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# *Interactive comment on* "Comment on: "Recent revisions of phosphate rock reserves and resources: a critique" by Edixhoven et al. (2014) – Phosphate reserves and resources: what conceptions and data do stakeholders need for sustainable action?" *by* R. W. Scholz and F.-W. Wellmer

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## General comments

Reply to Anonymous Referee 2 on "Recent revisions of phosphate rock reserves and resources: a critique" by Edixhoven et al. (2014) – Phosphate reserves and resources:

what conceptions and data do stakeholders need for sustainable action? by R. W. Scholz[12] and F.-W. Wellmer[3]"

This reviewer is correct in stating that the paper is more than a comment on the work by Edixhoven et al. (2014). The original title reads “Comments and thoughts emerging from the paper ‘Recent revisions of phosphate rock . . .’. ” We discussed at length with the editor of *Earth System Dynamics* whether or not this should be a separate research paper, and then followed the suggestion to keep it in the mode of a comment-based dialogue. Unfortunately, in the course of publishing, the phrasing “and thoughts” was canceled, as the editorial format did not allow for this. We suppose that this is related to the new format of interactive publishing, which calls for new categories that the reviewer as well as the authors will have to become acquainted with. If the paper is given an opportunity to be published, we will amend the title to clarify that and how the paper goes beyond comments about the paper by Edixhoven et al.

The reviewer is incorrect in suggesting that the authors did not read the Edixhoven et al. paper thoroughly. We have written a published, in-depth, and detailed review (Scholz & Wellmer, 2014) that pointed out tremendous shortcomings in the first version of the Edixhoven et al. paper (Edixhoven, Gupta,& Savenije, 2013) and a positive review (recommending acceptance; not publicly available) on the improved second version. The published third version is further improved and provides an important message on the inhomogeneity of the information labeled under phosphate rock (PR) in some papers and documents, and in the USGS Mineral Commodity Summaries. This is why the third version is a valuable contribution which deserved publication.

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The authors reject the Anonymous Referee's statement that "untrue statements are leveled at the Edixhoven et al. paper 2014" (C13) in our 'comments and thoughts . . .' This holds true for the refutations of the three claims that follow:

1. the "Factually untrue statement/Abstract): 'The present paper identifies and discusses basic conceptual errors . . . that predict a short or mid-term phosphorus scarcity"';
2. "the non-acknowledgement of the dynamics of reserves";
3. "the mixing of finiteness and staticness." (all quotes from Anonymous Referee, 2015)

Before we explain why the Anonymous Referee is wrong, let us briefly refer to propositional logic as the basis of scientific reasoning. A main principle of scientific reasoning is that it works with "true/valid" prerequisites, which only allow for valid/true conclusions. Thus, if we look, for instance, at a mathematical proof or any other causal reasoning, the lemmata and corollaries, i.e., the implicit prerequisites, have to be examined for their "validity." This, factually, has been one reason that the "comments and thoughts" on the Edixhoven paper dealt with the Hubbert curve analysis and its fundamentally incorrect application by Cordell et al. (Cordell, Drangert,& White, 2009; Cordell, White,& Lindström, 2011, April 4; Déry& Anderson, 2007), which is (implicitly) presented as one of the "motivations for the Edixhoven et al. paper."

But let us document in what way the Hubbert curve analysis has been utilized in part 1 of the Edixhoven et al. (2014) paper. In the second and third paragraphs you find:

> ... Numerous publications have modeled the depletion of PR reserves to occur by the end of the 21st century
> ... or peak phosphorus to occur within a few decades to some 60 years from now (Déry and Andersson, 2007; Cordell et al., 2009, 2011). The methodology behind the peak phosphorus hypothesis or peak theory ...



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> One point of criticism to the peak phosphorus hypothesis is that the modeling was based essentially on PR estimates sourced from the mineral commodity summaries (MCS) issued by the US Geological Survey (USGS).
>
> ... Importantly, the reserve base and the reserves include only those deposits which are demonstrated (measured and indicated), i.e., which have been established with sufficient geological assurance (USGS, 2014).

And in the fourth paragraph, they add:

> While the peak phosphorus hypothesis remains hotly debated, ....

Undoubtedly, just as these few lines reveal, Edixhoven et al. (2014) have built their paper on an "improper use of the Hubbert analysis (which simply uses the USGS estimates of reserves as a substitute of an estimate of ultimate recoverable resources)." This has been stressed in our review on the first paper and the abstract of our comment to Edixhoven et al. (2014) as it still applies fully to the published ESD paper. We are very concerned about such potentially misleading argumentation. The "peak phosphorus hypothesis or peak theory" (Edixhoven, Gupta,& Savenije, 2014a, p. 492) is nothing other than an incorrect application of the Hubbert curve method. This misapplication is not due to "estimates sourced from the Mineral Commodity Summaries (MCS) issued by the US Geological Survey (USGS)" (as Edixhoven et al. suggest) but because, in the case of phosphorus (Cordell, et al., 2009; Cordell & White, 2011), the reserves and resources are used in the Hubbert curve analysis and not "the ultimate recoverable resources."

The Anonymous Referee are correct when they state: "At no point in Edixhoven et al. is the term ultimate recoverable resource used." This is a fundamental error and is



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one of the reasons for outlining the (wrong) application and utilization of the Hubbert curve analysis, which is factually a synonym for *"peak phosphorus hypothesis or peak theory."*

We are not linguists, but we are concerned that the above-quoted sentences may be misinterpreted (by most people who are not literate in mathematical modeling). We think that the Edixhoven et al. text may be summarized in the following (incorrect) manner:

> The peak phosphorus hypothesis is criticized because it used USGS Mineral Commodity Summaries reserves data that have not been established with sufficient geological assurance (which may be considered the subject of the Edixhoven et al. paper).

Factually, this would be a complete distortion of the situation of the misapplication of the Hubbert curve analysis to phosphorus and may be used to detract from the fundamental critique that reserves and resources are the wrong units for a Hubbert analysis. The *"peak phosphorus hypothesis or peak theory"* (Edixhoven, et al., 2014a) is incorrect because (1) the "ultimate recoverable resources" for phosphorus are unknown, and (2) the world market for phosphorus is not a demand market (in which any quantity quantity available would be bought). Instead, as our 'comments and thoughts' outlined, the amount of resources and future accessible rock ores are that large that even the unlikely event of a tremendous increase in consumption (e.g., assuming an irresponsible and unsustainable quadrupling of today annual phosphorus use which is far beyond any published and reasonable scenario) would cause only a plateau of production and no peak phosphorus in the next century.

Unfortunately, the anonymous reviewers "can see nor purpose for these section." (C16) The purpose of the section was to acknowledge that the peak P hypothesis



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(i.e., the Hubbert analysis), which is mentioned seven times in the paper, is a fundamental misapplication for global phosphorus and to avoid statements that may mislead people who are literate in mathematical resources modeling such as:

> "... the peak phosphorus hypothesis remains hotly debated ..."

(Edixhoven et al. , 2014, fifth paragraph):

Concerning claim (2), "the non-acknowledgement of the dynamics of reserves," and claim (3), "the mixing of finiteness and staticness":

We are amazed to read that we failed to acknowledge the fact that Edixhoven et al. (Edixhoven, et al., 2013, 2014a; Edixhoven, Gupta,& Savenije, 2014b) state that the nature of reserves is dynamic. Indeed, on page 37 in Chapter 3, we say in the first sentence:

> "Edixhoven et al. (2013) acknowledge that "given the economic function of resource classifications, reserves and resources are dynamic" (p. 9, line 14). In the next sentence, we say that we "wonder to what extent this dynamic concept has actually been incorporated."

The statement of the anonymous reviewer is correct, namely, that Edixhoven et al. (2014) discuss the Rosemarin et al. (2011) paper in a "neutral tone." When Edixhoven et al. (2014), however, select from the various papers about phosphate reserves and resources only this one and discuss it in a "neutral tone" without qualifying it, we believe we are justified in assuming that Edixhoven et al. (2014) approve of the content, at least in principle. In the paper by Rosemarin et al. (2011), the reserve data are taken as fixed; in various scenarios, the consumption increased, thus decreasing the reserve/consumption ratio (R/C ratio). Mathematically speaking, the nominator is fixed and the denominator is increased. It is concluded, then, that the R/C ratio may



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be less suitable as an early warning indicator. Edixhoven et al. write (Edixhoven, et al., 2014a, p. 495):

> "As noted in the introduction, given the dynamic nature of reserves and resources, depletion of the reserves estimated in the IFDC report would not signify that there would be no phosphate rock left to mine. The potentially higher consumption rates do, however, point to another limitation to the concept of an R/C ratio which may make it less suitable as an early warning indicator."

Scholz and Wellmer (2013) point out that R/C ratios are commodity specific. This means that they are useful as an early warning indicator, as the R/C ratios – not their **absolute values** but the **developmental changes** – are of interest. Therefore, for scenarios it has to be taken into account that reserves grow with consumption. This is shown graphically in Fig. 3 of Scholz and Wellmer (2013), with the examples of the commodities copper, nickel, and cobalt. Below, in Table 1, we show this, in addition, for oil. Here the R/C ratio even increases, reinforcing our argument that not only the denominator has to be increased but also the nominator, if one accepts the dynamic nature of reserves.

**Table 1.** Balance of annual production and reserves with ongoing depletion

| | Annual Production | Reserves | R/C ratio |
|---|---|---|---|
| 1960 | 1,042.9 Mio to | 39,614.6 Mio to | 38 |
| 2013 | 3,617.3 Mio to | 202,702.7 Mio to | 56 |

(Source OPEC, 2015a, 2015b). (Barrels are converted into tonnes by the factor of 7.35.)

In addition, in our opinion, footnote 1 on page 495 of Edixhoven et al. (2014a) lends support to our understanding: The depletion numbers, according to Edixhoven et al.



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(2014a) interpreting the depletion numbers of Rosemarin et al. (2011), are taken starting from the year 2100 with today's known reserves. It is highly improbable that between now and the year 2100 nothing will be added to the reserves. The Raw Materials Agency of the German Geological Survey BGR regularly publishes brief commodity characteristics. In 2014, the Rohstoffwirtschaftlicher Steckbrief (engl. The Resource Economic Characteristics), for example, various exploration projects with so far known reserves and resources. It is highly probable that such resources are converted into reserves up to 2100. (The BGR report is in German, but the table on page 6 is self-explanatory, BGR, 2014) The same holds true for the vast resources of Morocco, as pointed out by the first reviewer (Mew, 2015).

These are the reasons why we say, on page 37, Chapter 3: "We wonder to what extent this dynamic concept has actually been incorporated."

At the beginning of our reply we say that the original title of our paper read "Comments and thoughts. . .." and the word "thought" unfortunately was dropped in the final version. Under "thoughts", we included the chapter 3.2 "The confusion between finiteness and staticness of reserves" (Scholz & Wellmer, 2015, p. 41). In this chapter among other aspects we outlined with the scenario for the Western Phosphate Field in the US, one of the largest phosphate provinces of the world, how technological development could change the total reserve picture – stressing the aspect of the dynamics of reserves.

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