN (with UNEP lead) would sanction a comprehensive white paper on global use of P in order to create global interest and to engage the UN country members. The paper would take 2 years to produce and pull together all the published material on the topic but also map out gaps and policy needs from global, regional and national standpoints. It would provide suggestions for a new governance body with key responsibilities.
2. The white paper would then be launched at a Global Phosphorus Conference held to further reinforce the urgency and importance of the issues surrounding P limitations, dependency, governance and the need for broad-based policies and practices to improve P sustainability.
3. The conference would be the first step towards a negotiated global UN convention (signed within 3 years) laying out the structure of a governance facility (the global phosphorus facility or GPF) funded on the basis of 5-year cycles by both government and industry that would enable sustainable practice implementation both in rich and poor countries identifying minimum standards and practices to ensure P, fertilizer and food security. The Facility would provide clarity on the geological knowledge base as well as on best practices along the entire value chain. It would provide the capacity of a clearing house on relevant knowledge and benchmarks for performance.
4. The GPF would also promote a new generation of best practices and green technology that optimize the steps in the value chain, improving the quality of waste streams (liquid and solid) including agriculture residues embedded in the circular economy in order to promote the transformation of waste production into secondary resource production. Guidelines would be produced promoting economic instruments to reduce wasteful practices and encouraging reuse processes throughout the value chain.

5. In order to succeed at this endeavour, the GPF would embark from the start on a global communications programme to help explain why the P question is central to future human health, welfare and development as we increase the present world population by 33 % to 9.6 billion by 2050. Through this effort the world will better understand the importance of P in relation to other critical substances such as carbon, nitrogen, potassium and sulphur in achieving food and climate security.

Conclusions

Phosphorus is an essential element with no substitute and is not properly understood by humanity as a critical substance for our survivorship as a species. This beckons a serious review of how it is being governed and managed. There are a number of key interacting factors contributing to the present poor level of P governance. These include the common perception among consumers and producers that P and fertilizers are ubiquitous without limits; little knowledge about the highly skewed geographic distribution of commercial amounts of RP, with domination in one country (Morocco); the absence of the UN system in monitoring availability and consumption of RP resulting in uncertainty about the size and extent of the commercial reserves; and the glaring inefficiencies in various steps in the phosphate value chain from "mine to fork".

Governance of P and RP is a complex topic since it spans over the entire value chain from mining and extraction to production and use of chemical fertilizers, the agricultural practices depending on soil characteristics and the crops being grown, food and fodder processing, consumption and waste systems including reuse throughout. The threats posed by P limitation cut across traditional jurisdictions and scopes of organization, and stretches across local to global scale levels. It is argued that MLG is considered an appropriate framework for dealing with complex multi-scalar problems of coordination and ineffectiveness such as those related to global P management due to its focus on activating relevant cross-level interactions. We consider P governance an example of Type 2 MLG following the current theory of complex governance systems since it envelops so many different stakeholders from both the public and private domains with specific policy problems.

Much can be learned from how other key minerals are governed and how mineral policies have evolved over the last 100 years plus. This puts the challenges surrounding P governance into perspective providing some proven examples regarding data collaboration and governance and may work best through a combination of top-down and bottom-up approaches. Still P is very different from most minerals since it is essential and non-substitutable. A structure for mapping has been suggested for the various components requiring improved management and monitoring and these together can lead towards building up of a comprehensive improved governance plan for the world. This includes a white paper, a global convention on P and the setting up of a monitoring and policy organization funded by government and industry, the GPF.

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