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Establishment of the Indicator for the Accounting of the Resource “Phosphate” in Environmental Assessments

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Reinhardt, Guido; Rettenmaier, Nils;
Vogt, Regine

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Contact:

Dr. Guido Reinhardt

ifeu – Institut für Energie- und Umweltforschung Heidelberg, Wilckensstraße 3, 69120 Heidelberg
guido.reinhardt@ifeu.de, +49-6221-4767-31

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Front page, top/middle: own pictures; tailings pile (top), raw phosphate (middle)

Front page, bottom: own picture

Contents

1 Objective

The objective of this paper is to establish an indicator to account for the use of the resource "phosphate" in environmental assessments (especially life cycle assessment), including corresponding units and conversion factors.

2 Background and technical terms

Phosphate rock is the basic raw material for the production of phosphoric acid and is used to manufacture fertilisers, animal feed, food and other industrial products. Fertilisers in agriculture account for 90% of global phosphate used [Brunner 2010 p. 870]. With a share of 85%, marine-sedimentary deposits dominate in phosphate rock mining, the remaining 15% is from magmatic deposits. Phosphate rocks include iron and aluminium salts as hydrated complexes with a large range of phosphorus and phosphate content. Guano-based deposits are largely exhausted [Killiches 2013 p. 9]. As of today, 52% of global phosphate mining is in China, 10% in the USA and 12% in Morocco (12%) [USGS 2019].

The process steps from open pit phosphate rock mining to marketable raw phosphate include grinding, washing, screening and subsequent flotation [Killiches 2013 p. 9]. Marketable raw phosphate has phosphate concentrations between 27% and 40% ([Gwosdz et al. 2006] quoted in [Killiches 2013 p. 10]). Recycled phosphate can be obtained from municipal sewage sludge using incineration or other processes [Pinnekamp et al. 2011; Spörri et al. 2017].

As a mineral raw material, phosphate is a non-renewable resource, unlike ammonia-based fertilisers requiring nitrogen from the atmosphere and energy. Depending on the source, the static range of global phosphate reserves is estimated to last only a few decades to a few centuries [Cordell et al. 2009; van Kauwenbergh 2010; Vaccari & Strigul 2011; van Vuuren et al. 2010]. This scarcity is exacerbated by world population growth and likely changes in consumption patterns [United Nations 2017]. This results in an increasing demand for phosphate.

Naming of phosphate-containing raw materials is not consistent in the literature. The following terms are often used as synonyms – at least in their German translation: phosphate ore, raw phosphate, phosphate rock, phosphorus resource. Examples of such definitions are:

- *(Phosphate) ore*: Ores are naturally occurring mineral aggregates of economic interest from which one or more valuables can be extracted by processing. In most cases, these are minerals containing more or less metallic components ([LUMITOS 2018] quoted from UK Institution of Mining and Metallurgy).
- *Phosphate rock*: In English-speaking countries, the term *phosphate rock* is used primarily, which after [Schweizer 2012] is translated to German as “Phosphatgestein” (*phosphate rock*), “Rohphosphat” (*raw phosphate*) or “Apatitgestein” (*apatite rock*) and can be used synonymously with the term *phosphate ore* as previously described. In the phosphate report by the Federal Institute for Geosciences and Raw Materials (BGR) [Killiches 2013], the term *phosphate rock* is used in addition of the general term *phosphate*.

- *Raw phosphate:* Many authors do not understand *raw phosphate* as the extracted raw material, but rather the processed, concentrated phosphate, e.g. already [Kongshaug et al. 2005; Patyk & Reinhardt 1997 p. 106], up to more recent publications such as [Killiches 2013 p. 9; Pinnekamp et al. 2011 p. 24]. In this sense, *phosphate ore* and *raw phosphate* differ in their phosphate content and in the processing steps.
- *Phosphate mineral:* minerals containing phosphate, such as apatite $Ca_5[(F,Cl,OH)|(PO_4)_3]$ as most important mineral.
- *Recycled phosphorous:* recovererd phosphorous from organic residues, e.g. sewage sludge.
- *Phosphorous resources:* Quantity of raw phosphate needed to produce a corresponding quantity of primary phosphate [Montag et al. 2015 p. 74]. However, sewage sludge and guano can also be regarded as a phosphorous resource, which is not in the sense of the mineral resource mentioned here.

- *BPL (Bone Phosphate of Lime):* tricalcium phosphate, 1% P_2O_5 = 2.185% BPL [United Nations Industrial Development Organization & International Fertilizer Development Center 1998 p. 109]; BPL with a value of 70% (corresponding to 32% P_2O_5) is used as a reference value for the price development of raw phosphate [IndexMundi 2018].

In the context of LCA studies, the following parameters are used to assess phosphate demand:

- *Phosphate resource equivalents*, in: [Neuberdt 2017] (average 25% phosphate content according to [Patyk & Reinhardt 1997 p. 106])
- *Phosphate ore*, in: [Patyk & Reinhardt 1997 p. 106]
- *Raw phosphate*, in: [Pinnekamp et al. 2011 pp. 22, 229] (average 30% phosphate content)

The above compilation may not be complete but is sufficient for the purpose pursued here. These terms refer directly to the single resource phosphate. On the other hand, the term *cumulated raw material demand (CRD)* is used for the total raw material expenditure [Giegrich et al. 2012]. The cumulated raw material demand includes not only the raw material expenditure through the extraction (rock mass of the starting material), but also all "spent primary raw materials, including the energy raw materials, along the value chain" [VDI 2016]. In LCA, CRD is used as an indicator in the inventory analysis. For the impact assessment within LCA, ifeu has developed a method that allows to assess the relevance of mass use (see [Detzel et al. 2016] or [Giegrich et al. 2016]). Currently, however, a full characterisation is not yet possible with the given data base.

In the context of this paper, the focus is on the different phosphate contents of the various deposits and not on the masses of raw materials accumulated in the further value chain.

3 Definition of the category indicator name

As an indicator of the resource phosphate, the cumulative raw material demand (CRD) should be used as a life cycle inventory parameter in LCA studies. The CRD for the phosphate demand describes the *amount of starting mineral (ore or rock) for the extraction of phosphate as well as all primary raw materials used along the life cycle*. The initial rock mass characterises the CRD of phosphate. In this sense, the terms *phosphate ore* and *phosphate rock* can be used synonymously.

Even though *phosphate ore* may be an easier term from a practical point of view (shorter and easier to read in graphs), *phosphate rock* is used as the term for the accounting for the resource phosphate.

For easier comprehensibility to the general public, the indicator can simply be called a *phosphate rock* or a *phosphate footprint*. This results in the terms:

→ *Phosphate rock demand* or *phosphate rock* (significant portion of the CRD phosphate).

→ The term *phosphate footprint* can be used for simplified presentations.

4 Unit, reference, conversion factors

Some specifications are necessary for the practical application or calculation of the phosphate rock demand.

The **unit** at the life cycle inventory level follows the logic for the cumulated raw material demand

→ phosphate rock standard in kg or abbreviated: phosphate rock (std) in kg

The term *standard* is needed since phosphate rock can have different phosphate contents depending on the origin, and therefore must be referred to a standardised value (see *conversion factor* in the next but one paragraph).

The **reference** is P_2O_5, raw phosphate or other forms such as PO_4^{3-} which will result from the question addressed (e.g. in LCA).

Conversion factor: Since phosphate rock can have significantly different phosphate contents, it is necessary to determine an average phosphate content of the phosphate rock. A variety of information and approaches exist in the literature.

- „Phosphate rock statistics are generally expressed as tonnes of product. The phosphorus content of the rock varies. Rock of sufficiently high phosphorus content (grade) to be acceptable commercially contains 30 – 40% P_2O_5" [Kongshaug et al. 2005].
- „Globally, on average, phosphate ores have a P_2O_5 content of around 30% ([IFA 2009; USGS 2008] cited in [van Vuuren et al. 2010]). In our calculations, we assumed an average P_2O_5 content of 30% for all the reserve and reserve base estimates, unless a specific grade was indicated. For China, we used a P2O5 content of 25% for the reserves and 20% for the reserve base [USGS 2008]. For the additional resources, we assumed a P_2O_5 content of 10 and 17.5%." [van Vuuren et al. 2010].
- [Jasinski 1999 p. 75.5] confirms the lower P_2O_5 contents in China, at least partially.

- [Truong & Zapata 2002 p. 17] mention an average of 27% P_2O_5.
- [Neukirchen & Ries 2016 pp. 258–259]: „Phosphorites are marine sedimentary rocks characterised by their high phosphate content of at least 15-20%. To be mineable, phosphate ore should contain at least 30% P_2O_5, preferably with calcium carbonate and only small amounts of iron and aluminium“.
- [Patyk & Reinhardt 1997 p. 106] report an average phosphate content of 25% in relation to the reference value P_2O_5 commonly used in agriculture, corresponding to 32% raw phosphate.

On the basis of sources listed, there does not seem to be any valid reason to deviate from the values given in [Patyk & Reinhardt 1997 p. 106], especially since there many other basic data for the provision of phosphate fertilisers for LCA were derived in detail.

As **conversion factor** for the phosphate rock based on [Patyk & Reinhardt 1997 p. 106] an average phosphate content of 25% based on the reference P_2O_5 commonly used in agriculture is used. This corresponds to 32% raw phosphate. This means,

→ 1 kg P_2O_5-fertiliser (mineral) corresponds to 4.0 kg phosphate rock (std) and 3.125 kg raw phosphate (std), respectively.

Notes:

- The reference here is limited to mineral fertilisers. The classification does not apply to organic fertilisers such as liquid manure, solid manure, natural fertilisers such as guano or phosphate recovered from sewage sludge. For those, specific procedures or deductions must be made depending on the question to be answered.
- When calculating the phosphate rock standard in life cycle assessments, all the products used that are manufactured from mineral phosphate or contain it, such as mineral phosphate fertilisers in particular, are taken into account. In case of a consequential modelling, additionally products are considered, which can replace products made of mineral phosphate without restrictions (and which are available in limited quantities during the reference period of the study).

5 Normalisation factors

For normalisation, average inhabitant equivalent values are proposed, as is common practice in many life cycle assessments. These values typically vary over time while there is not always an obvious trend (see Annex). Since fluctuations have been observed, especially in recent years, we choose the 5-year average as the average value. This results in the following values:

→ For reference area Germany: 16.1 kg phosphate rock (std) / (capita · year)

→ For reference area Europe: 23.1 kg phosphate rock (std) / (capita · year)

6 Application

For the use of the indicator, we suggest that in each study, the following should be added in an appropriate place (glossary, footnote, etc.) in the "Introduction / Use / Description" of the indicator

> "In this study, the indicator for the mineral resource consumption of phosphate is the demand for *phosphate rock* as a life cycle inventory parameter. The term *raw phosphate* refers to phosphate rock that has already been concentrated in a first processing step. Phosphate rock standard is used as the unit".

For the unit, we recommend that it be described in more detail in the glossary (or elsewhere) or that reference be made to this source.

The term *phosphate resource (equivalents)* like the term *phosphate resource* can lead to misinterpretations. For this reason we use the already introduced term

→ *Phosphate rock* or *phosphate rock demand* or *phosphate rock* (relevant subset of CRD phosphate).

→ For simplified communication also: *phosphate rock footprint* or *phosphate footprint*.

with the corresponding unit: "kg" at the life cycle inventory level

→ Phosphate rock standard or phosphate rock (std).

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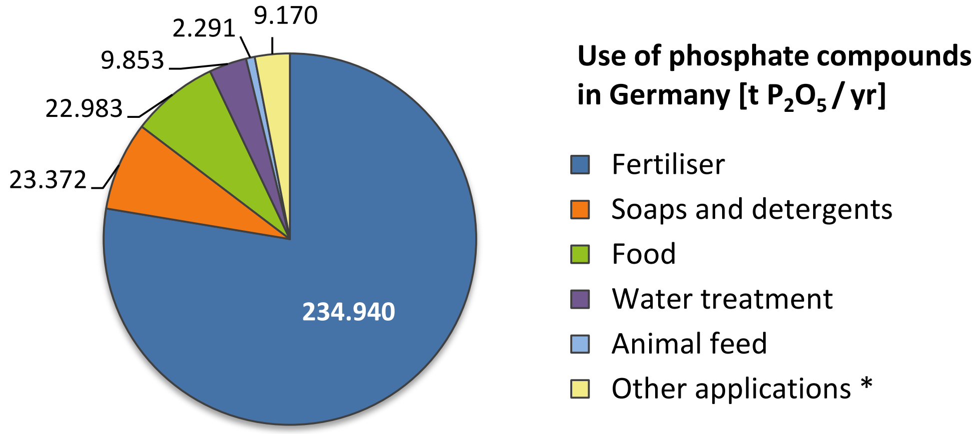
8 Annex

The basis for the calculation of the inhabitant equivalents is provided by the quantities of phosphate used for agricultural purposes [FAO 2018] and for other applications based on the data from [Pinnekamp et al. 2011] and [LAGA 2012] cited in [Montag et al. 2015]. Only few data on individual years are available for the phosphate use in other application areas. Since the few studies available on animal feed also included phosphate compounds of biogenic origin, only the proportion of mineral phosphate compounds in animal feed was roughly estimated here.



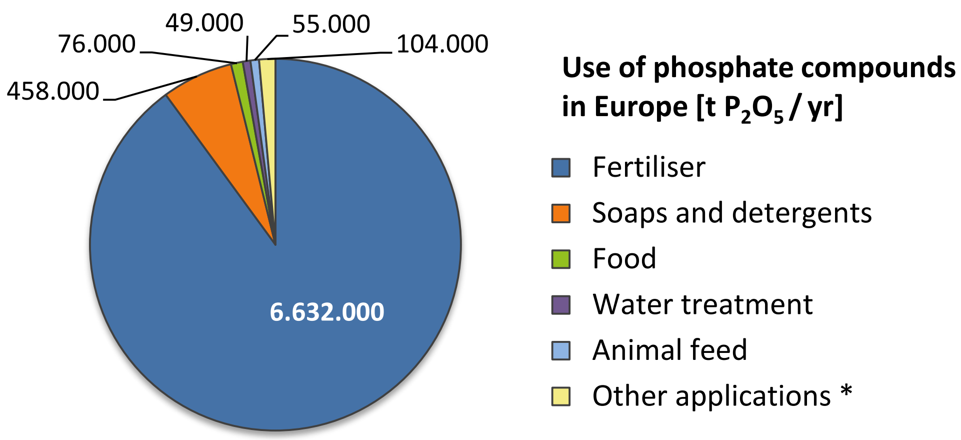


Figure 1: Use of phosphate compounds in Germany and Europe after [LAGA 2012; Pinnekamp et al. 2011].
* In Germany fertilisers account for about 80% of consumption and in Europe for about 90%. Other uses for phosphate compounds are: toothpaste, flame retardants, antifreeze, metal treatment, ceramics, leather processing, rubber production, activated carbon, fermentation processes.

The total phosphate consumption for Germany and Europe is shown in Figure 1. In Germany, about 80% of the mineral phosphate is used for fertilisers (according to [LAGA 2012]) whereas in the EU-28, it is about 90% [Pinnekamp et al. 2011]. The slightly different distributions are attributed to the fact that in Germany, compared to the EU-28, technical applications are more common.

Since the share of other applications is rather small compared to fertilisers, it is set that 80% of the total phosphate rock consumption in Germany is used for fertilisers. In order to obtain the total consumption, this 80% is then scaled up to 100%. From this total phosphate rock consumption, the average values per inhabitant are calculated using the number of inhabitants in Germany (Figure 2).

For the calculation of inhabitant equivalent values of the EU, it is set out that the distribution of use does not differ significantly from that in Europe as a whole, and therefore, starting from the above-mentioned 90%, a share of 10 percentage points is added to the fertiliser consumption for other applications. The specific phosphate rock requirement per inhabitant in the years 2013-2017 is used as the basis for calculating the 5-year average, which is selected as the inhabitant equivalent value for the normalisation of the phosphate rock demand (see Chapter 5).

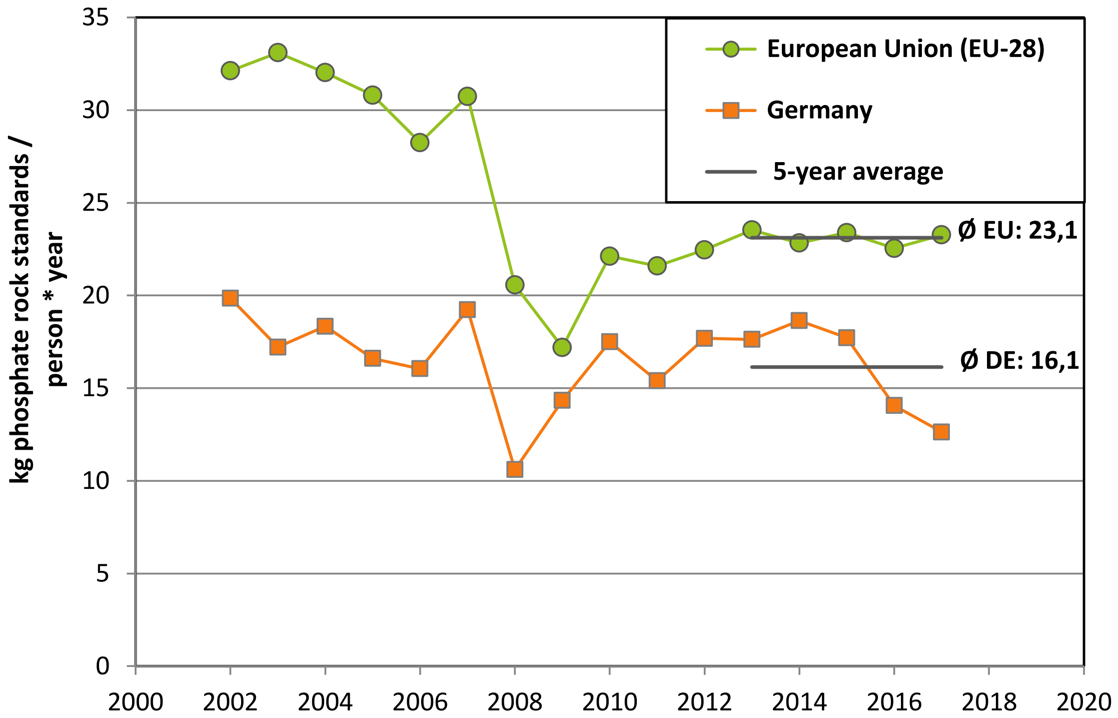


Figure 2: EU and German inhabitant equivalent values (own calculation according to [FAO 2018]).

Table 1: Deduction of the EU and German inhabitant equivalent values (own calculation according to [FAO 2018]).

Year	European Union (EU-28) [kg phosphate rock standard/ (capita year)]	Germany [kg phosphate rock standard/ (capita year)]
2002	32.1	19.9
2003	33.1	17.2
2004	32.0	18.3
2005	30.8	16.6
2006	28.2	16.0
2007	30.7	19.2
2008	20.6	10.6
2009	17.2	14.3
2010	22.1	17.5
2011	21.6	15.4
2012	22.5	17.7
2013	23.5	17.6
2014	22.8	18.6
2015	23.4	17.7
2016	22.5	14.1
2017	23.3	12.6