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Bio-based fertilizers: a practical approach towards circular economy

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Abstract

Purpose: The paper desribes issues related with fertilizer industry contribution to implementation of circular economy ideas. Although circular economy is widely discussed by academia and policymakers, it has only been fragmentally implemented in practice.

Methods: Fertilizer industry is the example of sector that has used the concept of recycling and by-products valorization since the early establishment in XIX century. For the past 100 years fertilizer technologies focused on the use of renewable resources. Nevertheless, the majority of manufactured products still bases on mineral deposits and fossil fuels.

Results: According to the assumptions of European Commission the contribution, of non-renewable resources in fertilizer production should reach 30 %. This can be accomplished only if there will be incentives for wastes valorization and fees for using non-renewable raw materials. Also REACH assumptions should facilitate using nutrients from waste by-products.

Conclusions: Because nutrients tend to be intensively mobilized from mineral deposits to the environment, an important aspect is to specify the leakage points of nutrients (ground water, air). This is significant to reduce the problem of eutrophication of surface waters due to the presence of nitrogen and phosphorus, originating from fertilizers leakage from the agricultural fields.

Keywords: nutrients recovery, nutrients cycle, fertilizer industry, Life Cycle Analysis, precision fertilization, preservation of deposits

Introduction

Serious challenges today include growing human population and the consequent security for food, energy and water [1]. Depletion of non-renewable resources has ecological and social consequences. Due to extended resource consumption above the limits with a number of negative footprints it is necessary to implement the concept of Circular Economy (CE) [2] that is currently promoted by the European Commission [3]. The Circular Economy Package was adopted by the Commission on 2nd December 2015. Additionally, regulations for extended producers responsibility in the European Union caused implementation of sustainability. Currently, circular economy and sustainability ideas are widely discussed by academia, industry and policymakers.

The circular economy concept

CE is a regenerative system in which resource input and waste, emission and energy leakage are minimised by slowing, closing and narrowing material and energy loops. This can be accomplished by design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling [4-5]. On the other hand, sustainability is the balanced integration of economic performance, social inclusiveness and environmental resilience, for the benefit of current and future generations [6]. The idea of CE is based on reuse, remanufacturing, recycling, disposal and natural cycles. This would embed end of life of material and product, their acquisition, refinement and would lead to the reduction of costs, time and energy [3]. CE and sustainable development are coherent. Ideally, it would be to adapt natural ecosystem cycles and utilize them in the production cycles. This approach would provide several environmental, social and economic benefits [3, 7].

Circular economy embraces integration of not only sustainability issues, but also business development. Moving towards circular economy requires many modifications in the whole organization and also involves its stakeholders [8]. The ability of implementation is related with the capability of an organization to manage innovation, which is a very important aspect of sustainable development. First of all, the organization should understand the challenges and barriers [2].

The current socioeconomic system is based on a linear economy: companies make products and the consumers use and dispose them [9]. Linear extract-produce-use-dump material and energy flow model that has been applied in practice is unsustainable. Circular economy provides the economic system that is cyclical and includes alternative flow model [3]. In material flow of linear economy, a virgin material enters the beginning of the value chain. This implies resource losses: production chain and end-of-life waste, excessive energy use and erosion of ecosystems. EU is obliged to make transition to a resource-efficient and regenerative circular economy [9]. Generally, the idea of material cycles has been circular. Although CE concept has been adopted by practitioners (policy-makers and business), the idea became rather theoretical and there is still a lot to do to make it implemented [3]. CE concept extends conventional waste and by-product utilization and recycling stressing on the utilization of the value embedded in materials valorization (obtaining as high value applications as possible). This is more than just recycling, that uses materials as raw materials [10]. Theoretically, it would be advantageous if CE would utilize nature's cycles for preserving materials, energy and nutrients for economic use [3, 11].

The circular economy has been defined as an industrial system that is restorative or regenerative by intention and design with the following principles: preserve and enhance natural capital, optimize resource yields and foster system effectiveness [9]. Holistic approach to sustainability involves changes from the creation of a product or service which determines the influence on the entire value chain. Design is of primary importance in supporting closed-loop supply chains [12]. The Circular Economy (CE) is known as a ‘closed loop’ economy. Holistic sustainability goals should be achieved through a culture of no waste. The end-of-life stage of products and materials must be replaced by restoration. Industries should be shift towards the use of renewable energy, the elimination of toxic chemicals and waste, with maximising design [12].

Barriers related to the implementation of circular economy in practice

However, beside a wide discussion, circular economy is only rarely and fragmentally applied in practice. The literature is mostly conceptual or theoretical. Besides the barriers are identified in research, they are rarely empirical [2].

Korhonen et al. [3] identified six main challenges that limit implementation of CE: concerning thermodynamics, definition of CE system boundaries and challenges in the governance and management of the CE-type inter-organizational and inter-sectoral material and energy flows. Implementing CE in the organization transforms the way companies do business, in particular in the manufacturing industry. A challenge is the transformation of production and consumption systems, including creation, fabrication and commerce [12].

Principles of the CE recommend limitation of careless resource depletion and revitalization of existing material value in industry: optimisation of the use of resources and energy through lifecycles, maintaining products and components in use for longer, materials cycle through the system as many times as possible through cascaded uses, utilisation of pure materials for improving quality of post-life use [12]. LCA and carbon footprint reduction tools should be valuable [12].

CE brings the idea of restoration and circularity instead of the traditional concept of end-of-life. It shifts towards the use of renewable energy, eliminating the use of toxic chemicals and aims for the elimination of waste through the superior design of material, products, systems and business models [9].

Biorefineries are only one of few examples of implementation of CE and can be a solution to waste disposal problems with production of fuels, power, heat and value-added products. The waste could become a source of biomass, recycled materials, chemicals, energy and revenue if wisely managed and used as a potential feedstock. The processes of valorization include: fermentation, anaerobic digestion, pyrolysis, incineration and gasification. The successful implementation of biorefinery concept should employ using life cycle assessment (LCA) [1].

Nutrients recovery in fertilizer production

Phosphate rock was listed as a critical raw material by the EU in May 2014 (European Commission, 2014) that should be a push for P recovery from wastewater and other renewable sources. The most important barrier for P recovery is legislation for phosphorus as a resource in fertilizer production or as a pollutant in wastewater treatment. Another challenge is to put recovered phosphorus on the market as compared to fossil fertilizers [13].

Important in green revolution was the invention of the industrial fixation of nitrogen and mining phosphate rocks from historical deposits to produce mineral fertilizers. The invention of the Haber–Bosch resulted in popularity of P- and N-fertilizers causing accumulated surplus of P in soils [14]. Green Revolution began in the 1940s, modern agriculture has intensified natural nutrients (N, P) cycles, showing concerns on their input and output [15]. Input includes: global spikes in the price of phosphate fertilizer together with depletion of phosphate rock – a problem to secure food for growing global population, consumption of animal-based foods and bioenergy sector; and output: excessive P deposition to surface waters causing eutrophication [15]. P acquisition and loss contributes to phosphorus cycle caused by human-intensified P flows to address the sustainability challenges posed by human dependence on P with understanding past trends for predicting the future [15].

The use of P is still inefficient, non-circular and dissipative and only 10% of the applied P reaches the consumer because of resource-scarce society losses (i.e. manure, excretion, erosion and leaching) [14]. At present phosphorus value chain is half-circular. As much as 80 % of phosphorus from non-renewable resources is not reused. The majority is lost in waste food, leaks to ground and surface waters (causing algal blooms), becomes accumulated in soils, sediments or unharvested biomass. More efficient use and recycling can improve the use of phosphorus through reuse of animal, food and human wastes [15].

Phosphorus is a non-renewable resource, essential for life and food production. Imbalanced global distribution of P is a geopolitical problem for Europe. The reserves of P are estimated to be exhausted within 50–400 years (Van Dijk et al., 2016). Morocco holds over 77% of global reserves, while China, Morocco and the US hold two-thirds of global production. Long-term indicators include: higher demand, lower quality, higher production costs predict that the price of P fertilizers will increase [16]. Europe has no phosphate rock reserves and relies on imported mineral phosphates. Phosphorus is also imported in food and animal feed. Food security in EU is dependent on a supply of mineral fertilizers from phosphate rock. EU should move towards a more resource efficient, closed-loop system which reduces overall consumption, prevents losses and recycles nutrients with greater efficiency [16]. On the other hand, there is P excess in nature that causes eutrophication. P challenge solutions include more efficient use of P in society by improvement of recycling [17].

Van Dijk et al. [17] carried out P flow analysis (PFA) studies that provided insight into how humans use and reuse P and pointed out P losses into the environment through identification of hotspots in society as a roadmap to P use security [17]. P flows and utilization as well as setting policies and strategic frameworks for P-management, take into account: agriculture, recovery, bioavailability and use efficiencies of nutrients [14]. Soil is a reservoir for fertilizer nutrients, whereby P is adsorbed to the clay surfaces, Al and Fe oxides, carbonates, organic matter, however the majority is not available to plants. In the past, soil P content and input from organic manure constitute the basis for the cultivation of plants. Because of higher food demand, mineral P fertilizers in the 20th and 21st centuries became the most important source of soil P. This caused P accumulation in the environment resulting in eutrophication [11]. A solution to this problem can be precision fertilization whereby fertilizer doses only supplement the quantity that has been removed with the crops.

It is necessary to become more efficient at every node of the value chain of fertilizers production and application. In phosphorus fertilizers industry, this includes improving the extraction efficiency from phosphate rock, producing fertilizers that make it possible to apply fertilizers optimally and precisely, it is necessary to formulate more efficient animal feeds, reduce food waste to reach more efficient phosphorus use [15].

Fertilizer industry and circular economy

Fertilizer industry faces the needs to implement the idea of circular economy. This is the recommendation of not only EU, but also industry organization Fertilizers Europe. According to this idea, the production of fertilizers should be closed in a loop. A part of raw materials should be substituted with agriculture residual biomass, e.g. post-harvest residues, residues from livestock production and slaughter or from food processing. Closing the loop will enable recovery of fertilizer nutrients from dissipation in the environment and disposal. Linear value chain, however begins with the natural resource and finishes with its disposal. By keeping the raw materials in use, they are prevented from becoming pollutants that lowers environmental damage [15]. The idea of circularity includes the use of by-products from one production process as raw materials [18].

The fertilizer industry from its establishment in the 19th century, has been partly circular and based on reuse and recycling. In the last 100 years, fertilizer industry uses the by-product ammonia and also a range of by-products from different processes. For fertilizer industry, the main objective of recycling to improve the technology by optimization of resource use, closing material loops and lowering emissions. The objective is to reduce dependence on non-renewable resources. This can be achieved, for example, through focus on industrial networks, both local, regional and on a European level. The fertilizer regulation was the first legislation proposed as part of the EU's circular economy package [18]. The mineral fertilizer industry is at the center of several important value chains [18]. The first ammonia was produced as a by-product of city-gas 150 years ago. Sulfur from oil and gas refineries was used to produce essential sulfur containing fertilizers or to use as the basis for the production of phosphate fertilizers [18]. Technical concept such as 'by-product use' is strictly related with the circular economy in practice. However, the barrier is that the EU Parliament suggests allowing the use of by-products on the condition that those by-products are compliant with REACH chemicals obligations [18]. On the other hand, EU hopes that bio-waste will replace up to 30% of the inorganic fertilizers currently used [18].

In the implementation of circular economy, of the primary importance should be clarification and harmonisation of the legislation. Needed is: EU-wide acknowledgement of recycled fertilizers, revision of the fertilizers regulation, quality control of the recycled fertilizers [13]. At present P recovery sector is heterogeneous with small production scale comparing to fossil fertilizers. Plant availability of new fertilizers from recovered nutrients is an important issue. Phosphorus use efficiency should be improved in the whole value-chain: from mine to farm to make the best use of the recovered phosphorus [13].

Recovery and recycle of P in human waste is a part of transition toward a circular P economy. Public perception of nutrient recycling from human waste will become a social norm [19]. A circular P economy is supported by ecological engineering and sanitation. A societal transition to a new circular nutrients economy is a great challenge that can only be met with an integrative approach with intense collaboration of different branches [19]. Funding initiatives, sponsored competitions and policy actions relevant to nutrients recycling are important steps towards circular economy. A part of it is The European Commission's "Towards a Circular Economy: A Zero Waste Programme for Europe" − part of the Europe 2020 strategy [19].

Circular economy approach in phosphorus industry can be improved by optimization P fertilization, collection and recycling of P-rich wastes, improving sewer systems in households, implementation tertiary wastewater treatment of biogenic compounds removal [17]. Although several technologies for phosphorus recovery have been elaborated, the very limited number have been implemented in technical scale. Recovery of mineral phosphorus from wastewater should become a fact, however still is not profitable [13].

Fertilizer technologies for circular economy

There are several bio-based wastes that could be used as a part of raw materials input. For instance, bones are a valuable and concentrated source of phosphorus. Of, course substitution of a part of phosphorite feedstock with bones will generate new technological problems, e.g. higher consumption of sulfuric acid required for hydroxyapatite solubilization in wet process phosphoric acid. In the case of using bones as a feedstock, a part of acid would be necessary for solubilization of organic matrix of bones. The source of nitrogen in fertilizers production could be any waste protein-rich materials, e.g. chicken feather. Digested with sulfuric acid keratinous materials could bring a solution of amino acids that are ready building blocks for plants. On the other hand, a renewable source of potassium could be ashes from power plants, especially from those that use biomass as the feedstock. New opportunities for circular economy creates utilization of waste biomass, e.g. post-extraction residues that could be enriched with micronutrient ions, such as ions of Cu, Mn and Zn to produce bio-based micronutrient fertilizers. The biomass tested was goldenrod and alfalfa.

Conclusions

The concept of circular economy bases on reuse, valorization, recycling and using natural cycles. It includes closing the process in a loop. Recycling relies on utilization and valorization of materials in order to preserve their value. In resource-efficient management a holistic approach on all related sectors in the system should be performed. Although the idea of circular economy is widely discussed scientifically and politically, it has only been fragmentally applied in practice. An example of this implementation is fertilizer industry, that since its establishment had a long history of recycle and use of by-products. Although EU expects that one third of currently used fertilizers from non-renewable resources, will be soon substituted with renewable sources, there are several barriers, mainly of legislative nature, that limit robustness of shift from linear to circular economy. An example could be REACH, directives on wastes or strict levels regulating maximum levels of contaminants in obligatory law. Tax incentives related to the valorization of waste and fees for the use of non-renewable resources could contribute to the development of implementation of CE. An important issue is also the indication of leakage points of nutrients to the environment.

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