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Interactive comment on "Recent revisions of phosphate rock reserves and resources: reassuring or misleading? An in-depth literature review of global estimates of phosphate rock reserves and resources" *by* J. D. Edixhoven et al.

Anonymous Referee #2

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This review has been written by Roland W. Scholz (roland.scholz@isc.fraunhofer.de) and Friedrich-Wilhelm Wellmer, former president of the German Geological Survey (BGR; Friedrich-W. Wellmer, fwellmer@t-online.de). Please consider this double-authorship if you make reference to this review

Due to the essentiality for food security, continuous increase of consumption, the finiteness of high ore phosphate deposits and specific dissipative property of phosphorus, the potential scarcity of phosphate rock (PR) reserves have become subject of special interest in recent years.

The Edixhoven, Gupta and Savenije paper provides a critical discussion on the use of key terms such as PR resources and reserves and the updating of the Moroccan reserves from 5,700 Mt PR to 50,000 Mt PR based on an IFDC report (van Kauwenbergh, 2010, p. 702). The paper points out the poor differentiation between "ore and concentrate" of PR in literature (p. 1006). The authors deal with the lack of transparency, consistency and validity of key data of reserves and resources. Though this intention is valuable and the paper nicely deals with the difference between "government reporting classifications" (p. 1014) and financial reporting (p. 1015), the paper insufficiently acknowledges the function that different classifications may have for certain questions and actors such as consumers which are interested in short-term supply security, mining companies or lending institutions which are interested in the lifetime of a mine, or governmental actors who take responsibility for different long-term societal resources security (see C1, below).

The Edixhoven et al. paper is neither (yet) an "in-depth literature review" nor does it adequately presents the issue of "recent revisions of phosphate rock reserves and resources" as the title suggests. In particular, the paper does not reference many important recent papers devoted to this subject. Thus it presents results from Hubbert curve applications and misses the discussion about adequate and inadequate applications of this method (see C2). For the reviewers, the biggest flaw is the insufficient incorporation of the dynamics which is linked in any quantitative estimate of reserves and resources. This led to an improper use of the concept of lifetime (C3). The paper acknowledges that reserves and resources are dynamic (page 1011). However, the authors do not draw the correct conclusion because the evolution of the interaction between societal demands, technology development and available/depleted resources is not properly acknowledged. There is no doubt that on the supply side the discovery of and/or production from new deposits including the improvement of recycling rates will take place as demand increases and phosphate reserves may become smaller (Scholz & Wellmer, 2013).

The paper is similar to many papers that have been written on near future phosphate rock scarcity because it refers to a static reserve concept and ignores both, i.e. how reserves depend on the technology and on the amount of money society is willing or forced to pay for something. The current history of phosphate mining and resources is characterized by an increase of phosphate reserves (measured by phosphate rock concentrate) providing a higher abundance than most other minerals and metals (C4).

It is irritating that the reviewed paper includes stories between the lines which may create incorrect impressions that IFDC and also USGS have undertaken activities to safeguard high estimates of reserves in Morocco or to "silently" correct mistakes (p. 1022, l. 19) of high estimates. We are highlighting this point as (e.g. with respect to foundation of Global TraPs) because such non-science based speculation may discredit the intention and reputation of institutions or projects (C5).

There are other flaws, such as an obviously wrong assessment of the increase of phosphorus demands caused by biofuel production (C6) owing not incorporating recycling streams. It is valuable to stress that with respect to classification, the question of why certain data for minerals, metals or commodities are generated is insufficiently explained (see p. 1014-1015). Any data and classification of resources is functional (i.e. serves to answer certain questions). Data collection has significant costs associated with its generation and represents a valuable good for companies. We should acknowledge that a different graininess/granularity or scale of time have to be linked to classifications and data for different stakeholders, though, as noted in the Edixhoven et al. paper, consistency and transparency of classification should be the aspiration.

Finally, minable non-renewable resources on earth do not have the character of a fixed pie which is presented on a table and which is eliminated if the pieces are eaten (C7). The authors apply an inadequate oversimplified rationale of the management of resources.

The Edixhoven et al. paper asks for more than a major revision. There is a broad range of issues which are presented in a biased and incomplete manner. Resources management is a genuine interdisciplinary field. However, we have to acknowledge that an analysis of this field does not only require the consideration of aspects of geologic, technological, natural sciences but also social sciences and even aspects of humanities such as social justice. A thorough analysis of the reality of reserves and resources management also asks for knowledge about insights from the practice of exploration, mining and resources management. This is also why this review has been written by two reviewers. The first reviewer (Scholz) is qualified in mathematical modeling and economics, environmental system analysis, decision research and risk analysis and has specialized in research on sustainable and resilient human-environment systems. The second reviewer (Wellmer) is specialized in geology, mining and geoeconomics. He worked for 13 years for the largest German nonferrous mining company and thus knows the constraints of generating and communicating data from a mining industry perspective. He also has the experience of working for two decades for the German Geological Survey (BGR) serving as president of this institution for a considerable period.

In order to allow for understanding certain arguments and conclusions of the reviewed paper, the reviewers provide a list of concerns (C1-C7). For each concern, some statements of the paper are noted in italics followed by arguments why the reviewers think that the reviewed statements and conclusions are wrong or do not meet science-based state of the art knowledge.

(C1) Not only the dynamics of the demand side, but also that of the supply side (including reserves) have to be acknowledged; the supply-demand interaction matters

Given the near total dependence of food production on PR (phosphate rock) data on PR deposits must be transparent, comparable, reliable and credible. (p. 1006) Due to various factors such as population growth, more phosphorus intensive diets (meat and dairy), and an increasing use of bio fuels, PR consumption is expected to increase significantly further over the next century (USGS, 2013). (p. 1007)

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Certainly the reviewers agree with the first statement as an important goal. The authors, however, do not seem to realize the reality in the geologic world, the nature of the reserve data available in the world, which can always only be a snapshot in a dynamically developing resource world. The authors acknowledge the dynamic nature of reserves and resources (p. 1011, line 4), but do not draw the proper conclusion. We have to understand the relation between societal demands, technology development and the depletion and availability of resources. Theories such as the Resource-based socio-technological theory (Lenski, 2005; Scholz, 2011, p.13) acknowledge this relationship.

To understand the character of reserves, one has to understand the total resource box, which covers everything which is available on Earth: reserves, resources and geopotential (see Figure 1) a) Reserves are defined as the category of total resources that can be economically extracted with proven technology and current economics (including available energy and environmentally and socio-economically acceptable conditions) b) Resources are known (to various levels of certainty), but are not economically viable at present c) The geopotential is not yet known but, by geologic reasoning, it can be expected to contain deposits that will be discovered by future exploration technologies.

Figure: The Total Resource Box illustrates the interrelationship and dynamics of reserves, resources, and geopotential; the area included by the dashed line outside the reserves box marks the resources and geopotential that will be converted to reserves next. This diagram (modified from that in Wellmer, 2008) follows the convention of earlier depictions (McKelvey, 1972; Thom, 1929; Zwartendyk, 1972) of using geologic/physical knowledge and economic viability as the horizontal and vertical dimensions of the defined "boxes." (Figure and figure legend taken from Scholz, Wellmer, & DeYoung., 2013)

The boundaries are always dynamic. What are resources today can be reserves tomorrow and vice versa. This applies also to the boundary between geopotential and

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reserves and resources. Due to exploration work or technological development geopotential can become reserves and resources. With respect to quantifying all reserves and resources, no company or institution has the interest or the means to do so. In general, companies only spend money, at a high risk, on exploration if they can bring the deposits quickly into production. In consequence, quantitative of reserves and resources can only be a snapshot within the dynamic process of resource evaluation.

Concerning reserves we also have to take into account the perspective: a) For companies, reserves are their working inventory. They, therefore, normally only gather data and estimate reserves for as many years of production as the cost associated with obtaining the data and their preference for business planning justify; i.e., the reserves may be more dependent on business planning models and investment alternatives than on the magnitude of minerals in the ground. These reserves normally have to comply with the JORC/CIM code for reserve reporting, today one of the international standards. b) Looking at government bodies, regional planning authorities often have to plan further ahead. The quantities have to be economically extractable before the planning permits are granted. But the "modifying factors" (like legal, environmental, social, and governmental factors) are not in place yetâĂŤthe task of such government bodies is to clarify the aspects of the "modifying factors." For these reasons, a government body would probably speak of reserves, although the JORC/CIM conditions are not fulfilled. Other levels of governments look at reserves and resources as future tax contributors or the cause for requiring subsidies for economic or national security reasons; these decisions sometimes involve time horizons that require analysts to look even further into the future. The same applies to phosphate reserves as a general concern, because phosphate is an essential nutrient that cannot be substituted.

Mining and exploration is the task of industry, normally not one of government agencies. Only in exceptional cases will government agencies drill in the forefront of industrial activities. In consequence for long term outlooks government agencies have to draw conclusions from drill hole information and grids which do not yet fulfill indus-

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try standards under rules of stock exchanges and financing banks. This applies also to a worldwide balance like the Mineral Commodity Summaries (MCS) of the USGS. Australia is a good example. The USGS uses in the MCS for their Australian reserve figure the Accessible Economic Demonstrated Resources (EDR), which is practically identical with the EDR figures (Australian Government, 2011; Lambert, Miezitis, Carson, & McKay, 2012). It is also a good example how, in a country which applies strict standards, the EDR figures (meaning the reserve figures in the MCS) can grow from one year to the other and how it relates to JORC reserves of industry. In 2010 the EDR for phosphate rock was 490 Mt, in 2011 it practically doubled to 950 Mt. The share which fulfilled the classification of reserves under the JORC system was only 280 Mt (30% of the EDR).

(C2) The Hubbert curve and peak phosphorus application to the global data are scientifically unacceptable

While there is broad agreement that PR is a finite resource essential for human survival, the longevity of minable PR deposits is the subject of intense debate. Articles have modeled depletion of PR reserves to occur by the end of the 21th century (Steen, 1998; Rosemarin, 2004; Vaccari, 2009), or peak phosphorus to occur within even a few decades from now (Déry and Andersson, 2007; Cordell et al., 2009). (p. 1007)

The uncritical way in how articles are cited that have modeled an end of peak phosphorus "by the end of the 21st century" (p. 1007) is absolutely unacceptable for a paper which pretends to offer an "in depth-estimate literature review of . . . global rock reserves . . ." (p. 1009).

All papers, which appeared in high ranking reviews which deal with the peak phosphorus "2032" or "by the end of the 21st century" paper have unambiguously shown that (a) the Hubbert curve application of Déry and Andersson (Déry & Anderson, 2007) or (Cordell, Drangert, & White, 2009) is the wrong mathematical model and (b) that the two main applications (i.e., with or without postulating knowledge about an ultimate recoverable resource) produce data which are in severe conflict with empirical evidence about the knowledge.

These reviewers provided a detailed refutation which – after a severe review process – was published in the same journal (Journal of Global Environmental Change) as the only paper which derived a statement on the depletion of "PR reserves to occur by the end of the 21th century." We just summarize the key arguments of three independent groups of scholars.

(i) Scholz and Wellmer (2013) stress and elaborate in some detail that there are two ways of use the Hubbert curve for global PR prediction. a) Type I is the way how M. King Hubbert (Hubbert, 1956, 1962) applied his method to the US crude oil production. The idea is that a logistic curve (or a Gaussian curve) is fitted to the historically recorded production data, based on a least square methodology. If you follow this standard way of application, then the prediction of all future global reserves provides an reserve estimate of 8–9 Gt PR (Ward, 2008). Thus we have an underestimation of the magnitude of factor 10 (ignoring that much of the resources may become reserves). Note that the increase of the global PR reserves is by no means only subject to the increase of the Moroccan data. Also the reserves without Morocco almost doubled and increased from 9.3 Gt in 1998 to 17.0 Gt in 2013. b) Type II asks for postulating that you know the URR. This has been done by Cordell et al. repeatedly. In the 2009 paper of Cordell et al., these authors made reference to the 18 Gt phosphate rock (USGS, 2008) which had been documented by USGS in 2007 which resulted in a peak in 2032 (Cordell et al., 2009). If you take the current USGS data (USGS, 2013), this way of misapplication results in a peak at the end of this century. c) There is no reason to assume that the USGS recording is complete. It just records the state of knowledge at the time of publication. We know from many other minerals that the reserves can increase (reserve growth), in particular if there has been pressure to launch comprehensive exploration for industry (which has been the case for oil, far more than for phosphate rock so far).

(ii) In his paper Peak Nothing: Recent Trends in Mineral Resource Production, which

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has been published in the Journal Environmental Science & Technology Rustad (2012) presents an analysis of oil and 36 minerals. There are two conclusions which may be taken from this thorough paper: a) “Although many strategic resources clearly do appear to exhibit logistic trends during their production histories, these trends have changed to exponential or even superexponential growth over the last 10−20 years.” (Rustad, 2012, p. 1904) indicating a new phase of industrialization. b) The Hubbert curve quite well matches the conventional crude oil production in the US (if we exclude oil production from unconventional sources such as shale oil). However this does not hold true for Global data. This, by the way nicely matches with the findings for phosphorus. Here the Hubbert curve well matches the exploitation of the Nauro guano production (Déry & Anderson, 2007). However, it completely misfits the global data.

(iii) Edixhoven et al.cite for the support of the ‘this century depletion’ statement the 2009 contribution in Scientific American magazine in which Vaccari predicts a depletion in 90 years based on a static lifetime prediction (i.e., dividing the documented resources by the current annual consumption of that time) using a reference of 15 Gt reserves (Vaccari, 2009). However, they do not even mention the later paper which Vaccari co-authored with the mathematician Strigul in the high ranking journal Chemosphere which already includes in the abstract the key message: The ”Hubbert-type extrapolations are not robust for predicting the ultimately recoverable reserves or year of peak production of phosphate rock.” (Vaccari & Strigul, 2011). Similar conclusions were already drawn by Harris (1977).

One may question why this severe neglect and biased review is presented in the beginning of the “Problem statement” (p. 1007).

(C3) Improperly interpreting and using the concept of lifetime (the R/C ratio)

“In view of the above, depletion of currently identified easily accessible deposits could occur at much quicker rates than suggested by the IFDC report, depending on how society responds to potential risks of long term PR scarcity (p. 1013)”.

The authors seem to misunderstand the character of the R/C ratio (reserve to consumption or reserves to production ratio, the differences of which over the long run are only influenced by the amount of stockpiling). This ratio is not the life time of a commodity. This has clearly been outlined in Scholz and Wellmer (2013). Also when discussing the Western Phosphate Fields (WPF) in the US, Scholz and Wellmer (2013) stressed the limitations of this R/C ratio. A large body of literature exists outlining the arguments for example from J. Zwartendyk, formerly with the Wenergy, Mines and Resources Canada, who called the life index a statistical mirage (see Zwartendyk 1974 or Wellmer 2008). We also wonder why it never occurred to the authors that the USGS in its Mineral Commodity Summaries and Minerals Yearbook publication does not never publish a lifetime or an R/C ratio (Jasinski, 2012; USGS, 2013).

Firstly, the units of reserves shall be explained. Companies have to report the reserves with tonnage and grades (see e.g. Joint Ore Reserve Committee JORC, undated). For global reporting it is standard to report reserves as marketable product. This is understood by geoscientists and engineer in the mineral resources field.

Secondly, it is wrong and far too pessimistic to assume that no new discoveries of PR deposits can be made and, therefore, the calculation of an R/C ratio is justified. The Australian example is given above how reserves (resources in the Australian nomenclature) can grow from one year to another. Examples for Brazil and Canada are given by van Kauwenbergh (2010). The standard publication monitoring world-wide exploration expenditures of the SNL Metals Economics Group states in its Strategic Report in November/December 2012: “Budgets totalling US-$ 2.75 billion for targets other than gold, base metals, diamonds, uranium, and PGM increased 32% from US-$ 2.08 billion in 2011, accounting for 13% of overall spending ... Potash and phosphates – by far the most popular target among the remaining commodities – attracted more than 27% (up from 21%) of the other targets." (SNL Metals Economics Group, 2012, p. 7). Why would companies spend money if discoveries and even increase their expenditures if discoveries are unlikely? In addition the effect of reserve growth has to be considered.

In sedimentary deposits like phosphate but also salt or coal the major replacement of mined inventory (reserves) occurs by so-called reserve growth. As explained above, reserves are the working inventory for companies. They, therefore, only gather data and estimate reserves for as many years as the cost associated with obtaining the data and their preference for business planning justify. So by detailed exploration resources of the same system of seams or layers in the forefront of the mining area are converted into reserves. If the frame work changes, like increase in capacity, also the planning horizon ahead normally changes and consequently the ratio of production and reserves.

Scholz and Wellmer (2013) explained that the R/C ratio can be a useful early warning indicator. Therefore, and because the ratio is not the life time, it is irrelevant to consider losses in the mining operation and in the beneficiation plant (Edixhoven et al. 2013, p. 1022, line 26). Only orders of magnitude matter. The relevant question is to understand the meaning of the absolute R/C ratio and the dynamics of reserve development.

Concerning the meaning of the absolute value of the R/C ratio: This ratio for PR is high compared to other commodities especially important metallic commodities, even not taking into account the increase of Moroccan reserves (see Scholz and Wellmer 2012 Table IV).

Concerning the dynamics of reserve development: a) Is the R/C ratio decreasing? This would be an early warning sign as outlined in the paper by Scholz and Wellmer 2012. b) Is the R/C ratio remaining steady within a certain corridor? This is the normal case for most of the commodities with R/C ratios far below the one for PR (see Scholz and Wellmer 2013 Fig. 3). Since for companies reserves are their working inventory, they explore only so much as to keep a balance (see above). c) Is the ratio increasing, i.e. the learning about reserves and resources is ahead of consumption? This is the case for PR. So mankind is on the safe side. The question of course is how long this will last. No doubt the share of secondary phosphorus has to increase. Research has to be intensified with the aim that secondary phosphate can increasingly be competitive with

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primary phosphate and take over an increasing market share. This can be observed with other commodities e.g. aluminum (Wellmer, 2008). A scenario for phosphate has recently been published by Koppelaar and Weikard (Koppelaar, 2013).

(C4) Understanding classifications and numbers from a functional perspective

a) Firstly it has to be stated that in all national and international classification systems to be able to classify ore reserves for company statements a "competent person" is required. The definition, similar in all classification systems, is: "A Competent Person must have a minimum of five years' experience working with the style of mineralization and type of deposit under consideration and relevant to the activity which that person is undertaking" (JORC undated). The equivalent is true for global reporting. There can be no doubt that the USGS mineral commodity specialists responsible for their chapters in Mineral Commodity Summaries and in the Minerals Yearbook as well as the IFDC experts have seen many deposits of phosphate rock and other mineral commodities worldwide and are very experienced long-term ore deposit experts who can draw many comparisons between deposits under exploitation and ones still not exploited. b) The second reviewer worked many years for the then largest German nonferrous mining company as responsible exploration manager. He knows many cases where resources converted to reserves and vice versa. This only underlines the dynamic nature of reserves and resources outlined above. If substances drop out of the reserve category, this does not mean that the substances are not there. In most cases it means that the economic situation has changed or experts ruled that the degree of geological knowledge is not high enough and more exploration work is needed.

No clear cut exactly defined boundaries between reserve/resources categories exist. Two different competent persons do not necessarily come to the same conclusion. Reserve/resource classification is not an exact science.

1.) "Granularity"

The second author is well aware of the issue of "granularity". The three dimensional

UN Framework Classification (UNFC) system was invented by the Federal German Geological Survey BGR. The inventor was Dietmar Kelter (Heiberg & Wellmer, 2012). He and the second author together developed the well-known, three-dimensional cube model with a three-digit number code that is displayed in all UNFC publications. It was originally developed for the UN–ECE (Economic Commission for Europe) to harmonize coal reserve classification systems primarily in Europe and the former COMECON and later extended to other commodities and adopted by the UN ECOSOC Resolution 2004/233 for worldwide application- “a universal translation system to speak one language.” How difficult it can be to fit a specific country system into the new UNFC shows very well the Russian example as outline by Gert (2007). The proper transferal of Russian categories was also the reason for the changes in the MCS of the Iraqi figures in the USGS reporting from 2012 to 2013. Transferring substances from reserves to resources, however, does not mean they are not there. It means more work is necessary for resources to be converted again back to the reserve category.

When the UNFC was invented the granularity followed accepted practices and tried to reach as much consensus as possible. It is up to each country, however, to decide what categories it reports. A good comparison of the UNFC to the Australian but also to other country systems is given by Lambert et al. (2012).

The authors deplore the suggestions by the IFDC to simplify the granularity of the USGS system, to discard the category “reserve base” (van Kauwenbergh 2012) and only use the categories “reserves” and “resources”. The authors do not seem to be aware why the USGS stopped using the category reserve base already in 2010 for reasons outlined below.

Reserve base is defined as: "That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources)" (USGS 2013). One reason to create the category reserve base was because " the reserve base is independent of short –term variations of price or other short-term economic factors and changes only by losses from production and increases from discovery and technologic improvements" (USGS and USBM, 1982).

Estimates of reserve base were made by the former US Bureau of Mines using cost models and physical information about identified resources that were not currently "reserves" (marginal reserves and some part of subeconomic resources) to calculate amounts beyond current reported reserves that had a "reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics." The funding support for the cost models and collection of the physical information about deposits was discontinued in 1995 (deYoung Jr., U.S. Geological Survey, oral communication, 2011). Because the cost models were not updated anymore the USGS discontinued reporting estimates of the reserve base category in 2010. Although it may be desirable for certain aspects to have the category reserve base, the fact is that, the suggestion by the IFDC for only two main categories has been realized since 2010.

The question has to be asked, however, how desirable it really is to spend means on obtaining a high granularity for reserves and resources with an R/C ratio larger than 100. The boundaries can only be defined with economic and technical criteria derived from the present state of technology. Looking at other commodities with a more transparent data base like for example copper: Who would have dared to predict 100 years ago, when the average grade of copper mined was above 1%, that 100 years later copper ore was profitably mined with grades below 0.4%? This occurred with constant prices in real terms in the long run (Scholz and Wellmer 2013, Chapter

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4.2 and Fig. 14).

It would be much more worthwhile to establish learning curves as tools to extrapolate into the future about grade developments, increase in the efficiency of beneficiation, increase in mining efficiencies to mine seams with higher waste: ore ratios etc.

2.) Company data transfer to one world number

Transfer of drill hole distances from one country to another

The reserve data published by the U.S. Geological Survey (USGS) annually in the Mineral Commodity Summaries (MCS) are considered by many to be the most reliable figures on mineral reserves in the world. Many users of reserve data cite the MCS as their source – frequently without understanding the dynamic character of these figures and their limitations. Sometimes it is even believed that it is the task of the USGS to actively determine the reserves and resources of the world as a world authority. The USGS, however, explicitly states in Appendix C of the MCS that it does not directly measure reserves; it collects information from a variety of publicly available sources which are examined and screened and does not check or investigate reserves and resources in the ground.

If done within the UNFC system transferal of national data to the USGS system used in the MCS is simple. An excellent example may be the Australian data as outlined above. The Australian government authority Geoscience Australia determines EDR Economic Demonstrated Resources (Lambert et al. 2012). The USGS uses accessible EDR for the Australian reserve figures in the MCS, which is practically identical with the EDR figures (Australian Mines Atlas 2011). It is also a good example how in a country which applies strict standards the EDR figures (meaning the reserve figures in the MCS) can grow from one year to the next one. In 2010, EDR wars490 Mt, in 2011 it practically doubled to 950 Mt. The share which fulfilled the classification of reserves under the JORC system was only 280 Mt (30% of the EDR).

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The authors criticize the Moroccan reserve numbers of the IFDC and the MCS. They compare distances of drill holes for reserve determination of the US with the ones in Morocco. Although the Moroccan and the US deposits are of the same sedimentary type there are differences from region to region. The authors neglect such possibilities. This is also the reason that "competent persons" are required as described above to judge which rules can be transferred and which one have to be modified for what reasons. It is not appropriate from a geostastatistic view to apply the same sampling (drilling) plan for different sites to assess reserves.

For comparison we shall use another commodity which also occurs in seams normally continuing over large distances similar to phosphate seams and for which more data are available: coal. The Australian regulations for coal accept for the highest category of measured inventory coal and measured coal resources a drilling grid up to 500 m, "but the distance may be extended if there is sufficient technical justification to do so (Coalfields Geology Council of NSW and Queensland Mining Council, 2003). The Canadian regulations accept for the same categories for a certain coal type 800 m (Hughes, Klatzel-Mudry, & Nikols, 1989). The same is true for the Ukraine (Schmidt, 2007) – all three very experienced coal mining countries. For the category "indicated" the distances are in Australia 1000 m (which as before may be extended), in Canada up to 1600 m, in the Ukraine up to 4000 m.

This underlines the necessity to have (geological) competent persons for reserve/resource classification and also persons with specific commodity and country knowledge, conditions which are fulfilled in the USGS and the IFDC.

(C5) Transdisciplinary processes such as the Global TraPS project should be presented in a correct, well-referenced, unbiased and fair manner

Following its report, IFDC created a network, Global TraPS (http://www.globaltraps.ch). This network focuses on the supply side of phosphorus and aims to bring together members from practice ien academia in order to foster knowledge to deal with the

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problem of phosphorus. The project is co-led by the CEO of IFDC as a “practice” representative, while Dr. R. Scholz of the Swiss Technology Institute represents academia. Along with industry, the network attracted numerous scientists and organizations as members. (p. 1008-1009)

This statement well represents the sloppiness of this “in-depth review.” But, it also may include some phrasings which are close to miscrediting IFDC and the Global TraPs project. Factually, the foundation of Global TraPs has nothing to do with the IFDC report (the first reviewer and initiator of the Global TraPs project even did not know IFDC nor the Van Kauwenbergh (2010) report when he initiated Global TraPs). Also the statement that Global TraPs focuses on the supply side is incorrect.

Let us briefly document the superficial and biased review:

(i) It is wrong that “IFDC created the network” (p. 1008) Global TraPs has been initiated first by science. This is well represented in a paper published in Science of the Total Environment: “The Global TraPs project was initiated by science (Scholz, Ulrich) in 2010 and the overall project started under the joint leadership of Dr. Amit Roy (IFDC) and Prof. Roland Scholz (ETH Zurich) on February 6, 2011. ... All nodes are led by key stakeholders, one each from practice and science and facilitated by a transdisciplinarity coordinator, a person who is experienced in theory-practice dialogues. ... The Global TraPs project is unique, as it includes key stakeholders along the whole value chain including USGS,UNEP, FAO, IPNI, fertilizer mining companies and traders, farmer organizations, recycling companies, environmental NGOs such as Greenpeace and a wide range of top scientific institutions from various parts of the world. Also, its co-leadership guarantees a balanced contribution by science and society and its diverse stakeholders.” (Scholz , Ulrich, Eilittä, & Roy, 2013, p. 801-802)

But also the Global TraPs homepage (http://www.globaltraps.ch), which is cited by Edixhoven et al., provides unambiguously picture which is in contrast of the statements of Edixhoven et al.

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In Global TraPs Newsletter 1 from December 2010, the first sentence reads: Welcome to Global TraPs “The Global TraPs project is taking shape. Core members from the academic community and from government organizations are joining the project team. We are starting to communicate with potential participants from industry and to identify project resources.” In Global TraPs Newsletter 2 from March 1011 you may read: “Dr. Amit Roy (IFDC) has accepted co-leadership. We are pleased to announce that IFDC, represented by Dr. Amit Roy, will join ETH Zürich, represented by Dr. Roland Scholz, in leading the Global TraPs project. On February 1, Dr. Roy and his team members . . . met with project leader Roland Scholz and project manager Andrea Ulrich at IFDC headquarters at Muscle Shoals, Alabama. They held in-depth discussions about the goals, outcomes and methodology of Global TraPs. On February 3, Dr. Amit Roy accepted the principal practice leadership role. Below is a joint statement from the project leaders.

(ii) It is a wrong presentation that Global TraPs “focuses on the supply side of phosphorus.” (p. 1008). The guiding question of the Global TraPs project (see Newsletter 5, November 2011) reads: Global TraPs guiding question: What new knowledge, technologies and policy options are needed to ensure that future phosphorus use is sustainable, improves food security and environmental quality and provides benefits for the poor?

And the visions of Global TraPs are elaborated in the forthcoming book: Scholz, R. W., Roy, A. H., & Hellums, D. T. (in press). Sustainable phosphorus management: a transdisciplinary challenge. In R. W. Scholz, A. H. Roy, F. S. Brand, D. T. Hellums & A. E. Ulrich (Eds.), Sustainable phosphorus management: a global transdisciplinary roadmap. Berlin: Springer. On page 1 of Chapter 1 you find the following sentence: “The key view of Global TraP is the supply-demand chain and the vision CLoSD (See Global TraPs Newsletter 11). . . . The conceptual vision is elaborated in the Closed Loop Supply-Demand Chain Management of the anthropogenic portion of (CloSD Chain Management) phosphorus flows in this chapter.“

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(iii) Finally, Global TraPs is not just a network but a transdisciplinary project focusing the integration of knowledge from science and from practice. Global Traps has many features such as co-leadership of practitioners and scientists who have been chosen to properly have the knowledge accessible that is needed to sufficiently cope with the complexity of phosphorus management.

(C6) Biofuel may most likely have lower impact on P consumption due to already practiced recycling For instance, Rosemarin et al. (2011) calculated that IFDC's 60 000 MtPR concentrate could be depleted within 172 yr if the anticipated population growth is taken into consideration (255MtPR consumption by 2100), or 2100), or 126 yr if Africa would develop its agriculture and experience a green revolution. Under this assumption, global PR concentrate consumption would be 314 MtPR concentrate by 2100, double the quantity on which IFDC based its depletion analysis of current reserves. The authors also calculated that if bio fuels were to supply for 10% of global energy requirement, the reserves reported by IFDC could be depleted in 48 yr, at which point global PR consumption would reach 475 Mt PR annually. (p. 1012)

Again the reference to Rosemarin's calculation (published in a non-refereed source), about the impact of biofuel (instead of 172 yr, a depletion in 48 yr) shows that the authors are not informed about the material flows and existing recycling loops in biofuel production. A large share of the global biofuel production comes from (Brazilian) cane production and (U.S.) maize production. But, there is a very strong recycling loop with respect to P as distiller grains and oilseed meals replace grain in livestock feed.

However, the main concern is with land use and food prices. Compared to this, the impact on P is low. The calculation of Rosemarin et al. (2011) seems questionable as it obviously does not include the dried distillers grains with solubles (DDGS) for ethanol productions. Similarly the (re-use of the biodiesel oilcake is not considered.

The first reviewer should mention that he (not being trained material processing engineer) had to learn the above in a discourse with industry (from P. Heffer, IFA) lines.

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This example makes clear that a systemic view is needed and the multiple tradeoffs of resources management should have been considered.

"The biofuel feedstocks are expected to increase. According to a 2011 IFA estimate, biofuel feedstocks received 0.21 Mt P yr-1 (Heffer, 2013). This makes around 3.0% of world phosphorus fertilizer applications. We should note that but most of the phosphorus found in the feedstocks ended up in oilcakes and slurry which is recycled and thus not lost. Thus, the net impact (after deduction of the phosphorus ending up in co-products) would be much smaller, below 1% (Heffer, 2013)." (Scholz, Roy, & Hellums, in press)

C7 Properly understand dynamics of multiple dynamic processes Scholz and Wellmer argue that one "can define a sustainable P cycle if – in the long run – the economically mineable (primary and secondary) reserves of P increase higher than the losses (i.e. dissipation) to sinks which are not economically mineable" (Schollz and Wellmer, 2013, p. 14). This notion of sustainability, however, requires infinite "reserve growth" which cannot continue forever if the source from which the reserves are derived is finite

There are strictly infinite monotonically increasing sequences which are bounded. The sequence may serve an as it converges to the value . Here, URR is a fixed real number which denotes the Ultimate Recoverable Resources of phosphorus (URR) measured by tons of phosphorus or phosphate (rock) concentrate. Naturally, the example is not a good example but may well show in what way the increase of recycling and access of phosphorus from other sources has to be related to the decrease of accessible phosphorus. With phosphorus, we are not facing the situation in which we are fixed pie on a dessert table which is unretrievably disappearing. Further, URR if we refer to mineable phosphate ore is not a known or currently well accessible number. The report of Orris & Cernoff (Orris & Chernoff, 2004) identifies about 1600 phosphate deposits and occurrences in over 80 countries. Most of these deposits and occurrences are poorly assessed. The potential of offshore deposits are not discussed.

Though the reviewers argue that we have to close the phosphorus cycle by environmental and other reasons (see Scholz and Wellmer, 2013). The proposed notion of sustainability does not ask for “infinite “reserve growth”” but for progressively closing the phosphorus cycle and taking less so that the reserves will not fall below a certain amount (e.g. measured by lifetime as a vulnerability indicator). And as, we have noted, the URR is not a fixed entity such as a pie on a table. What we will know in 400 years about reserves, mining and recycling and what is economically mineable may be certainly much higher.

Further research The authors state at the end of the Abstract “Further research is required as to the quantity of PR deposits and their viability for future extraction”. We are in full agreement with this statement. The aim of the Global TraPs project is to improve transparency as an element of supply security with the following elements a) monitoring of material flows b) improving the understanding of the dynamics of reserves and resources. c) better understanding of the geopotential as a source of future reserves (here an excellent base to continue is the IGCP-project 156: Phosphate deposits of the world from 1977 to 1988 (Cook & Shergold, 1986)) d) understanding learning curves for future PR supply .

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