An innovation systems model for innovation research in the bio-economy

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Abstract: To cope with diverse global pressures, the petroleum based economy is transitioning to a bio-economy. Radical and incremental changes in the involved industries will be the cornerstone to successfully innovate towards this more sustainable system. However, the traditional innovation models such as technology push and market push will not suffice. Their inflexible, linear, uni-disciplinary, closed approach is unable to consider the diverse, multi-disciplinary aspects of the innovation system, leading to inefficient innovation efforts. Despite many valuable contributions, the widely recognized innovation system approach lacks the sophisticated models of the other, more traditional approaches. We therefore build on previous innovation models and related literature to develop a model for innovation research in this innovation systems perspective. The result is a comprehensive model with four important features. Innovation research is done in an (i) inter- and transdisciplinary manner to take into account the different techno-scientific aspects as well as socio-economic aspects of innovation. Also, the boundaries of the process and organization are systematically opened to a (ii) network with a wide variety of stakeholders to benefit from the various advantages of stakeholder participation. Furthermore, the process has no explicit starting point (iii) and is conceived as (iv) cyclic with possibilities for iteration and feedback to fully exploit the advantages of networking and stakeholder participation. In this paper this new model is developed and further illustrated with three bio-economy cases.

Keywords: System innovation, Bio-economy, Conceptual model, Participation

Introduction

Because several global trends threaten to undermine welfare worldwide, radical changes towards more sustainability are needed in the material and agri-food systems (Paredis, 2011). The agri-food system is mainly organized as a food-providing industry, often using wasteful production methods. To increase its sustainability, the agri-food industry is making a transition towards becoming a supplier of bio-material for the whole bio-economy. The bio-economy comprises of those industries that produce renewable biological materials as well as the industries that process those materials into products like food, feed, bio-based products and bio-energy (OECD, 2013). With this transition more of the available biomass will be used in a more efficient way. To realize this transition, incremental innovations alone will not suffice. More radical technological innovations, known as system innovations, are crucial for a successful transition to a more sustainable system (Van Humbeeck, 2003).

Due to its complexity, the applied innovation research providing those innovations will have to be organized on the interface of different disciplines. Biotech researchers and developers therefore have to take into account both techno-scientific aspects as well as the socio-economic aspects such as social norms, legislation, supply chain formation, logistical challenges, cost efficiency, end user adoption and market formation. However, classic science-driven innovation research models often focus heavily on the scientific and technological aspects while only briefly examining the socio-economic issues at the end of the research process. This frequently results in a multitude of unrevealed barriers that prevent end-user adoption.

Thus, these classic research models which are often restricted to a single discipline and usually follow a linear process from research over development and demonstration to diffusion, will not suffice to develop innovations that help the agri-food industry's transition. To circumvent the barriers biotechnological inventions face and to identify the underlying multidisciplinary bottlenecks, methodologically innovative, more holistic research approaches are needed.

In this paper we build on relevant innovation concepts, such as open innovation (e.g. Chesbrough, 2012) and Technological Innovation Systems (TIS) (e.g. Geels 2002), to develop a model for innovation research in the bio-economy. The model is multidisciplinary, dynamic, flexible and nonlinear. It takes into account the importance of end-user adoption from the initial phase of the research process. With intense multi-stakeholder participation as the backbone of the model we identified a number of research steps, structural components and research functions needed for biotechnological innovation research. The practical implementation of the model is illustrated by means of three empirical research cases in the bio-economy.

The remainder of this paper is structured as follows: in the next section, we elaborate on the important properties of an innovation model in the innovation system perspective. All identified key properties for innovation research are then bundled into a conceptual model useful for research in the bio-economy followed by a more detailed explanation of the initial phase of the model, the scope definition phase. Next, three illustrative empirical cases from the bio-economy are described and their empirical implementation of the scope definition phase is explained. After discussing our findings, this paper ends with formulating some conclusions and avenues for further research.

Properties of the innovation model

To make the transition to a bio-economy, numerous incremental and radical innovations need to be developed. These necessary innovations need to be applicable in the field and wanted by the industry, end-users, policymakers and special-interest groups. Currently, most agricultural innovation researchers use a linear model of knowledge creation and transfer of technology (Hermans, 2011). This science driven approach is designed to aid in answering a fundamental scientific question, starting from the latest scientific and technological state of the art (EU SCAR, 2012). These traditionally follow a linear path, assuming that innovation stages follow each other seamlessly (Gallagher et al., 2012). The results are techno-scientifically sound inventions, but these inventions are often inapplicable to real world problems. One of the main reasons for the inapplicability are undiscovered bottlenecks which hinder the market adoption. These bottlenecks can originate from different dimensions of the dominant socio-technical regime. Geels (2002, 2005) distinguishes six dimensions that form a socio technical regime: user practices and markets, science, technology, culture, policy and industry.

In order to identify and develop solutions for the diverse bottlenecks, integrated knowledge of multiple scientific disciplines is required. The knowledge needed for biotechnological innovations is far too complex for a single organization (Van Haverbeke and Cloodt, 2006). However, numerous organizations try to generate, develop, build, market, distribute and finance the innovative ideas by themselves (Brocco, 2012). Given that technology is becoming increasingly complex, multidisciplinary and dynamic (Holl and Rama, 2011), the traditional, linear, science driven approach with its uni-disciplinary focus and closed boundaries, is no longer sufficient (Bigliardi et al., 2012).

Innovation is therefore increasingly approached from a systems perspective. The system approach states that innovation is a collective activity involving many actors which is influenced by the institutional setting and corresponding incentive structures, including the market as well as government policies (Gallegher et al., 2012; Klerkx et al., 2012b). Another concept, similar to innovation systems, is sociotechnical system which is related to transition theory. This theory recognizes that major transitions through innovations not only involve technological changes, but also changes social aspects such as user practices, regulation, industrial networks and infrastructure because these different system aspects are linked and aligned (Geels, 2002; Hekkert et al., 2007).

These system perspectives thus acknowledge the inseparability of social and technical aspects in an innovation process. The dynamic co-evolution of these dimensions identified by Geels (2002, 2006) can provide both opportunities and bottlenecks for innovation processes and in order to identify these multi-dimensional opportunities and bottlenecks, linkages have to be made across disciplinary boundaries and between theoretical development and professional practice, transcending any academic disciplinary structure (Hadorn et al., 2006; Pohl, 2005; 2008; 2011).

Transcending these boundaries requires systematically opening up the organization, during all phases of an innovation project, to a network with a wide variety of stakeholders. Stakeholder participation provides access to various types of multidisciplinary knowledge from these different expert stakeholders (Voinov and Bousquet, 2010; Kutvonen, 2011; Bigliardi et al., 2012; Gallagher et al., 2012) relieving the individual organization of the task to generate these different types of knowledge internally. Also, despite the additional costs that developing and maintaining a network brings, the financial research cost per organization is reduced by participation (Sarkar and Costa, 2008; Chesbrough, 2012; Bigliardi et al., 2012). An additional significant advantage is the beneficial influence of stakeholder participation on market adoption, as participation is known to decrease time to market (Chesbrough, 2012; Gallagher et al., 2012; Giannopoulou et al., 2011; Holl and Rama, 2012; Sarkar and Costa, 2008), to help gauge which new concepts stakeholders are looking for (Von Hippel, 1987; Spithoven and Teirlinck, 2006), to help create awareness, legitimacy, support and credibility for the outcome of the innovation research (Van haverbeke and Cloodt, 2006; Caird et al. 2008; Sarkar and Costa, 2008; Arnold and Barth, 2012), and to facilitate market formation (Von Hippel, 1987; Spithoven and Teirlinck, 2006; Te Brömmelstroet and Schrijnen, 2010).

In this multi-stakeholder, multi-disciplinary setting, learning between collaborating partners plays a vital role, necessitating a process with frequent iteration and feedback to be able to repeat process stages to undertake corrections, adjust to unforeseen developments and correct mistakes (Bruns et al., 2008; Hadorn et al., 2006; Pohl, 2005; 2008; Hermans, 2011; Gallagher et al. 2012). This implies that innovation processes should be organized in a non-linear, iterative, flexible way with interconnected cycles (Kroon et al., 2008; Bruns et al., 2008; Arnold and Barth, 2012; Gallagher et al., 2012; Pullen et al., 2012).

Organizing the innovation process in this open way entails that an organization's innovation process does not have an explicit, fixed starting point. While every innovation sprouts from an innovative idea, the process of the innovating organization does not, by definition, have to start with idea generation. For instance, idea generation can be skipped when a stakeholder offers a partnership to further develop a prototype he is working on.

In summary, innovation models in this system perspective should be (i) organized in an inter- and transdisciplinary manner to take into account the different techno-scientific aspects as well as socio-economic aspects of innovation. Also, the boundaries of the process and organization are systematically opened to a (ii) network with a wide variety of stakeholders to benefit from the various advantages of stakeholder participation. Furthermore, the process has no explicit starting point (iii) and is conceived as (iv) cyclic with possibilities for iteration and feedback to fully exploit the advantages of networking and stakeholder participation. In what follows, the participatory innovation model is developed.

Development of a Conceptual Model Useful for Bio-technological Research

In order to perform innovation research taking into account multiple disciplines, diverse stakeholders, and nonlinear, dynamic aspects, a participatory innovation model is needed. We construct this model based on work from amongst others Bergek et al. (2008), Bruns et al. (2008), Gallagher et al. (2012), Fetterhoff and Voelkel (2006), Wallin and von Krogh (2010), Nambisan et al. (2012) and own insights. The result is a model consisting of eight phases: an innovation impulse, a scope definition and actor identification phase, a stakeholder selection phase, a problem identification and idea generation phase, a project design phase, a research and development phase, real life small scale tests, and the market formation and knowledge diffusion phase.

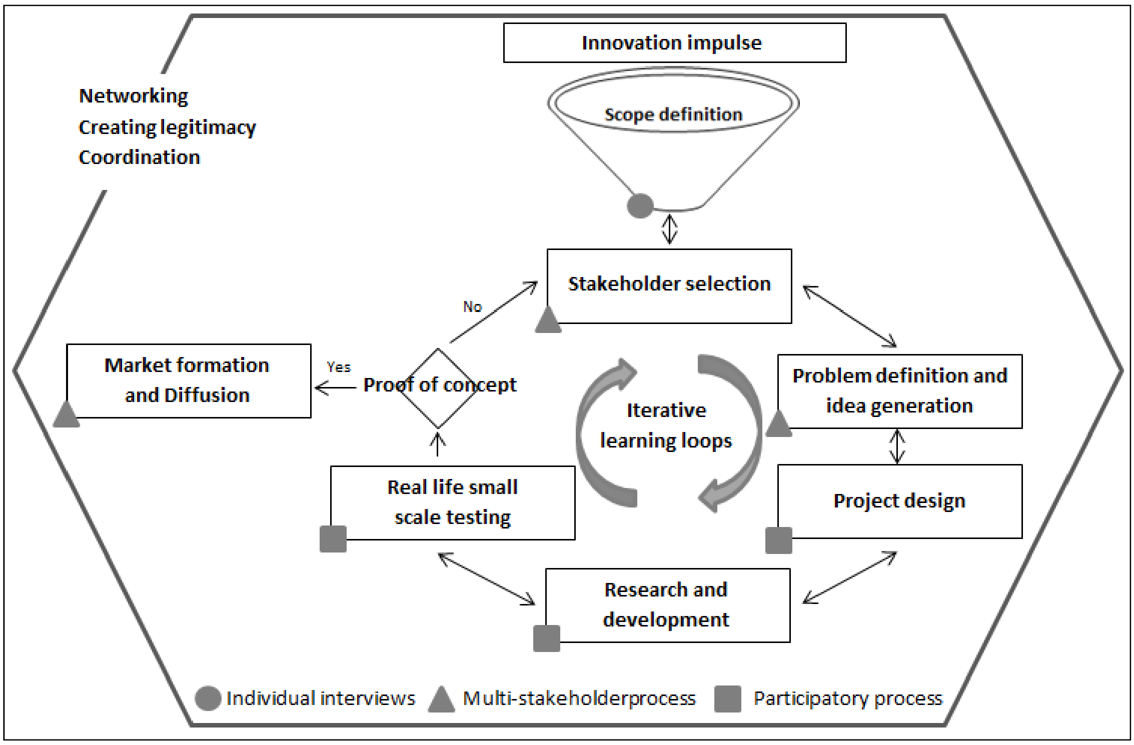
The innovation impulse is the inspiration that starts an innovation research process. It stems from a challenge, opportunity or problem in society, a supply chain, an industry or a single organization. This impulse can thus be diverse in scale and origin. It can originate from a research institution that wants to investigate ways to help remedy a societal pressure such as the increased resource scarcity. Likewise, the impulse can be a logistical problem experienced by a supply chain member.

This impulse leads to the statement of a broad research goal. The broad research goal for the research institute will be 'to develop an innovation that reduces resource use', while the broad goal of the supply chain member will be 'innovate the production process to eliminate the logistical problem'. Whatever the source and scale of the innovation impulse and the resulting broad research goal, it has to be compelling enough for different stakeholders to encourage their participation in the subsequent research and development process.

The broad research goal resulting from the innovation impulse can be met using diverse possible innovation research pathways. Each pathway has its own advantages and disadvantages, depending on the presence or absence of different bottlenecks. Separating the high potential pathways from those with lower probabilities of success, is done during the scope definition phase. This phase identifies and narrows down the number of innovation pathways, using a quick scan of relevant literature and stakeholder consultation. Also during this phase, the innovation network is expanded with stakeholders that can aid in the research process, starting with narrowing the research scope. This important exploratory phase is explained in more detail in the next section of this paper, including three illustrative cases.

From the innovation network that was built in the scope definition phase, a number of stakeholders are selected for further investigation of the identified high potential research pathways. The selection is based on aspects such as the match between the desired resources (both human and financial), the level of trust between stakeholders, the necessary roles in the innovation research process etc. After the stakeholder selection phase, the participating stakeholders enter a problem definition and idea generation phase. In this phase, the group of participating stakeholders reviews the research goal and potential pathways identified during the scope definition phase. As a group they help pinpoint other problems and opportunities that were missed in the scope definition phase. Once the problems and opportunities are clear, the heterogeneous stakeholder group with multidisciplinary knowledge helps to generate ideas that result in integrated win-win solutions for every stakeholder involved. The next step is to translate this in a project design. In this design the necessary research is described and the tasks and corresponding roles are divided. Once the project design is formulated, a research and development phase can start. During this phase, the different ideas that were identified during the idea generation phase are developed and tested for feasibility. The options that yield positive results are then tested in small scale tests in the real world. With a proof of concept, a phase of diffusion and market formation can begin.

Figure 1: A nonlinear, iterative model for innovation research in the bio-economy



Source: Bergek et al. (2008); Bruns et al. (2008); Gallagher et al. (2012); Fetterhoff and Voelkel (2006); Wallin and von Krogh (2010); Nambisan et al. (2012) and own insights

Although the research process above is described in a linear fashion, the execution is not. Figure 1 shows the different phases as a flexible, nonlinear, iterative learning process. The nonlinear, flexible use translates in the possibility to swap around different phases or the (partial) integration of different phases to better suit the specific needs of the research. For instance, during the problem definition phase, some basic R&D tests can be conducted to better understand the problems or opportunities. Another example is going back to an actor selection phase during R&D because some essential type of capital is missing. One can also (partially) cycle the process several times, for instance first as an exploratory cycle to assess the feasibility of several high potential research pathways and then a more profound cycle concentrated on the pathway with the highest potential. Another option is to repeat some smaller partial cycles, such as a loop of project design, R&D and real life testing until the result is satisfactory or looping the actor selection phase and problem identification phase until all the right stakeholders are selected and every angle of a potential pathway is covered.

Also in figure 1, the different phases are linked with an interaction mode that best suits it. Examples of modes are individual interviews, multi-stakeholder processes and participatory processes. These linkages are another example of the flexibility of this model. Using some multi-stakeholder processes in addition to individual interviews during the scope definition phase for instance, can be more efficient to narrow the research scope. Furthermore, while conducting the innovation research, the participating stakeholders are responsible for overlapping activities such as further networking, the creation of legitimacy for the innovation and the coordination of the research efforts. Because the scope definition phase is a crucial step in determining the followed innovation pathway, it is further explained in the next part of this paper.

Detailed Development of the Scope and Actor Identification Phase

The scope definition and actor identification phase is a broad exploratory phase that connects the innovation impulse with the first innovation phases. In this phase the research field within the scope based on the innovation impulse is briefly explored pursuing two objectives. The first objective is to adjust the scope of the research in order to better delineate what the subject of research is. Depending on what the scale of the innovation impulse is, the scope will need to be widened or narrowed. When the innovation impulse is a rather narrow research goal, like the improvement of a company's production process, the scope will need to be widened to see the bigger picture. Modifying one company's production process can have consequences for the whole supply chain. The scope will thus need to be widened from a fragmented research goal of a single company to a coordinated and integrated research goal with potential gains for every stakeholder involved. With a very broad and general research goal, such as increasing sustainability in the bio-economy, the scope will need to be narrowed down to a coordinated and integrated innovation research goal in order to be workable. All research goals originating from the innovation impulse thus have to be viewed from a multi-disciplinary, integrated value- and supply chain perspective, taking bottlenecks and opportunities of all involved stakeholders into account.

To identify which innovation pathways can lead to such an integrated research goal, they have to be analyzed and evaluated. An important criterion that determines the feasibility of an innovation pathway is the presence or absence of bottlenecks that hinder development and implementation. As previously mentioned, such bottlenecks can arise from all six dimensions of the current socio-technical regime: user practices and markets, culture, science, technology, policy and industry (Geels, 2002; 2005). Determining the different bottlenecks can be done by scanning relevant literature and through stakeholder participation.

Identifying stakeholders interested in joining the innovation network around the innovation impulse is the second objective of the scope definition phase. Primary sources to find relevant stakeholders are industry associations, patent analysis and expert interviews (Bergek et al., 2008). Relevant stakeholders are those stakeholders that can help identify bottlenecks or that can provide financial capital or supporting resources. Generally, information about user practices and markets can be obtained from end-users and supply chain partners. Supply chain partners and industry associations are well suited to isolate the industry bottlenecks. Research institutes have expertise to help identify scientific and technological bottlenecks. Policy makers are well suited to pinpoint bottlenecks in policy and laws. Cultural bottlenecks are more general in nature, and can be provided by every stakeholder group. Not only do their areas of expertise differ, different stakeholder groups also have different incentives for participating in innovation research. Industry partners for instance are looking for innovations that will increase their profitability, environmental NGO's seek sustainability, research institutes are after scientific challenges, while policy makers and governments want societal benefits. A valuable research pathway thus offers promising incentives or opportunities for the different involved parties combined with manageable identified or anticipated bottlenecks.

The joint definition of an integrated research goal, as well as the innovation network formation, co-develop during this phase. The followed scope definition process indicates which stakeholders are contacted for information and cooperation, but the stakeholder interaction also influences which direction the scope definition process takes. Through this constant interaction, both the scope definition and actor identification objectives can be achieved thoroughly though quickly. In what follows, three empirical cases from the bio-economy are presented as an illustration of the above mentioned aspects of the scope definition phase. We start by giving a short description of the cases using their innovation impulse followed by summarizing the bottlenecks and opportunities identified using the scope definition phase as well as how the phase assisted in building the innovation network.

Description of Empirical Cases

The following three bio-economy cases are all initiated by a public research institute in Flanders that specializes in applied research in the agricultural and fisheries sector. After a brief description of the innovation impulse that led to the startup of the projects, we illustrate how the different researchers made use of the scope definition and actor identification phase in the next section. All three cases are using the conceptual model presented in this paper.

The first case focuses on valorization of by-products from agricultural production and processing. Despite continuous efforts to increase the efficiency of agricultural production and industry processing methods, large quantities of by-products are still generated. A large part of the plant-based by-products are currently treated as waste and thus not or only partially valorized. Given pressures such as the increasing resource scarcity, this suboptimal usage of by-products is a waste of potentially valuable resources. The increasing number of research that is being done on the higher valorization of diverse streams of agricultural by-products, is showing promising results. This is the innovation impulse for the first case, resulting in a research project with the broad starting goal: the high-value valorization of vegetable and fruit by-products from the agri-food industry. Which by-products and which valorization methods will be pursued should be determined during the start of the innovation research process.

The innovation impulse for this first case is in part responsible for the innovation impulse for the second case. The intense use of farmland puts pressure on the fertility of the soils. With the valorization of by-products being a hot topic, an increasing number of by-products that normally remain on the field are now removed. This results in a gradual decrease of organic matter content and in nutrient leaching, important factors in soil fertility. Composting by-products can be a sustainable solution for this problem, as compost is a slow working fertilizer that is a source of stable organic matter with large quantities of stable carbon. Compost also increases soil biota, thereby increasing disease resistance and decreasing the need for pesticides. Despite these benefits, compost is hardly ever used by farmers, indicating that there are different bottlenecks hindering this. This led to a research project with the innovation impulse: the valorization of by-products from agriculture and horticulture through composting. Here, in contrast to case one, the type of valorization is already determined, composting. The main challenge at the start of this case is identifying the bottlenecks and selecting which bottlenecks will be the focus of the project.

The innovation impulse that motivated the third case originates from the ‘discard ban’ measure to reform the fisheries industry into a sustainable industry that only fishes at maximum sustainable yield level. With this ban, discarding damaged, undersized, quota restricted or low value fish will no longer be allowed. This means these economically less interesting fish will take up a considerable part of the available hold space, since avoiding unwanted fish in the nets is impossible with the current fishing technology used in Flanders. Currently, for undersized or underutilized fish landed, only relatively low value pathways of animal feed and energy production exists. Without more profitable ways to valorize these discards, the profitability of this already highly competitive business is further pressured. This resulted in a research project with the innovation impulse: a valuable use for discards, valorizing unwanted and underutilized fish.

Application of the Model to the Cases

In case one (fruit and vegetable by-products), the first goal in the scope definition was to determine which by-product will become the focus of the innovation research process. After listing all cultivated crops in Flanders, the first step was to evaluate them on four criteria: by-product availability (crop production volume, number of volume by-products per crop, seasonality), geographical spread, current application of the by-products and the necessity to adjust harvesting techniques. Based on these criteria, five crops were further scanned for potential. One of these crops is Belgian endive, as it has four streams of by-products, a year round availability, a geographically concentrated cultivation and no major adjustments have to be made to the harvesting technique. Scanning the literature and current research projects revealed that little research is performed on Belgian endive, indicating a lack of knowledge about its biochemical components. To get a better idea of the composition of Belgian endive, the literature on chicory, a vegetable from the same botanical family as endive, was explored and revealed the potential presence of several high value components. More research into the current applications of Belgian endive by-products revealed a valorization as feed for animals or as input material for compost, while the potential for higher valorization is present. Since food processing companies feel that food by-products should be used in food applications as much as possible, the possibility of a food application was investigated. More specifically, to circumvent the novel food regulations, the possibility of extracting food additives was explored. Inulin is such an additive that is currently extracted out of chicory. Inulin is thus an interesting pathway for valorization of Belgian endive by-products since there is a market for it and an industrial scale extraction process exists.

This information was collected by scanning relevant literature and by consulting multiple different stakeholders such as farmer advisors, the industry association representing the fruit and vegetable processing companies, fruit and vegetable processers, farmers, several organizations with expertise in the cultivation of Belgian endive and the national federation of food processing companies. These consultations form the basis for the innovation network, the second goal of the scope definition phase. This because many of these stakeholders can play a role later in the research process. Furthermore, the consulted stakeholders provided contact information of several potentially interesting other stakeholders.

The second case, concerning composting, used the scope definition phase to identify all bottlenecks and opportunities concerning on-farm composting. A first identified issue is the subsidies that are given for the generation of green energy out of biomass. This results in considerable amounts of biomass used as a green energy source, which in turn leads to a shortage of woody material. This important fiber rich component gives structure to compost. Several possibilities for solving this shortage of wooden materials were identified: lab tests show that by-products from nature conservation can be used as fiber rich material, clippings from road sides show potential, tree breeders have green and brown waste that can serve as a substitute and fruit cultivators have fiber rich pruning waste. A second consequence of the subsidies is that composting by-products is economically less attractive than using by-products as an energy source. Another bottleneck is the very complex regional legislation concerning composting resulting in required permits, as many by-products are currently considered waste products. The need for compost and willingness to use it on farms was also investigated. The fruit sector and biological farmers are looking for a general soil improver with high water retaining capacity and high organic matter content that is uncontaminated with pathogens and weed seeds. Additionally, the time of nitrogen-release should match with the needs of the crops, something which is currently impossible. Tree breeders are also looking for a general soil improver to maintain the organic matter content of the soil. A general reoccurring concern from the farmers is that the compost quality is inconsistent, making it unreliable. There is thus a need for clear compost parameters and adjustment of the process in such a way that the compost consistently meets those parameters. Companies that use potting media are looking for a substitute for peat, an unsustainable input material in potting media. Using compost as a substitute could be a possible research pathway. A qualitative compost requires several diverse by-products, which are often unavailable at the individual company. Getting the by-products all in the same place, forms a logistical challenge. This means getting the material from someplace else, creating an additional (transport) cost. A last identified bottleneck is that composting requires a significant investment in machinery and manpower.

Intense stakeholder interaction was used to collect this information. Several compost researchers, farmers from different agricultural activities, tree breeders, small businesses specialized in composting, nature conservators, as well as the national farmer association, the Flemish composting organization, national federation for potting media, a research institute specialized in fruit cultivation, a producer of grass sods and an industrial composter were contacted to acquire a multi-dimensional view. These stakeholders, especially the industry associations, as in case one, also offered contact information of other potentially interesting stakeholders. This case also used the scope definition phase to start building an innovation network consisting of stakeholders from diverse stakeholder groups.

The discard ban case faces a significant policy bottleneck as it remains unclear what the final policy on the discard ban will look like. It could be that the European Union decides that the obligated landings or processed products cannot be sold with a profit. Another possibility is that some valorization options will be prohibited, such as applications for human consumption. This could be a possible issue when pursuing high valorization options. Another issue is the uncertain availability since the amounts of fish being discarded on vessels depends on a multitude of variables like time of fishing, fishing ground, fishing technique, weather, etc. This makes estimating the total volume of bycatch that will have to be landed very difficult and estimating the bycatch of a single fish species nearly impossible at this time. To overcome this difficulty and to compensate for seasonal differences, the chosen valorization pathway has to be applicable to a whole group of fish (flatfish in Flanders) and not only to one specific species. Fish silage is a product that offers a lot of opportunities to meet those requirements. Furthermore, this relatively simple technology requires lower investment costs compared to the production of its competitor, fish meal. The process is also very flexible because the size of the containers can be adjusted to the supply of fish. As long as the silage is kept in sealed containers it can be conserved for up to two years without loss of quality. A research opportunity presents itself in trying to reduce the water content (currently 80%) of the silage to reduce transport costs. Another challenge is increasing the protein content of silage, which is currently only 15%. Fish silage can be marketed as a fertilizer or as animal feed. However, the agricultural industry has prejudices towards the use of fish products in animal feed due to fish odor and/or taste in the meat, milk and eggs. But fish silage has the benefit of having a malty smell and not leaving a taste in animal products. However, because Flemish pig farmers do not use mash diets, there is currently no market for fish silage as an input material for pig feed.

Stakeholder consultation and network formation remains limited in this case. Aside from consulting fisheries and animal feed researchers and a government official, not much contact with stakeholders has been made. The most important reason for this is the uncertainty about the way the discard ban will be implemented, as it significantly influences which stakeholders will be relevant for the innovation research.

Table 1 gives an overview of the different bottlenecks and opportunities presented in the three cases. It clearly shows that opportunities (+) and bottlenecks (-) concerning innovation arise in all regime dimensions. In order to identify these diverse opportunities and bottlenecks and to be able to generate solutions for them, a multi-dimensional perspective and research approach is thus needed.

Table 1: Overview of identified bottlenecks (-) and opportunities (+) in bio-technological cases

	By-products of Belgian endive	Composting by-products	Silage from fisheries by-products
User practices and markets	+ Current low value applications + Existing market for chicory-inulin	+ Compost has product properties several agricultural subsectors are looking for	- No market for products from bycatch + Possible markets for fish silage
Culture	+ Food by-products should be used in food applications		- Agricultural sector fears a fishy odor in their products + Silage does not have a fish odor
Science	- Little knowledge about biochemical components	+ Substitute for peat needed - Optimize composting process	- Low protein content in silage - High water content in silage
Technology	+ No major adjustment needed in harvesting technique + Little adjustments to inulin extraction process		+ Fairly simple and flexible technology
Policy	- Novel food regulation	- Subsidies for green energy from biomass - Complex regional regulations - Many by-products are considered waste products	- Uncertain implementation of the discard ban + No recognition of food safety organization needed
Industry	+ Adequate by-product availability + Year round availability + Geographically concentrated	- Shortage of woody materials +/- Woody material available in some sectors but no established supply chain - Collection of by-products in one place - Investments in composting machinery and manpower	- Uncertain available bycatch + Lower production cost compared to fish meal + Long shelf life

Discussion

The flexible and iterative nature of the research process is also illustrated in these cases. Case one and three used the scope definition phase mainly to narrow down the different possible innovation pathways, while case two used it to broaden the view and to identify all potential bottlenecks and opportunities that different stakeholders experience. Furthermore, in case one, a focus group was used to check correctness of gathered data and to receive information, while the other cases relied more on individual interviews. Another example of the flexible and iterative use of the model is the preliminary research conducted in case two. This created a learning loop, giving information about the feasibility of different nature management by-products. The cases further show how important stakeholder participation is to quickly expand the knowledge of the individual organization. For instance, thanks to stakeholder interaction in case one, an additional potentially valuable by-product of endive was discovered. The importance of the scope definition phase as a networking phase is also illustrated. Both in case one and two the innovation network expanded during the scope definition phase due to acquired contact information from other stakeholders. The co-development of the integrated research goal and the innovation network is demonstrated as well. For instance, in case one, based on interviews, the harvesting technique becomes a criterion for selection, indicating the importance of consulting stakeholders with this technical knowledge. Another example is how, in case three, the prejudice towards fish products by farmers influences the direction of search towards pathways with limited odor problems.

Although the three cases offer an illustration of how the innovation process can be approached using this model, they all show several limitations. Two important limitations are the number of cases and their diversity. More cases originating from different innovation impulses can confirm the validity of the model. Furthermore, in this paper we especially focus on the first phases of the innovation model. In addition, important aspects such as arrangements about roles, responsibilities and division of outcomes, important issues in collaborative innovation research projects, are not treated here. Stakeholder selection criteria, evaluation tools and process measurements and how to evolve from an innovation network towards a supply chain are other examples of important issues.

Conclusion and Avenues for Future Research

Due to the multidisciplinary nature of bottlenecks that hinder innovation adoption, a nonlinear, flexible, iterative research approach with intense stakeholder interaction is required. In this paper we propose such a conceptual model. An innovation research model is needed to provide a rationale to evolve from an innovation impulse to a technologically sound and supported innovation. Such a rationale helps to structure the complex process of innovation research and can give guidance and support to every stakeholder involved. It can furthermore form a basis for continuous discussion and realignment amongst the diverse group of participating stakeholders.

As illustrated in three cases, a scope definition phase is needed to either broaden or narrow the starting innovation impulse towards a workable, integrated research goal and to identify the most promising valorization pathways. Furthermore, in the scope definition phase, by identifying and interacting with diverse stakeholders, the innovation stakeholder network is constructed which will support the remainder of the innovation research.

As well as further validation of the innovation research cycle, more research on best modes of stakeholder interaction, network arrangements and monitoring and evaluation tools is needed.

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Annex: Analytical framework to evaluate the technical proximity to organic farming

CROPPING PLAN (1 POINT)*

Variables	Classes of scores		
	< 0.5	0.5	1
Number of botanical families	> 5	4	1-3
Total number of crops	> 7	5-7	< 5
Presence of pulses	Pulse fodder crops	Pulse non-fodder crops	None

* In view of the specific difficulties of converting to OF with sugar beet (no organic market in France), a surcharge of 0.5 points is applied to farms that have a sugar beet quota to signify a distance from OF.

CLEANING CROPS/WEED-PRONE CROPS RATIO (1 POINT)

Variables	Classes of scores		
	< 0.5	0.5	1
Ratio	> 0.5	0.3-0.5	< 0.3
Number of cleaning crops	> 2	2	0-1

CROP SEQUENCE (3 POINTS)

Variables	Classes of scores		
	1	2	3
Type of sequence in relation to agronomic risks	Low risks (with sunflower, field beans or pulse fodder crops)	Intermediate (with maize or peas)	High risk (with rapeseed, potato or sugar beet)
Predominant sequence	Predominance of intermediate sequences and low risks (> 50%)	Risky sequences (50-70%) and share of other types of sequence	Predominantly risky sequences (> 70%)

WEED MANAGEMENT (4 POINTS)

	Variables	Classes of scores			
		1	2	3	4
PREVENTIVE	Share of winter crops	Close to a 50/50 balance; share of winter crops between 40 and 60%		imbalance; share of winter crops < 40% or > 60%	
	No tillage/tillage	100% tillage	Mainly tillage	50/50	Mainly no-tillage
	Preventive levers	cover crops, covering power of crops	Stale seed bed	Delayed sowing date for wheat	No preventive lever
	Length of sequence	long > 4 years		short < 4 years	
CORRECTIVE	Herbicide strategy	Reduced doses on several crops		Reduced doses on wheat, tolerance for weeds > 0	No reduced dose, tolerance for weeds 0
	Mechanical weeding during cultivation	On cereal crops, even for trials	On traditionally hoed crops (sugar beet, rapeseed, maize, etc.)	Minority or trial on a non-cereal crop	none

FERTILIZATION MANAGEMENT (4 POINTS)

	Variables	Classes of scores			
		1	2	3	4
PREVENTIVE	**Pulses in the cropping plan**	Large surface areas under pulses (> 15%) including pulse fodder crop	Surface areas between 5-15%	Surface areas < 5%	No pulses
PREVENTIVE	**Intermediate crops**	Pulses; considered as green manures	intermediate crops important in strategy but improvement underway	Practiced but seen as a constraint or compliance with regulations	Not practiced
CORRECTIVE	**Mineral fertilization strategy**	Stated wish to reduce doses of nitrogen	Adjustment and respect for a maximum dose	Insurance and adjustment in relation to crops and varieties	Insurance and decision-aid tools to steer inputs
CORRECTIVE	**Organic inputs**	Integrated on the sequence and generalized to reduce mineral fertilizers	Generalized on a crop	Practiced but on small surface areas	Not practiced

MANAGEMENT OF PESTS AND DISEASES (4 POINTS)

	Variables	Classes of scores			
		1	2	3	4
PREVENTIVE	**Choice of variety**	All resistant or hardy varieties	Mainly hardy varieties	Mainly sensitive varieties	Only sensitive varieties
PREVENTIVE	**Implementation of the principles of integrated farming**	All the principles on several crops (integrated farming system)	Implementation of all principles on all types of wheat	Implementation on wheat of several principles but not all and not on all the varieties	None or one (e.g. delayed sowing date for wheat)
PREVENTIVE	**Reconfiguration of plots**	implementation	No implementation		
CORRECTIVE	**Fungicide – insecticide strategy**	Acceptance of no treatment	Objective one fungicide and zero insecticide on wheat. In dose reduction, use of intervention thresholds.	Fungicide and insecticide depending on the years, reduction of dose, use of intervention threshold	Fungicide, insecticide, full doses, systematic
CORRECTIVE	**Reduction of TFI (/ regional TFI)**	Reduction of TFI on all crops	Reduction of TFI on wheat	Reduction of TFI on some varieties of wheat	No reduction

WHEAT MANAGEMENT (3 POINTS)

Variables	Classes of scores		
	1	2	3
Mineral and organic fertilization	Organic input (in addition to mineral)	No organic input but reduction of mineral inputs	No organic input. High levels of mineral fertilization (> 180 nitrogen units for regular wheat; > 220 nitrogen units for high-protein wheat)
Chemical and mechanical weeding	Mechanical practiced (even as a complement or a trial)	No mechanical weeding but reduction of chemical weeding (number or TFI)	No mechanical weeding. Weeding difficult to improve.
No-tillage/tillage	Systematic tillage	No-tillage for certain types of wheat	Generalized no-tillage
Integrated production	Implementation of all the principles of integrated farming	Implementation of certain principles or certain types of wheat	No principle implemented
Reduction of treatments	Dead-end possible for fungicide and insecticide	TFI reduced on fungicide and insecticide at least on certain types of wheat	No TFI reduction for fungicide and insecticide