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How to Advance Sustainable Innovations for Circular Bioeconomy: Perspectives from a Public Research Institute

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Abstract

This paper develops an innovation mapping tool for circular bioeconomy products in the context of a Finnish public research institute. The aim of the tool is to improve invention and innovation process to enable efficient invention transfer and eventually the production of innovations. The mapping tool, i.e. questionnaire was developed for the Natural Resources Institute Finland (Luke), combining risk management, new product development, and innovation process perspectives. The authors interviewed researchers, developed the framework based on the interview analysis and tested the tool in a workshop and with the selected bioeconomy case product (suberin). Key findings from the case study are 1) for a bioeconomy product to be successful, it is necessary to understand the entire value chain, especially the needs of end users and markets; 2) the sustainability risks (including the regulatory environment), and risks and responsibilities among the participants in the development process need to be carefully defined. In addition, the research and innovation process could ideally involve stakeholders at an early stage in order to better meet their expectations.

Keywords: Invention; Innovation; Risk Management; Public Research Institute; Bioeconomy; Circular Bioeconomy.

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1 Introduction

The world is facing complex problems such as climate change, pollution, resource scarcity, and biodiversity loss and should urgently transition to more sustainable practices (Rockström et al., 2009; Steffen et al., 2015). Sustainability transitions are enabled by sustainable innovations stemming from research – both private and public organizations. Transition to the bioeconomy and especially the **circular bioeconomy**[1] is seen as advancing sustainability by reducing dependence on

1. **The bioeconomy** covers all sectors and systems that rely on biological resources, their functions and principles. It includes and interlinks land and marine ecosystems and the services they provide. To be successful, the European bioeconomy needs to have sustainability and **circularity** at its heart. This will drive the renewal of our industries, the modernisation of our primary production systems, the protection of the environment, and will enhance biodiversity (European Commission, 2018, p. 4).

fossil fuels, advancing resource efficiency, and enabling the utilization of biomasses and following cascade principles (OECD, 2018; Stegmann et al., 2020).

However, there are relatively few studies that approach the circular bioeconomy from the innovation management perspective, although the importance of knowledge generation and innovation is seen as crucial for the transition to the circular bioeconomy (Van Lancker et al., 2016, p. 60). Importantly, the transitions literature, especially strategic niche management, emphasizes the role of niches (protective spaces for innovations, e.g. market or technology niche) that have the potential to challenge the current regime (Schot & Geels, 2008; Smith & Raven, 2012). However, the role of some actors like public organizations (de Vries et al., 2016), especially public research institutes (PRI), is less prominent, which risks the picture of development of e.g. niche or even path-breaking innovations being insufficiently rich, or that all the actors needed for successful innovations or commercialization will not be considered (Benz, 2022; Walrave et al., 2018). This paper focuses on the challenges of invention and innovation process development of a public research institute to enable efficient invention transfer and the production of innovations. In addition, this paper combines new product development, innovation process, and risk management perspectives, especially in a context of the circular bioeconomy, to identify relevant questions to enhance the process.

1.1 Definitions of innovation process and innovation management

The work of Singh and Aggarwal (2022, p. 191) has recently contributed to a **unified definition** of innovation. They argue that innovation can be defined as "the operationalization of creative potential with a commercial and/or social motive by implementing new adaptive solutions that create value, harness new technology or invention, contribute to competitive advantage and economic growth".

Linear and stage-gate models have been prominent approaches to the **innovation process** (Cooper, 2011; Godin, 2006), and both are firm-centric. More recently, models have evolved toward more participatory approaches, such as **systemic innovation**, i.e., "the innovation process is constructed in such a way that the participants within it use methodologies, methods and techniques to make their thinking and action more systemic" (Midgley & Lindhult, 2021, p. 643). In addition to the critical role played by participants in the innovation process, there are critical factors in the management of innovation: the involvement of relevant stakeholder groups and network management to enable truly **collaborative innovation** (e.g. triple and quadruple helix approaches) (Barrie et al., 2019; Carayannis & Campbell, 2009; Van Lancker et al., 2016). In addition, the role of **transformative social innovation** in the context of more technical product or service innovation may be of interest. Pel et al. "conceptualize social innovation in terms of changing social relations, and transformative change as the process of challenging, altering, or replacing dominant institutions in a specific socio-material context" (2020, p. 2). However, in the context of the circular bioeconomy, social innovation and inclusion require more research (Ludvig et al., 2019; Souza Piao et al., 2023).

In addition, there is a wealth of literature on the innovation management of business organizations. The goal of the innovation process in business organizations is to generate profits through innovation, and the need for renewal and innovation is imperative (Afuah, 2003). The importance of knowledge as an economic driver has implications for innovation management, which is a key determinant of competitiveness in the modern knowledge-driven economy (Hidalgo & Albors, 2008). The process of innovation has been described as having three stages: invention, implementation, and diffusion (Osborne & Brown, 2013). The focus of innovation in the private sector is on products, services, processes, markets, strategies, business models and management innovations. The same is true to the public sector, but in addition there are policy and governance innovations (Bekkers et al., 2011; Osborne & Brown, 2013). The invention phase can be seen as equally applicable to both public and private organizations, although there are differences, for example, in the management of inventions and intellectual property rights (IPR). However, the implementation and diffusion phases are critical to the success of the innovation. A public organization, such as a research institution, may sell or license its IPR to a private organization, which is then responsible for the implementation and diffusion phases (Osborne & Brown, 2013).

The importance of public organizations for the innovation process has been studied and acknowledged in the innovation management literature: see, for example, systems of innovation (Edquist, 2001; Edquist Charles, 2010), the triple helix (Cai & Etzkowitz, 2020), and more recently innovation ecosystems (Mazzucato & Robinson, 2018; Yin et al., 2020). Innovation and **new product development** (NPD) are often viewed and researched from the perspective of business organizations (Adams, 2016; Geissdoerfer et al., 2018; Hart et al., 2003; Pedersen et al., 2020). In addition, innovation and NPD are often viewed as an intra-organizational process, with certain entry or exit points to the external environment, and actors involved in extensive knowledge and information exchange: the collection of market data and customer needs, technological and scientific knowledge, and concepts of new business models (Kratzer et al., 2010; Lewandowski, 2016; Rainey, 2005). Innovation of sustainable products, services, or product–service systems is not only driven by material supply or demand (Kim & Chai, 2017), customer needs, regulations, or public policies. It is also very much a question of **sustainable business model** design (Doganova & Eyquem-Renault, 2009; Geissdoerfer et al., 2018). For that matter, business models are themselves a source of innovation (Geissdoerfer et al., 2018). To promote a circular bioeconomy perspective, it is crucial to move from organization-based or internal innovation strategies to more ecosystem-based co-innovation and systemic innovation, while also considering social aspects. **Innovation ecosystems** offer a promising approach to enhance sustainable innovation and tackle issues related to cross-organizational collaboration and value co-creation (Gomes et al., 2018; Yin et al., 2020). Additionally, the literature on systems of innovation has been predominantly influenced by actor-focused approaches advocated by regional or national innovation systems, which often propose linear and local solutions for the development of innovation systems. However, this approach has limited value as it fails to consider the complex social and value chain dynamics involved in value creation. (Jucevičius & Grumadaitė, 2014; Yin et al., 2020, p. 125).

Value chains add another dimension to the circular bioeconomy**.** The dynamics of the value chains are complex, as the production of end products typically involves several steps: cultivating a renewable raw material or the collecting a biomass sidestream, logistics to a "refinery" location, refining or converting the biomaterial into a product (e.g. the extraction of a substance), producing the end product application (e.g. a cosmetic consumer product where the original product is used), and distributing the end product to the end user. Furthermore, to prevent any waste all sidestreams from the entire value chain should be utilized, in addition to following the cascading principle. When dealing with potentially lengthy value chains, the circular bioeconomy necessitates increased cooperation and the development of new business models (Klitkou et al., 2019). The complexity of value chains (or even ecosystems) also requires different kinds of understanding of the potential risks and responsibilities.

1.2 Context of the case study

The paper presents a case study of the Natural Resources Institute Finland (Luke), a Finnish **public research institute** (PRI), and its processes of innovation transfer to private companies in the circular bioeconomy market. However, there is limited research on this topic (Kang, 2021; Siegel et al., 2023). Moreover, in the Finnish context, public research institutes[2] have been overshadowed by universities in relation to knowledge transfer to the private sector (Davey et al., 2018; Husso & Moilanen, 2021). Natural Resources Institute Finland (Luke)[3] operates under the Ministry of Agriculture and Forestry and aims to promote sustainability and well-being using renewable natural resources. Luke's task is to promote competitive businesses based on the sustainable use of renewable natural resources. To fulfil this task, research can produce inventions, such as products that aim to develop circular bioeconomy businesses and markets.

Researchers play a key role in producing innovative research results and **inventions**. Inventions are one measure of Luke's research impact. A well-protected invention can also provide a significant advantage to a SME seeking growth opportunities.

In Luke, the law of employment inventions[4] applies. According to the law, the employee must notify the employer, and the employer decides whether to take possession of an invention. If the employer chooses not to take possession, the inventor can use the results of their creative work independently. With the guidelines for inventions, Luke aims to encourage the making and reporting of inventions and their protection through intellectual property rights (IPR)[5].

Luke's internal development project aimed to improve the impact of research results by identifying sustainable new bio-based products (e.g. protected by patents). Additionally, the project aimed to identify the business and market needs of selected products, as well as potential risks. A comprehensive risk assessment is one way to address the challenges of the innovation process and product development in the circular bioeconomy.

1.3 Risk management in the circular bioeconomy innovation context

As discussed, circular bioeconomy innovations deal with products using natural renewable resources. In this study, the focus is on the potential features (both internal and external) of circular bioeconomy innovation but also to find risk management solutions to problems that hinder the development and production processes of the potential innovation. In general, innovation potential is lower if the main risks of the innovation cannot be managed. Enterprise risk management and new product development are processes that both often employ the integration of methods to handle multifaceted holistic risks or problems in innovation, i.e. infrastructure, resources, production process, logistics, people, values, and the environment (COSO, 2004; Rainey, 2005).

Risk management is coordinated activities to manage and treat risks in an organized way (ISO 31000, 2018). A risk is an event that has typically had hazardous consequences with a certain frequency or probability. The positive side of a risk also considers the opportunities of that risk and the possible benefits of risk taking (CAS, 2003; ISO 31000, 2018). A systematic risk management procedure is also seen as a method for handling holistic risk management (Lanne, 2007). This includes a procedure for defining context and finding information for risk identification, risk analysis, risk treatment, and monitoring (CAS, 2003; ISO 31000, 2018; SFS-IEC 60300, 2000). First, the system context for enterprise risk management is defined. The risk management context includes the directions for risk identification and risk analysis, which should then be

2. In Finland, there are currently 12 publicly financed research institutes in seven administrative sectors. The primary task of state research institutes, which are the main actors in sector research, is to acquire, produce, and provide information as the basis for political decision making and the development of society. https://www.stat.fi/meta/kas/valtutklait_en.html

3. www.luke.fi

4. https://www.finlex.fi/fi/laki/ajantasa/1967/19670656

5. IPR are intangible rights and are usually divided into 1) copyright and 2) industrial rights. Luke's operations generate research results that are protected by intellectual property rights. Copyright is the author's right to their literary or artistic work. Industrial rights, on the other hand, are exclusive rights that protect inventions, for example.

connected with enterprise strategy, activities, resources, people, and the environment. The risk matrix is a typical tool in risk assessment for combining the risk likelihood and impact (Pritchard, 2010). Various enterprise risk management tools are also used in some bioeconomy sector risk management studies (Leppälä, 2016; Leppälä et al., 2015). Managing risk usually depends on the context and focus of the risks. Risk management can be seen as tools like risk mapping, contracts, collaboration methods, network management, conflict handling, communication planning, Canvas planning, PEST or PESTLE analysis, cost benefit, risk benefit, cost utility methods, etc. These tools can be useful in circular bioeconomy innovation design and risk management (Cabric, 2015; COSO, 2004; Leppälä, 2016; Pritchard, 2010). In this study, the focus is on a circular bioeconomy innovation process case and its risk mapping.

2 Materials and Methods

This paper presents the development of an innovation process for a public research institute, the Natural Resources Institute Finland (Luke), aimed at facilitating efficient invention transfer and promoting innovation. In addition, the paper integrates perspectives on new product development, innovation process, and risk management, particularly in the context of the circular bioeconomy, to create a useful tool for enhancing the process. This study's products are bioproducts targeted to circular bioeconomy markets because they represent the inventions i.e. research products of Luke. The research approach used is the constructive research approach, which aims to solve problems by producing constructions. The constructive method employs procedures and testing as an iterative process to develop, for example, workable management tools and techniques. The case study data is based on interviews with Luke's innovation experts and an expert workshop for innovation process modeling (see Table 1). Constructive research often utilizes qualitative data but as it is used in mixed methods research, it could also include quantitative data (McGregor, 2018). However, this study systematically applies qualitative research methods and content analysis to develop an inductively derived model for the innovation process case. Additionally, authors mapped drivers and barriers of the suberin product (Mayring, 2014).

Table 1. Materials of the case study.

Type	Number of participants	Materials produced	Products discussed
Interviews with circular bioeconomy innovation researchers	6 (Principal researchers, senior research scientists, scientific experts)	Interviews produced 40 pages of notes of which 14 pages on suberin.	Suberin (x2), tannins, betaine, stilbenes, industrial wood construction, and engineered wood products
Workshop for circular bioeconomy innovation experts	10 - Seven principal researchers, senior research scientists, scientific experts. In addition, three workshop organizers	7 completed workshop templates resulted in 66 pages of material.	Suberin was presented as an example case for all participants. Phenolic compounds from blackcurrant press-cake, new fiber sources, and fiber properties for sustainable packaging, fats from insect production (x2), wood-based antivirals, liquid from pyrolysis (x2)

Based on the literature on sustainable innovation and new product development (NPD) (Adams, 2016; Rainey, 2005) and the enterprise risk management framework (ISO 31000), the authors developed a comprehensive questionnaire consisting of 27 questions (see Appendix 1). This set of questions was used in the interviews with the circular bioeconomy researchers. The interview data was analyzed using content analysis (Mayring, 2004).

After analysis the questionnaire was divided into 10 sub-themes. These sub-themes were then tested in Luke's circular bioeconomy expert workshop, and the final analysis was conducted to design a questionnaire or tool for circular bioeconomy innovation mapping. Additionally, the case product was selected (suberin) based on analysis. In the content analysis of the case product, it was essential to systematically look at the innovation case and collect the relevant findings from the analysis for the development of innovation planning methods. Additionally, drivers and barriers of suberin case were mapped. Figure 1. describes the research and data collection process.

2.1 Formulating the interviews

The questions in the questionnaire were developed iteratively, utilizing the authors' different areas of expertise, including product and business development and risk assessment and management (see Appendix 1). Questions 1–9 deal with the product itself, its production, value chain and production environment, and stakeholder expectations. Questions 10–13 and 17–24 focus on risks, vulnerabilities, regulation, potential permits and the safety of production, and the product itself. Questions 14–18 assess the business potential and market issues, while Questions 25–27 evaluate the next steps and financial opportunities, both internal and external, for advancing research and product development.

The questionnaire was tested by interviewing six highly experienced researchers or experts from Luke. They had either produced a bioproduct invention or had been deeply involved in the

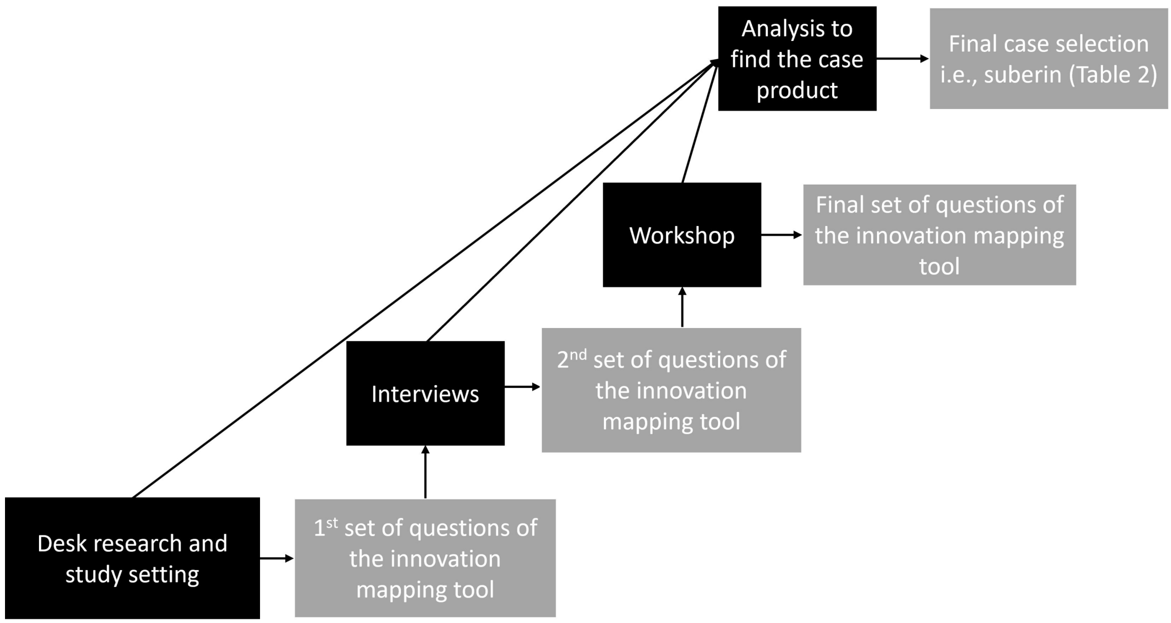

Figure 1. Research and data collection process.

research process of one. The selection of interviewees developed during the process to obtain the views of researchers with a knowledge of different kinds of bioproducts and markets.

The interviews were conducted online via Teams due to Covid-19 restrictions and long travel distances. They lasted between 1.5 and 2 hours. The interviewees were willing to discuss their work, and it was easy to persuade people to be interviewed. Some interviews were recorded using the Teams functionality, and detailed notes were written during all the interviews. During the interviews, notes were shared on a computer screen to allow for immediate corrections if any errors were made. Additionally, the interview notes were sent to the interviewee for their review and correction to ensure technical accuracy. The interviews resulted 40 pages of notes, which were then compiled into a table. The authors independently analyzed the data and made observations and notes. Summary and conclusions are presented in Table 2.

2.2 The expert workshop test

Based on the feedback of the interviewees and the analysis of the interview data, the questionnaire was developed to be more compact, finally comprising 10 questions in addition to background questions. The workshop method, which involves collaborating with experts from various fields, is commonly used in risk management to identify effective management solutions for problems and risks. The circular bioeconomy industry sector encompasses various natural resource disciplines, such as land use, agriculture, forest research, the aquatic sciences, gaming, and environmental research. Eventually, workshop templates or worksheets (in Finnish and in English) were developed for the internal researcher workshop based on 10 questions. The workshop participants (10) were the interviewed researchers, their colleagues representing other product and process owners (the organizational research group manager, Lukes's IPR manager, and the head of the organizational unit). Seven participants returned completed workshop templates.

Table 2. Analysis of all the products from interviews and workshop: + means that certain feature applies to the product and empty means product lacks that feature. Based on situation in 2022.

	Products of the interviews					Products of the workshop				
	Suberin (x2)	Tannins	Betaine	Stilbenes	Engineered wood products	Black-currant press-cake (x2)	New fiber sources for packaging	Fats from insects	Wood-based anti-virals	Liquid from pyrolysis (x2)
Feasibility*										
Environment	+	+	+	+	+	+	+	+	+	+
IPR			+						+	+
Economic	+	+	+							
Technical**	+	+	+				+		+	+
Regulatory	+	+	+		+		+			
Raw material availability	+	+	+	+	+		+		+	+
Personnel capacity in Luke	+					+	+			+
Low risk or uncertainty level***	+	+	+		+		+		+	
Availability of end product options	+	+					+			
Comments from experts in Luke	High potential	Not ready for commercialization	One end product commercialized	Not ready for commercialization	Luke's role only supportive	Not ready for commercialization	Proceeding in research projects	Regulatory issues	Commercialization started	Regulatory issues

* + = there is knowledge in Luke about the feasibility dimension

** e.g. piloting / testing knowhow and capabilities

*** Low risk is defined from the point of view of Luke i.e. risk to proceed with the product towards commercialization.

Table 2 presents the results of the analysis of the products obtained from the interviews and workshop. The final case product was selected by excluding products with risks, those not ready for commercialization, such as fats from insects and liquid from pyrolysis due to regulatory issues hindering the market access. Tannins, stilbenes, and black-currant press-cake were also excluded. Already commercialized or on the way to be commercialized, such as wood-based anti-virals and betaine were also excluded because they currently do not need support. In addition, Luke's role in engineered wood products' development is more supportive and does not involve any IPR, thus it was not included. The two remaining products, suberin and new fiber sources for packaging, have been identified as having great potential by Luke experts. However, there were several packaging projects on going, so there was no urgent need for additional support. As a conclusion suberin was chosen as a case product. Additionally, above table was sent to the researchers who had been interviewed or had participated the workshop, and their comments were collected.

3 Results

The development of the first set of questions was conducted iteratively. Authors brought two interviews into the final analysis (about the suberin product) to be used as a case. However, the experiences and feedback from other four interviews had an influence when further developing the questionnaire.

3.1 Interviews and innovation questionnaire tool

First, the interview analysis produced basic information about the product suberin, raw materials, availability, production, current and potential end products, and markets. Furthermore, the analysis produced insights into knowledge gaps. These questions are especially for internal innovation process development i.e. evaluating market opportunities for different end products.

Our case product, suberin, is a cell wall macromolecule of plant bark that forms a protective layer. It consists of long-chain fatty acids (suberic acid) and glycerol. The rubbery suberin is an important ingredient in e.g. cork. Its main function is to prevent the movement of water and dissolved substances: i.e. it forms a moisture-repellent surface.

Suberin is currently used in the cosmetics industry for skin protection and softening. Suberin can also be used to replace plastic in the paper and cardboard industries. An alternative water-repellent surface would promote a transition away from e.g. fluorine-based treatments of textiles and accessories in the fashion industries. In general, suberin has the potential to replace fossil-based materials in many kinds of different products. However, all end product applications require laboratory and further pilot testing before their true potential is known, in addition to scaling up to the industrial scale.

Plenty of raw material (bark) is available, e.g. from sawmills. Currently (2022), product development is still at the laboratory scale, i.e. there has been no piloting or upscaling so far. Estimations of raw material availability or some other production costs were mentioned, but no comprehensive business potential calculations or estimations were available. On the other hand, new projects have proceeded where business calculations are included.

There was some understanding of risks at the general level concerning research process and facilities, the technologies used, laboratory and small-scale production, small-scale automation, the maintenance of research instrumentation, the product's and end product's general use, impacts on business reputation, information security, personnel safety, the required expertise and its protection, and customer, financial, legislative, and environmental risks. However, it was unclear who had the responsibility of certain risk and risk assessments or risk management during different product development phases. Although not within the core knowledge of a researcher it is important to consider how these perspectives can be included.

The researchers found it difficult to separate product and end product applications during the interviews. Additionally, it was not always clear how the end product application and its market were selected. It appeared that there was no systematic process before the selection. Furthermore, roles, needs, and expectations of stakeholders were not systematically determined, or there was no time or resources available for this activity. Due to these limitations, the understanding of the entire value chain, including profitability and actors, was somewhat limited. On the other hand, it is difficult to make the evaluation without business partners and a clear selection of end product. Another major limitation identified in the interviews was knowledge of upscaling technologies. However, it was often mentioned that the comprehensive utilization of the raw materials and the potential sidestreams to secure solid circular business model is closely connected with business feasibility.

Furthermore, there was a need for a more comprehensive understanding of Luke's role in the entire research and product development process. This was also relevant in relation to risk assessment and management. To facilitate research and product development at Luke, a development plan with interim goals, results, and costs would be beneficial. However, this may require internal funding. Table 3 present a summary of the analysis of case suberin interviews for developing an internal innovation process.

Table 3. Analysis results of suberin interviews for developing internal innovation process.

Questions	Why is the question asked?	What information is gained?	Key observations for Luke's innovation development and knowledge gaps
Background information	To find all the expertise, and where it is in Luke.	Name, location, organizational place, expertise.	There is a need for a multidisciplinary group to help the innovation process.
Product, its use, value chain, and production	To understand the current market and potential of the product and its other uses (if any).	Suberin is a cell wall macromolecule of plant bark. Its main function is to prevent the movement of water and dissolved substances.	The product and the end product applications were not clearly distinguished.
End product /application, its use, value chain, and production	To understand the application and the markets of the end product, and how they have been evaluated during the research process.	Currently used in cosmetics industry (skin protection and softening). Could replace fossil-based materials in different end products.	It was not always clear how the end product application and markets have been selected. Customers' and stakeholders' needs and expectations were not always systematically defined.

Questions	Why is the question asked?	What information is gained?	Key observations for Luke's innovation development and knowledge gaps
Business evaluation and potential	To understand the potential markets, and how they have been evaluated during the research process.	Plenty of raw material (bark) is available. The product development is still at a laboratory scale; no comprehensive business calculations were available.	Understanding of the business models needed. Knowledge of scaling up and technologies is lacking. Understanding of Luke's role in the process unclear.
Risk assessment	To understand the risks, and how risks have been considered during the research process.	There was some understanding of risks at a general level. The main challenge was that the participants could not think about the potential bioeconomy product consequences and potential risks during the industrial production process. They were more interested in the research process.	There is a need to define the sustainability risks of the bioeconomy product and risks of the development process and responsibilities among the development process participants.

Further content analysis of the suberin interviews identified the external drivers and barriers in the circular bioeconomy product value chain (Table 4).

Renewable raw materials can be a driver as they offer diverse selection i.e. alternatives, which increases production resilience. However, changes in product composition may pose standardization challenges.

Furthermore, logistics for raw materials (or sidestream materials) may present challenges, as they are often distributed over a large geographical area, making collection resource-intensive (barrier). However, the optimization of logistics through digitalization can improve collection efficiency. The current use of raw materials for energy is highly competitive, which hinders the development of new usage options. Currently, the best option is to have a raw material source nearby, such as having the production site located next to a sawmill.

It is impossible to patent the production technology of suberin (no novelty), and this is a major barrier to production investments. Therefore, there is not enough suberin available for end products, which is a major barrier. However, it may be possible to patent end product applications, but this has yet to be explored and may prove to be a driver. Another perspective for end products is to think about short vs. long development processes, e.g. drug development vs. food or cosmetic end products. Drug development can take decades and requires more risk taking and investment than the shorter processes for food or cosmetic products.

Different approaches to EU regulation were also discussed. According to the interviewees, it was possible to either standardize the product (i.e. suberin) or the production process, which can be a driver. On the other hand, EU or national regulation can be a barrier if meeting the requirements increases costs unduly, e.g. too much for small actors.

Luke and a researcher can assess project or small-scale and low-volume production risks. When a product is licensed, or a patent is sold, the business partner is responsible for risk assessment and management of its own processes. Risk assessment and management can be a driver of cost savings or cost reduction by preventing a risk from materializing. Risk assessment and management is a barrier if it is seen only as time consuming and costly. In addition, risks are different for different industries, for small and large companies, and at different stages of product development. All of this adds to the complexity of risk management, but it also offers rewards, security and resilience when done correctly.

Radical or "incremental" innovations were not discussed explicitly, but rather implicitly. Clearly, radical and incremental innovations have different drivers and barriers. If innovation fits into the current system or regime (incremental innovation), it is potentially easier to accept and scale up because appropriate infrastructure or institutions are in place. On the other hand, these previous investments create systemic infrastructure or institutional barriers (i.e., a stagnant regime) that prevent radical innovations from being scaled up. Radical innovations may need government support to succeed (e.g. wind power and electric cars).

Circular bioeconomy products potentially increase sustainability (driver) by replacing fossil materials with renewable ones, the product is potentially safer, and ultimately provides a better brand image for the brand owner. According to the interviewees, some funding is available (driver). Often a sustainable new business is expected to be economically viable at an early stage (barrier). On the other hand, supporting structures are available, e.g. business incubators and support for start-up entrepreneurs (especially in the university context). To conclude this section, it is crucial for both companies and researchers to understand the entire value chain and the needs of the various actors involved.

The circular bioeconomy innovation questionnaire tool was redefined based on the results of the interviews (Tables 3 and 4). Redefinition resulted in 10 questions: background information; product, its use, networks, and production; end product/application, its use, networks, and production; business evaluation and potential; risk assessment.

3.2 Workshop testing the questionnaire

Based on the interview analysis, the preliminary circular bioeconomy innovation mapping tool was developed and tested in the internal expert workshop at Luke. The tool includes simplified sub-themes formulated for the questionnaire for preliminary innovation mapping (Table 5). Based on these questions, workshop templates or worksheets (in Finnish and in English) were developed for the internal researcher workshop. The invited participants were the interviewed researchers, their colleagues representing other product and process owners (organizational research group manager, Luke's IPR manager, and head of organizational unit). In the workshop, there were 10 participants, of whom seven returned completed workshop templates. At the beginning of the workshop suberin case was presented as an example and then innovation mapping questions (Table 5) were presented one by one with example answers from the suberin case. After each mapping question there was time for participant questions and time to write the answers (related to their own product they wanted to test with the tool).

Table 4. External drivers and barriers identified from the suberin interviews (content analysis).

Value chain factor	Drivers	Barriers	Development activities and observations
Renewable raw materials	Diversity of raw materials.	Changes in product composition due to diversity.	Challenges in standardization.
Logistics of the raw materials	Digitalization.	Expensive logistics. Current raw material usage is competitive.	Production close/next to raw material source.
End product	Patenting opportunities for the end products.	No patent for the production process – no suberin available for the end products. Complete utilization of the raw materials is important (no waste).	Short vs long development/research processes. The longer the process, the greater the role for patents, risk taking, and bigger investments.
EU regulation	Standardization of the product or the process.	Compliance with EU and national regulation may be resource-intensive.	Protection of consumers, but also reduces business risks.
Risk assessment and management	Potential costs savings and reduction.	Can be resource-intensive.	Risks vary, depending on end product contexts. Understanding of the context/market is critical. Assistance and support are needed.
Radical and "incremental" innovation	Incremental innovation is easier to fit into the current system.	Present structures and institutional barriers.	Radical innovation often needs external e.g. governmental support.
Benefits	Sustainability. Better brand image. Funding availability.	New business is expected to be quickly economically feasible.	Understanding and ability to build the value chains are crucial.

Table 5. Questions for innovation mapping and summary of the workshop.

Question #	Observations and development ideas from the workshop
Background information: person's name of and expertise. Define the product and its innovativeness.	Need to clarify the terms, e.g. end product vs product. Focus on one end product application at a time and some systematic analysis before the selection.
1. Describe the research area, present internal experts, and need for new expertise.	Identify of the product and source of information. Map current expertise of the work group.
2. Product, its features, use, and customers.	Information about the development stage of the product – e.g. TRLs (technology readiness levels). A better understanding and description of the value chain is needed. One product and end product at a time, iterative process.

Question #	Observations and development ideas from the workshop
3. Production environment, production methods, volumes, and sidestreams or by-product.	Refinement of the term "production environment" is needed, i.e. the production environment of the product: estimates of potential production volumes, dependence on raw material supplies, equipment, chemicals, technologies, and potential alternatives.
4. Different stakeholders and their role in the product development and their expectations.	List needed of different types of stakeholders to help researchers identify them (raw material production, production of the product, production of the end product, and end users). Question should clearly be about value chain/networks.
5. Ownership of the product, production or processes, Luke's and stakeholders share/role.	More emphasis on IP rights. Patent mapping often needed. Information on existing and pending patents (Luke's and others). Estimate of business potential.
6. Distribution channels.	Clarification needed between product sales and end product sales.
7. Vulnerability assessment.	Clarify context and identify key risks between industry/business risks and our own, e.g. pilot risks. Suggestion: identify risks and later agree responsibilities with business partner.
8. Legislation, permits, regulations, market barriers, product image.	Question should mention different levels of legislation and regulation (local, national, EU). Support is needed to identify and understand the legislation. The business partner company must also understand, or the knowledge should be outsourced.
9. Risk mapping during the product lifecycle and sensitivity of production to disruptions. .	This question is too difficult. Later, if there is a partner, this can be reviewed together.
10. Resource and information requirements in the near future.	Generally, a difficult question. The role of internal and external networks is important.

The final summary of the innovation mapping tool is presented in a Table 6, which shows the key points to consider at the beginning of the innovation process in the context of this study.

Table 6. Innovation mapping tool

Key points in innovation mapping
Background: Define the product and its innovativeness
1. The field of research and the organization's expertise and resources
2. Product features and needs among customers and stakeholders
3. Production environment and process (methods, volumes, and sidestreams) and business potential
4. Stakeholder mapping in the development process
5. Ownership roles of the product production is clarified
6. Sales channels
7. Vulnerability assessment
8. Terms check: legislation, permits, regulations, market barriers, etc.

Key points in innovation mapping
9. Risk mapping (later when business or customer stakeholders are involved)
10. Future resource and information needs

In the case of Luke's innovation process, it was necessary to emphasize the requirements of the whole circular bioeconomy product value chain, especially the needs of end users. Circular bioeconomy research should involve stakeholders at an early stage to better meet their expectations and to ensure the smooth progress of the innovation process. Some stages of the bioeconomy innovation process require information from external stakeholders – for example, what kind of natural resources are used, and how this affects the environment (air, land, water) and the economy. Risk mapping was an example where the consequences of business, production, or safety risks require information and knowledge at the enterprise-level and was not available thus should be considered in later phases of innovation tool development.

4 Discussion

The aim of this paper was to develop the innovation process of a public research institute Natural Resources Institute (Luke) to enable efficient invention transfer and ultimately innovation. In addition, the study combined the perspectives of new product development, innovation process, and risk management, especially in the context of the circular bioeconomy, to develop a relevant tool to improve the process. The case study data collection was based on interviews and a workshop with innovation experts. In the content analysis, it was essential to systematically look at the innovation case product (suberin) and collect the relevant findings from the analysis for the development of innovation mapping tool.

As a result, an innovation mapping tool for circular bioeconomy innovation product development was developed. It includes a ten-key-point questionnaire to define the product and its innovativeness. The key points are 1. the field of research and expertise resources in the organization; 2. product features and needs among customers and stakeholders; 3. the production environment and process (methods, volumes, and sidestreams); 4. stakeholder mapping in the development process; 5. clarified ownership roles of the product's production; 6. sales channels; 7. the vulnerability assessment; 8. the evaluation of legislation, permits, regulations, market barriers, etc.; 9. risk mapping (done later, when business partners are involved); 10. future resource and information needs.

The needs of the end users and customers were identified to be important for the innovation process. In the circular bioeconomy sector, there are also other notifiable stakeholders, such as environmental or agricultural associations, that can help identify stakeholders or even stakeholder needs. The application of the three-step model (Figure 1): product, end product applications, and an analysis of the options (adapted from Robinson et al., 2013) provides an important perspective for this analysis. This model can be applied to describe the circular bioeconomy innovation process as many products and by-products start in the "middle of the innovation process", i.e. the invention is an unintentional "by-product" of a research project. However, customer and stakeholder needs should be considered at every stage of the circular bioeconomy innovation process – the earlier the better.

Although the above model describes and potentially improves the existing innovation process in Luke, it still lacks a clear connection with the stakeholders *before* the product and analysis phase. In fact, the whole research process could be more participatory (Van Lancker et al., 2016) and

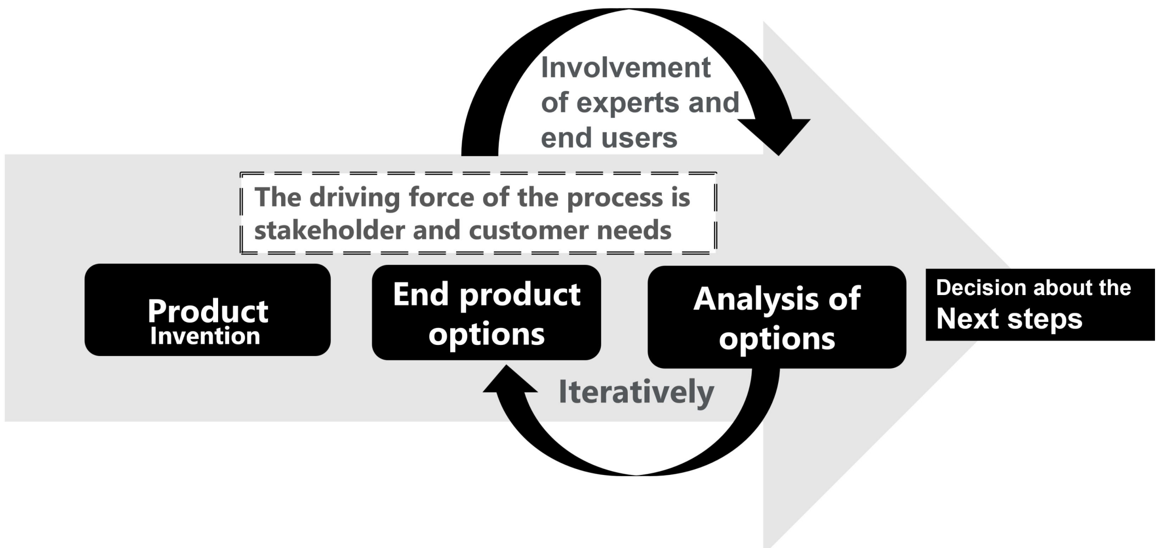

Figure 2. Suggested three-step model for Luke: product, end products, and systematic analysis of options – stakeholder and customer needs should be a driving force for the whole innovation process. Modified from Robinson et al. (2013).

involve stakeholders from the beginning of the formulation of the research problem and questions. Even the research itself could be co-designed (Lang et al., 2012; Mauser et al., 2013). This perspective also contributes to risk management reducing the risk of failure and the selecting the "wrong" end product. However, this is somewhat idealistic, as stakeholder needs are often not easily identifiable, or they are not yet clear enough to build a coherent research project. In addition, other innovation mapping tools like a bioeconomy canvas (Lewandowski, 2016) can be utilized more in the future. This can assist in presenting innovations to potential collaborators, investors, stakeholders, etc. Risk management tools can also reveal the benefits and pitfalls of products, marketing features, etc.

There are differences in the way a research institution, a university, or even a company organizes its innovation process. This means that the risks and risk management of the process are different. Each has different legislation that determines how inventions can and should be handled (especially a university vs. a public research institution). The design and provision of efficient legal intermediary practices and organizations are important in the context of the triple helix; university/PRI–industry–government cooperation (Tuunainen, 2002). Mourik and Raven argue "that SNM (strategic niche management) should focus on *niche level management* as opposed to individual experiments" (2006, p. 2). As the transition to a circular economy requires the formation of entirely new value chains and management of broader niche innovation networks, triple helix-based systems mediation is therefore needed to overcome the long-standing institutional separation and resistance to innovation and transformation between the helices (Barrie et al., 2019; Tuunainen, 2002). Here, the ecosystem approach can be the solution, be it the innovation or the business ecosystem (Gomes et al., 2018).

The generalizability of this study needs to be further tested (next phase or study), but the authors believe that this innovation mapping tool can be applied to other sectors where the situation is similar i.e. a product (invention) may have several end product applications and there is a need for multifaceted analysis to be able to select the potential end product and market. This result represents the first phase of the constructive approach.

The weakness of this research lies in the limited number of interviewees related to suberin as a case product. However, during the analysis (including the workshop material), the authors could see that the same themes started to reappear (Table 2), so a kind of saturation was reached. Another shortcoming of this paper is the issue of IPR – how to protect and still be open in communication – also during the innovation process. This will be especially true if this tool is further developed for use with external business partners interested in Lukes's invention or IPR.

Future research objective is to develop this tool to better serve collaboration with external stakeholders, especially in the business environment, to help identify the potential end products, synergies, and opportunities, as well as risks. It is also important to have a clear understanding of the responsibilities related to risks identified.

Future research needs to focus more on the challenges of business collaboration of the public research institute and the difficulties of transferring research results to the market (e.g. Tuunainen, 2002). The tool developed in this study may help to alleviate this challenge. In addition, more research is needed on social and social-material innovation. These issues and aspects are important to enable a just sustainability transition and a circular bioeconomy.

5 Conclusion

An innovation mapping tool for circular bioeconomy product development was created as a result of this work. The tool is designed to meet the needs of public research institutes and consists of a ten-point questionnaire to define the product and its innovativeness. The analysis is conducted in three steps: product, end product applications, and an analysis of the options, as shown in Figure 2. This model is relevant because many products, particularly in the circular bioeconomy, are 'side-products' of a research project. However, to ensure the success of the end product, it is crucial to comprehend the demands of the entire circular bioeconomy value chain, including the requirements of end-users. This perspective also contributes to risk management, reducing the risk of failure and the selection of the wrong end product.

The innovation mapping tool has the potential to improve the innovation management process of circular bioeconomy products. The suberin test product revealed some caveats in the Luke's innovation management process. To ensure the success of a bioeconomy product, it is crucial to comprehend the requirements of the entire value chain, particularly the needs of end users and markets, not to forget starting point i.e. raw material supplies and logistics. Additionally, it is essential to carefully define the risks of the product, including the regulatory environment, as well as the risks and responsibilities of the participants in the development process, especially later when process involves business partners. This tool includes assessment of environmental, social, and economic risks to provide a holistic view.

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7 Appendix 1

The questions used in the interviews:

1. Name, team (organizational team of Luke) and field of study

2. Location (Luke office location)

3. What products or biomaterials are you researching? Select one for this interview.

4. In what kind of production environment is the product in question manufactured, and which companies manufacture or could manufacture it? What kind of raw materials are utilized, and where and how are they processed?

5. What the product can be used for? (Now – In the Future?)

6. Who needs the product, and why?

7. What kind of stakeholders are needed to produce the product/raw material in question (from the perspective of the entire value chain)? What investments and partners are needed in the production process?

8. How can it be produced, and how much can be produced (potentially)?

9. Who owns the intermediate and final/end products of the production process?

10. Are there potential vulnerabilities or risks at the production/processing site?

11. Are there any information security risks during the research, design, or manufacturing of this product?

12. What kind of skills and personnel are needed for processing and production?

13. Is the product safe for end users, or what should be done to make it safe?

14. Can you estimate the production costs? What about further processing (pilot/factory scale)? What kind of investments and resources are needed for that?

15. How much are the potential profits (cost-revenue/unit) likely to be (compared to existing products if any)?

16. What other products or by-products are there or could be generated during the production process?

17. What are the sales channels for the product or the end product?

18. What is / could be the image of the product?

19. Are there any vulnerabilities in the production process that should be investigated? In which stages of the production process there are uncertainties?

20. Are there other risks associated with the production process that have not yet been mentioned?

21. Are there environmental risks associated with the production process? What are the main environmental risks of the product?

22. What permits are required? What laws/regulations need to be reviewed? What about social acceptability? Is there something that could prevent the product entering the market? Barriers to production?

23. Is risk mapping necessary for the product's life cycle? Production inputs – Manufacturing – Sales – Use – Post-processing?

24. How can different crises or production interruptions affect production or business (e.g. regional, natural, national, or political crises)?

25. What kind of investments and resources are still needed to proceed? Does Luke have any resources available?

26. Who could finance the development of the product in question?

27. What research expertise and resources should be strengthened at Luke to enable the research or development of the product?

Biographies

Titta Tapiola. Titta Tapiola has a diverse background, both through education and work experience. She has extensive experience from marketing and business development both from private and public sectors. She has degrees in natural sciences, business studies and lately also in futures studies. Currently she works as a research scientist and doctoral researcher at Natural Resources Institute Finland (Luke). Her doctoral thesis belongs to the discipline of futures research.
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CRediT Statement: conceptualization; formal analysis; investigation; methodology; writing – original draft; writing – review & editing

Jarkko M. Leppälä. Dr Jarkko Leppälä works for Natural Resources Institute Finland (Luke) leading several safety and risk management projects. For 20 years, Leppälä's research field has been agriculture safety management, farm safety culture, small business risk management, holistic farm organization and work management.
ORCID: https://orcid.org/0000-0001-5187-7185
CRediT Statement: In methodology risk management conceptualization and analysis, investigation, supervision, writing

Maryam Ghalibaf. Dr. Maryam Ghalibaf, a research scientist with a PhD in Applied Chemistry, specializes in lignocellulosic biomass valorization techniques, including chemical fractionation methods and thermochemical conversion techniques for creating innovative biobased value chains and sustainable products. At the Natural Resources Institute Finland (Luke), her primary focus lies in fostering creativity to promote environmental sustainability within the framework of a circular economy.
ORCID: https://orcid.org/0000-0002-1887-2726
CRediT Statement: conceptualization; data curation; funding acquisition; investigation; project administration; resources; supervision; validation; writing – review & editing