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Environmental and resource implications of phosphorus recovery from waste activated sludge

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ABSTRACT

Phosphorus is an essential mineral resource for the growth of crops and thus necessary to feed the ever increasing global population. The essentiality and irreplaceability of phosphorus in food production has raised the concerns regarding the long-term phosphorus availability and the resulting food supply issues in the future. Hence, the recovery of phosphorus from waste activated sludge and other waste streams is getting huge attention as a viable solution to tackle the potential availability issues of phosphorus in the future. This study explores the environmental implications of phosphorus recovery from waste activated sludge in Denmark and further elaborates on the potential availability or scarcity issue of phosphorus today and 2050. Life cycle assessment is used to assess the possibility of phosphorus recovery with little or no environmental impacts compared to the conventional mining. The phosphorus recovery method assessed in this study consists of drying process, and thermal gasification of the waste activated sludge followed by extraction of phosphorus from the ashes. Our results indicate that the environmental impacts of phosphorus recovery in an energy efficient process are comparable to the environmental effects from the re-use of waste activated sludge applied directly on farmland. Moreover, our findings conclude that the general recommendation according to the waste hierarchy, where re-use of the waste sludge on farmland is preferable to material and energy recovery, is wrong in this case. Especially when phosphorus is a critical resource due to its life threatening necessity, lack of substitution options and potential future supply risk originating due to the high level of global supply concentration.

1. Introduction

The management of natural resources and their use may have a profound effect on the long term availability of resources for future generations. Phosphorus (P) is an indispensable mineral resource for life. The sustainable management of this resource is central to the development of life on earth. It is an essential plant nutrient, which is necessary for crop and animal feed production. Availability of phosphorus to feed ourselves in the years to come got high attention during the recent years because: global population is growing at a high rate and we are expected to be 9 billion people by the mid of this century; nutrition value is expected to rise in the poor countries of Asia and Africa; and it is a limited non-renewable resource with no substitutability for its primary application in fertiliser production. So, it becomes extremely important to explore any potential supply constraints of phosphorus considering the future high demand. Meanwhile, it becomes vital to seek solutions such as substitution possibilities, more efficient primary production, reduced consumption and better recovery from the waste streams (Cordell and Neset, 2014).

Waste activated sludge is produced in waste water treatment plants in large amounts. It is done partly with the purpose of removing phosphorus from sewage before it is discarded to the environment. The waste activated sludge is often used as a fertiliser on farmland due to its considerable phosphorus content. However, one of the challenges of using activated sludge on farmland can be the content of other hazardous substances (e.g. chromium, nickel, polyaromatic hydrocarbons and others). If the amount of these substances exceeds the maximum permissible values, it cannot be used on farmland. Moreover, there might be emerging organic pollutants that may cause a risk of which we are not aware today.

The phosphorus is also not utilized 100% when waste activated sludge is applied directly on farmland within the same season as it is applied (Huang and Shenker, 2004). However recent studies show that a long time horizon probably will make the phosphorus

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utilised fully (Huang et al., 2011). Therefore this is probably not an argument for extraction.

In addition to phosphorus application as a fertiliser on farmland, extraction of phosphorus could provide the possibility of using phosphorus for other purposes. Hence, phosphorus recovery from waste activated sludge and other waste streams can help to decrease the possible resource constraints resulting from increased demand of phosphorus in the future.

Secondly, if it is possible to find an appropriate methodology for utilizing and extracting the phosphorus resource as well as other resources like energy in the waste activated sludge, it would be of significant value. The recovery of phosphorus from waste activated sludge has been the focus of many studies, in order to determine the process efficiencies, costs and benefits for the recovery of phosphorus and thereby assess the potential for an environmentally beneficial recovery. Various methodologies and their efficiencies regarding the phosphorus recovery have been investigated in several studies. Phosphorus can be recovered from water phase of waste activated sludge or recovered from the waste activated sludge ash.

Latifian et al. (2014) and Nakakubo et al. (2012) explored recovery from the water phase (e.g. formation of struvite) and the efficiency of the recovery. They showed a recovery efficiency of up to 85%. Weigand et al. (2013), Xu et al. (2012) and Ottosen et al. (2013) have explored the techniques on extraction of phosphorus from sludge ash, where the recovery of phosphorus from ash is shown possible with high efficiencies of up to 95%.

A common tool for assessing the costs and benefits with respect to environmental impacts is Life Cycle Assessment (LCA). Combining this methodology with the knowledge of the techniques and efficiencies can provide more understanding of future potential pathways for recovery of phosphorus.

Johansson et al. (2008), Linderholm et al. (2012) and Nakakubo et al. (2012) have explored different techniques for recovery of phosphorus and have assessed their environmental feasibility using LCA. Johansson et al. (2008) concluded that the effect of the adjoining systems (i.e. the effect of avoided fertiliser and handling) were the most significant parameters influencing the results. Linderholm et al. (2012) found that applying sludge on farmland is the most efficient option in terms of energy and emission of greenhouse gases. They also concluded that phosphorus recovery from ash is too costly in terms of energy and greenhouse gas emissions. Nakakubo et al. (2012) have compared different technological systems but have not considered the adjoining systems i.e. the effect of the avoided use of other fertilisers. According to the conclusions of Johansson et al. (2008), this may be an important parameter lacking in their study. Nakakubo et al. (2012) found two recovery methodologies to be superior with respect to greenhouse gas emissions. The phosphorus recovery technology based on gasification and extraction and the phosphorus recovery based on composting followed by phosphorus recovery from the water phase. Nakakubo et al. (2012) did not consider applying sludge directly on farmland as this was not relevant for the scope of their study.

This study aims to assess phosphorus recovery from the waste activated sludge ash in an energy efficient process and aims to evaluate the environmental costs and benefits using LCA to determine whether it is possible to recover phosphorus from waste activated sludge ash in an environmentally feasible manner. The technique assessed in this study is phosphorus recovery from ashes. It is also characterised by recovering the energy in the sludge for CHP (combined heat and power). Apart from assessing the environmental impacts associated with the recovery of phosphorus from the waste activated sludge, this paper also discusses the criticality aspect of phosphorus in near and long term future along with the potential role of recycling in lowering the phosphorus criticality.

Resource criticality is a relatively new term with no standard definition yet. Criticality can be defined as the vulnerability of a system such as technology, corporate, economy or the world as whole to the potential supply risk of resources it depends on. Criticality studies have been made at corporate, national and regional levels, e.g., the National Research Council (USA) in 2008 published a study on critical minerals for the U.S. economy where they used a matrix consisting of two dimensions: supply risk and the importance of supply risk, to show the criticality level of the mineral. The minerals placed on the high ends on both axes were considered highly critical. Later in 2010, the European Commission came up with a study on defining critical raw materials for the EU (European Commission, 2010). This study used the same matrix principle as developed by the National Research Council (2008) but replaced the axis named importance of supply risk with economic importance. Recently, Graedel et al. (2012) have published a detailed methodology to identify the critical metals. They have introduced a third axis of environmental risk and thus proposed a three-dimensional criticality space to identify the critical resources. Majority of the criticality studies so far have considered only metals. During the recent years, a German study (IWD, 2010) considered phosphorus as a critical resource in its role as a nutrient. Scholz and Wellmer (2013) have elaborated further on this issue and have differentiated between the earlier used terms i.e., availability and scarcity, and the new term criticality. More recently, the European Commission (2014) has considered phosphate rock in its criticality assessment study, where it is considered as a critical resource, though with the current low level of supply risk and moderate level of economic importance for the EU. In the current study, we have discussed the criticality issue of phosphorus in detail, not only for the current time period but also for the long-term future (2050), and how the recovery of phosphorus from sewage sludge affects the overall criticality of phosphorus.

2. Methodology

In order to assess the environmental impacts of phosphorus recovery from waste activated sludge as well as the associated resource implications, methodology has been divided into two sub-sections: LCA and the criticality assessment. A detailed description is presented in the following sections.

2.1. LCA model

LCA is a standardized (ISO, 2006a,b) and widely accepted tool to systematically assess and compare the environmental impacts of different products and processes. The environmental assessment of phosphorus recovery from waste activated sludge presented in this study is performed by using the consequential LCA (Ekvall and Weidema, 2004). The LCA was carried out using the ILCD methodology (European Commission – Joint Research Center, 2010) for the environmental impact categories of climate change, photochemical ozone formation and acidification. There has been added an extra category to keep track of the biogenic carbon with a characterization factor of 1 for CO_2 per CO_2 equivalent and 2 for CO. Biogenic carbon is often considered neutral in relation to global warming. In this case the application of the sludge might result in different release of the biogenic carbon to the atmosphere and therefore it has to be accounted for. The categories listed are the ones where the most significant effects are found in the current system after normalization. Moreover, the Danish EDIP 2003 methodology (Miljøstyrelsen, 2005; Wenzel et al., 1997) is used for assessing the resource depletion due to its consistency with the criticality assessment