Circular Economy of phosphorus – challenges and findings in performing comparable LCA-studies of phosphorus-recycling

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Abstract. The European Union listed Phosphorus as a critical raw material. Large amounts of phosphorus are found in sludge from sewage treatment plants, from which the raw material can be recovered as fertilizer. Within the project RePhoR, funded by BMBF, recommendations to strengthen the recycling of phosphorus from sewage sludge will be developed that are methodically derived from a life cycle assessment (system perspective), an economic feasibility study and a social acceptance study. A special focus is on the comparability of various recycled fertilizers and consequently on the settings of different life cycle assessments (goal and scope) because they differ significantly in their fertilizing effect. Furthermore, combinations of different recycling technologies by extending the system boundaries will be evaluated with respect to the circular economy potential. Due to the early stage of the project, concrete results are still pending.

1 Introduction

Phosphorus is an elementary raw material without which life on this planet is unthinkable. The reserves, estimated to have a reserves-to-production ratio of about 318 years [1], are distributed among only a few countries, so that the European Union has included phosphorus in the list of critical raw materials [2]. Large parts of phosphorus can be found in sewage sludge from wastewater treatment, out of which the raw material can be recovered as fertilizer. This process approach can contribute significantly to the EU Action Plan for a Closed Loop Economy [3].

As part of the RePhoR research project [4], a sustainability assessment of the various phosphorous recovery processes is performed. A distinction is made between processes that recover phosphorus from sewage sludge directly at the sewage treatment plant with recycling rates of max. 35 % and processes that extract phosphorus from the ash following incineration of the sewage sludge with recycling rates of over 80 %. (Fig. 1)

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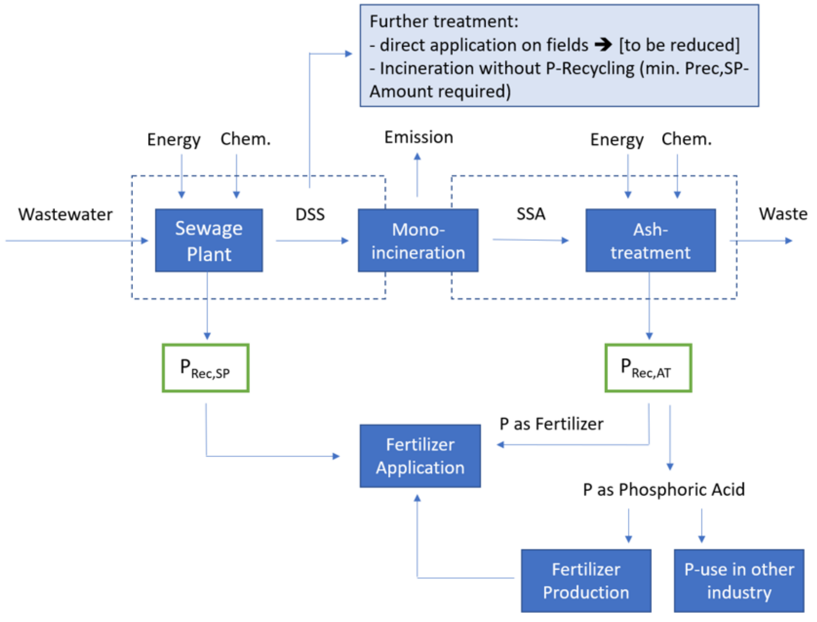

Fig. 1. System boundaries of different phosphorus recycling technologies (DSS: Dried Sewage Sludge; SSA: Sewage Sludge Ash; P: Phosphorus; PRec,SP; P-Recycling on Sewage Plant; PRec,AT: P-Recycling from Ash Treatment).

A special focus in the current project phase is the life cycle assessment (LCA) of the technologies, which was in the field of interest in several publications before [5, 6, 7, 8, 9]. The respective subprojects are preparing an LCA for their process approach, which is coordinated by the participating transfer project TransPhoR. The challenges of this coordination to ensure the comparability of the LCAs represent the core of this article. Due to the heterogeneous approach in the recovery of phosphorus, the definition of the target and investigation framework within the scope of the LCA according to ISO 14040 [10] presents itself as a particular challenge. Four essential aspects will be examined in more detail within the scope of this article:

1. the separation of the secondary function of the production of a secondary phosphorous fertilizer on a wastewater treatment plant from the primary function of wastewater treatment with sewage sludge generation;
2. the achievable recycling rate (a higher recycling rate is often associated with higher environmental impacts);
3. the plant availability (the different modes of action of the fertilizers make a direct comparison difficult);
4. the use phase of the fertilizer (many parameters independent of the fertilizer [soil type, groundwater-floor distance, plant type, etc.] influence the evaluation).

2 Investigation approach

Functional unit

The primary function of a wastewater treatment plant is to clean wastewater. The removal of phosphorus, which accumulates in the sewage sludge, is only a secondary function and primarily serves to optimize the process of sewage sludge treatment since an excessively high phosphorus content in the sewage sludge can lead to incrustations in the digesters, pipes, and dewatering aggregates [11]. With this in mind, the secondary function of recovering phosphorus from sewage sludge is difficult to distinguish from the primary function of wastewater treatment. Thus, it is not possible to clearly assign a process serving phosphorus removal to one of the two functions. A proportional allocation would be formally possible, but ultimately associated with great uncertainties.

Another possibility is a comparison of a wastewater treatment plant with phosphorus recovery and a reference plant without (Fig. 2). Ideally, the difference represents the effort (in terms of energy, auxiliary materials, etc.) that must be expended for the additional phosphorus recycling.

By referring to a reference plant with the primary function "wastewater treatment", the functional unit is set to the usual design parameter for wastewater treatment plants, which is given as "treatment capacity per inhabitant and year". The recovered phosphorus in this case would be integrated into the system via credits. Optionally, the difference from WWTPs (Waste Water Treatment Plants) with and without phosphorus recovery can be related to the recovered amount of phosphorus.

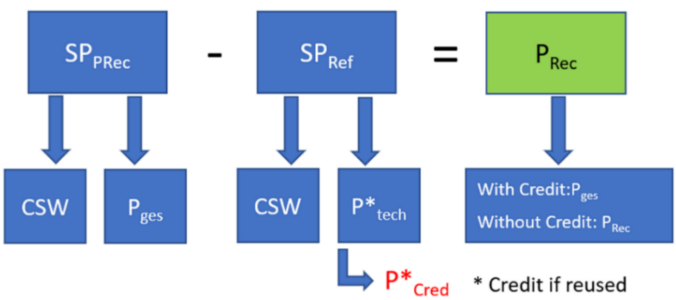

Fig. 2. Comparison of phosphorous recovery technology with reference plant without phosphorus recycling (SPPRec: Sewage Plant incl. P-Recycling; SPRef: Sewage Plant excl. P-Recycling (Reference); CSW: Cleaned Sewage Water; Pges: Amount of P recycled; PRec: P-Recycling; Ptech: technically required P-Recycling; PCred: Credit for reused P).

Recycling rate

Higher recycling rates generally require greater process engineering effort and correspondingly higher energy and auxiliary material input. This is offset by a higher credit due to the larger quantity of recovered material. However, the credit approach alone does not meet the goal of a closed-loop recycling economy. Particularly in the case of recycling critical raw materials, it seems appropriate to apply a greater energy input rather than a critical raw material input.

An adjustment of the impact category "resource consumption", e.g. by a higher weighting of critical raw materials, does not seem reasonable, since a comparability of life cycle assessments would no longer be given due to the dynamic development of the list of critical raw materials.The project will investigate to what extent a higher effort to increase the recycling rate is compensated by the allocation of credits.

In addition to the approach of future more efficient technologies and the conversion to regenerative energies, it is also conceivable to measure the credits, due to the saving of primary material, not on the basis of real environmental burdens (these do not include lacking environmental standards), but to apply them fictitiously as they would be if European environmental standards were met.

Plant availability

For the investigation of plant availability, which is the actual function of the fertilizer, accompanying experiments will be carried out on standardized soils. The growth trials will be used to show which fertilizers achieve comparable fertilizer effects and which parameters are decisive for this. The water solubility approach is well known and is used to describe the plant-available portion of a fertilizer [12]. However, depending on different plants, it is shown that a water solubility of the phosphorus portion does not necessarily have to be given in order to be nevertheless available to the plants. [11] In the further course of the project, the results of the plant trials will be incorporated into the life cycle assessment of the fertilizers via the comparative variable of the functional unit.

Use phase

The use phase of a product partly determines the result of a life cycle analysis. In relation to fertilizer, this is the application to agricultural land. The resulting environmental impacts depend, on the one hand, on the properties of the fertilizer and can be assessed insofar as they depend on the quality of the product. Here, for example, residual contents of heavy metals or the water solubility and thus the relocatability of nutrients in deeper soil layers up to the aquifer are to be mentioned. On the other hand, however, soil parameters or the type of agricultural use also play a role, which are independent of the quality of the fertilizer.

This problem is comparable to building materials, whose subsequent use in a wide variety of building types does not necessarily reflect the quality of the building materials. For example, highly efficient building materials in non-insulated buildings can perform worse than less efficient building materials in low-energy buildings simply because of a poor balance in the use phase. [13]

Within the scope of the project, approaches are being pursued both to include the deployment phase in the life cycle assessment and to outsource and separately consider this use phase. The accompanying investigations on standardized soils are intended to standardize the consideration of this important phase of the life cycle. Concrete results are still pending.

3 Conclusion

In the RePhoR project, different technologies for the recovery of phosphorus from sewage sludge or sewage sludge ash are compared on the basis of a life cycle assessment. A comparative statement based on the results of the life cycle assessments of the subprojects requires a coordinated approach considering the very different qualities of the secondary products (different requirements regarding plant availability, potential applicability of higher-quality products in other economic sectors, maximum achievable recycling rates …). In addition, it must be taken into account that in the present case the production of secondary fertilizer is not the main focus of the system under consideration but the wastewatertreatment, which for technical reasons also requires the removal of phosphorus from the sewage sludge. Thus, it has to be clarified which part of the wastewater treatment plant is to be allocated to phosphorus recycling. This can be done by not only the approach of an allocation but also the relation of a plant with phosphorus recycling to a reference plant without phosphorus recycling. At the present stage of the project, the points have not yet been finally fixed with the subproject participants. However, it is becoming apparent that the secondary fertilizers under consideration offer differently pronounced advantages that must be presented in the comparative evaluation. In this respect, a comparison on different scenarios could be useful, which clearly points out these specifics in each case.

Acknowledgements

We would like to thank the Federal Ministry of Education and Research in Germany (BMBF) for funding this work which was carried out as part of the project “RePhoR – Regional Phosphorus Recycling”.

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