Emerging value chains within the bio-economy: structural changes in the case of phosphate recovery

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1. Introduction

Since the last fifteen years, we are witnessing a growing necessity to shift from a fossil- to a bio-based economy (McCormick and Kautto, 2013; Golembiewski et al., 2015). On the one side, there is an increasing need to reduce carbon footprint associated with the usage of fossil resources, and, on the other side, we need to find alternative and sustainable sources to replace scarce minerals. In other words, we need sustainable production systems which in turn can allow facing the global challenges related to the climate change, growing population, and natural resource scarcity (Schmid et al., 2012; McCormick and Kautto, 2013). Therefore bio-economy, that "encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy" (European Commission, 2012, p. 5), is getting increasingly important. Indeed, through a well implemented bio-economy, it seems possible to achieve global objectives, like a reduction of dependence from fossil materials, a more rational natural resource stewardship, and an enhanced food security (Langeveld et al., 2010; European Commission, 2012). However, those transformation activities are complex and require links in the value chains beyond traditional uses (Sheppard et al., 2011). These value chains could not only consist of new linkages, but also be completely redesigned in some cases.

Moreover, the bioeconomy is characterized by a cross-industry nature, as a variety of sectors, technology platforms and production systems are involved to substitute scarce resources by waste streams and/or byproducts. In this case, innovations can generate spillovers involving a unique technology basis between two or more sectors which are hitherto separated (Golembiewski et al., 2015). Those technology-push innovations lead to converging sectors, and, consequently, accelerate emerging new value chains (Boehlje et al., 2011) between different industrial sectors (Bröring and Cloutier, 2008).

Furthermore, innovations including the utilization of biological resources and materials deriving from recycled low value by-products and waste streams are often associated with novel processing technologies and therefore often cause a high risk perception instead of seeing potential advantages (Ekman et al., 2013). For industrial partners at the B2B-level, adoption and diffusion may be hindered by challenges and market barriers like high switching costs, missing downstream processing technologies or a lack of existing quality standards, missing industry standards, novel regulations or lengthy regulatory approval processes. As a result successful product and process development within a bio-economy is more demanding and multidimensional as societal concerns have to be taken into account (Paula and Birrer, 2006).

According to this background, this paper aims to analyze the challenges to tackle when novel value chains emerge in the particular case of recovery of phosphate – a non-renewable and scarce resource – from agricultural waste, implementing a newly developed enzymatic-bioengineering process.

The remainder of the paper is, thus, organized as follows: in the next section, the conceptual framework of the analysis is described, by explaining the mechanisms involved in the process of emerging value chains in case of converging industrial sectors. Then, the case of phosphorus is deeply depicted, in order to highlight its pivotal role in the agri-food system, the challenges connected with its extraction and the necessity to find alternative solutions and production methods, which leads us to define our objectives and research questions. Further, in section 3, the methods adopted in the research, with reference to the chosen case study, are presented together with a description of companies interviewed. The results are reported and discussed in sections 4, by illustrating, first, how the current phosphate value chain is organized and how it might change when implementing the innovative bio-based process of phosphate recovery and, second, by narrating the outcomes of the interviews carried out which enabled us to answer to our research questions. Finally the main findings are summarized in the conclusions, outlining also some practical implications.

2. Conceptual framework

2.1. The emergence of novel value chains in the bio-economy

In the value chain theory, the classical concept describes the flow of a product or service from its original state until it reaches the consumer. Kaplinsky and Morris (2001) differentiate between four main activities within a value chain: design and product development, production, marketing and consumption and recycling. From a practical perspective, value chain structures are highly complex. In the bio-economy, in particular, value chain processes need to cope with the requirements to be sustainable and competitive against fossil processes at the same time (Sheppard et al., 2011). As mentioned before, innovative technology platforms allowing to achieve these requirements give often rise to novel value chains stemming from sectors so far separated- In the literature, three types of emerging value chains are witnessed: substituting value chains, complementing value chains and cross-linking value chains (Figg. 1 and 2).

As depicted in Figure 1a, substituting value chain structures replaced the structures of the previously established value chains (1 + 1 = 1). Since the substituting process is slow, traditional value chains do not disappear immediately but rather little by little until the novel value chain remains solely (Quintana-Garcia and Benavides-Velasco, 2006). A classical substituting value chain presents the emergence of the smartphone, which builds upon the value chains of cameras, mobile phones, music players as well as basic computer functions (Hacklin et al., 2009). Often, substituting value chains lead to the emergence of hybrid products, which offer the combination of multiple functions in one product (Bröring, 2010).

Figure 1b illustrates complementary value chains which integrate alongside the existing value chains and exist in addition to these (1 + 1 = 3). In this construct the complementary value chain realizes synergies and combined functionalities of the established value chains (Quintana-Garcia and Benavides-Velasco, 2006). An example of this phenomenon is the emerging value chain of functional foods, which does not replace the respective value chains in the food and pharmaceutical industries, but finds its place as a complementary structure between these (Bornkessel et al., 2014).

Eventually, value chains can also emerge by novel cross-linkages (Fig. 2). In this case, existing value chains will neither be substituted nor complemented, but rather new links between individual stages of existing value chains are made and allow an independent value chains to emerge. This cross-linking can be classified as a special case of the complementary value chains (Hacklin et al., 2009). Such new networks will take place, for example, when by-products and waste streams are fed into cascade utilization. Biomass production highlights this phenomenon in which resource and technology bases are challenged by new actors and relationships (Haberl and Geissler, 2000; Dautzenberg and Hanf, 2008).

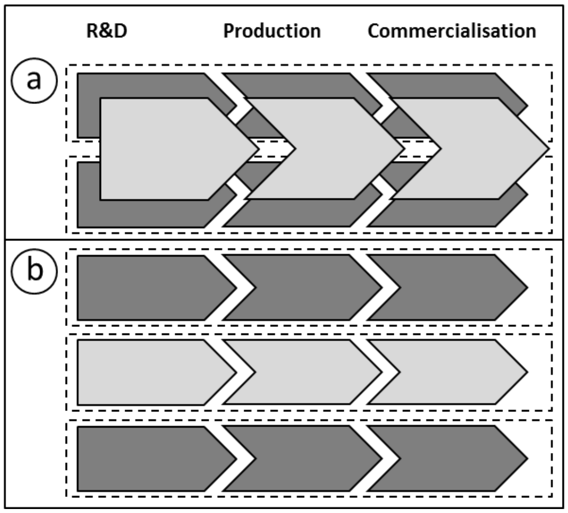

Figure 1: (a) Substituting and (b) complementing value chains
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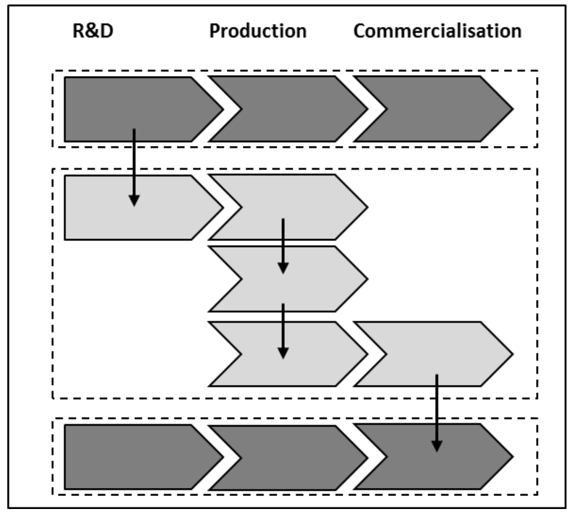

Figure 2: Cross-linking value chain
Source: own illustration

2.2. The importance of phosphate stewardship and the necessity for alternative and sustainable sources

Cascade uses of byproducts, giving rise to emerging value chains, are particularly advantageous when it comes to find solutions for sustainable stewardship of scarce resources. One of these is represented by phosphorus. It is extremely necessary for plant growth, since it constitutes the main raw material for fertilizers, the demand of which is doomed to increase, due to a progressively growing population (Withers et al., 2015a; Rosemarin and Ekane, 2016); thus, it is crucial for agricultural production, which is always more intensive. The phosphorus included in fertilizers derives from rock mined phosphate, making it a non-renewable resource (Rosemarin and Ekane, 2016). This fact determines the continuous dependence from phosphate reserves[1], whose timespan is still not clear and not officially established, even though potential scenarios are arising (Ulrich et al., 2013; Edixhoven et al., 2014; Rosemarin and Ekane, 2016). According to

[1] Phosphate reserves are defined as "geological deposits containing phosphate that can be economically extracted" (Rosemary and Ekane, 2016, p. 268) using existing technology (Van Kauwenbergh et al., 2013). Reserves must be distinguished from phosphate resources, which instead refer to all forms of phosphate available (including reserves), which potentially may be produced in the future (Van Kauwenbergh et al., 2013).

Cordell et al. (2009) the duration of phosphate reserves will last at maximum 40 years, Wellmer and Becker-Platen (2007) extend their forecast to 81 years, whereas Elser and Bennett (2011) argue that reserves might still resist for 400 years, following also the estimates made by the US Geological Survey in 2011. Even though these continuously changing scenarios make somehow difficult to develop a consistent governance policy, however one cannot deny that these reserves are progressively diminishing and, thus, it is possible to assert that phosphorus represents a scarce resource in order to ensure food security (Rittman et al., 2011).

As shortly mentioned above, phosphate is essential for producing food, since it is needed for fertilizers, and through this application it enters the agri-food system. Moreover, it has other industrial applications, such as soaps and detergents, food and beverages, water treatment, toothpaste.

The main challenge to address is constituted by the necessity to maintain the phosphate's supply higher than the demand. In particular, the demand for fertilizers – representing the main destination use (80%) for phosphate rock (Rittmann et al., 2011) – should be taken into account. FAO (2015) estimates assert that the demand of phosphate fertilizers is increasing 2.2% per year, especially in developing countries (Rosemarin and Ekane, 2016). Europe and North America have instead a stable demand, since they only need small applications to integrate the harvest losses (Cordell et al., 2009). The increasing need for fertilizers in developing and densely populated countries is due both to the growing population with consequent greater food necessity and to the changing consumer preferences. In particular, beyond the fact that we will reach nine billion people to feed by 2050, in Asia (especially in China and India) we are witnessing a growth in consumptions of meat and dairy products, which need more phosphate than other goods to be produced due to the larger feed volume and consequent bigger need for forage (Cordell et al., 2009; Rosemarin and Ekane, 2016).

Furthermore, another problem affecting the stewardship of this scarce resource is related to the geographical location of the reserves and, thus, to geopolitics. Indeed, Morocco and Western Sahara hold 75% of world phosphate reserves, and together with China, Algeria, Syria, South Africa and Jordan, they cover 90% of the overall phosphate rock (USGS, 2015). It is worth to mention that, among these countries, China has imposed a 135% export tariff on phosphate to protect domestic supply. Therefore, the fact that phosphate reserves are concentrated in politically unstable countries and that Morocco occupies Western Sahara and controls its phosphate reserves is a sign of power imbalance and could lead to potential tensions, due to the political situation in North Africa and the difficulty for most farmers from poor countries to access to phosphate fertilizers at the current prices (Cordell et al., 2009; Elser and Bennett, 2011; Mayer et al., 2016; Rosemarin and Ekane, 2016).

Finally, albeit being so important for agriculture and food production, we have to underline that phosphate is also subject to huge losses in its pathway from mines to the final users (Cordell et al., 2009; Elser and Bennett, 2011): from an initial quote of 17.5 million tons, after having taken out the 20% destined to other uses than fertilizers, only 3 million tons reach the final users. We can count losses due to distribution, soil erosion, crop pests/diseases, post-harvest losses, food waste, human excreta (Cordell et al., 2009; Elser, 2012). Despite representing a bottleneck for the efficiency of the phosphate supply chain, these losses throughout the system constitute also an environmental problem, especially related to water pollution (eutrophication) due to the leakage of excess phosphorus into wastewater, radioactive by-products and presence of heavy metals (Cordell et al., 2009).

All these issues clearly motivate why there is a need to find sustainable solutions to address the resource scarcity challenge and to enhance the phosphate chain efficiency. We should go in the direction of reusing waste and/or recycling by-products containing phosphate in order to recover and use it for industrial purposes avoiding or decreasing the dependency from mine extraction in the long run (Mayer et al., 2016). This also might foster a better empowerment of stakeholders increasing their awareness about global phosphate limitations and their influence on policy decisions (Rosemarin and Ekane, 2016). Even though only a small amount of phosphorus is currently recycled due to greater costs of recovering than extracting it (Mayer et al., 2016), in the literature there are already proposals of technologies and methods to recover phosphorus, such as spreading of sewage sludge and phosphorus recovery from municipal solid waste incineration fly ash (Kalmykova et al., 2015), and capturing, converting into inorganic form and recovering phosphorus from animal waste (Rittman et al., 2011).

Despite the higher recovery costs, several benefits emerge when considering the total amount of products and services we can obtain from phosphorus capture and reuse, thus supporting this policy (Mayer et al., 2011).

Those phosphorus recovering activities lead to novel value chain structures, which use innovative technologies from distinct industries that require firms to close knowledge and competence gaps (Golembiewski et al., 2015). As Golembiewski et al. (2015, p. 314) say, "converging technologies lead to the horizontal integration of agriculture with other industries. Thereby, new value-added chains connecting the production of biomass, chemicals and energy have to be designed by an integrative application of technologies. The resulting new competitive settings demand for acquiring new capabilities and resource access via collaborations and open innovation approaches".

2.3. Objectives and research questions

Against this background, the paper seeks to qualitatively address the main challenges that can arise whenever different industries converge and novel value chains emerge. To this end, we have taken phosphate as a case study, by analyzing the possibility to recover it from agricultural byproducts, such as rapeseed and sunflower oil press cakes, through an enzymatic-bioengineering process. In particular, the innovation embodied in this process consists in mobilizing and recovering the phosphate, contained in rapeseed and sunflower oil press cakes, by adding an improved variant of the enzyme phytase, and in converting it to polyphosphate of industrial value (Fig. 3). In this way, we could obtain several advantages: first, the produced polyphosphate is completely "bio-based" as it stems from agricultural byproducts; second, the oil press cakes, after the treatment with the optimized phytase, become less rich in phosphate and are, thus, better digestible for monogastric animals (e.g. pigs, chickens) which are fed with these cakes; third, from the environmental point of view, the risk of water eutrophication is reduced, as well as the over-fertilization due to agricultural waste streams (Shilton and Blank, 2012).

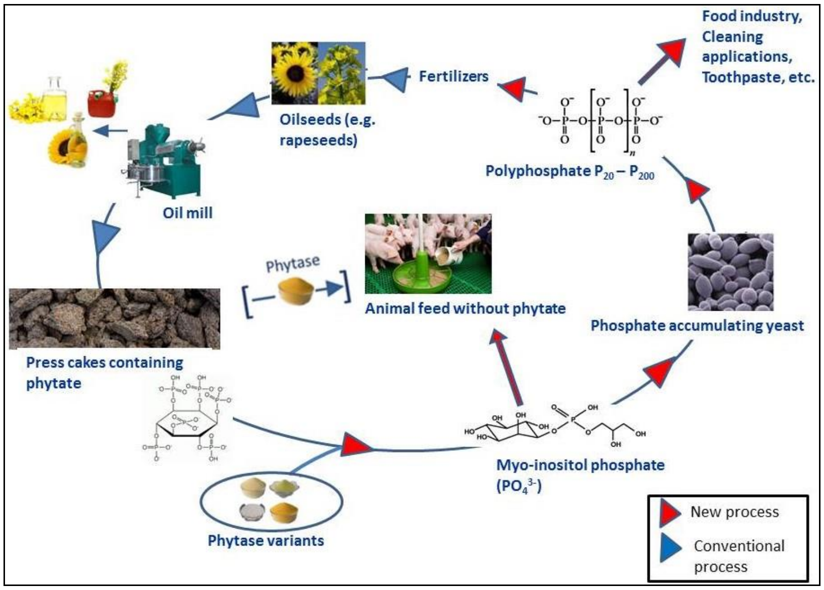

Figure 3: Process of recovering phosphate from oil mill press cakes
Source: own illustration

This innovative process implies that value chains hitherto separated (oil press cakes, enzyme, feed products, polyphosphate) converge, giving rise to a potential new value chain and leading to unavoidable structural changes in the business models of involved chain actors and in the relationships among them.

In the present paper we aim to investigate how chain actors might organize their practices in order to implement this new process to recover phosphate and obtain polyphosphate of additional value. This motivates the following research questions:

RQ1) What are the main bottlenecks and challenges that chain actors should overcome in order to implement the project of a bio-based phosphate recovery from agricultural byproducts?

RQ2) What are the main changes in the value chain structure that can occur whenever sectors hitherto separated converge into a novel value chain?

3. Methodology

In order to address those exploratory research questions this paper is based on a case study approach (Glaser and Strauss, 1967; Yin, 1994). In particular, as mentioned above, phosphate has been taken as case study, as it represents a non-renewable and scarce resource, whose stewardship and ultimately recycling is one of the great challenges of humankind.

Moreover, this phosphate case study is the focus of a project in the frame of which this paper is carried out. The project is called “Efficient phosphate recovery from agro waste streams by enzyme, strain, and process engineering” (P-ENG) and it is funded by the

North-Rhine-Westphalia Strategy Project BioSC (Bioeconomy Science Center[2]), which is aimed at providing the structural, scientific and technological bases to develop exploratory and interdisciplinary research topics for a sustainable bio-economy. This is achieved through the synergistic bundling and integration of existing research skills and innovative technology platforms along a common strategy and a commonly oriented policy. In particular, the P-ENG project addresses two key topics in terms of phosphate stewardship: avoiding the use of phosphate rock for polyphosphate synthesis due to hydrolysis of plant phytate and reducing over-fertilization due to lowering the phosphate content of agricultural waste streams. In this context, we provided our expertise in agri-food economics as well as in technology and innovation management in order to analyze the current phosphate value chain and the scenarios which might arise by implementing the innovation embodied in the P-ENG project, which constitute the aim of the present paper.

Starting from the description of the conventional supply chain, characterized by distinct flows and actors, we carried out a value chain analysis (Kaplinsky and Morris, 2001) in order to depict how the current value chains are working and how the emerging value chains might be organized in case of implementation of the newly developed bio-based process to produce polyphosphate. To this end, we conducted expert interviews with some of the actors of the value chains involved in the process to test and investigate which would be the main bottlenecks and challenges to be faced in case the new bio-based value chain would definitely emerge. The interviews have been conducted via phone, by previously having settled the appointments and explained the innovation embodied in the project as main argument which the interview had been focused on. The companies interviewed are representatives of a polyphosphate producer (A), a rapeseed oil cake producer (B) and an enzyme producer (C). All these companies are located in Germany, in the region of North-Rhine-Westphalia. These companies have been chosen due to their working relationships with project partners.

Company A manufactures and markets approximately 100,000 tons of phosphate per year with about 700 employees. Phosphate is extracted from mines located on the "Plateau des Phosphates" in Morocco. After a cleaning procedure, phosphate is transformed into pure phosphoric acid, which is the basis for the entire product portfolio of the company. Even though phosphate has its main market in fertilizers, company A operates in the market of additive formulations for other industries, like detergents, food, and pharmaceuticals. Indeed, phosphate is used in the detergent production, whereas in the food industry, it serves to ensure many foods to remain healthy and appetizing, especially increasing the shelf life and quality. For example, additives containing phosphate include cheese spreadable products, raising agents, and stabilizers for baby foods. Moreover, it is part of toothpaste formulation, and has other applications in the pharmaceutical, metal processing and plastics industries. In company A, the business lines have their own development units, which consist of application-technology specialists. In addition, it has a central, cross-business line area "Innovation & New Business Development", which deals with medium- and longer-term development projects and has a relevant network consisting of partner companies, universities and research institutes.

[2] For further details, please visit the website: www.biosc.de

Company B is active in the market of rapeseed oil and cakes. From rapeseed, their production is divided in 60% cakes and 40% rapeseed oil. The latter gives 30% more value added than the former. Concerning rapeseed press cakes, they produce 80% of kernel cakes and 20% of shell cakes, with a half price compared to kernel cakes. Kernel cakes constitute a cold meal which is sold to feeding companies which in turn prepare feeding mix for chickens, starting from the cakes and adding other compounds of nutritional value, like vitamins and minerals.

Company C produces integrators for the feeding industry and pre-mix which are going to be added to the feed meals. Indeed, normally the enzyme phytase constitutes an additive to be included in the feed mix in order to make the phosphate digestible for monogastric animals, and the price of phytase is determined by the quantity of phosphorus which is able to release.

4. Results and discussion

4.1. The innovative process of a "bio-based" polyphosphate and the emerging value chain

The innovative process developed to recover phosphate from rapeseed oil cakes to obtain polyphosphate determines a substantial change in the value chain, as reported in figure 4. Indeed, this new process leads to the emergence of a new value chain following the model of a cross-link value chain stemming from the convergence of separated value chains and the cascade usage of byproducts.

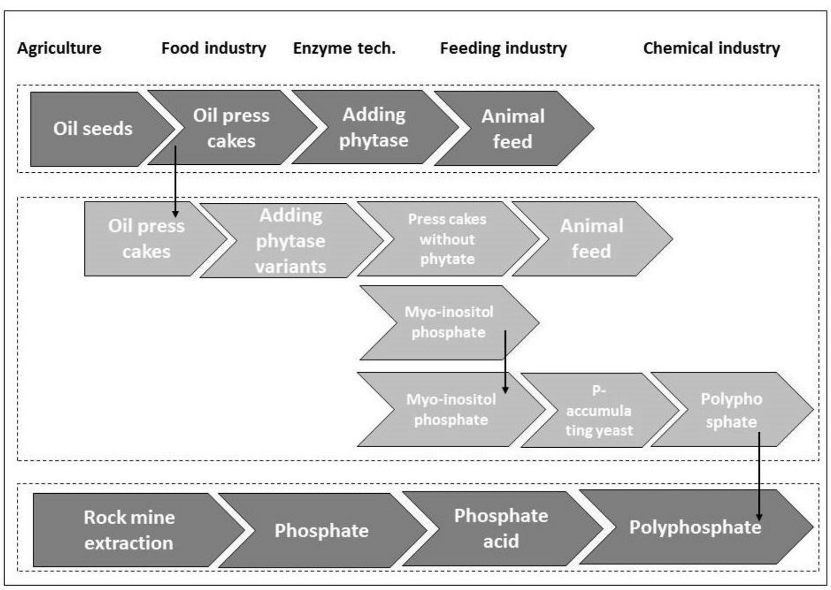

Figure 4: Cross-linking value chain in the case of recovering phosphate to obtain bio-based polyphosphate
Source: own illustration

The oil press cakes deriving from the rapeseed oil production, instead of being delivered directly to the feeding industry, are treated with a variant of the enzyme phytase in order to obtain press cakes with a lower amount of phosphate and a phosphate digestibility for animals of 70-80%. Moreover, the phosphate released, in the form of myo-inositol-2-

phosphate is recovered and constitutes the precursor of polyphosphate, after having being accumulated through a yeast action. The polyphosphate is thus available for all formulations, from fertilizers to food industry. So, the original value chain of rapeseed oil is then connected to the phosphate one through the cascade usage of byproducts.

The benefits provided by this new approach concern the opportunity to recover the phosphate one step before than in the conventional process in order to give to the animals a meal already lower in phosphate, which in turn is better available for the animals by the effect of the phytase variant which allows the phosphate bound in the phytate to be released and accessible for the animals. Indeed, while the non-treated rapeseed meal has only 22-33% of phosphate digestibility (P-efficiency), by treating the feed with the phytase variant, it is possible to get an increase of P-efficiency of 70-80%. That means that the quantity of phosphate excreted by the animals undigested and unused is much lower than in the conventional process, decreasing the water eutrophication. Furthermore, trace elements, which are normally bound by the phytate, can be released as well and do not need to be supplemented in the feeding mix. In addition, after the phosphate recovery, the proportion of rapeseed meal could be increased in the feed, because there is no more phytate, which deteriorates the absorption of minerals. Thus, it is no longer necessary to reduce the amount of the shred to escape a bad P-efficiency. Ideally, all phosphate that the animal receives through the food can be metabolized.

4.2. Potential scenarios of emerging value chains

Regardless of the numerous potential advantages brought by this innovative process, its market adoption and diffusion present several challenges. Companies interviewed highlighted several problems, mainly connected with logistic and necessity of new investments.

Company A is potentially interested since it recognizes the possibility to apply a premium price on the new form of polyphosphate produced, as it would be completely bio-based and it would constitute a sustainable ingredient with an eventual clean label to be developed. Nevertheless, considering that this company is selling polyphosphate formulations targeted on their customers' requirements according to the final destination products, it is depending on yeast fermentation data to determine the properties that the bio-based polyphosphate should have to develop the required functionalities in their final product. Since this new process is still in an embryonic stage, these data are still difficult to estimate. Moreover, company A does not have the know-how in biotechnology needed to run a bioreactor (which is necessary in the new process), and the same happens for company B, leading to a problem of missing resources and competencies. This implies that implementing the bio-based process to recover phosphate requires an investment not only in capital, but also in human resources.

Moreover, company A highlighted some regulatory issues. Indeed, as this new bio-based polyphosphate has actually a new form, because it is obtained through new enzyme variants and yeast accumulation and, thus, presents new properties, it is possible that new regulations are also needed according to different end uses and this leads to uncertainties about the actual implementation of the process on behalf of company A which has the direct access to the market.

Another bottleneck regards the fragmentation in the sector of oil cake producers which determines difficulties for company A to integrate backward along the chain in order to establish contract relationships with press cake suppliers. This issue would arise in particular if the bio-based process of phosphate extraction would be carried out by company A (Fig. 5), which should buy a considerable amount of press cakes to ensure an adequate production to cover the requests of its customers. Thus, a first issue would be to conduct a market research to select the suppliers of oil cakes. Secondly, a tight relationship should be also settled with the enzyme producer, since it would be responsible of the production and supply of phytase variants, which in turn allow obtaining polyphosphate with particular characteristics. Since company A is strictly dependent on the properties of polyphosphate to deliver to its customers a product which satisfy their needs according to the required functionalities and the final use, this step of the bio-process becomes extremely crucial.

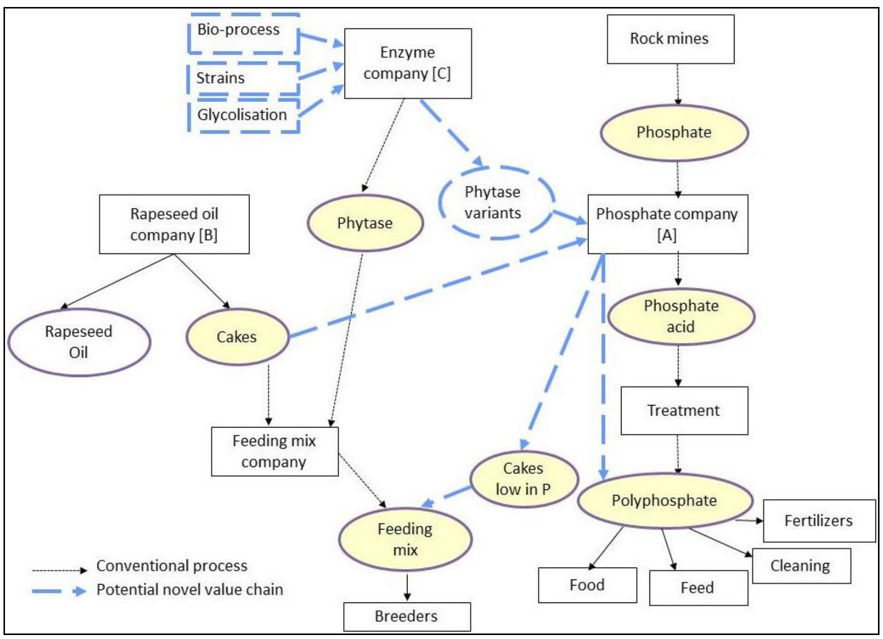

Figure 5: Potential emerging value chain in case the bio-process to recover phosphate is carried out by the polyphosphate producer (company A)
Source: own illustration

At the same way of company A, also company B, representing oil cake producers, shows some doubt in integrating forward in the chain. On one side, in the case of the value chain depicted in figure 5, it should add one extra selling flow for its press cakes directed to company A, instead of normally delivering them to the feeding industry. This might let emerge bargaining power and pricing issues. However, hypothesizing a second possibility, where company B would extract phosphate directly from its oil cakes, it should change its process, by treating oil cakes with phytase variant before delivering them to the feeding industry (Fig. 6). This entails, on one side, to invest in a bio-reactor and acquire the associated know-how, as mentioned above, and, on the other side, to establish new relationships to build new product flows for delivering both the polyphosphate to company A and the treated oil cakes low in phosphate content to the feeding industry. In addition, new relationships should be also established with company C, as it would supply the phytase variant.

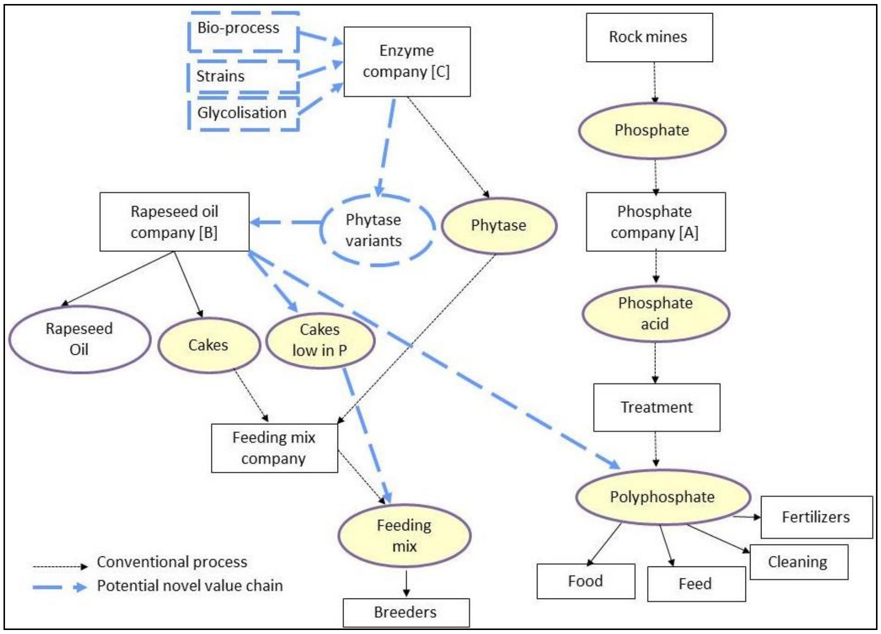

Figure 6: Potential emerging value chain in case the bio-process to recover phosphate is carried out by the oil cake producer (company B)
Source: own illustration

Company C definitely plays a minor role in the value chain management, since it would not have any different investment, but they should just have to implement in the laboratory the bioengineering process to obtain the appropriate phytase variants. Nevertheless, respondents from company C also envisaged another possible value chain (Fig. 7) where the phosphate extraction is done by the feeding mix company, which already receives the oil cakes from the oil cake producer and the phytase from the enzyme company. Apart from investing in a bio-reactor and the consequent know-how needed (as it would happen in the previous scenarios), the major issue for the feeding mix company would be to integrate itself forward in the value chain and make a connection with the polyphosphate producer which in turn has the access to the market. This would entail the setup of a complete new product flow with the polyphosphate company and the convergence of two separated sectors.

Given these challenges, one possible solution highlighted by all the respondents is to involve a new chain partner, who could act as a "collector" for the press cakes and the enzyme phytase and run the bio-reactor to deliver the bio-based polyphosphate to company A, which in turn could enter the market (Fig. 8). This is clearly a relevant logistic change that might overcome many of the bottlenecks underlined. First, the new agent should already have the necessary resources and know-how to run the bio-reactor. Second, it could constitute a "hub" point to collect raw materials, process them and sort the end products by final destinations. That is why it should be also appropriately geographically located, quite close to the other chain actors, in order thus to create a kind of "bio-based polyphosphate district" which could help to decrease logistic and transportation costs and make the overall process even more sustainable.

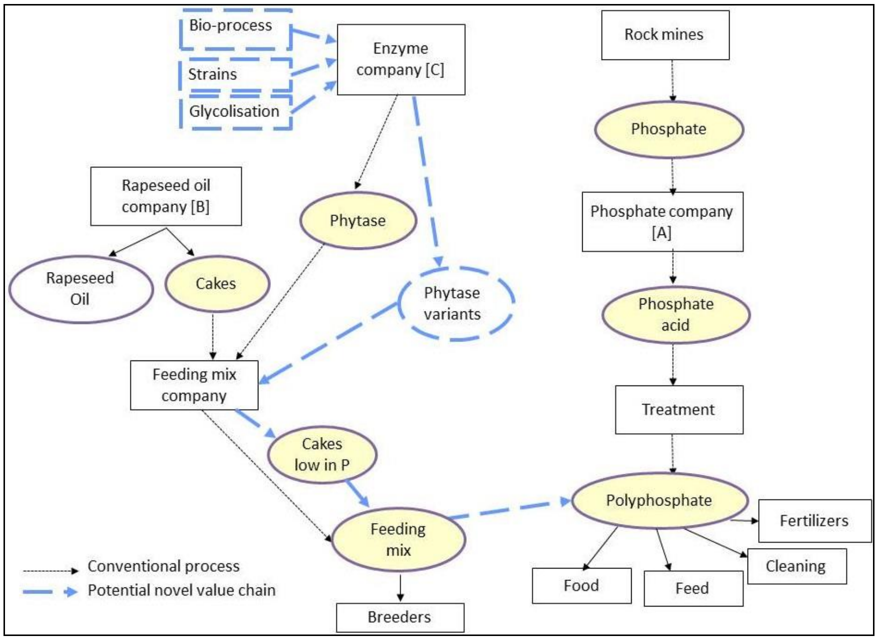

Figure 7: Potential emerging value chain in case the bio-process to recover phosphate is carried out by the feeding mix producer
Source: own illustration

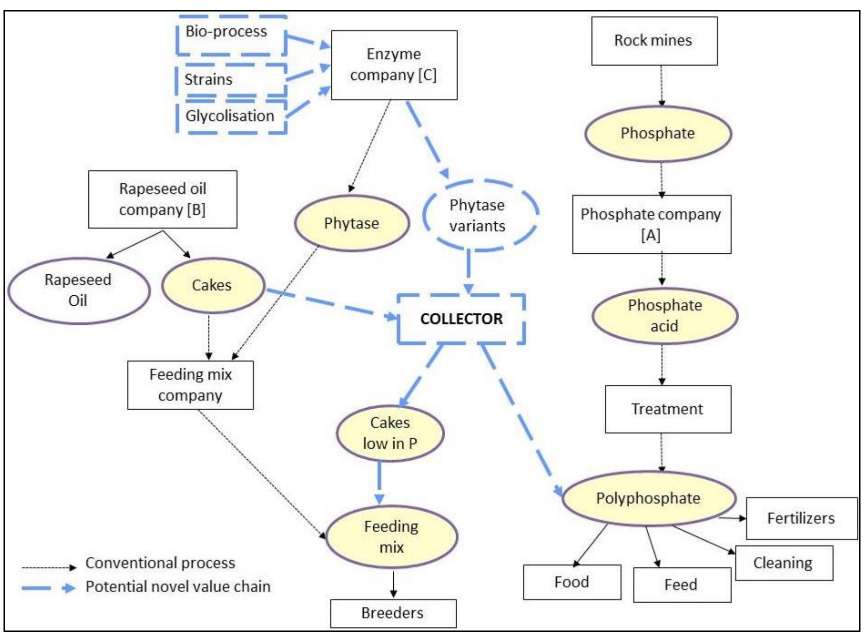

Figure 8: Potential emerging value chain in case the bio-process to recover phosphate is carried out by a collector
Source: own illustration

Finally, the companies interviewed expressed their doubts about the efficiency of the process in terms of coverage of the phosphate needs. The respondents feared that this bio-based polyphosphate would represent only a niche market. Nevertheless, the market size of polyphosphate is 2,500 tons SHMP[3] per year in Germany[4]. This amount of polyphosphate could be covered almost exactly by the amount of oil press cakes. Indeed, according to the German Federal Ministry of Food and Agriculture (BMEL), 8.2 million tons oil press cakes and meal shred were available in the fiscal year 2012-13 in Germany. Out of this amount, 250,000 tons of oil cakes shred can be used for energy production (BMEL, 2014). With a phosphate content of 1%, this corresponds to 2,500 tons, equal to the annually consumed SHMP.

5. Concluding remarks

The literature commonly agrees about both the pivotal role that phosphorus plays in the agri-food system and the necessity, at the same time, to find alternative means for its sustainable recovery, given its finite nature (Rittman et al., 2011; Withers et al., 2015a; Rosemarin and Ekane, 2016; Mayer et al., 2016). Nevertheless, even though there are plenty of examples of innovative ways to obtain bio-based phosphorus (Rittman et al., 2011; Kalmykova et al., 2015), scholars are mostly concentrated in describing and analyzing how the new technologies will work, but nobody seems interested so far in evaluating what is going to happen in the value chain as a whole, in case some new technology will be implemented.

The present paper aimed to close this gap by analyzing, first, the bottlenecks and challenges that chain actors should overcome in order to implement the project of a bio-based phosphate recovery from rapeseed oil press cakes and, second, the main structural changes that might arise in the value chain whenever sectors hitherto separated converge into a novel value chain, such as in the case of phosphorus recovery.

The novel emerging value chain based on the production of bio-based polyphosphate recovered from rapeseed oil press cakes through the action of an improved phytase variant seems already worth the extra investment as this technology allows saving resources and not being dependent on phosphorus imports; moreover, the polyphosphate can be used directly in the food industry and in the other sectors of interest as well as the oil cakes can be used as feed less rich in phosphorus, contributing thus to a better environmental effect.

Despite the underlined advantages, our findings from the expert interviews revealed several bottlenecks, mainly connected to the hesitation of respondents in making new investments in terms of equipment and know-how, to the missing competencies, and to the difficulties in integrating different sectors, such as those of rapeseed oil cakes and phosphate. Furthermore, structural changes needed to implement the novel bio-based

[3] Sodium hexametaphosphate (SHMP) is a hexamer of composition $(NaPO_3)_6$. It has several end uses, especially as emulsifying agent. Indeed, it can be utilized as an active ingredient in canned milk, cheese powders and dips, spreading cheese, whipped topping, as well as in toothpastes (Barz et al., 1999; FDA, 2014)

[4] These data have been provided by project partners from the Institute of Applied Microbiology of RWTH Aachen University (Germany)

technology make the process still far from being actualized. Indeed, logistically, there might arise several possibilities according to who would engage in the phosphate extraction from oil press cakes. At the moment the solution which seems to best fit all current chain members is involving a new chain member to act as a "hub" for collecting the press cakes, running the bio-reactor, and delivering the end products to the final destination (feeding industry and phosphate industry).

This structural change might lead to several benefits and managerial implications. First of all, the collecting actor will already own the necessary resources and competencies allowing overcoming the problem of missing equipment and knowledge. Second, it would be located close to the other chain members in order to facilitate the product flows of raw materials and end products. In this way the transportation costs and the gas emissions will be reduced as most as possible. Third, the geographic closeness among chain actors might lead to the development of an industrial district (Marshall, 1920; Schmitz and Musyck, 1994), specialized in the production of bio-based polyphosphate stemming from agricultural byproducts, such as rapeseed oil press cakes. The creation of such a district could have several advantages, like the possibility to differentiate the end products with an "umbrella brand" which can justify a premium price, to establish a network helpful for sharing resources and knowledge, to develop further open innovation projects.

Limitations of this study are connected with the small number of companies interviewed, which represent only a starting example of actors which are already involved in the project. At present, the interviews had the objective to investigate the possible future scenarios, but concrete data about product and financial flows are not available yet to have a clear picture of the implementation and scale-up of the technology.

Further research, thus, will include the enlargement of the sample of companies interviewed, also involving the feeding industry and organizations of oil seeds milling companies. Moreover, it will worth to analyze a real feasibility scenario in order to increase the awareness of chain actors about scarce resources and the necessity to get engaged in sustainable solutions to recover them.

Therefore, we could conclude that, even though the proposed bio-based process is still in an embryonal stage, there is a certain interest in the perspective to profit by a bio-based source of phosphate. Nevertheless, several challenges emerged, related to competencies, logistic and chain relationships which motivate the necessity to go deeper in this research field to find feasible and sustainable solutions to put in practice.

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