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Thomas Lager, Anders Fundin

Innovation methodologies and Design Thinking as supporting instruments in the development of non-assembled products

Sebastian Walther, Renata Dobrucka, Stephan Haubold

A review on influence factors promoting or inhibiting the transfer of research from universities into start-ups

Johanna Thomann, André Heeres, Errit Bekkering

The Northern Netherlands: Transformation of a gas-producing region into a forerunner in the biobased circular transition

Joerg von Hagen

Ecosystem for Greentech start-ups in the Rhine-Main-Neckar metropolitan area requiring dedicated technology infrastructure

The 5th advanced "International Workshop on Innovation and Production Management in the Process Industries" will be convened at KTH, Royal Institute of Technology, 11-12 October, 2023, in Stockholm, Sweden (https://www.kth.se/ipm2023).

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Aim and Scope

The Journal of Business Chemistry (JoBC) focuses on current developments and insights at the intersection of management and chemistry, biotechnology or pharmacy.

The JoBC provides an international forum for researchers and practitioners in companies, research institutes, public authorities, consultancies or NGOs to present and discuss current challenges as well as potential solutions in an interdisciplinary manner. Thus, the JoBC aims to foster the dialog between science and business, to support management practice in the chemical and pharmaceutical industry and to indicate where further research from academia is needed. The JoBC offers high quality publications with academic standards, a fast publishing process and global reach. With this multidisciplinary and boundary-spanning approach, the JoBC intends to become the leading journal for decision makers in the chemical and pharmaceutical industry.

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Letter from the Editors

Regional innovation ecosystems

The term innovation ecosystem describes a network of companies and other entities through which information and resources flow to create value and is an analogy to natural ecosystems. As natural ecosystems differ, each region provides its own unique conditions for the emergence of innovations. Thus, taking into account the regional conditions is a crucial factor. The articles in the Practitioner´s Section deals with the transformation of the Northern Netherlands and Greentech startups in the Rhine-Main-Neckar metropolitan area, addressing the specifics of the respective region. Are you more interested in innovation methodologies? In this case, we recommend starting with this issue´s research paper.

The research paper "Innovation methodologies and Design Thinking as supporting instruments in the development of non-assembled products" by Thomas Lager and Anders Fundin assesses the suitability of those methodologies for the innovation process of non-assembled products. The authors´ review and theoretical analysis show that aspects important for process-industrial application are missing in Design thinking, that both methodologies differ significantly, and that they are complementary in use. Nevertheless, the authors conclude that companies could profit from an in-depth understanding of both methodologies. To address the question when which methodology should be selected, the authors provide a framework showing the applicability of methodologies during different phases of the innovation work process.

Sebastian Walther´s, Renata Dobrucka´s and Stephan Haubold´s research paper "A review on influence factors promoting or inhibiting the transfer of research from universities into start-ups" summarizes the current state of research and identifies research gaps. Comparing different surveys, the authors formulate the hypotheses that the factors promoting spin-offs from universities are comparable across different countries while the inhibiting factors depend on economic and cultural influence.

Johanna Thomann, André Heeres, and Errit Bekkering explore the transformation from a fossil-based to a biobased economy using a regional example in "The Northern Netherlands: Transformation of a gas-producing region into a forerunner in the biobased circular transition". At first, the characteristics of the region are described and with the help of a SWOT analysis, the initial situation is presented to the reader. In the following, the developments from 2010 until today are discussed and opportunities arising for the region are shown. The authors see economic potential arising from the creative combination of available feedstocks and point out the importance of the framework conditions and close intersectoral collaboration.

The second contribution in our Practitioner´s Section comes from Joerg von Hagen. His article "Ecosystem for Greentech start-ups in the Rhine-Main-Neckar metropolitan area requiring dedicated technology infrastructure" deals with the question if the Rhine-Main-Neckar metropolitan area offers sufficient support for Greentech startups from ideation to commercialization. The author concludes that the ecosystem provides good conditions for startups which could and should be improved by a better connection between the stakeholders, e.g., by a cluster.

Please enjoy reading the first issue of the twentieth volume of the Journal of Business Chemistry. We are grateful for the support of all authors and reviewers for this new issue. If you have any comments or suggestions, please do not hesitate to contact us at contact@businesschemistry.org. For more updates and insights on management issues in the chemical industry, follow us on LinkedIn: http://www.linkedin.com/company/jobc/ and subscribe to our newsletter.

Janine Heck	Bernd Winters
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Call for a Special Issue of Journal of Business Chemistry (JoBC)

Thomas Lager*, Peter Samuelsson, Per Storm*****

Corporate process innovation management capabilities: Digitalization and sustainability perspectives

Setting the scene

Introducing the "family" of process industries

The "family" of process industries spans multiple industrial sectors—Mineral and Materials Industries, Mining and Metals Industries, Steel Industries, Petrochemical and Chemical Industries, Pulp and Paper Industries, Generic Pharmaceuticals, Food and Beverages Industries and Utilities (Lager, 2017b). One fundamental difference between companies in the process industries and those in assembly-based industries is that supplied and delivered products in the process industries are materials rather than components (Frishammar et al., 2012, Simms et al., 2021), a fact which affects not only the upstream supply chain of incoming materials but also the downstream supply chain of outgoing products (Lager and Blanco, 2010). Moreover, in assembly-based industries, a new product is usually produced in a new production setup, whereas a new production system or technology in the process industries usually must be integrated within an existing plant structure (Samuelsson et al., 2016). If a company relies on captive (company-owned) raw materials, the characteristics of incoming materials not only will predispose the selection of unit processes and production system design (Lager et al., 2017) but also may influence certain finished product properties (Linton and Walsh, 2008). Raw material variability will also sometimes influence the production system's receiving capability (Soman et al., 2004), especially in the food industries where raw materials are perishable (Van Donk, 2001, Van Donk and Fransoo, 2006).

The production yield in the process industries is dependent on both raw material characteristics (Finch and Cox, 1988) and production system capabilities (Lager, 2017a, Taylor et al., 1981). Meanwhile, products manufactured in the process industries are often next to homogeneous substances (Chronéer, 2003), and their inner structural characteristics largely determine their functionalities in B2B customers' production systems (Motta et al., 2015). The product innovation time cycles in many sectors of the process industries are often extended to protect customers from unforeseen difficulties (Pisano, 1997), requiring time-consuming pilot-planting or full-scale production trials (Frishammar et al., 2014, Tottie et al., 2016). In an early study of the 2,000 top worldwide investors in research and development (R&D), about 30% of those companies belonged to the process-industrial cluster (Lager, 2010).

Managing innovation in the "family" of process industries

In the adoption of Woodward's (1965) perspective on company behaviour, Barnett and Clark (1996) suggested that innovation in the process industries is primarily enabled by "process innovation" as the difficult and constraining aspect of product development. The importance of process

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innovation in the development of a corporate strategy was recognized by Skinner (1974, 1978), and his position was underscored in an article titled “The shareholder’s delight: companies that achieve competitive advantage from process innovation” (Skinner, 1992, Skinner, 1996). The vital importance of a profound understanding of the production process for innovation in a process-industrial context has since been confirmed in many studies (Floyd, 2010, Frishammar et al., 2013, King, 2009, Lager et al., 2017).

Brown et al. (2005) proposed that “there is a need to view operations management as part of a fluid, interactive, mutually beneficial series of relationships between raw materials and the end customer”. Conceptualizing operations management for the process industries in such a broad manner pinpoints the significant importance of the complex process and value chains in this cluster of industries (Tottie and Lager, 1995). Whilst early integrative development of product and production technology is desirable in other manufacturing industries (Bruch and Bellgran, 2014), the integrative perspective on raw materials, process technology, and products needs to be given much stronger consideration in process-industrial product and process innovation (Hullova et al., 2016, Lager, 2017b). The intimate coupling between products and related production process technology (Frishammar et al., 2013) thus makes the development of non-assembled products, in reality, the development of new or improved process technology (Hullova et al., 2019); “the process is the product” (Rousselle, 2012). Whilst product innovation must always start and finish with the customers, process development is a more in-house affair. According to the Oslo Manual (OECD, 2005), process development can be defined as follows:

Process development (process innovation) is the implementation of new or significantly improved production or delivery methods. This includes significant changes in techniques, equipment and/or software.

The Oslo Manual further states that, “with respect to goods, the distinction is clear”. The customer for process innovation is thus primarily an internal customer, and the following slightly modified extended complementary definition underline these ideas:

Process development could be defined as development mainly driven by internal production objectives. Such objectives may be reduction of production costs, higher production yields, improvement of production intensities, environment-friendly production, etc. (Lager, 2002). In many sectors of the Process Industries, process development is mainly prompted by the needs of production (internal customer). Another internal customer to process development is the company’s own product development (Lager, 2010).

In a study of process innovation in the process industries (Lager, 2010), 40 percent of total company R&D expenditure, as an arithmetical average for all companies, was spent on process development.

Corporate process innovation management capabilities: Digitalization and sustainability perspectives

There are a number of process-industrial characteristics that will influence digitalization, sustainability and sectoral convergencies. In reference to the previous sections, one strategic capability of utmost importance in the process industries is thus related to company management of process innovation.

Managing process innovation in the perspective of digitalization and sustainability

Companies in manufacturing industries today generally consider digitalization and sustainability as top strategic priorities, but they sometimes face difficulties in embracing these approaches in an operational mode. However, Industry 4.0 offers the potential for increased automation and flexibility of company production processes, and digitalization is thus driving new process innovations (Blackburn et al., 2017, Iansiti and Lakhani, 2014). There is a need for process innovation to consider an integration between individual equipment, connected smart devices, dynamic software systems, smart logistics systems and suppliers (Horváth and Szabó, 2019). Aaldering and Song (2021) concluded that not all sectors of the process industries can be regarded as laggards in terms of incorporating digital capabilities and that the Biotechnology, Pharmaceutical, Food and Beverage, Energy and Oil and Gas sectors have demonstrated a higher IT affinity. In a study of building digitally-enabled process innovation in the process industries, Chirumalla (2021) concluded that the transition to digitalization and sustainability will most likely require new strategies, work processes, organizational structures, operation modes, and capabilities.

Sustainability is of growing urgency to companies in the process industries (Kaplinsky and Morris, 2018), and environmental innovations give opportunities to respond to concerns over not only the depletion of natural resources but also the use of raw materials with negative environmental impacts (Yu et al., 2016). In a process-industrial context, sustainability aspects must be included not only in the development of new product concepts but also in the development of a related process concept (including a raw material concept). In a similar vein, and in the consecutive product development phase, further sustainability perspectives on product design are to a large extent dependent on an integration of sustainability aspects in the preliminary design of the related production process (Lager et al., 2022). However, companies in the Forest Industries and Mineral Industries, generally with captive raw material supplies of sustainable raw materials, face different challenges compared with companies in the Chemical Industries and some in the Food and Drinks Industries, depending on their position in the supply/value chains.

In conclusion, in perusing corporate process innovation management capabilities through the lens of digitalization and sustainability, it is evident that an enhanced management of process innovation stands out as a vital management capability in order to pursue successful corporate digitalization and sustainability agendas. In the following section, a number of areas of Process Innovation Management have been listed in the form of potential topics for further research. These include, for example, process innovation strategies (Chesbrough and Appleyard, 2007, Chiaroni et al., 2010, Larsson and Bergfors, 2006, Leker et al., 2018), structural organizational and cultural aspects on process innovation (Bergfors and Lager, 2011, Hofstede, 1993, Schein, 2009), the process innovation work process (Lager, 2000, Lim et al., 2006, Pisano, 1997), collaboration with equipment and raw material suppliers (Aylen, 2013, Lager et al., 2015, Rönnberg Sjödin et al., 2011), inter- and intra- technology transfer (Lager and Frishammar, 2012, Lager and Hassan-Beck, 2020, Lessing and Leker, 2006, Malik, 2002), application development (Storm and Lager, 2014), and measuring process innovation performance (Chiesa et al., 2009, Lager and Hörte, 2005, Schumann et al., 1995). Fostering such corporate process innovation management capabilities will most likely be of importance and possibly a prerequisite for successful digitalization, industrial symbiosis and future sectoral convergencies in the cluster of process industries.

Suggested research topics of interest

The overall theme for this Special Issue is management of process Innovation within the broad family of process industries in the perspective of digitalization and sustainability. Interesting empirical insights or theoretical and conceptual contributions are invited. Possible research topics include, but are certainly not limited to, the following lines of inquiry:

- Process Innovation strategy design and portfolio balancing of process innovation projects of different degrees of newness in a process-industrial context.
- Designing structural organizational frameworks for product and process innovation from the viewpoint of digitalization, sustainability, and sectoral convergencies.
- Reconfiguring a company process innovation work process for non-assembled products from the perspective of digitalization and sustainability.
- Methodologies and best practices as supportive instruments for an enhanced process innovation work process.
- Success factors and key performance indicators for enhanced future process innovation performance.
- Revisiting the "S-curve" concept and process innovation road-mapping methodology for strategic process innovation.
- Project management and project compression mechanisms for complex collaborative strategic long-term process innovation projects.
- Exploring new or improved innovation management capabilities and knowledge areas in response to process-industrial digitalization and sustainability challenges.
- Fostering a sustainable company innovation culture in "production-oriented" process-industrial operational environments.

- Open production as “wall-to-wall” raw material supplier integration and equipment supplier integration in company production process systems.
- The search for effective coordination mechanisms and collaborative models for customer and end-user interactions in complex process-industrial supply/value chains in view of future sectoral convergencies.
- Managing process innovation in the perspective of physical exchange of raw materials, by-products, energy, and water; industry symbiosis.
- Managing intra- and inter-firm collaboration and technology transfer as supporting mechanisms in digitalization and sectoral convergences.
- pplication development in the adaptation of B2B customers’ production processes to supplied new or improved products.

Submission process & important dates

Direct manuscript submission to the Journal of Business Chemistry

Prospective authors are welcome to contact the guest editors to discuss initial ideas for papers for this Special Issue (SI) and related questions about submissions. Full papers must be submitted to the Journal of Business Chemistry no later than September 30, 2023. Papers will be subject to the JoBC double-blind peer-review process. A guide for authors, sample copies and other relevant information for submitting papers are available at http://www.businesschemistry.org. The timeline for the SI is as follows:

- Deadline for full paper submission: September 30, 2023.
- Deadline for resubmission of all revised papers after guest editors’ comments: December 31, 2023.
- Notification to authors of papers selected for the SI and start of the peer review process: January 31, 2024.
- Expected time of publication: Fall 2024.

Manuscript submissions, also intended for workshop presentations

The 5th advanced (invitational) “International Workshop on Innovation and Production Management in the Process Industries” will be hosted at KTH, Royal Institute of Technology, Stockholm, Sweden, 11–12 October 2023. As part of the paper development process for this Special Issue in the Journal of Business Chemistry, prospective authors are also welcomed to attend this workshop and to develop an early abstract of their paper.

Please see https://www.kth.se/ipm2023 for further information. Workshop participation is not a prerequisite for SI authors and will not influence the selection of SI papers for full peer review. The timeline for such submissions is as follows:

- Deadline for submission of abstracts for workshop participation: April 30, 2023.
- Notification of acceptance for workshop participation: May 15, 2023.
- Workshop registration: May 31, 2023.
- Full paper or working paper submission: September 30, 2023.
- Workshop: 11-12 October 2023.

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Research Paper

Thomas Lager*, Anders Fundin**

Innovation methodologies and Design Thinking as supporting instruments in the development of non-assembled products

In a review and theoretical analysis, Quality Function Deployment, Design Thinking and complementary methodologies have been assessed as supporting instruments in the development of non-assembled products. The findings demonstrate that QFD and DT characteristics substantially differ and that DT lacks many aspects of importance for process-industrial application. However, the results show that the methodologies are complementary in use; thus, an in-depth knowledge of both methodologies could create a company competitive advantage in product innovation. Companies in the process industries are thus advised to use the results as a guiding framework for methodology selection and use in the different parts of the product innovation work process.

1 Introduction

Product innovation is of such strategic company importance today that it is usually managed as a formal work process (Melan, 1992), often in the form of a Stage-Gate decision model (Cooper, 2014; Cooper and Sommer, 2016) and sometimes within a business process management framework (Jeston and Nelis, 2018). Such a customized work process, adapted to company product-market conditions and driving innovation of new or improved products on the market, constitutes a dynamic capability in a company strategic perspective (Teece, 2009; Teece and Linden, 2017). However, research on product innovation in the process industries is scarce (Hirsch-Kreinsen, 2008, Lager and Bruch, 2021; Robertson et al., 2009), and little work addresses why, how, and when product innovation methodologies could be deployed as supporting instruments for an enhanced company work process. This study aims to close this gap by reviewing and theoretically analyzing the usability of methodologies as supporting instruments for the product innovation work process in the development of non-assembled products.

The "family" of process industries spans multiple industrial sectors—Mineral and Materials Industries, Mining and Metals Industries, Steel Industries, Petrochemical and Chemical Industries, Pulp and Paper Industries, Generic Pharmaceuticals, Food and Beverages Industries and Utilities (Lager, 2017b). The products supplied to and delivered by companies in the process industries are materials, instead of assembled products or single components as in other manufacturing industries (Storm et al., 2013). A formal definition of the construct "process industries" is given in Appendix A. A strong interrelationship between product and process innovation is often necessary for good innovation performance in the process industries (Lager, 2002; Lager and Hörte, 2005a; Lager and Hörte, 2005b), and new or improved product development actually involves the development of a new or improved production process (Etinne, 1981). Hullova et al. (2016) and Reichstein and Salter (2006), discussing the importance of the interrelationship between product and process development, suggested that they should be viewed as "siblings" rather than "distant

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cousins". In the process industries, the environment for product pre-development activities and product design is a laboratory (Lager, 2000), rather than a design office as in other manufacturing industries, and development of prototypes is replaced by pilot planting when the production process is finalized and when test batches for customers are supplied (Lager, 2000; Pisano, 1996; Pisano, 1997). In consequence, the configuration of the product innovation work process must be adapted to inherent and contextual process-industrial conditions, and innovation best practices, tools, and supporting methodologies must in a similar vein be adapted to the development of non-assembled products.

Many best practices and methodologies for product innovation have demonstrated enhanced innovation performance in use (Graner and Missler-Behr, 2012; Lager, 2005a; Nijssen and Lieshout, 1995; Yeh et al., 2010). Even so, one should consider organizational solutions not only to foster sustainability (Day, 1993; Lager, 2017d) but to ensure that future critical sustainability needs can be met (Deleryd and Fundin, 2020; Hallencreutz et al., 2020). When a single methodology is assigned to "overall control", this is called a "multimethodology" approach (Mingers and Brocklesby, 1997), and the further combination of methods into innovation methodologies for product innovation contributes to improved methodology use (Hidalgo and Albors, (2008). The product innovation methodologies of Quality Function Deployment (QFD) and "Design Thinking" (DT) were thus initially selected as "overall control" methodologies applicable to the total product innovation work process, whilst a number of complementary methodologies were selected in a multimethodology approach. Moura e Sá (2016) analyzes the core principles of those methodologies and concludes that many similarities exist. In this study, the comparative analysis of QFD and DT is extended to their use in product design for manufacturability and in the design of non-assembled products. Most importantly, the analysis of the two methodologies is conducted to assess their usefulness in different stages of the product innovation work process.

This exploratory study is part of a broader research initiative seeking an enhanced innovation work process for non-assembled products in the process industries (Lager and Simms, 2020), with the following general research question: *What are the main building blocks, incorporated concepts and related constructs of a generic "structural process model" that can serve as a guiding template for company design or reconfiguration of a formal innovation work process adapted to process-industrial conditions in the development of new or improved non-assembled products?* In light of the previously presented research problem, the specific research questions for this study are:

RQ1 *What are the principal characteristics of the QFD methodology and the Design Thinking approach, as holistic management tools and supporting instruments for the innovation work process in the development of non-assembled products?*

RQ2 *What is the potential usefulness of alternative supporting and complementary product innovation methodologies during different phases of the product innovation work process for non-assembled products?*

This article is organized as follows. In the next section, the process-industrial context is introduced, work process fundamentals are discussed, and afterwards the selected research design is presented. Thereafter, the discriminant validity of the individual characteristics of the QFD and DT methodologies is analyzed in light of the literature. These and a number of complementary methodologies are then reviewed and analyzed as supportive instruments for the innovation work process for non-assembled products. Finally, the results and theoretical contributions are discussed, and conclusions are presented along with directions for further research.

2 Frame of reference

2.1 Production system characteristics and product innovation in the "family" of process industries

Brown et al. (2005) note that "there is a need to view operations management as part of a fluid, interactive, mutually beneficial series of relationships between raw materials and the end customer." Thus, the simplified structural model in Figure 1 illustrates the process-industrial material transformation system from supplied raw materials to finished products (Storm et al., 2013).
If a company in the process industries relies on captive raw-materials, there are few alternatives for the supply of

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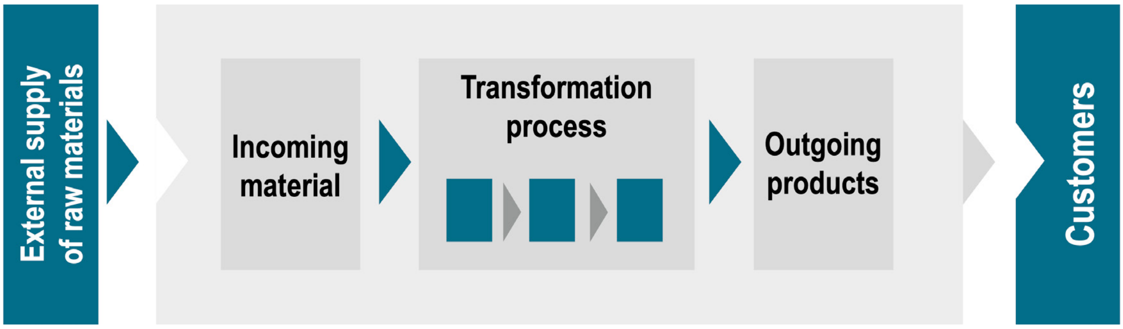

Figure 1 A simplified model of the production system in the process industries (Storm et al., 2013).

incoming materials, which both determine the design of the production system and influence the quality of finished products (Samuelsson et al., 2016). The production process yield is generally related to raw material characteristics and is an important target figure in operations. With respect to material flow patterns and transformation characteristics, the raw material is "reconfigured" and product differentiation occurs as the material moves through the production system in the process industries (Burbidge, 1982; King, 2009), whilst in other manufacturing industries the materials remain essentially the same during the manufacturing process (Floyd, 2010). In other manufacturing industries, common practice is to produce a new product in a new production plant, whilst a new product in the process industries often must be integrated into an available production plant structure.

Products manufactured in the process industries are largely homogeneous entities, and the material complexity is often high even for seemingly simple products (Chronéer, 2005). Addressing scaling problems is an important development task as a new concept moves from laboratory to pilot plant to full-scale production. Pilot and demonstration plants thus bridge basic knowledge generation and industrial application (Frishammar et al., 2014), and the time frame from ideation to industrial implementation in production plants (Bergfors and Lager, 2011) is often 3–5 years (Warren et al., 2000); in Big Pharma, it is 5–10 years (Pisano, 1997). The reasons for this include both inherent difficulties in developing new products as such and strong customer risk-avoidance, which may necessitate time-consuming pilot plant testing and full-scale production trials (Tottie and Lager, 1995). Consequently, a product innovation work process for non-assembled products must not only be adapted to inherent process-industrial innovation and contextual idiosyncrasies but also consider the interdependencies between product innovation and related innovation of process technology.

2.2 Introducing the concept of formal work processes and a generic "structural process model" for the development of non-assembled products

A formal explanation of how work should be accomplished, clarifying ownership and process users, process input and output, decision structures and checklists, is usually called a "formal work process" (Andersen et al., 2008; Lager, 2010; Melan, 1992). Such processes help familiarize new employees with company best practices and enable seasoned practitioners to develop and accumulate new knowledge for enhanced work process execution. However, they are rarely designed to meet future company needs, because they have gradually emerged over longer periods with regards to circumstantial operational challenges (Hammer, 1990; Hammer, 2007). Cooper and Kleinschmidt (1986) conceptualized the Stage-Gate product innovation work process as a number of "stages" separated by "gates" as decision points, from idea to product launch. Further research by Cooper (1994) and other scholars (Bower and Keogh, 1996), suggests that such work processes should be more flexible and adaptable to different project characteristics (Cooper and Sommer, 2016). However, the Stage-Gate process can be regarded as a "de-facto decision model" for product development work processes, forming "a blueprint and conceptual map to move from idea to launch" (Cooper, 2008 p.214). While Cooper and Edgett (2012) demonstrated that an efficient Stage-Gate process drives business performance, the model has been criticized for its lack of iterative loops. In spite of doubts raised by Eisenhardt and Tabrizi (1995) with regard to the model's inflexibility (Unger and Eppinger, 2009), a visual shared model of the

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product innovation work process must be acknowledged as a success factor in product development (Cooper, 1994; Cooper, 2012; Cooper and Kleinschmidt, 1993; Lee-Hansen and Ahmed-Kristensen, 2011; Unger and Eppinger, 2009).

In a previous part of this research initiative, a theoretical model has been developed (Lager and Simms, 2020), adapted to process-industrial conditions, as a five-stage generic "structural process model" of the innovation work process for non-assembled products (see Figure 2). The model incorporates the three main building blocks, Pre-product development, Product development, and Post-product development, anteceded by a Contextualization phase and supplemented by a Post-launch follow-up phase. From early concept development during pre-product development to industrialization in post-product innovation, the integration of product innovation and process innovation is depicted in an iterative fashion. Consequently, the further development of a product concept into a final product design is thus actually the further development of an associated process concept into a final process design and production set-up. The use of alternative supporting methodologies is pinpointed in blue in Figure 2, illustrating that the use of supporting methodologies should be considered not only during Pre-product development but throughout the total product innovation work process.

3 Research approach

3.1 General

According to Zahra and Newey (2009), theorization involves "a creative synthesis of existing theoretical insights by capitalizing on the intersection of two or more fields and/or disciplines". In the process of theorizing in the specific process-industrial context for product innovation, knowledge from the areas of Innovation Management (IM), Business Process Management (BPM), and Total Quality Management (TQM) can be merged. Torraco (2005) notes that such theoretical integrative research "reviews, critiques, and synthetizes representative literature on a topic in an integrated way such that new frameworks and perspective on the topic are generated". In the article "Theory Construction as Disciplined Imagination," Weick (1989) further acknowledge that:

Theorists often write trivial theories because their process of theory construction is hemmed in by methodological strictures that favour validation rather than usefulness.... Theory cannot be improved until we improve the theorizing process, and we cannot improve the theorizing process until we describe it more self-consciously and decouple it from validation more deliberately.

The research approach in this study follows this advice in the analysis of methodology characteristics in the perspective of product innovation work process configuration.

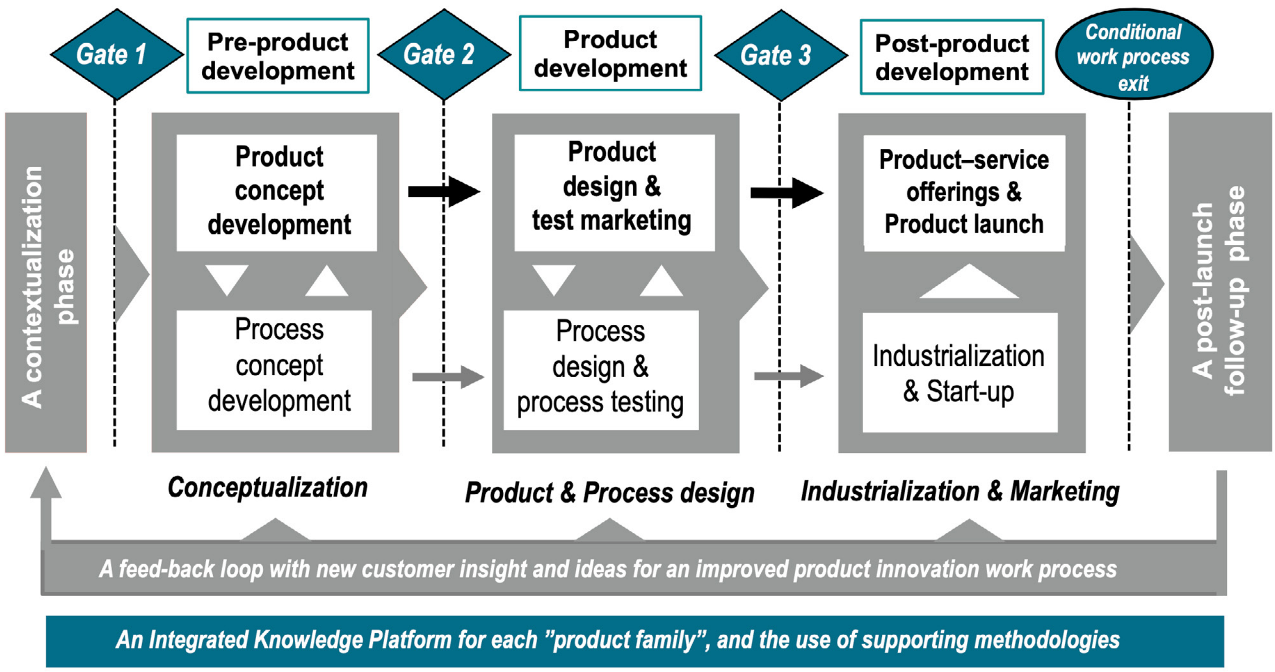

Figure 2 A slightly modified generic "structural process model" of the innovation work process for non-assembled products in the process industries (Lager and Simms, 2020). The topical area for this study is marked in blue.

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3.2 The research process

In the frame of reference (see Section 2), the process-industrial context is initially introduced and discussed, and a generic "structural process model" is presented as a point of departure for the literature review of potential supporting methodologies in product innovation. Two overarching product innovation methodologies in use were identified: Quality Function Deployment (QFD) (Akao, 1990; Akao, 1997; Cohen, 1995, Lager, 2017d; Lager, 2019; Mizuno and Akao, 1994; Zairi and Youssef, 1995) and the more recent Design Thinking (DT) approach (Beckman and Barry, 2007; Carlgren et al., 2016; Dell'Era et al., 2020; Gruber et al., 2015; Micheli et al., 2019; Nakata, 2020; Owen, 1997; Sobel and Groeger, 2013; Uebernickel et al., 2020). These will be reviewed and discussed in-depth in Section 4. A number of characteristics related to QFD and DT were thus identified and related to the different parts of the product innovation work process presented in Figure 2. Care was taken to discuss, clarify and present each selected characteristic to avoid misconceptions and to facilitate their proper use in further research and in practical use by industry professionals. The QFD and DT methodologies were then reviewed and analysed regarding their applicability and usefulness as supporting instruments in the development of non-assembled products. The subject of "validity" is complex (Moore, 1991):

A variable is a valid measure of a property if it is relevant and appropriate as a representation of the property. Does the process measure what you want to do? To discuss the issue sensibly, we must ask validity for what purpose and validity for what population.

Discriminant validity (Persson, 1997) measures the difference between individual measures or properties—in this study, between the characteristics of QFD and DT. The discriminant validity of the individual characteristics of QFD and DT was thus examined and reviewed in light of the literature and of the rigor with which the characteristics are defined for each methodology. The results are presented in Section 4.3 in a "heat map" with selected supporting references. In the analysis, the methodology characteristics were presented for each methodology, and the methodological usability was further assessed in the context of a process-industrial work process context for product innovation. Thereafter, in a review of publications related to both methodologies, a number of complementary methodologies used in part or all of the product innovation work process were identified (Albors-Garrigos et al., 2018; American Supplier Institute, 1992; De Waal and Knott, 2013; Hidalgo and Albors, 2008); these are presented in Section 5.1. Referring to the introductory statements by Weick (1989) and Zahra and Newey (2009), the estimation of the validity of the individual characteristics was not based on a collection of new empirical evidence but solely on available information from the literature reviews.

4 A review and analysis of the applicability of QFD and Design Thinking as overarching methodologies in the development of non-assembled products in a process-industrial context

4.1 Quality Function Deployment (QFD)

QFD appears complicated at first glance, and technical personnel might tend to respectfully ignore it, but the data can be considered as an accumulation of the past that can be added to or improved with each new development cycle and therefore becomes an important asset to the company. - Dir. Nakahita Sato, former Director of Toyota Auto Body (American Supplier Institute, 1989)

The Quality Function Deployment approach in product innovation originated in the early 1970s at Mitsubishi's Kobe Shipyard and is today one of the most commonly used methodologies in product development (Akao, 1990; Mizuno and Akao, 1994). The methodological breakthrough is often ascribed to Toyota Auto Body when QFD was deployed to solve the problem of poorly designed cars. The methodology succeeded in generating exceptional outcomes in company product development (Akao, 2003), and its industrial usability has been demonstrated in many areas, including interfacing customers (Cristiano et al., 2001; Griffin, 1992; Martins and Aspinwall, 2001), interfacing production (Stitt and York, 1993), interfacing suppliers (Asari and Batoul, 1996), and as an instrument for integrating sustainability perspectives in product innovation (Puglieri et al., 2020; Rihar and Kusar, 2021).

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4.1.1 The House of Quality

Common to all QFD systems is the *House of Quality* (HoQ) matrix (Hauser and Clausing, 1988). In the HoQ, the qualitative *Customer Requirements* WHATs are translated in the relationship room into measurable *Design Requirements* HOWs (Day, 1993). The *Customer Requirements* and their importance ratings and benchmarking are collectively called *Voice of the Customer*, which is often used as a stand-alone part of the QFD methodology (Cohen, 1995). In the HoQ, the metrics for measuring customer demands are developed, and then a technical benchmarking can be performed, and target values can be assigned (Lager, 2019). In the "roof" of the matrix, individual *Design Requirements*' relationships and their "friendliness" or "hostility" toward each other can be assessed (Tottie and Lager, 1995). The selected *Design Requirements* can then be further progressed into the production process, in the use of different QFD systems.

However, if one tries to build a *House of Quality* on a full spectrum of *Customer Requirements*, one will soon discover that the corresponding number of *Design Requirements* will be huge. This will result in a matrix that will be too large and unmanageable, which is one serious complaint from practitioners using the QFD methodology. Because of that, it is highly advisable to start focusing QFD activities on the "core product" and select such requirements for the building of a *House of Quality* (Lager, 2019). Requirements related to "packaging", "logistics (good material delivery)", and "good service and support", are certainly also important, and in interaction with B2B customers it is advisable to explain the initial focus on the "core product" in order to avoid an impression that other requirements will be ignored. Later on, and after the development of separate *Voice of the Customer and/or a House of Quality*, interactions between the different matrices can be achieved using the Correlation Matrices in a combined roof.

4.1.2 Phase progression

While seeking technical solutions is the major concern in product design, it is at the production stage that product costs are committed, product quality is determined, and lead times for product launch are set (Jiao and Simpson, 2007). Because of the previously noted strong relation between product functionalities and the production system in the process industries, it is thus essential for a QFD system to be able to translate and progress *Product Design Requirements* from the HoQ into the production process. Phase progression with the Multiple Progression QFD system (Lager, 2005b) can help to achieve this objective in a process-industrial context through the development and use of the Process Matrix and the associated Raw material Matrices. In the Process Matrix, measurable product attributes are related to the selected unit process configurations and associated process conditions for the production process (Tottie et al., 2016). In the production of new or improved products, the usability of the Process Matrix during production plant start-ups has also been proven (Scheurell, 1993). ***In reference to Figure 2, the QFD methodology can be deployed in the pre-product development phase, the product development phase, the post-product development phase, and the subsequent marketing and sales of new products (Lager, 2019).*** This is a significant aspect of the use of the QFD methodology, since product innovation projects are often delayed because of production start-up problems. However, the Process Matrix can be used not only at the production planning stage but also as a facilitating tool in training plant operators in advance of plant start-ups (Scheurell, 1992).

4.1.3 Process-industrial QFD experiences

Even if the QFD references often are somewhat old, since they report from early trials when the methodology was introduced in industry, lessons learned remain valid useful for industry practitioners. Experiences from use in the Mineral and Metal Industries are generally positive (Mongeon, 1996), and it is demonstrated that in B2B relations the "customer" is in reality the customer's production process (Tottie and Lager 1995; Tottie et al., 2016). In the use of QFD in the Food and Beverage Industries (Lager and Kjell, 2007; Viaene and Januszewska, 1999) the importance of phase progression is recognized. The early QFD experiences from the use in the Japanese Chemical industries (Nippon Zeon and Nippon Carbon) underscores the importance of the development and use of the correlation matrix. A series of articles from the Canadian Forest Industries (Hanson, 1993; Scheurell, 1992; Scheurell, 1994; Stitt and York, 1993) illustrate the usability of the methodology in many applications, such as new products and processes, new products with existing processes, product and process improvements and cost programmes.

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4.2 Design Thinking (DT)

Design Thinking (DT), or "design-led innovation", is a rather recent approach in product innovation. However, referring to the notion of open innovation as "old wines in new bottles" (Trott and Hartman, 2009), industrial design as a discipline which recommends an early integration of product "form" and "functionality" and disregards design as only a final cosmetic layer is nothing new in product development. Thus, DT involves borrowing designers' tools to develop a deeper understanding of customers' needs (Liedtka and Ogilvie, 2012).

Gruber et al. (2015) define DT as a human-centered approach to innovation that puts the observation and discovery of often highly nuanced, even tacit, human needs right at the forefront of the innovation process. They further advocate that to get value of a more "designerly" approach, a company must consider not just the technological system constraints but also the sociocultural context. They propose the following Design Principles: (1) Identify real and compelling needs; (2) Focus on value and values; (3) Design the employee experiences, not just workflow and tools; (4) Collaboration, co-creation, co-production; (5) Sensory and emotional engagement; and (6) Creating a narrative.

Charles Owen (1997) advocates that conventional development must be supplanted by a greater focus on "details" (better user functionality and symbols) and by better "concepts" and "product integrity" related to corporate identity and branding. He advocates for less focus on "how to make the product" instead of "what to make". Finally, he argues that: *"From the design perspective, quality as craftsmanship is achieved through attention to issues of engineering design for manufacturing"*, an opinion rarely expressed in DT-related publications. Too much focus on customers and end-users diverts attention from other stakeholders that sell, transport, maintain, repair and retire the product (Owen, 1997).

One important lesson from a more "design-oriented approach" is that, to build design capabilities, companies must pay more attention to stakeholders' use of potentially new products. Beckman and Berry (2007, p. 32) articulate this as follows:

At the heart of good observation are activities that provide the designer or innovator an opportunity to understand how his or her product or service is being used, and how its benefits are derived in the context of use. …To elicit these stories, the observer must be naïve, ask probing questions, and strive to understand WHY.

Beckman and Berry (2007, p.41) further argue that a new product concept also should include "product value propositions": *A value proposition in the practitioner process is defined as a description of the tangible benefits customers will derive from using a product or service. As such, the value proposition is distinct from the set of features or capabilities the product or service must have to deliver those benefits*.

Reviewing Beckman and Barry's (2007) recommendations and considering how they could be methodologically operationalized demonstrates the importance of improving pre-development innovation activities. DT focuses on "product creation" in a broad context and team functioning. As such, Uebernickel et al. (2020, p. 18) stress the importance of empathy; team autonomy; failing forward, often, and early; team members' multi-disciplinarity and diverse educational backgrounds; and a T-shaped profile of team members, drawing knowledge from an expert domain and connections with other domains (Uebernickel et al., 2020, p. 56). DT is today also deployed in a wider context to foster, for example, sustainability-oriented innovation development (Buhl et al., 2019).

4.3 QFD and DT characteristics in the context of non-assembled product development

4.3.1 QFD and DT's similarities in product innovation

Development of Customer Requirements WHATs in the Voice of the Customer corresponds to articulating "product value propositions" in design-led innovation, while development of the Design Requirements HOWs in a HoQ corresponds to translating value propositions into "product features" (Beckman and Berry, 2007). Further, probing into the deeper underlying value propositions by asking WHY is the classic recommendation to QFD users when the customers focus to much on the Design Requirements. The fuzzy front end

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(FFE) of product development was introduced (Smith and Reinertsen, 1991) as the first stage of the New Product Development (NPD) process, covering the period from idea generation to approval to the next stage of product development. Cooper and Kleinschmidt (1995) discovered that: "The greatest differences between winners and losers were found in the quality of pre-development activities". Verworn et al. (2008) articulated their research results as follows:

Although customer requirements were fairly well known at the end of the fuzzy front end phase, product specifications – exactly what the product should look like – were not as clearly understood. This was even more the case for radical new product development projects. There seems to be a lack of communication between marketing and technical functions or the customer requirements were not translated into technical language.

However, the traditional use of the HoQ for such a translation was not recognized. Herstatt et al. (2004), compared front-end activities of Japanese and German companies and find that Japanese companies rely on more formal approaches to reduce uncertainty during the FFE. In a follow-up study, Herstatt et al. (2006) conclude that: *to know customer requirements is not sufficient in itself; the gathered information has to be translated into technical specifications and integrated into the product concept; both of these activities were more often carried out by successful companies than unsuccessful companies.*

Reid and de Brentani (2004), examining the FFE of discontinuous innovation improvements, recommend that: "Management should provide a managed decision support system for codifying tacit knowledge specifically designed to support movement of information through the FFE". The matrix approach in the use of the QFD system has proven to be an excellent instrument for capturing tacit knowledge (Tottie et al., 2016). In conclusion, several similarities exist between the QFD and DT methodologies, but similar aspects are often disguised in the use of different constructs and wordings. Moreover, previous research on general product innovation supports the use of QFD and DT for translating qualitative customer demands into more measurable product specifications.

4.3.2 The discriminant validity of QFD and DT in the development of non-assembled products

Table 1 presents the methodology characteristics related to the different product innovation work process phases. A number of characteristics of the individual QFD and DT methodologies are illustrated and assessed in a heat map, with selected supporting references. The overall impression from the "heat map" is that red areas in one methodology often correspond to white or green areas in the other, indicating more of a complementary relationship than a methodological similarity, especially during the Pre-product development phase. Even if the methodologies in some areas overlap, reflecting a methodological similarity (same color), the overall conclusion is that QFD and DT methodologies are not "two sides of the same coin", and the results thus support a second article and a revised perspective by Muora e Sá (2018). Both methodologies adhere to a general and strong customer-oriented product innovation philosophy during *pre-product development*, but the individual approaches are somewhat different. While the QFD methodology's strong points are process clarity and the translation of the "customer space" into a "product space", DT focuses more on creativity tools, early customer interaction and co-development in the context of customer "product-in-use". With regard to product design team autonomy and a proper balance of "formality" and "freedom" in innovation, DT generally favors the latter; consequently, it is sometimes experienced as diffuse by industry professionals (Nakata, 2020 p. 771). In the *Product-development* and *Post-product development* phases, the overall weakness of DT is the lack of product "producibility" aspects. In the design of non-assembled products, DT's focus on prototyping is a major disadvantage in process-industrial use; on the other hand, design for processability is well-addressed in the Multiple Progression QFD system adapted to process-industrial conditions (Lager, 2005b). The two corresponding white areas related to product innovation's "work-process integration" highlight a general weakness of both methodologies—an issue underscored by the lack of work process clarity for DT. In conclusion, the two methodologies are different but should be regarded as complementary, and in-depth company knowledge of both could thus create a competitive advantage in company product innovation of non-assembled products.

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Table 1 A comparative analysis of the QFD and DT methodologies in the development of non-assembled products. The areas are presented in a simplified "heat map" (Red = Strongly articulated; Yellow = Medium articulated; Green = Weakly articulated; White = Not an articulated characteristic).

Work process areas	Methodology characteristics	Quality Function Deployment (QFD)	Design Thinking (DT)
General	Methodology approach and philosphy	Product innovation focus. Collection of Customer Requirements in F2F interviews. A number of matrices the outcomes (Mizunu and Akao, 1994)	Applicable for all kinds of innovation. Focus on customer "context of use". Prototyping outcome (Owen, 1997; Micheli et al., 2019; Meinel et al., 2020)
	Integration with industry work process models like Stage-Gate	So far not really well delineated. Often only recommended for pre-product development phase. (Lager, 2019)	Generally non existing in methodology presentations but recommended in pre-product development (Franchini et al., 2017; Gruber et al., 2015; Nakata, 2020)
	Organizational perspectives	Cross functionality strongly recommended (Cohen, 1995; Griffin, 1992)	Cross functionality recommended but even more focus on individuals with different personalities (Carlgren et al. 2016; Hölzle and Rhinow, 2019)
	Stimulation of creativity and the team	Not explicity stated in presentation of the methodology but in recommendation of supporting tools (Day, 1993; Lager, 2005a)	Strong focus on creativity and supportive tools and instruments (Micheli et al., 2019; Uebernickel et al., 2020; Dell'Era et al., 2020)
	Capturing tacit information	Not often explicitly stated but very efficient during matrix development (Tottie et al., 2016)	Not often explicitly stated
	Capturing sustainability information	Proven evidence of usability but the area is still in an emergent state. (Puglieri et al., 2020; Rihar and Kusar, 2021)	Some evidence, but the area is still in an emergent state. (Redante et al., 2019)
	Methodology work process structural clarity	Very systematic and understandable (Cohen, 1995)	Experienced by industry professionals as difficult to comprehend (Sobel and Groeger, 2013; Carlgren et al., 2016; Eradatifam et al., 2019; Roth et al., 2020)
Pre-product development	General customer focus	Strong B2C and B2C applicability. The customer production process is often the real customer (Lager, 2017; Lager, 2005)	Strong focus on consumers B2C, (Micheli, et al., 2018; Nakata and Hwang, 2020) Methodology not so applicable on B2B customers.
	Consideration of sociocultural system context	Not explicitly stated	Strong focus and consideration (Beverland and Farrelly, 2007; Uebernickel et al., 2020)

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	Positioning against competitor products	Voice of the Customer is including Customer Benchmarking and House of Quality Technical Benchmarking, (Akao, 1990; Lager, 2019)	Generally not explicitly stated
	Customer interaction	No focus on customer interaction during development, generally only in F2F interviews and surveys (Cohen, 1995)	Early customer interaction in their natural environment. An ethnographic approach. (Uebernickel et al., 2020; Olsen et al., 2005)
	Co-creation and co-development with customers	Not explicitly stated.	Co-development strongly recommended. (Gruber et al., 2015; Liedtka and Ogilvie, 2012)
	Test marketing	Not explicitly stated in the core methodology.	Focus groups and product clinics are recommended (Uebernickel et al., 2020)
	Translation "customer space" to "product space"	This is a QFD strong point and it is carried out in the House of Quality (Hauser and Clausing, 1988; Mizuno and Akao, 1994)	It is mentioned but sometimes in reversed order (Gruber et al., 2015) but not really prescribed
	Output from the ideation phase	Concept generation not focused in "vintage" QFD, but in the Multiple Progression mpQFD (Lager, 2005)	Concept generation rarely discussed. Strong focus on Value Proposition and identification of "user value" (Beckman and Berry, 2007; Gruber et al., 2015)
Product development	Design for manufacturability	This is included in QFD methodology in phase progression (American Supplier Institute, 1989). Design for Processability top-priority in mpQFD. (Lager, 2017)	Rarely mentioned (Owen, 1997) but generally ignored.
	Design for sustainability	The mpQFD system is suitable for process-industrial production system sustainability. Still emergent (Lager, 2019).	Non existant
	Output from the development phase	Experimental results from laboratory tests of customer functionality, pilot planting and sometimes demonstration plants results in the downstream matrices (Lager, 2005	Development of prototypes is top priority and strongly recommended. Not applicable for non-assembled products.
Post-product development	Production system design and industrialization	Very little focus on this area	Non existant
	Product launch, and marketing approach	Very little focus on this. Customer Process Matrix B2B products (Lager, 2019).	Non existant

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5 A review and analysis of complementary methodologies as supporting instruments for the innovation work process for non-assembled products

Apart from the QFD and DT product innovation methodologies, a number of methodologies can be used alone or as complementary methodologies in different parts of a product innovation work process. The selected methodologies to be used in this study should not be regarded as a complete list of possible alternatives; rather, the selection is based on which methodologies are most often discussed in relation to QFD and DT use.

5.1 A review of complementary methodologies to QFD and DT

This section is a brief overview of the methodologies and their tentative positioning in relation to the work process introduced in Figure 2.

5.1.1 Kano's theory of attractive quality

The simplified and extended version of Kano's theory of attractive quality (usually referred to as *the Kano model*) is used today as one of many market research methodologies, and there are numerous publications supporting its usefulness in product innovation (Witell et al., 2013). In customer interviews, the customers usually only articulate the requirements that Professor Kano termed *Performance Quality Requirements* but not their *Basic Quality Requirements* and certainly not their *Attractive Quality Requirements* (sometimes called "WOWs"). The Kano model uses the two dimensions *Customer satisfaction* and *Degree of achievement* (Kano, 2001; Kano et al., 1984). In a normal interview situation, customers usually focus on and only articulate *Performance quality*, and the relationship can generally be simplified as a straight line. The more Customer Requirements are satisfied by the product, the more satisfied the customer will be. The customer does not usually even consider the requirements of a *Basic quality* nature, a fact which is important for product developers to remember since such requirements often must be generated internally in the R&D department. If *Basic quality* requirements are not satisfied, the customer will generally be truly dissatisfied. *Excitement quality* customer requirements are normally requirements that are totally new and of a kind that customers do not (yet) expect to find in products (Lager, 2019). ***The Kano model is sometimes integrated or used in combination with the QFD methodology*** (Matzler and Hinterhuber, 1998; Tan and Shen, 2000), ***but generally only in the earliest part of the product innovation work process*** (see Figure 3).

5.1.2 Conjoint analysis

If all customer requirements are satisfied, the product price will often be too high for most customers; thus, the "perfect" product is often a compromise. Conjoint ("consider jointly") analysis is a survey-based statistical technique in market research that determines how customers value different product attributes that together make up an individual product or service (Green et al., 2001). A major assumption in conjoint analysis is that products are decomposable into separate attributes, constituting a bundle of attributes (Gustafsson, 1996). The objective is to determine what combination of a limited number of attributes is most influential on respondent choice or decision making. A number of potential products are presented to survey respondents, and, by analyzing how they make choices between these products, the implicit valuation of the individual elements making up the product can be determined. The findings of Silayoi and Speece (2007) in a conjoint analysis show, for example, that packaging design plays the most important role overall in consumers' likelihood to buy. ***Because of the limited number of product attributes that can be used in conjoint analysis, it is recommended to use this methodology as a second step after the use of the QFD methodology and the collection of the large number of customer requirements*** (Katz, 2004) (Figure 3).

5.1.3 Concept generation and concept selection

The importance of development of concepts in product design was identified by Stuart Pugh (1981), who proposed a process for minimizing conceptual vulnerability. In the management of "product definitions", a similar construct, Bacon et al. (1994) suggested that a robust product definition should include: target market segments and related channels; product price, functionality and features; and allocation of resources to complete product development. Detailed product specifications were not deemed necessary,

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but the need for a further "management of product definition change" was stressed. Burchill and Fine (1997) proposed that concept development should rest on the use of the House of Quality in the QFD methodology and transfer from this "requirement space" into an "idea or solution space"; then, from a number of concepts, the use of the Pugh selection process was recommended.

In a review of alternative concept-developing methods, denominating concept selection as the "Rubicon in the design process", King and Sivaloganathan (1999) concluded that the QFD methodology combined with the Pugh selection system was preferable. In a study of "concept shifting" in radical product innovation (Seidel, 2007), it was concluded that focus on front-end concept generation practices may not be sufficient. Later changes are likely to be important, and maintaining dual concepts was also recommended. The concept development process begins with a number of divergent ideas that must pass thorough a convex lens that converges the large number of ideas into the selected concept. Since it is too expensive to keep all options open and try everything, developing just one "best concept" (the common managerial practice) leaves a lot of money on the table if the customer is not interested in that masterpiece (Liedtka and Ogilvie, 2012); thus, multiple concept development is recommended. ***In conclusion, the use of concept development and selection methodologies primarily occurs in the first phase of the product innovation work process but may also be of importance during the second phase*** (see Figure 3).

5.1.4 Target costing and design for manufacturability

Subtracting the product's profit margin from expected selling price will secure that products are profitable when launched (Cooper and Slagmulder, 1997): *By setting target costs based on market-driven selling prices, target costing transmits the cost pressure that is placed on the firm by the marketplace to everyone involved in the design process. Through this pressure, target costing focuses the creativity of the firm's designers on developing products that satisfy customers and that can be manufactured at their target costs.* Ease of manufacturing of new or improved products is nothing new in other manufacturing industries, and for decades the mantra of "design for manufacturability" has been well recognized and acknowledged in industrial life (Boothroyd et al., 1994). Product developers of excellence today certainly acknowledge the need to manufacture products in cost-efficient production processes in the process industries (Monden, 2000), but they usually do not recognize the importance of a very early integration between the work process for the development of new or improved products and the development of related and necessary new or improved production process technology. In the process industries, design for processability is of even higher importance because of the product properties' integration with production process configurations (Lager et al., 2017); see further Figure 2. ***Even if preliminary cost estimates must be made during the early conceptualization phase, target costing is usually used in the product development phase*** (see Figure 3).

5.1.5 Platform-based design of non-assembled products

A product platform can be defined as a set of subsystems and interfaces that form a common structure from which a stream of related products can be developed and produced efficiently (Meyer and Lehnerd, 1997); the leading principle is to balance the commonality potential and differentiation needs within a product family (Halman et al., 2003). The necessity for companies in manufacturing industries to use a platform philosophy related to product variety needs has been well advocated (Jiao and Simpson, 2007). Suh (2001) conveyed the important message that a product platform must be well integrated with process and supply platforms. However, since the above platform concept for assembled products cannot be applied to non-assembled products, a different conceptual framework for platform-based design of non-assembled products has been proposed by Lager (2017c). ***The applicability of the new framework was investigated in a survey in the Nordic process industries*** (Samuelsson and Lager, 2019), ***which suggested that it could be deployed in the design of non-assembled products and as an instrument in an assessment of corporate strategic production capabilities.***

5.1.6 GEMBA

In an attempt to develop a more in-depth understanding of a customer's use of a product, it can be advantageous to investigate their behavior in their use of a product in its natural environment. Some organizations require design teams to work in customers' organizations for a considerable period to pursue this ethnographic approach, sometimes

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called "walking in the customer's shoes" (Terninko, 1997). In Japanese, this approach is called "GEMBA", and the methodology focuses on a thorough understanding of the customer and the customer's behavior together with the product in his specific context. However, the collection of sound demographic data on the users is always a necessity. A product developer can thus spend several months "going native" with the user in order to experience how the customer utilizes the product. Product developers of products for industrial B2B customers may thus work together with the customers in their production plants in order to experience how the product is used in the customer's production process (Lager, 2019). ***The GEMBA methodology is often used in later phases of product innovation but could certainly be of interest as a tool for understanding B2C and B2B customer requirements.***

5.2 The usefulness of supportive innovation methodologies during the different phases of the product innovation work process for non-assembled products

In Figure 3, the conclusions from the previous review of QFD, DT, and complementary methodologies have been translated into a heat map, and the methodologies have been tentatively positioned in the perspective of the product innovation work process presented in Figure 2. It is acknowledged in Figure 3 that both the QFD methodology and Platform-based Design are applicable throughout the total work process in the development of non-assembled products. On the other hand, the Kano model and Design Thinking are primarily tools for the pre-development phase, while the GEMBA method is more to be regarded as a tool for manufacturing excellence.

6 Conclusions, research contribution and future research

Based on a literature review of QFD, Design Thinking, and complementary methodologies for product innovation, the potential usability of methodologies in different parts of the product innovation work process for non-assembled products has been theoretically assessed. In reference to RQ1, the results from the theoretical analysis of QFD and DT characteristics affirm that the two methodologies should be regarded and deployed as different but complementary. However, DT lacks aspects like adaptability to B2B customers in a process-industrial context and experimental and pilot planting development, and it also displays a low connectivity to the production process, making it less usable as an overarching methodology in the development of non-assembled products. Thus, it is advisable to use DT as a complementary methodology, supporting inclusion of creative personalities and co-development and establishing

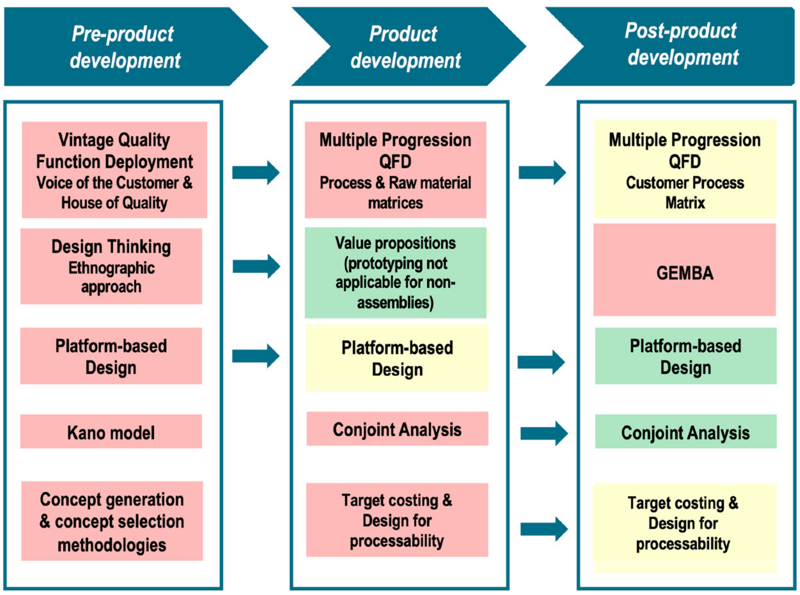

Figure 3 Applicability of supportive innovation methodologies during the different phases of the innovation work process for non-assembled products. The areas are presented in a simplified "heat map" (Red = Very useful; Yellow = Medium useful; Green = Weak usefulness).

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a broader perspective on sociocultural aspects. The QFD methodology could consequently take a more holistic management perspective in product innovation of non-assembled products, while DT and other complementary methodologies could be used in the different parts of the product innovation work process in a multimethodological perspective.

Referring to RQ2, based on the review and analysis of selected complementary methodologies in the perspective of the work process for non-assembled products, the applicability of the different methodologies differs for different parts of the product innovation work process. Corley and Goya (2011) propose two utility dimensions for a theoretical contribution of research findings: practical utility and scientific utility. Regarding practical utility and management implications, the findings from this study suggest that in the development of non-assembled products in the process industries, the QFD methodology can be deployed as a holistic management and supporting instrument. It is thus further advised that the DT approach together with the presented methodologies should be considered as complementary methodologies, contingent on company innovation culture and its unique operational and product-market conditions.

The major theoretical contribution of this study is the assessment of QFD and DT characteristics related to the product innovation work process for non-assembled products. While this study focuses on supporting methodologies for the development of non-assembled products, the research results could also be of interest for companies in other manufacturing industries, since several of the presented methodologies are not context-specific. However, the indicative theoretical findings should be further empirically tested, focusing on methodology usability in different stages of the product innovation work process and how supporting methodologies could be integrated. In a movement towards societal satisfaction (Deleryd and Fundin, 2020), QFD and DT as complementary tools could be one approach to develop both effectiveness and efficiency. Process industries with challenging sustainability targets aiming for operations with a balance of economic, social, and ecologic sustainability requirements will require better integration of available concepts as a means to not only fulfill but also surpass expectations of customers and stakeholders according to Kano's theory of attractive quality (Kano et al.,1984; Kano, 2001), still valid after almost 40 years of deployment. With today's broader stakeholder perspective (Hallencreutz et al., 2020), future research also has an interest in how the increasing numbers of stakeholders could be adapted into present methodologies.

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Appendix A

An intentional definition by Lager has been selected for this study:

The process industries are a part of all manufacturing industries, using raw-materials (ingredients) to manufacture non-assembled products in an indirect transformational production process often dependent on time. The material flow in production plants is often of a divergent v-type, and the unit processes are connected in a more or less continuous flow pattern.

The following industrial sectors have been selected for inclusion in the process industries cluster from all manufacturing industries included in the statistical classification of economic activities in the European community (NACE, 2006) (NACE codes in parenthesis):

Mining & metal industries (05; 06; 07; 24); Mineral & material industries (minerals, cement, glass, ceramics) (08; 23); Steel industries (24.1; 24.2; 24.3); Forest industries (pulp & paper) (17); Food & beverage industries (10; 11); Chemical & petrochemical industries (chemicals, rubber, coatings, ind. gases) (20; 22); Pharmaceutical industries (incl. biotech industries and generic pharmaceuticals) (21); Utilities (electricity & gas, water, sewerage, waste collection & recycling) (35; 36; 37; 38).

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Research Paper

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A review on influence factors promoting or inhibiting the transfer of research from universities into start-ups

The aim of this paper is to provide an overview of the state of play in the transfer of chemistry research from universities to start-ups and to look at factors that promote or inhibit this process. Therefore, in the first step, important definitions such as innovation, technology transfer, start-up, and key sectors are explained. In the second step, key findings about key industries and the chemical industry are summarized. In the third step, examples of factors that promote and inhibit technology transfer as well as studies, their methodologies, and results are presented, described, and classified. In the fourth step, the state of knowledge regarding the technology transfer from scientific research into start-ups in general and for chemistry research in special is summarized. Finally, hypotheses, deriving from the state of the art are formulated suggesting further research in this field.

1 Introduction

In Germany, about 17,000 students study chemistry every year with about 1,000 professors (Statistisches Bundesamt (Destatis), 2022; Society of German Chemists, 2020). At the same time, only 175 - 249 business foundations are founded in the chemical industry each year (Haubold and Calhanoglu). This means that the growth potential for chemistry, with a share of 0.2 % of start-ups in Germany, is below expectations (Opinion Leaders Network, 2022). This paper provides an overview of the factors promoting or inhibiting the transfer of innovation and technology from university departments to start-ups deriving from chemistry research. First, in total 70 sources were screened and reviewed from which 8 sources were found to be relevant for further analysis in more detail. Second, relevant indicators from all relevant studies were identified, and the number of appearances of said indicators was counted, resulting in a so-called score of importance (SOI) (Aksah et al., 2016). Third, the indicators were sorted by the rank of their SOI providing a list of inhibiting and promoting fac-tors, starting with the highest SOI. Finally, two hypotheses were identified suggesting further research. The terms innovation, technology transfer, start-ups, spin-offs from universities, and key sectors are defined in the next sections.

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2 Theoretical background

New start-ups create new jobs (Schlaegel and Koenig, 2014), open up new application possibil-ities and technologies, and provide new incentives and innovations that can lead to changes in market structures (Konrad-Adenauer-Stiftung registered association, 2015).

Innovation originates from Latin meaning renewal or change. Dörr et al. (2014) defined innovation as a process starting from an idea transformed into a product or a service (invention) which has not existed before finally being introduced to a certain market (diffusion) (Wolf et al., 2021). Thus, formula 1 defines the term innovation.

$$\text{Innovation} = \text{idea} + \text{invention} + \text{diffusion} \quad (1)$$

Technology transfer is defined as the transfer or movement of know-how as a process in which adaptations to local conditions occur within as well as between countries (Kanyak, 1985; Chun, 2007; Chung, 2001). The transfer of knowledge can take place through the dissemination of research knowledge, for example through conferences and scientific publications, the training of a qualified workforce, and the commercialization of knowledge. The latter can take place through patents, the founding of a company, spin-off companies, or through contracts with industry, e.g., through licenses (Bolzano et al., 2021). For the development of innovative products, universities are considered as research centers that provide organizational skills, resources, and knowledge through research and teaching (Arenas and González, 2018).

Universities provide support in the form of entrepreneurial idea development, strategic planning, or university-industry cooperation (uic) (Marzocchi et al., 2019). Others support mechanisms described include Science, Technology and Engi-neering Entrepreneurship Education (STEE) for entrepreneurial education and training, of stu-dents or individuals with engineering, technology and science majors or careers (Fayolle et al., 2021), as well as technology transfer offices (TTOs) for commercialization of research results (Holgerssona and Aaboen, 2019).

Currently, there is no single definition for start-up companies, in general. Therefore, four ex-emplary definitions are given below.

1. Wierciński (2016) defines start-ups via the "Lean Start-up" method as a temporary organization in search of a repeatable and scalable business model (Ries, 2011; Blank, 2013)

2. Peter Thiel, founder of PayPal, chairman of Palantir, defines a start-up as a company with the goal of creating a monopoly in a niche market and only then expand-ing into new markets (Thiel and Masters, 2014).

3. the founder of Y Combinator, Paul Graham, defines a start-up as a company de-signed to grow quickly (Graham, 2012).

4. the German Forum Startup Chemie defines chemical start-ups as companies that have not yet established themselves as a manufacturing chemical company with a fixed prod-uct portfolio, but which take on typical start-up functions, such as the development of new products and processes or the provision of specialized services for chemical com-panies (Gehrke and Rammer, 2019).

Innovations for the economy can be gained, among other things, through the knowhow and technology transfer of university spin-off (USO) (Joachim Herz Stiftung, 2021). A university spin-off is defined as a new company founded by faculty members based on intellectual proper-ty from their research. This allows university technologies to be disseminated and commercial-ized by academic entrepreneurs. By localizing knowledge, university spin-offs are described as a local phenomenon and thus offer a contribution to industry formation and economic dyna-mism (Hayter, 2013).

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Since research at universities is conducted in a vast variety of subject areas and topics, it can be of interest to assign them to so-called key sectors, such as the technology-, IT- or the chemical sector. Key sectors can be described as the most valuable sectors of an economy (Hewings, 1982). The identification thereof is made under the consideration that economic sectors do not exist in a vacuum but that there are many cross-industry linkages between them. Key sectors are defined as sectors with close interdependencies with other production sectors. These interdependencies can consist of the use of products produced by others and the use of products produced by others (Temurshoev, 2004).

Within the EU countries, the important sectors identified were wholesale trade, construction, food and beverages, real estate, and chemicals. On the technology side, chemicals, electrical energy, natural gas, base metals, and machinery and equipment were identified. For Germany, the most important sectors are motor vehicle trailers and semi-trailers, other business services, machinery and equipment, construction, and chemicals (Alatriste-Contreras, 2015). The European Union is the world's largest producer of chemicals and is also at the forefront of technological development within this sector. This makes the chemical industry a key sector of the European economy and will be described individually below (Eder and Sotoudeh, 2000).

The fact that chemistry is a part of nearly every value chain of all physical products, creates opportunities for chemical entrepreneurship and innovation (Abigail et al., 2022). With this in mind, global challenges such as human health, crop production, energy generation or storage, water supply security, or climate change can only be solved with chemical innovations (Confalone, 2014; Sachse and Martinez, 2016). Within the chemical industry, the need for new innovation approaches and partnerships is described for future innovation projects. The need for redesigned or newly established value chains as an alternative to new chemical substances is pointed out by Landwehr-Zloch and Glaß (2020).

The best-known models for investigating factors influencing the intention and willingness to start a business are the entrepreneurial event model (EEM) (Shapero, 1984) and the theory of planned behaviour (TPB) (Ajzen, 1985). Within the EEM, business start-ups are seen as the result of external changes and triggering events that influence the perception of individuals (Shapero, 1984). The TPB examines attitudes towards behaviour, the subjective norm and per-ceived behavioural control, i.e., key motivational factors that influence intention, which is considered a precursor to the performance of behaviour (Ajzen, 1985).

The motivation for this review article is the interest in the start-up activity from chemistry faculties leading to innovations in the chemical industry. The aim is to get a general understanding of the factors and whether the number of start-ups generated from chemistry faculties is relatively high or low. The facilitating factors are interesting for strategic measures by decision-makers to support and enhance start-up activities. The hindering factors serve as barriers and provide the opportunity for further research to overcome them. Since the literature search resulted in only one specific publication related to chemistry start-ups, the further investigation of promoting or inhibiting factors regarding the technology transfer from universities into start-ups was done with a more general approach.This approach is supported by Landrya et al. (2006) stating the importance of spin-offs from universities in general because of their access to highly specialized resources like expertise and laboratory infrastructure.

3 Methods

For this work, the literature on chemical start-ups and chemical innovation was analyzed, covering a time range from 1982 until 2022 derived from academic journal articles and books (45 sources in total). A search for publications with the keywords "entrepreneurial event model" and "theory of planned behaviour" yielded 1,410 and 125,000 hits respectively. This recognizes the TPB as a better-known research model. The addition of "chemistry students" reduces the number of hits to 79. The evaluation of these papers revealed one study from India (Abigail et al., 2022). Due to the lack of data for the individual factors and the evaluation as a group, there is no evaluation for the influencing factors. Due to a lack of evaluable studies on the influencing factors among chemistry students in particular, the following evaluation of 8 out of 34 surveys was carried out on influencing factors in general, irrespective of the

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origin, level of education, income, and subject area of the participants, for an initial overview of important influencing factors. Only studies were used which evaluated the factors individually or gave the result of the survey and did not combine them into groups. The selected studies are based on an identical methodology and thus enable a comparison.

Second, relevant indicators from all relevant studies were identified, and the number of appearances of said indicators was counted, resulting in a so-called score of importance (SOI) (Aksah et al., 2016). The objective of the SOI is to classify the different inhibiting and promoting factors for business start-ups from the various publications. To summarize the findings, we analysed the SOI based on the respective rankings within the respective surveys. The most fre-quent factor was rated with 3 points the second with 2 and the third with 1 point. If factors were ranked equally, they were listed twice. The final rating of importance is determined by summing up the individual points. The comparison of the respective total SOIs yields the most important factors from the selected studies. Third, the indicators were sorted by the rank of their SOI providing a list of inhibiting and promoting factors, starting with the highest SOI.

4 Results

General factors

Studies examining entrepreneurial intentions in different countries often focus on three basic factors: culture, business climate, and education. Culture is defined as a set of shared values and beliefs between groups of people (Ajzen, 1991). The study of Engle (2008) examined twelve countries (Bangladesh, China, Costa Rica, Egypt, Finland, France, Germany, Ghana, Russia, Spain, Sweden and the USA) regarding their intentions for entrepreneurial actions in relation to their cultural background. Thereby, the cultural differences were confirmed in terms of attitude towards behaviour, social norms and perceived self-control.

The second factor, differentiates countries in terms of the level of economic development or climate, thus differentiating entrepreneurial intent. The economic environment affects the level and type of entrepreneurial activity, especially when comparing developed and developing countries (Iakovleva et al., 2011). The Global Entrepreneurship Monitor (GEM), was launched in 1997 to study this variability in entrepreneurial activity in a total of 59 countries (Sternberg et al., 2022). The research on entrepreneurial activities in developing and developed countries shows that university students in developing countries are more likely to have entrepreneurial intentions than those in developed countries.

The third factor examined considers entrepreneurial education. Giacomin (2011) asked whether entrepreneurial education should be the same in each country or if there should be an adaptation to the cultural context. Within the survey, entrepreneurial intentions and their relationship with entrepreneurial education were examined among American, Asian, and European students. The results indicate that cultural differences should be taken into account when developing entrepre-neurship education programs.

Factors that promote

Entrepreneurship Education (EE) can be understood as a course or program within a training or study program that encourages entrepreneurs to start a business (Graevenitz et al., 2010). EE within higher education can influence entrepreneurial intentions in two ways. The first way was investigated by Kolvereid (1997), who found that students who took an EE course during their studies had higher entrepreneurial intentions than those who did not. The second possibility was investigated by Franke (2004) referring to the general educational envi-ronment at the university and whether it supported the creation of new businesses. The results show that entrepreneurial intentions correlate with the students' assessment of the university environment. The article by Abigail (2022) et al. examined the impact of incorporating EE into the undergraduate chemistry curriculum in India. It compared surveys of students with EE in the curriculum with those without. The results indicate a positive effect of EE. At the same time, this survey represents the only one specifically referring to chemistry students (Abigail et al., 2022). Packham et al. (2010) compared the impact of EE on the entrepreneurial attitudes of French, German and Polish students. They found that entrepreneurship education had a positive impact on intentions to start a business in France and Poland, but a negative impact on German students, specifically male students.

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The articles analysed and their surveys are based on single-country studies such as Malebana (2014) in South Africa, Sandhu et al. (2011) in Malaysia, Sarri et al. (2018) and Greece, multi-country comparisons such as Pruett et al. (2009) with USA; China and Spain, Sesen and Pruett (2014) with Turkey and USA or Giacomin et al. (2011) with USA, China, Spain, and Belgium. Another cross-country comparison was made by Kanama (2021) through Japanese data with Giacomin et al. (2011) data. The data can be found in Table 1 with the respective source, country, and number of participants. Table 1 thus serves as a summary of the collected factors that promote entrepreneurial activity.

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Table 1 Score of importance for factors that promote (№* ´= No indication in the publication abbreviation).

Factors	Source	Number of participants	Country	Points	Score of importance (SOI)
Implement my own idea	Pruett (2009)	312 - 317	USA	3	
	Pruett (2009)	591 - 603	Spain	3	
	Pruett (2009)	130 - 136	China	3	
	Kanama (2021)	№*	Japan	2	
	Kanama (2021)	121	Japan (gr)	2	
	Giacomin (2011)	317	USA	3	
	Giacomin (2011)	422	India	3	
	Giacomin (2011)	417	Belgium	3	
	Giacomin (2011)	333	China	3	
	Giacomin (2011)	604	Spain	3	
					28
Independent	Malebana (2014)	329	South Africa	3	
	Pruett (2009)	312 - 317	USA	2	
	Pruett (2009)	591 - 603	Spain	1	
	Pruett (2009)	130 - 136	China	1	
	Sesen (2014)	316	USA	3	
	Sesen (2014)	459	Turkey	3	
	Giacomin (2011)	317	USA	1	
	Giacomin (2011)	422	India	2	
	Giacomin (2011)	417	Belgium	3	
	Giacomin (2011)	333	China	3	
	Giacomin (2011)	604	Spain	3	
					25
Creating something of my own	Pruett (2009)	312 - 317	USA	1	
	Pruett (2009)	591 - 603	Spain	2	
	Pruett (2009)	130 - 136	China	2	
	Sesen (2014)	316	USA	2	
	Sesen (2014)	459	Turkey	2	
	Sandhu (2011)	267	Malaysia	3	
	Kanama (2021)	№*	Japan	1	
	Kanama (2021)	121	Japan (gr)	1	
	Giacomin (2011)	317	USA	2	
	Giacomin (2011)	417	Belgium	3	
	Giacomin (2011)	333	China	3	
	Giacomin (2011)	604	Spain	3	
					25

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Factors	Source	Number of participants	Country	Points	Score of importance (SOI)
Contribution to the regional community	Kanama (2021)	№*	Japan	3	6
	Kanama (2021)	121	Japan (gr)	3	
Social environment welcomes entrepreneurship	Sarri (2018)	419	Greece	3	3
Challenge	Malebana (2014)	329	South Africa	2	2
Create jobs	Sesen (2014)	316	USA	1	2
	Sesen (2014)	459	Turkey	1	
Personal development	Sesen (2014)	316	USA	1	2
	Sesen (2014)	459	Turkey	1	
Vision of becoming an entrepreneur	Sandhu (2011)	267	Malaysia	2	2
Need for control	Sarri (2018)	419	Greece	2	2
Part of career planning	Sandhu (2011)	267	Malaysia	1	1
Use one's creative taletnts	Malebana (2014)	329	South Africa	1	1
Need for achievement	Sarri (2018)	419	Greece	1	1
Quality of life	Giacomin (2011)	422	India	1	1

Table 1 shows a clear gradient between the individual factors from the studies. The factors “Implement my own idea”, “Create something of my own” and “Independent” were named most frequently within the surveys analysed. Thus, these factors are the factors that promote entrepreneurial activities the most. The evaluation of variance shows no cultural differences for the factor "Implement my own idea", in contrast to the factors "Independency" and "Creating something of my own", which showed a cultural difference in the variance of the SOI. The cultural differences do not allow any conclusion to be drawn about the level of development of the countries, as the rating of "Independency" shows with ratings of one point (Spain, China, USA), two points (USA and India), up to three points (South Africa, USA, Turkey, Belgium, China and Spain). It is interesting to note the different ratings of the countries that were considered in several surveys, such as the USA, Spain, or China. This suggests an influence of the samples surveyed and the respective point in time.

Factors that inhibit

Analogous to the promoting factors, the evaluation of the hindering factors is also carried out. In addition to the articles on the promoting factors, the evaluation of Karimi et al. (2017) with participants and the comparative study of Doanh (2018) with Vietnamese and Polish students will be carried out. The SOI was calculated analogously to the SOI for the promoting factors. Table 2 serves as a summary of the collected factors that promote entrepreneurial activity.

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Table 2 Score of importance for factors that inhibit (№* ´= No indication in the publication abbreviation).

Factors	Source	Number of participants	Country	Points	Score of importance (SOI)
Lack of initial capital	Pruett (2009)	312 - 317	USA	2	
	Pruett (2009)	130- 136	China	3	
	Pruett (2009)	591 - 603	Spain	3	
	Kanama (2021)	№*	Japan	1	
	Doanh (2018)	198	Vietnam	2	
	Doanh (2018)	243	Poland	3	
	Giacomin (2011)	317	USA	2	
	Giacomin (2011)	417	Belgium	2	
	Giacomin (2011)	333	China	3	
	Giacomin (2011)	604	Spain	3	
	Giacomin (2011)	422	India	3	
					27
Excessively risky	Pruett (2009)	312 - 317	USA	3	
	Pruett (2009)	130 - 136	China	2	
	Pruett (2009)	591 - 603	Spain	2	
	Kanama (2021)	121	Japan (gr)	1	
	Giacomin (2011)	317	USA	3	
	Giacomin (2011)	417	Belgium	3	
	Giacomin (2011)	333	China	2	
	Giacomin (2011)	604	Spain	2	
					18
Lack of knowledge	Sesen (2014)	316	USA	3	
	Sesen (2014)	459	Turkey	3	
	Kanama (2021)	№*	Japan	2	
	Kanama (2021)	121	Japan (gr)	3	
	Doanh (2018)	198	Vietnam	3	
	Doanh (2018)	243	Poland	1	
					15

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Factors	Source	Number of participants	Country	Points	Score of importance (SOI)
Current economic situation	Pruett (2009)	312 - 317	USA	1	
	Pruett (2009)	591 - 603	Spain	1	
	Giacomin (2011)	317	USA	1	
	Giacomin (2011)	417	Belgium	1	
	Giacomin (2011)	333	China	1	
	Giacomin (2011)	604	Spain	1	
	Giacomin (2011)	422	India	2	
					8
Experience	Sesen (2014)	316	USA	2	
	Sesen (2014)	459	Turkey	2	
	Kanama (2021)	121	Japan (gr)	2	
	Giacomin (2011)	422	India	1	
					7
Locus of control	Karimi (2017)	346	Iran	3	3
Lack of social networks	Sandhu (2011)	267	Malaysia	3	3
Lack of entre-preneurial competence	Kanama (2021)	№*	Japan	3	3
Economic barriers	Sarri (2018)	419	Greek	3	3
Need for achievement	Karimi (2017)	346	Iran	2	2
Followed by lack of resources	Sandhu (2011)	267	Malaysia	2	2
Public policy	Sarri (2018)	419	Greek	2	2
High taxes	Doanh (2018)	198	Poland	2	2
Risk aversion	Sesen (2014)	316	USA	1	
	Sandhu (2011)	267	Malaysia	1	
					2
Lack of ideas	Pruett (2009)	130 - 136	China	1	1

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Factors	Source	Number of participants	Country	Points	Score of importance (SOI)
Attitudes towards entrepreneurship	Karimi (2017)	346	Iran	1	1
Lack of support, structure, and fiscal costs	Sesen (2014)	459	Turkey	1	1
Business risk barriers	Sarri (2018)	419	Greek	1	1
Competition	Doanh (2018)	243	Vietnam	1	1

Table 2 shows a clear gradient between the individual factors from the studies. The most frequently mentioned factors in order of importance are: inhibiting entrepreneurial activities “Lack of start-up capital”, “Too much risk” and “Lack of knowledge”. The variance for these factors shows a cultural influence, as with the factor "Lack of initial capital". While China, Spain, Po-land, and India ranked this factor as the most obstructive, the USA, Vietnam, and Belgium ranked it as the second most obstructive, and respondents in Japan ranked this factor third. Another influencing factor is the survey sample, see for example the US results, highest prioritisa-tion in 2009 & 2011 for "Excessively risky" and in 2014 for "Lack of knowledge". This suggests either a temporal influence due to a generational change or different cultures in the surveyed samples. Another influencing factor is shown in the study by Kanama (2021) et al. with the educational level of the students surveyed. With regard to technology transfer in chemical research, it became clear that more surveys need to be conducted to get a clearer picture of the factors that promote and inhibit technology transfer from the university to start-ups.

5 Discussion

The chemical industry can be described as a key industry due to the diversity of products and possible applications. Technology transfer from universities is a key area for innovation in the chemical industry. In addition to sufficient skilled workers, new ideas and innovations are also needed to cover the demand described by Temurshoev (2004). The lack of publications in the area of innovations or technology transfer within the chemical industry shows the clarity of the need for research. The factors evaluated show overlaps in some areas such as the desire to implement one's own ideas or the lack of start-up capital. The chemical industry, with its investment costs in equipment or research, for example, has higher capital requirements than a start-up in the service sector. At the same time, differences are shown between countries and cultures, but also between levels of education and disciplines. At the current state of the art, the literature shows a research focus on students from the fields of business administration or economics (Karabulut, 2016). Therefore, the results of the studies cannot be directly transferred to students of natural science subjects due to the different contents of the subjects.

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6 Conclusion

Business start-ups are playing an increasingly important role not only in practice but also in science. Knowledge about start-ups is an elementary factor in this. The present work opens up a research gap by linking existing knowledge and the analysis for the natural sciences. For further research, the use of a comparative study of different countries is recommended, as well as the evaluation according to various demographic factors such as gender, culture or the level of education among chemistry students. At the current state of research, there are studies on the factors that promote or inhibit spin-offs from universities. The results show that the factor "Implement my own idea" promotes spin-offs regardless of culture and generation. While the factors "Create something of my own" and "Independent" were prioritised although they have a temporal as well as cultural variation. This leads to hypothesis 1 (H1).

H1. The factors that promote spin-offs from the university are comparable across different countries.

The inhibiting factors "lack of start-up capital", "too much risk" and "lack of knowledge" show variances due to social differences or generational differences. A difference in time and the respective level of education cannot be ruled out as influencing factors. This leads to hypothesis 2 (H2).

H2. The factors that, in the view of the respondents, inhibit a spin-off from the university depend on economic and cultural influences.

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Practitioner's Section

Johanna Angela Thomann*, André Heeres and Errit Bekkering*****

The Northern Netherlands: Transformation of a gas-producing region into a forerunner in the biobased circular transition

The Northern Netherlands is an unique environment for sustainably-minded (bio)chemical businesses due to the regional availability of renewable feedstock, energy and existing infrastructure as well as the proximity to excellent knowledge centers and upscaling facilities. Within the last decades, several developments unravelled in the biobased circular transition. Exploring how these developments were initiated, the article means to show the opportunities that this region has to offer today. It also makes a strong argument for the economic potential arising from the creative combination of available feedstocks in an innovative ecosystem providing necessary frame-work conditions and fostering close intersectoral collaboration.

1 Introduction

The Northern Netherlands, spanning between the provinces Friesland, Groningen and Drenthe, is characterised by wide and open windy fields located at the North Sea/Wadden Sea coast. With a number of inhabitants of around 1.8 million, the North is less densely populated than the rest of the country and it has a strong agricultural sector (IWCN, 2022). While horticulture for flowers and vegetables is typical for the west of the country, crops like sugar beets, potatoes, rapeseed, corn, hemp and grass land are more prominent in the Northern parts close to Germany. As a consequence of this agricultural heritage, large food manufacturers like Cosun Beet Company (sugar beets) and Royal Avebe (potatoes) were established in the region. Due to the occurrence of salt layers from remnants of primeval seas, both sodium chloride and magnesium chloride are mined locally. Moreover, the Northern Netherlands has a strong chemical sector with two complementary industrial clusters. The cluster in Delfzijl in the province of Groningen focuses on the production of basic chemicals, while the cluster in Emmen in the province of Drenthe is specialised in polymer materials. The region is home to well-respected knowledge institutes including the University of Groningen, Hanze University of Applied Sciences in Groningen, the Stenden University of Applied Sciences in Drenthe/Friesland and Wetsus in Leeuwarden in Friesland.

Another characteristic of this region are its large natural gas reservoirs. The Groningen field is one of the world's largest gas fields with a capacity of 2,800 billion m³ (Nederlandse Aardolie Maatschapij NAM, n.d.). This led to a strong historical reliance on natural gas that was also important for the development of the energy intensive chemical clusters. Indeed, the share of natural gas in the national primary energy demand in 2010 was as high as 48.2%, whereas renewables contributed a mere 4%. The extraction of natural gas constituted 90.6% of the national energy production in 2010 (Energie Beheer Nederland EBN, 2022). Tragically, the exploitation of these gas reservoirs was associated with increased occurrences of earth quakes, thereby damaging houses in the province of Groningen. When the strongest earthquake occurred in 2012 with a magnitude of 3.6 on the Richter scale, the government responded to the public`s anger

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and their environmental concerns. Consequently, plans for the phasing out of the gas extraction in the Groningen field by 2022 were published (Ministerie van Algemene Zaken, 2022). However, this had the loss of approximately 20.000 jobs as a consequence (Province of Groningen, n.d.). At the same time, the financial crisis in 2008 had also left its mark on the economy. Companies started to struggle with high energy prices and finding skilled workers due to trends of urbanization and other demographic changes. Meanwhile, warnings of the consequences of global warming and the call for climate action from scientists around the world received more recognition in the public discourse leading up to the Paris agreement in 2015 (United Nations Framework Convention on Climate Change, n.d.). With the growing awareness for sustainability, discussions on business practises that would respect planetary boundaries gained more and more attention questioning the linear fossil-fuelled extract-use-discharge system.

The situation of the chemical clusters at the time was described in a report from 2014, in which current struggles were addressed and a vision for the clusters was drafted (Willems, 2014). According to this source, the clusters were already working closely together as was reflected by a high labour productivity and a partly shared, decently functioning infrastructure. Nonetheless, common utilities within and in-between the clusters needed be further optimized (e.g. energy and waste flows). This included a joint steam pipeline for a closed-loop heat system. Innovation and entrepreneurship were lagging behind while the focus remained on the production of low-value bulk products. Chemicals produced in the chemical cluster Delfzijl included methanol, glycerol, sodium chloride, hydrochloric acid, sodium hydroxide, hydrogen peroxide, chlorine, monochloroacetic acid, formaldehyde and ethylenediamine. For the production of polymer materials (mainly polyesters like PET and aramides), the clusters in Delfzijl and Emmen were mostly relying on imports of fossil-based feedstocks like terephthalic acid, aniline, 1,4-butanediol, p-xylene among others.

Better alignment of the chemical clusters with the nearby knowledge centres was stressed as action point to promote the valorisation of academic knowledge and thus innovation. For this, suitable upscaling facilities were needed enabling research on all technology readiness levels (TRL). Along side, opportunities were identified in organising effective branding and acquisition for both clusters. This would help bridging public and private sectors as well as offer support for companies in business development and organising funding. For an overview of the situation 10 years ago, a SWOT analysis was performed (Table 1).

Table 1 SWOT analysis of the Northern Netherlands in the 2010s.

Strengths	**Weaknesses**
⇨ Agricultural sector ⇨ Large gas reservoirs ⇨ Complementary chemistry clusters in Delfzijl and Emmen ⇨ Knowledge centers (University of Groningen, Hanze University of Applied Sciences, NHL Stenden, Wetsus)	⇨ Strong focus on low-value bulk chemicals and materials ⇨ Strong national reliance on natural gas from Groningen
Opportunities	**Threats**
⇨ Alignment of chemical clusters with the knowledge institutes ⇨ Organising and strengthening of common utilities within and between clusters ⇨ Branding and acquisition for both clusters ⇨ Connecting the agricultural, energy and waste sectors to the chemical sector ⇨ Growing awareness for sustainability and transition to a biobased circular economy	⇨ Earthquakes, damaged houses, loss of trust of citizens ⇨ Financial crisis ⇨ Issues to find human resources and skilled labour ⇨ High prices of energy

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Out of this situation, the need for a strategic repositioning became clear. As a consequence, ambitions were born to transform the regional economy into a biobased, circular one and as a joint initiative Chemport Europe was kicked off.

2 Transition into the biobased circular economy

The transition towards a biobased circular economy takes place against the background of the climate crisis caused by the exploitation of fossil carbon and associated accelerated greenhouse gas emissions (Krätzig, 2019). Biomass, as an available renewable carbon source, is seen as a practical, more sustainable and thus favorable alternative (Yang et al, 2021; Escobar and Laibach, 2021). The origins of the biobased economy and the drafting of the bioeconomy strategy in the European Union were described elsewhere (Patermann and Aguilar, 2018; European Commission, 2018).

In a biobased circular economy, production processes are optimized and strongly integrated and use minimal resources such as water, energy and materials. The industrial activities are powered by renewable energy leading to substantially lower greenhouse gas emissions. The input streams are sustainably sourced moving away from fossil fuels and feedstock. Circularity in the context of biomass valorization refers to a cascading use of these raw materials; an approach that is applied in integrated biorefinery systems (Escobar and Laibach, 2021). Overall, maximal reuse and recycling of streams is aimed for, turning the linear system in to a circular one. This is also reflected in product design by building for longevity and durability (University of Groningen–Industry Relations Office, 2020; Yang et al, 2021).

3 Developments in the energy sector

As the topic of biobased circular economy is inherently intertwined with the energy transition, a discussion of one would be incomplete without talking about the other. For that reason, the developments in the energy sector will be described before delving into the biobased circular economy.

Here, energy transition refers to the change from a mostly fossil-based system geared to natural gas towards a renewable, largely decarbonized energy system. Besides changing the energy source, a crucial aspect lies within its responsible use. Electrification and optimization of industrial processes are on the agenda to yield highest possible energy efficiency in the chemical clusters. Local use of energy with as little conversion steps as feasible can be a way to reduce energy losses.

The clusters` main energy sources to date consist of coal, natural gas, household waste, biomass and electricity. Electricity and heat are thereby produced from various sources and either supplied to the energy grid or directly to industrial end-users. To date, the largest part of hydrogen in the cluster Delfzijl is produced from natural gas. This grey hydrogen serves as feedstock for the production of hydrogen peroxide and methanol. Hydrogen as by-product of chlorine production is currently used for heat and electricity production. By now, steam pipelines have enabled a closed-loop system for heat within the cluster.

Due to the planned electrification of industry, built environment and mobility, electricity demand is expected to increase significantly. In the current cluster energy report, energy by coal is expected to be fully replaced by bioenergy from waste biomass and green gas from biomass fermentation. It is expected that the demand in natural gas in the chemical cluster will only decrease from 13.1 TWh/year to 11.2 TWh/year by 2030 (Water Energy Solutions, 2022). In this projection, natural gas-based power plants remain in operation and a number of factories will not have adapted their processes. These developments are strongly affected by prices for natural gas, electricity and CO_2.

Towards 2050, a further increase in electricity consumption is expected. Natural gas consumption by the chemical cluster will be reduced to 3.7 TWh/year, but 19.7 TWh/year will still be needed for electricity generation in Eemshaven. Electricity producers in Eemshaven therefore plan to incorporate capture of CO_2 emissions into their operation for usage in other sectors (CCU) or storage in empty gas fields and potentially salt caverns (CCS) (Water Energy Solutions, 2022). Indeed, Carbon Capture and Storage (CSS) is also pursued as a national strategy with the North Sea Energy Outlook from 2020 indicating a total available storage capacity of 1.400 Mt in empty gas fields on the Dutch continental shelf and expected levels of CO_2 storage of 10.2 Mt per year in 2030 (Cleijne et al, 2020). A number of these empty gas fields are also located close by.

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Being located at the North Sea coast, the North will play an important role in the roll-out of renewable energy capacity due to available space and favourable wind conditions. Off-shore wind energy is a crucial part of Dutch climate policy. Here, Delfzijl and Eemshaven are suitable locations to bring this electricity on-shore. Current targets for 2030 are a supply of offshore wind energy of 21 GW equalling to 16% of the current Dutch energy demand and 75% of current electricity needs. Importantly, the electricity demand is expected to grow over time. The North Sea Energy Outlook has indicated that an offshore wind capacity between 38 - 72 GW is needed by 2050. As a reaction to this, the North Sea Agreements contains plans to explore suitable spaces for another 20 to 40 GW of offshore wind energy capacity to meet the predicted demand (Netherlands Enterprise Agency RVO, 2022; Ministerie van Economische Zaken en Klimaat, 2020).

To adapt to the weather-dependent supply of solar and wind energy, bioenergy and hydrogen as energy carrier will diversify the energy mix. Notably, the Northern Netherlands has ambitions to become the leading hydrogen valley in Europe building on several strategic advantages. These are namely its expertise in gas trading, transport and storage, existing pipeline networks and infrastructure, the industrial clusters and off-shore wind parks. In a recent study, the suitability of the existing gas infrastructure was examined for the transmission of hydrogen (HyWay 27, 2021). In The Netherlands, different pipelines (i.e. for low and high caloric natural gas) are built in parallel throughout the country. With the phasing out of the gas extraction from the Groningen field (which is currently slowed down due to the difficult situation in the European gas market (Ministerie van Economische Zaken en Klimaat, 2022)), it becomes feasible to free up not needed capacity for green hydrogen.

With the replacement of valves and cleaning of pipes, the refurbished infrastructure is highly suitable for hydrogen and thus constitutes a cost effective step in the energy transition. New pipelines will only be needed to a small extent connecting industrial clusters, hydrogen producers and storage locations to the main grid where needed (Gasunie, 2022). The report provides an estimate of investment costs of around 1.5 billion euros (HyWay 27, 2021).

In the North, a newly developed polymeric pipeline will be employed for local hydrogen transport within the cluster in Delfzijl that is low in cost and easily extendable (Groningen Seaports, 2022). Moreover, the deep-sea port in Eemshaven, salt caverns for underground storage and a newly built LNG terminal enable import and distribution of hydrogen in The Netherlands and Western Europe providing access to European off-take markets (Water Energy Solutions, 2022).

As an European model region, they aim to demonstrate an integrated sectoral approach and develop functioning self-sustaining business models surrounding a green hydrogen economy for which they received an EU grant of 20 million euros (Clean Hydrogen Joint Undertaking, 2020; Fields, n.d.). In an integrated value chain production, distribution, storage and end-use of green hydrogen are neatly connected. These ambitions are reflected in various ongoing projects along the entire value chain (Water Energy Solutions, 2022; Province of Groningen, 2020). In the NorthH2 project, plans were mapped out to expand the capacity of electrolysers using off-shore wind energy to produce 800.000 tonnes of green hydrogen per year by 2040 (Chemport Europe, 2020). Near term focus lies on the production of hydrogen as feedstock for the chemical industry. As a long term outlook, off-shore electrolysers are currently debated as additional hydrogen supply. Using existing gas pipelines for hydrogen transport and direct use of off-shore wind energy would circumvent the necessity of installing new cables in the marine environment and associated energy losses.

4 Intersectoral approach for a biobased circular economy

The circular resource and product streams in a bioeconomy require a concerted effort of different sectors. Looking at the chemical sector, implications and links with the energy, agricultural and waste sectors can be identified. Firstly, links between the energy and the chemical sector through H_2 and CO_2 as well as heat and electricity will be discussed. Secondly, links between the agricultural and chemical sector through biorefinery or biotechnological approaches will be highlighted. Lastly, the future role of the waste sector is explored employing principles of circularity. Relevant flagship projects that were started in the region will be introduced exemplifying the innovative potential of intersectoral collaboration.

Hydrogen links the energy sector with the chemical sector functioning as both energy carrier (Power2Gas) and renewable feedstock (Power2Chemicals). Green hydrogen

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could replace grey or blue hydrogen in several processes such as the Haber-Bosch process to yield ammonia. Furthermore, it could be used for organic transformations of biomass-derived products and/or end-of-life plastics. Captured carbon dioxide is another important link being seen as carbon source for chemicals (Frieden, 2021). Of high interest is the production of green chemicals/fuels like methanol or kerosene using CO_2 and H_2 as feedstock, most often via syngas. Using microalgae and CO_2, biotechnological production of acetic acid and other compounds becomes feasible (Photanol, n.d.). Moreover, Avantium is looking into possibilities of using carbon dioxide for electrochemical valorisation routes, that they refer to as Volta technology (Avantium, 2021). The value of the chemicals made should thereby carry the cost of green hydrogen, electricity and/or CO_2 capture. Current benchmark is often a fossil based chemical without the costs of externalities and with the benefits of scale and 100 years of optimization. However, the chemical industry falls under the EU emission trading system (ETS). Through capping the amount of emission allowances and phasing out of free allowances in the future (KPMG, 2022), CO_2 – intense products will become more costly providing an advantage for low-emission biobased alternatives.

The value of the agricultural setting of the Northern Netherlands becomes apparent considering (bio-)chemical valorisation routes of agricultural products and residual streams. In 2017, Heeres and Heeres identified promising chemicals for this purpose by means of literature study and market and cost analysis. Target compounds of this report included epichlorohydrin, gluconic acid, levulinic acid, polyglucuronic acid, 1,2- and 1,3-propanediol, ethylene glycol, sorbitol, isosorbide and the aromatic compounds benzene, toluene and p-xylene. All of these can be synthesised from biobased feedstock, namely either glucose, cellulose, starch or glycerol using only reagents that are already available in the cluster.

Later in 2020, the saccharide agenda was published. This was meant as a roadmap for the use of (poly)saccharides as platform chemicals to produce various (di)alcohols and (di) acids (ter Braak and Smit, 2020). Conversion to other sugars such as xylitol and production of polyhydroxyalkanoates (PHA) was envisaged as well. The reconsideration of saccharose from sugar beets as chemical feedstock can thereby be seen as a response to decreasing demand and discussions on the negative health impacts of sugar consumption. More broadly, other 1st generation sugars like potato starch, 2nd generation sugars from woody biomass and 3rd generation sugars from residual streams are potential feedstocks as well. The saccharide agenda examined economic and technical viability of target compounds like monoethylene glycol (MEG), acetic acid, 1,4 butanediol (1,4 BDO), 2,5 furandicarboxylic acid (FDCA), xylitol and polyhydroxyalkanoates (PHA) (ter Braak and Smit, 2020). Some of which are currently used by regional companies but are mostly imported and sourced from fossil carbon (1,4 BDO and acetic acid).

An advanced example for the use of 2nd and 3rd generation sugars can be found at Avantium. The company developed and optimized a process to yield industrial sugars and lignin from agricultural residues. This so-called DAWN technology reached pilot-scale and uses hydrochloric acid produced in Delfzijl. The obtained sugars serve as feedstock for the production 2,5-furandicarboxylic acid (FDCA) and monoethylene glycol (MEG). A pilot plant to produce plant-based MEG was built in 2019. In 2022, Avantium begins the construction of its FDCA flagship plant that utilizes fructose as feedstock. The two compounds MEG and FDCA are the starting materials for the production of polyethylene furanoate (PEF). They are looking into the commercialisation and large scale production of biobased PEF that can be used for packages, textiles or foil (Avantium, 2021). Lignin, as by-product, has potential both as feedstock itself or fuel, due to its high energy content.

In a circular economy, products are kept in use for as long as possible and waste is redefined as resource. In a chemical context, plastic wastes and sewage from wastewater treatment plants become interesting as resources. Thus, the waste management sector is connected to the chemistry sector as well.

In terms of wastewater treatment, Paques and Paques Biomaterials are to mention. Paques is a globally active service company specialized in wastewater treatment and resource recovery from sewage including nutrients, metals and cellulose from toilet paper (Recell Group BV, 2022). Paques Biomaterials is a spin-off that dedicated research towards the microbiological production and extraction of polyhydroxyalkanoates (PHA) using wastewater as feedstock (Paques Biomaterials, n.d.). Paques Biomaterials plans its demonstration plant for 2023 to validate the concept and scale-up the production of this naturally occurring,

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biodegradable polyester. Later on, a commercial extraction facility with a capacity of 6 kton PHA/year is planned in the industrial park Emmen (Gielen, 2022).

Another interesting approach is carried out by the start-up BioBTX in Groningen, which is a spin-off from Symeres and Ecoras. Employing integrated cascading catalytic pyrolysis techniques, they demonstrated how widely used aromatic compounds can be obtained from diverse waste products in two steps. These are pyrolysis in the absence of oxygen and subsequent aromatic formation in a catalytic reactor (*ex situ*) from which pure aromatic compounds can be isolated. Benzene, toluene and xylenes produced in this way serve as drop-in chemicals substituting fossil-based counterparts. Residual streams range from plastics to contaminated biomass. After the development of a mini plant, scale-up to commercial levels is aimed at. Besides that, downstream processing of aromatics is investigated to obtain other chemical building blocks (BioBTX, n.d.).

The chemical cluster in Emmen is very active in the field of recycling and biobased production of polyesters and aramides to reduce greenhouse gas emissions and move away from fossil feedstock. In the following, a few examples of ongoing efforts in the cluster are highlighted.

Mechanical recycling of polyethylene terephthalate (PET) is rendered difficult when the collected material is coloured, contaminated or mixed with other types of polymers. The CuRe project is a low energy chemical recycling process of such difficult to recycle end-of-life polyesters. After sorting and washing, partial depolymerisation, purification and repolymerization yields colourless granules similar to those obtained through mechanical recycling of clear/blue and clean polyester. The CuRe system allows for adaptation to different waste streams by incorporating modular add-on technologies. Partners of the CuRe consortium are Morssinkhof Group, DuFor/ Cumapol Group, DSM-Niaga and NHL Stenden University of Applied Sciences. Located in Emmen, the pilot plant has a capacity of 20 kg/h using a continuous process. The next phase after validation would be the conversion of a polymerisation line at Cumapol to the CuRe recycling system enabling an additional capacity of 25 kta (CuRe Polyester Rejuvenation, 2022).

At Clariter, challenging plastic waste of polyolefins (i.e. PE, PP and PS) can be chemically recycled to yield solvents, waxes and oils. Their three step process consists of thermal cracking, hydrocracking and distillation/separation (Clariter, 2022a). Together with regional partners, they plan to start a plant in Delfzijl with a processing capacity of 350,000 t/year in 2025, which would then be the largest sorting plant for the chemical recycling in Europe (Clariter, 2022b).

At Tejin Aramid in Emmen, aramide products are produced, one of which is Twaron© – a p-phenylene terephthalamide (PPTA), which is made from the monomers p-phenylenediamine (PPD) and terephthaloyl dichloride (TDC). Considerable effort has been put in setting up recycling programmes, that collect end-of-life Twaron© from industrial customers. These collected waste streams and process scrap material are turned into aramide pulp at their own recycling facility. Here, re-spining of recycled material is explored for yarn-to-yarn recycling (Teijin Aramid, 2021).

In 2020, a successful pilot study served as a proof-of-concept that biobased drop-in chemicals are suitable for Twaron© yarn production (Figure 1). While the biobased aramide yarn showed the same properties, it had a lower

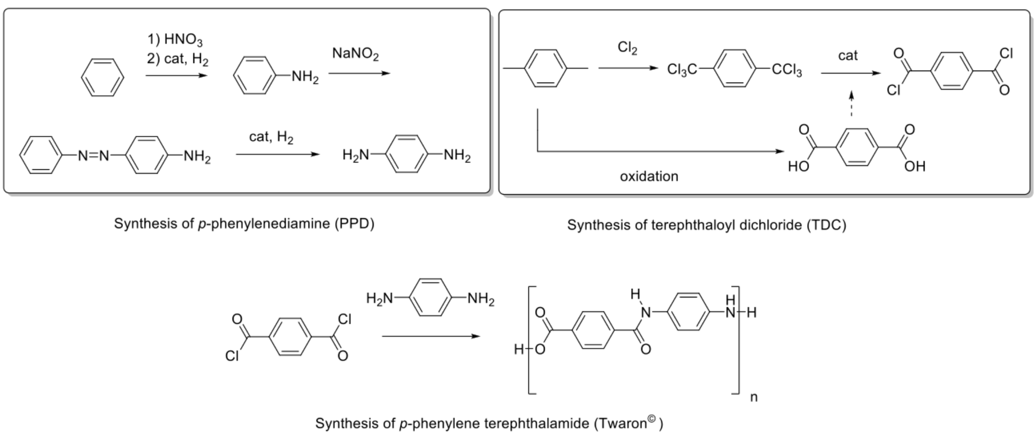

Figure 1 Synthesis of p phenylene terephthalamide (Twaron©) using biobased aromatics from BioBTX as feedstock.

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CO_2 footprint. Collaborators were BioBTX, that provided biobased aromatic building blocks and Symeres, a company specialized in performing organic chemical research (Teijin Aramid, 2021).

Similarly, it was possible to demonstrate the production of bio-PET (polyethylene terephthalate) . Here, glycerol served as feedstock for the BioBTX process. Syncom was responsible for the conversion to suitable precursors terephthalic acid, while Cumapol and API performed the polymerisation to yield biobased PET. In collaboration with DuFor, Aarts Plastic and the Stenden University of Applied Sciences, the bio-PET was then formed into small containers for cosmetics (Kupfer, 2016).

These flagship projects ranging from biobased building blocks, drop-in chemicals and polymers to effective recycling strategies show ambitions and ongoing developments in the region. It can be seen that with a portfolio of available feedstocks, existing infrastructure, scientific creativity and entrepreneurship, important problems of the chemical industry can be addressed and economic value can be created!

5 With a portfolio of available feedstocks, existing infrastructure, scientific creativity and entrepreneurship, economic value can be created!

A smaller scale example of close collaboration among local entities can be found in the Innovation Hub East-Groningen (IHOG). The hub was founded in 2019 as a collective of four local companies and two collaborating knowledge institutes with the goal to foster product innovations with regional feedstocks. The involved partners are the potato starch manufacturer Royal Avebe, Nedmag mining and producing magnesium salts and oxides, the hemp producer Hempflax and Zechsal who produces cosmetic products. Combined, eight feedstocks are available in Eastern Groningen: potato starch and protein, magnesium hydroxide, chloride and oxides and hemp fiber, proteins and CBD oil. Out of combinations of these feedstocks, ten application-oriented projects were developed. Research themes evolved around sustainable construction materials (i.e. starch-based adhesives and fire-resistant hemp materials for construction and insulation), dietary supplements (i.e. combinations of hemp and potato protein, Mg-fortified modified starch) and higher valorisation of hemp fiber (Innovation Hub East Gronignen, n.d. a). This way, IHOG has been involved in 230 student projects in 2021 in law, science and engineering, marketing and business and economics and even art. Indeed, a remarkable project has been conducted with the art academy Minerva of the Hanze University of Applied Sciences in Groningen. The design of Conscious Furniture collection, that was exhibited on the Dutch Design week in Eindhoven in 2022, is uniquely fit to communicate the IHOG`s mission and make it tangible for a wider audience (Dutch Design Week, 2022). The collection was prepared from hemp fibers, starch and magnesium additives. The National Program Groningen recently awarded a subsidy of 1 million euros to support the research projects with the aim of creating more employment and strengthen the local economy (Innovation Hub East Groningen, n.d. b).

6 What are framework conditions for such collaborations?

So after discussing developments in the transition towards a biobased circular economy, we can identify key framework conditions proven essential. It started with a shared vision and ambition. To shape this vision, time is needed as well as discussion and input from many stakeholders. Key framework conditions are the proximity of excellent knowledge centers, research and upscaling facilities, good coordination and connection between involved parties and available financing. The central role of existing and shared infrastructure was already discussed when describing developments in the context of energy efficiency and energy transition.

The University of Groningen (RUG) and the Hanze University of Applied Sciences both have a good international reputation and accomplished research groups concerned with chemistry, biorefinery and biotechnology. Notably, the RUG is among the top 100 worldwide and home to the Nobel prize winner in Chemistry in 2016 (University of Groningen, 2022). Moreover, they formed a collaborative for research regarding the bioeconomy region Northern Netherlands BERNN (Bio Economy Region Northern Netherlands, n.d.). The Stenden University of Applied Sciences has expertise in polymer chemistry and material science. Its ambition is to become a research hub for sustainable plastics for businesses in The Netherlands (NHL Stenden, n.d.). The

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recently started Greenwise Campus in Emmen is focusing on closing the polymer loop (Greenwise Campus, 2022). Wetsus on the other hand has world-wide reputation for excellence in sustainable water technologies (Wetsus, 2022).

They bring value through academic knowledge and research in early TRL but also through the development of human capital on various education levels in the region. Skilled (international) workers that are bound to the region and can identify with sustainability goals of local businesses would be the ideal scenario fighting trends of urbanization and demographic changes.

The steps needed to bring an idea to a commercial product can be categorized as technology readiness levels (TRL). Levels entail basic technology research (1-2), research to prove feasibility (2-3), technology development (3-5), technology demonstration (5-6), system/subsystem development (6-8) and lastly, system test, launch and operation (9). For successful implementation, it is pivotal to be able to carry out research throughout these phases. The Northern Netherlands provides such research and upscaling facilities that are specialized in different research areas ranging from (bio)chemistry, renewable energy and hydrogen innovations, sustainable water technologies to polymer recycling (Chemport Europe, 2022a).

Highlighted here are the Zernike advanced processing facility (ZAP) and the Chemport Innovation Center (CIC). The ZAP facility can accommodate research projects regarding biomass valorisation and biobased chemistry on TRL 3-6. Notably, the earlier introduced start-up BioBTX is currently making use of ZAP facilities. It also takes in an educational role by organizing diverse events meaning to increase awareness for sustainability and green chemistry among students and researchers. For more mature projects, the Chemport Innovation Center (CIC) is the right address being located in the industrial area in Delfzijl. Here, start-ups can conduct research in the demonstration phase on TRL 6-8. Thereafter, CIC provides guidance for the transition towards market launch through its network, knowledge and permits. Finally, commercial scale can be organised and settled within the industrial areas in Delfzijl or Emmen.

In order to effectively stimulate the transition, the region established Chemport Europe. Chemport Europe describes itself as innovative ecosystem for chemicals and materials in the Northern Netherlands with a mission to accelerate the transition towards a biobased circular economy (Chemport Europe, 2022b). Founded by public and private partners, including the knowledge centers, it coordinates and schedules the activities in this field.

The organization Chemport Europe is divided in the pillars circular plastics, biomass, hydrogen and CO_2. The major key performance indicators of the ecosystem are reduction of CO_2 emissions, new economic activities (start-ups, new companies, additional investments of local companies) and employment. Furthermore, Chemport Europe assists with finding a suitable location and funding, has an extensive network of companies and offers help for growing businesses in the form of legal advice, marketing services, development programmes and permissions for processes. Chemport Europe bridges the public and the private sector by coordinating and initiating collaborations involving businesses across value chains, the government and knowledge centers. Indeed, it is seen as important to involve end-users where possible to avoid the pitfalls of a market push. As the name implies, while being rooted in the Northern Netherlands, creating links to European partners and international consortia is seen as imperative.

Summarising these different developments, an overview of currently available basic chemicals and biobased, renewable feedstocks from the energy and the agricultural sector as well as currently produced polymer materials/end-of-life plastics is given in Figure 2. With these platform chemicals and materials at hand, the biobased production of several other chemical building blocks can be envisioned and explored for profitable business cases. Some have been or are currently realized including the production of biobased aromatic compounds using either glycerol, low-value agricultural or plastic waste by BioBTX and are thus shown in the red block in Figure 2. Many more combinations are theoretically feasible and are listed in the yellow block in the figure below that have not been explicitly mentioned in the text.

After revising the status ten years ago and discuss current developments and regional success stories, another SWOT analysis is performed for the status of today.

Strengths of the Northern Netherlands for realizing the biobased circular economy lie within its knowledge centers that hold expertise in relevant research areas and educate the

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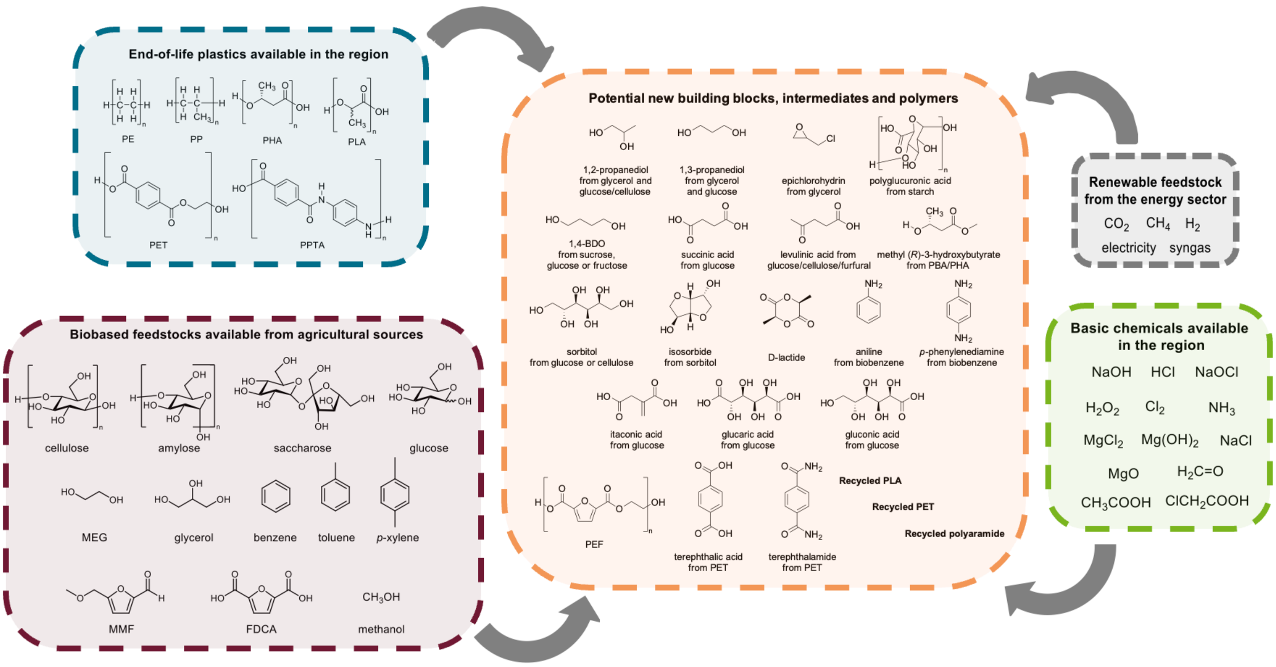

Figure 2 Synthesis of new propositions/high value chemicals from end-of-life plastics (blue), biomass (red), the energy sector (grey) and available reagents in the chemical clusters (green).

next generation of skilled workers. The agricultural heritage of the region as well as its expertise in gas production and trade can be carried over in the biobased circular economy keeping the links between sectors in mind. Undoubtedly, the chemical clusters Delfzijl and Emmen remain a strong side of the region. The elaborated flagship projects were developed from scratch within the region making use of the available research and upscaling facilities. These partially already led to the availability of biobased building blocks and intermediate for the chemical industry, inviting more valorisation routes and innovation. The clusters are well connected through Chemport Europe and linked to the public space. More strengths lie within the existing infrastructure for gas and electricity and logistics including harbours. Lastly, the availability of sufficient renewable energy is paramount for the future.

In terms of weaknesses, the share of renewables in the national energy mix to date is still relatively small (10.2% of the national primary energy demand in 2020) (Energie Beheer Nederland EBN, 2022). Visibility of the Northern Netherlands is an issue as headquarters of companies mostly are not located in the North. More entrepreneurs and skilled workers are needed to make the best use of the academic knowledge that lies at its doorsteps. Threats for the transition are delays and setbacks in the urgently needed expansion of renewable energy production and accommodation to its inherent volatility. These can be caused by enormous price fluctuations for oil and gas in the crisis-plagued energy markets and a potential restarting of gas extraction in Groningen.

Economic depression and unforeseen events (wars, pandemics) are serious threats as well. Moreover, lagging regulation can hinder good developments, for example regulations concerning waste management have to be adapted to enable its use as resource. Generally, with the progression of global warming extreme weather events will increase that will directly or indirectly affect The Netherlands.

Ending on a positive note, the North offers tremendous opportunities to realize the energy transition and the transition towards a biobased circular economy by close intersectoral collaboration and good use of available financing. The economic potential of such a transition should be reflected in larger employment and enhance the location`s attractivity for companies and people, while better education and academic research in the field will pay off in human capital later on. There is support from society for the circular transition and a shared, uniting ambition to meet the climate goals of the Paris Agreement.

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Table 2 SWOT analysis of the Northern Netherlands in 2022.

Strengths	Weaknesses
⇨ Excellent knowledge centers ⇨ Expertise in chemistry, biotechnology and biorefinery ⇨ Expertise in recycling (Emmen) ⇨ Human Capital (students) from well-known institutes ⇨ Strong agricultural sector providing biomass and CO_2 ⇨ Chemical clusters Delfzijl and Emmen ⇨ Flagships projects all developed in the region (BioBTX, Paques Biomaterials, CuRe) ⇨ Accessibility of building blocks/intermediates ⇨ Well-organized, strong collaboration between private and public through Chemport Europe ⇨ Research and upscaling facilities (TRL 1-9) ⇨ Infrastructure and logistics ⇨ Access to renewable energy ⇨ Space	⇨ Visibility ⇨ Headquarters R&D of most companies not within the region ⇨ Not enough entrepreneurs ⇨ Valorisation of academic knowledge ⇨ Shortage of skilled labour for companies ⇨ Small share of renewable energy in the Dutch energy mix
Opportunities	**Threats**
⇨ Close collaboration of sectors (agriculture, energy, waste, chemistry) ⇨ Energy transition: hydrogen valley and offshore wind parks ⇨ Financing available to support the circular transition (subsidies) ⇨ Economic potential of the biobased circular transition ⇨ Substitute the employment previously active in gas mining activities ⇨ Increase attractivity of location for people and companies ⇨ Human Capital, educate the next generation of workers ⇨ Support from society for the circular transition ⇨ Meet the climate goals (CO_2 neutrality) ⇨ Increasing prices of CO_2 emissions (EU ETS) ⇨ Underground infrastructure that could be used for gas storage (i.e. salt caverns)	⇨ Unstable energy market ⇨ Unforeseen events (war, COVID, etc.) ⇨ Economic depression ⇨ Restarting the gas mining ⇨ Supply of renewable energy is growing slowly ⇨ Climate change: weather extremes, rising sea levels ⇨ Lagging regulation

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7 Conclusion and Outlook

In recent years, several promising developments are coming forward in the Northern Netherlands giving hope for the chemical industry to overcome its fossil fuel addiction. Providing necessary infrastructure, logistics and expertise combined with access to renewable energy and feedstocks, the Northern Netherlands is an attractive location and partner for sustainably minded businesses and start-ups that aim to play a role in the biobased circular transition. Making use of upscaling facilities within a well connected ecosystem, available renewable building blocks and intermediate chemicals, entrepreneurs will find great inspiration and opportunities in the North to develop new combinations and grow together. That is, of course, only within planetary boundaries that respect the agreed upon environmental targets for 2030 and 2050 (European Commission, 2019). The authors strongly believe that there is huge potential and willingness of this region to become a forerunner and an ally for the transition towards a circular and biobased economy in Europe. With the omnipresent crises, it is more than ever necessary to work together across sectors and regions and not loose our focus on the reorganisation of our current unsustainable practises (Paulus, 2021).

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Practitioner's Section

Joerg von Hagen[1,2,3]

Ecosystem for Greentech start-ups in the Rhine-Main-Neckar metropolitan area requiring dedicated technology infrastructure

Is the Rhine-Main-Neckar Greentech Ecosystem prepared to support start-ups along the entire development process from the ideation to commercialization? The developments of novel products and services required in Greentech, specifically in the deep technology sectors of chemistry, green and white biotechnology, and material sciences requires extensive infrastructure. This includes dedicated laboratories, technical equipment, and scale up options like pilot plants, the establishment of which requires cost intensive investment. In chemistry and biotechnology, besides the technical challenges, the regulatory aspects pose a major barrier to the success of start-ups at a certain development stage (Technology Readiness Level [TRL]) and are thus identified as key hurdles for funding new businesses. These and similar hurdles can be addressed while bringing an idea to fruition in a Greentech environment since such ecosystems allow for parallelization of workflows for multiple projects, taking advantage of centralized functions and expertise. In the Rhine-Main-Neckar [RMN] metropolitan area, a united approach from politics, academia, transfer units and technology hubs, accelerators, and industry is being put into place to offer start-ups a tailormade Greentech environment to grow ideas that are urgently required to create a more sustainable economy and combat the climate crisis.

1 Introduction

Greentech Ecosystems, just as in the case of their natural counterparts, are complex interacting networks that require balanced participation of all of the partners involved. Natural ecosystems are characterized as being stable environments where organisms symbiotically interact with other constituents of the system. However, the individual organisms in these natural ecosystems often have no choice in being a member or participant in this environment. Natural ecosystems result from natural local circumstances, evolutionary forces, and in the antrophocene age also human interference, often without regard for the eventual destabilizing outcomes.

In contrast, we treat business ecosystems as the purposive interplay between societal institutions and individual human economic action on a local level. In modern, globalised societies, economic actors may freely choose to participate in any particular ecosystem according to their bespoke preferences. Therefore business ecosystems compete to attract ideas, talent and capital. As an ecosystem is a local network, which is in some facets in competition with other ecosystems, it is important to highlight the increased opportunity to gain benefits and support from e.g., venture capital firms, globally acting companies, and importantly, talents creating new ideas. Sustainable entrepreneurial ecosystems are defined as an interconnected group of actors in a local geographic community committed to sustainable development through the support and facilitation of new sustainable ventures (Cohen, 2006). To realize a transformation in society and science, it is important to understand the urgency with which the actions to mitigate the continued rapid increase in the exhaustion of our planet's resources are needed to prevent a mass extinction of our natural ecosystems. Climate change initiatives lead

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by the next generation have gained traction on multiple fronts owing to both their contribution as individuals and as a new generation of employees in the economic network of companies and organizations. In doing so they embody the voice of change instrumental in building internal pressure to concretely initiate "economic action". One way to achieve this deep-seated structural change while harnessing existing structures is via "business ecosystems" fostering Greentech start-ups. This work focuses on Greentech start-ups that work in e.g. biotechnology, chemistry, or material sciences, which require cost intensive technical development support from ideation up to commercialization, be it laboratory, pilot plants, or dedicated access to specialized equipment. Besides its technical infrastructure, the RMN Greentech ecosystem analyzes if all other required stakeholders are involved to the degree that the ecosystem is capable of developing successful start-ups.

For the economic activities, several stakeholders like Start-up, Universities, Technology Transfer units, and Accelerator and Hubs (figure 1) are required (Ferrary & Granovetter, 2009). These need to be orchestrated to avoid redundancies causing wanton use of resources, but also to develop an ecosystem to be efficient and self-optimizing and to expand. Growing an ecosystem and its continued expansion is relevant for its economic sucess and stability. This is because after a certain critical mass is attained, the ecosystem tends to gain broader attention which acts as an important feeder of new start-ups into the ecosystem. To establish a start-up ecosystem with high performance, it is important to understand the different performance indicators crucial to each of the various stakeholders in the network, which range from measuring actual performance of the start-up as teams and the funding activity. There is also the venture capital (VC) perspective, which extends from market reach and scaling opportunities as well as research and patent activities, especially when considering universities and associated transfer units. This case-study analyzes the Greentech ecosystem in the Rhine-Main-Neckar (RMN) metropolitan area (figure 1) which basic setup is comparable to those of other clusters. For further understanding of Greentech ecosystems, from the perspective of central stakeholders, the following article will provide insight into how the RMN ecosystem is set up. For this purpose, facts will be summarized and contextualized for the German or global ecosystem (figure 1, grey dots) with additional information where required for the support functions also part of the complex ecosystem network (figure 1, blue dots).

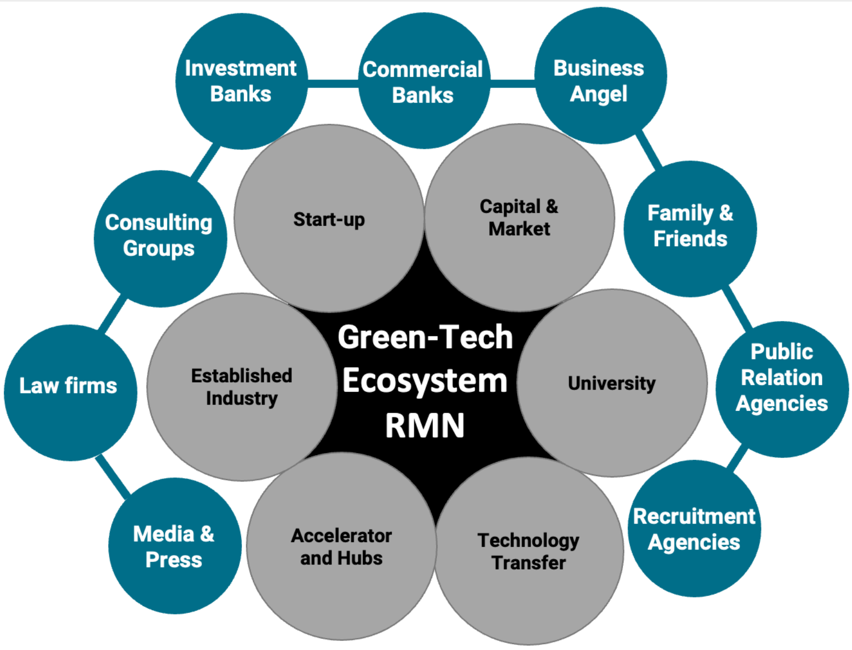

Figure 1 Ecosystems Rhine-Main-Neckar network (modified from Ferrary & Granovetter, 2009) – Accelerating the transformation in Greentech requires a mixture of already existing infrastructure in the regional ecosystem from idea to industry scale. Grey circles show inner ecosystem stakeholders with a strong inner network – outer circles represent additional ecosystem partners with more specific, but not less important touchpoints and interactions to the inner community along the development process from idea to mature business.

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2 Materials

This work analyzes the support functions and stakeholders in the Rhine-Main-Neckar Greentech ecosystem along the development path for products and services of start-ups to highlight the strength and weakness of the supporting infrastructure. The aim of this capability analysis is to find gaps in the ecosystem. This outcome of the gap analysis is a basis to work with politics, academia, and industry in the RMN region to implement missing supporting elements along the well described metrics of the TRL. In this work, the RMN Greentech Ecosystem is analyzed to examine if all required functions to support Greentech start-ups are present and exist to: (1) Support functions established along the entire TRL scale, (2) Understand if all elements of a Greentech start-up ecosystem are in place, (3) Understand if these elements are nascent or disconnected and require special attention to grow and connect. This would require Ecosystem building at the intersection of stakeholders along the TRL. Access to funding along the TRL is also examined. These seed investor communities bring capital along with business and industry expertise, and connections to customers and global start-up ecosystems in the RMN area. Finally, industrial interest and the extent of the support to be rendered to the Greentech cluster is evaluated.

The analysis will specifically focus on the following stakeholder groups:

- Rhine-Main-Neckar Ecosystem
- Capital & Market: Greentech Market and regional financial stakeholders
- University landscape in the Rhine-Main-Neckar area
- Technology Transfer Units
- Industry in chemical and white biotechnology and material sciences
- Start-ups

3 Results and Discussion

Rhine-Main-Neckar Ecosystem

A start-up ecosystem requires the infrastructure necessary for businesses to operate, which means the minimal requirements from infrastructure and operations, supply chain, commercial functions and finance. To build and grow an innovative, competitive cluster in the sector of Greentech in the middle of Germany in the Rhine-Main-Neckar area (figure 1), it is pertinent that it has the capability to nurture the funding of start-ups developing breakthrough technologies (Ferrary & Granovetter, 2009) in the transformation

Figure 2 Map of the Rhine-Main-Neckar (RMN) metropolitan area – The towns Frankfurt, Mainz and Darmstadt (black dots) are members of the Rhine-Main Universities (RMU). The states with different institutions, universities and corporates listed below belong to the broader Rhine-Main-Neckar ecosystem (grey dots). Scale – 50 km (modified from Kraemer et al. 2022).

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towards a Greentech Economy. Ideally, this should be complemented with incremental innovations that generated by the established industrial sector in chemistry, green or white biotechnology, and material sciences. With the above outlined prerequisites, the aim is to build and grow a strong ecosystem in an area that covers regions from four federal German states between the states of Hesse, Rhineland Palatinate, and northern Baden Wurttemberg (figure 2).

As detailed in figure 1, the success of the start-up ecosystem depends primarily on the regional presence of the inner circle stakeholders with strong interconnection and established processes and expertise to adequately support the newly formed start-ups. This is essential as the needs of the start-up grow from an idea to the expansion and building of factories. Which also results in a positive economic outcome of increased attractive job offerings in Greentech companies.

Capital & Market: Greentech Market and Regional Financial Stakeholders

Venture capital firms in the RMN area are well established and major global banks have offices in Frankfurt and are already well underway especially in the start-up community for e.g. the TechQuartier in Frankfurt. Leveraging the expertise towards the Greentech industry is an intrinsic motivating factor for banks as already they experience the need and willingness of their customers to invest in sustainable financial products. But this goes beyond financial offerings highlighted by the product developments required for the green transformation as indicated by the seven key lead markets defined by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Berger, 2021), figure 3. The Green innovation consists of either green products or green processes and services. Greentech comprises technologies for energy saving, pollution prevention, waste recycling, green product designing, and corporate environmental management (Chen et al., 2006) and are some of the key attractive financial markets.

To assess the vitality of the local start-up ecosystem regarding quality, quantity, and ease of access to funding in the RMN region in Greentech, it is important to identify capital investors with expertise and interest to fund longer term projects, as Greentech often requires technical development and Capex expenditure over years rather than month. Therefore, access to funding should start as early as possible, tracking early-stage funding rounds to assure the entrepreneurs are getting the support required. Here especially, local investors will help to better understand the investment trends in a local ecosystem and regional investors will help to connect to foreign VCs already investing in the local start-up ecosystem and allow to build bridges and make regional start-ups more competitive abroad, which is important for the reputation and attractiveness of the entire ecosystem. Here it is important to mention that building a tech ecosystem may take years to decades and requires continual effort and investment (Darko, 2019); in particular, the funding dictates where innovation evolves. However, here VCs play a central role beyond funding as they select the most attractive projects in the ecosystem and help the start-up to embed themselves in the network (Ferrary & Granovetter, 2009). The idea and foundation for innovation starts with VC as one of the key elements of the infrastructure of

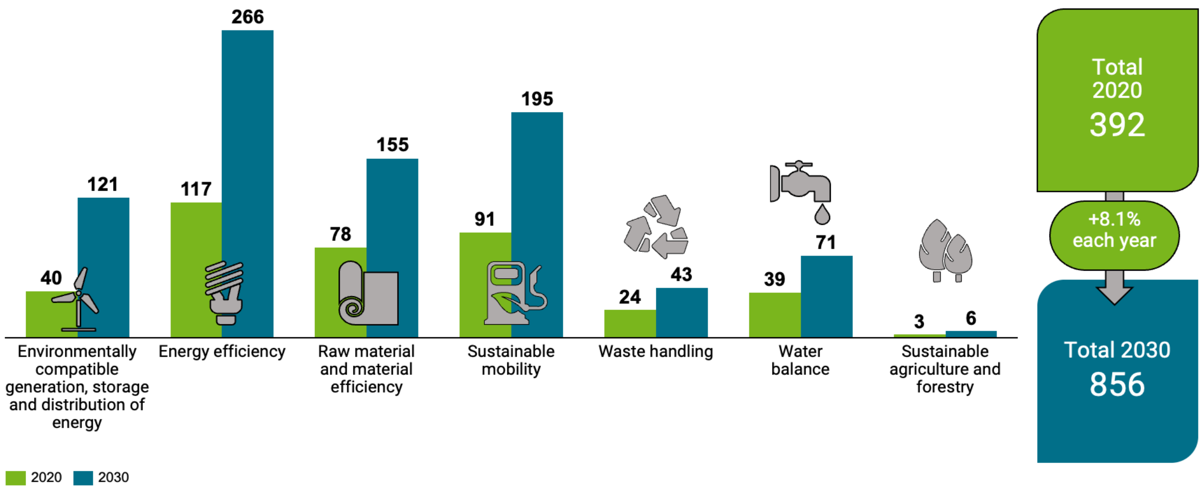

Figure 3 Major seven Greentech lead markets modified from Berger R., (2021). Numbers in billion €, on average 8.1% increase in revenues are estimated between 2020 from 392 billion€ to 856 billion € in 2030 in Germany.

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innovation (Powell et al., 2002). For a successful ecosystem, a one hit wonder is not enough, since the success of one start-up valued over 1 billion € in the ecosystem is regarded as a unicorn even if it may raise attention and attract further start-ups to the ecosystem. But to be sustainable one needs a continuous flow of novel ideas and start-ups to ideally attract and cultivate multiple future successes. In a functioning Schumpeterian ecosystem failing start-ups will quickly disappear and their resources redirected to promising new ones .The continuous attraction of new start-ups requires financial support in various phases to become successful, and besides the business of VC firms the federal and state government programs are important to feed the finance consuming Greentech start-ups as they often require costly equipment, laboratory and pilot plant infrastructure, as well as skilled technical personnel. In Germany in 2022, 18.6% of startups received funding from VC, 13.1% from banks, and 15.9% from strategic investors like family offices, but most startups relied on their own budget (74.9%) or family and friends (23.3%) taking into account that startups used multiple financing options (figure 4). The governmental programs reached 46.6% of the start-ups, but with significant regional or state differences, and with 31.2% Business Angels played a major role in financing the German start-up community (Kollmann et al., 2022) especially in mid-phases along the development process. In addition to government funding, industry funds, banks, private, and family and friends' financial investments for start-ups, the Business Angels Network Germany published that in 2016, around 7500 active Business Angels invested a total of 650 Mio Euro in the development of start-ups (Guenther, 2016).

University landscape in the Rhine-Main-Neckar area

To maintain the flow of constant innovation and funding of start-up in the RMN area, universities are essential talent developers and idea creators. Here a regional cluster comprises numerous well ranked research universities like Darmstadt (*269), Frankfurt (*340), and Mainz (*427) in the inner region as well as in proximity like Karlsruhe (*136), Heidelberg (*65), Mannheim (*423), Gießen (*490), and Marburg (*701) along with multiple Max Plank institutes, Fraunhofer institutes, European Molecular Biology Laboratory (EMBL) and the German Cancer Research Center (DKFZ), etc. to mention some institutions with a well-known world-wide reputation (* QS World University Rankings 2022). Universities fulfil the central tasks of creating an environment where talents are attracted because of the reputation and the offered research fields and infrastructure. These talented students need a setup where they can unfold their ideas supported by an excellent academic scientific surrounding. In the RMN area this pool of ideas is enormous and not only are the universities important for the success of a functional start-up setting. Within the RMN Greentech ecosystem, there are dedicated technologies in research groups and departments where technical engineering, material science, biotechnology, and chemistry are subjects of world class research. In these faculties, novel ideas for the green transformation originate to develop new products and services. In the Greentech Ecosystem of the RMN region, two technical universities are members of the TU9–German Universities of Technology, namely Darmstadt and

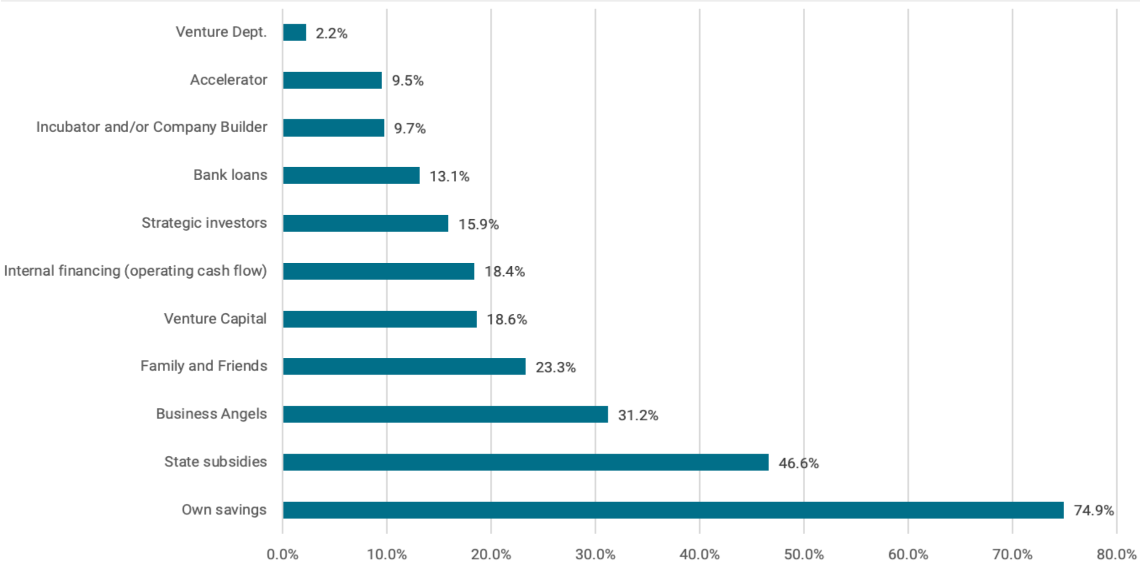

Figure 4 Financial sources and funding for start-up in Germany in 2022 (modified from Fichter and Olteanu, 2022) n= 1594.

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Karlsruhe, which excel in pioneering creative research in engineering and the natural sciences to feed the local ecosystem with groundbreaking innovation through collaboration with academics worldwide. One way of doing this is through programs such as "Unite!" which is a European University alliance of innovation, technology, and engineering. As a strategic, agile, and dynamic alliance of 9 universities with a total of 167000 students and 36700 graduates as of 2018, there is a strong focus on basic future-oriented science with the sense for urgent need in GreenTech (Winkler et al., 2020). In addition, the participating RMN universities have extended research and cooperation networks, and partners around the globe in industry, mid-sized enterprises, and start-ups, which allows to identify key technologies and make them accessible to the local ecosystem by technology transfer units of the universities and thus pave the path for additional novel developments and take off new businesses.

Technology Transfer Units

In the RMN ecosystem, universities offer different models and strategies to translate academic research to business by supporting scientists to pursue the career path to start their own business. In Germany, this is still not a common widespread personal development path besides either the academic or industrial career paths. Stimulating scientists and graduates to start their own businesses requires dedicated support around certain aspects. In the first place, a key question to address is the intellectual property right of the invention the start-up would need to develop unique products or services. As the first experiments are typically conducted in the academic research groups led by a senior researcher and professors, the start-up needs to assure access to the IP rights under promising conditions, which would make starting a new business worthwhile. The Goethe University of Frankfurt as an example has implemented the technology transfer office INNOVECTIS, which enables scientists and companies with patent management and commercialization research and development projects, spin-offs from the university and scientific consulting. Similarly, the Technical University Darmstadt has implemented the networking platform HIGHEST as the Innovation and start-up Center, where founders are supported with a wide range of services for setting up a company. HIGHEST regards themselves as companions, starting from the idea to the scientific knowledge leading finally to a newly funded start-up. The service covers coaching, networking events, contacts to relevant players in the business, sciences, and politics as well as the search for investors and expertise and knowledge regarding funding programs and the already above-described access to IP by a process in place called IP for shares where the start-up pays back money when they are successful in the market and earn money. A third example that extends the offering from Fintech to Greentech is the TechQuartier (TQ) based in Frankfurt, which is unique in that it offers for B2B start-ups a partner network. Based on their technology needs and challenges, start-ups are regularly matched, introduced, and connected through the TQ scouting team. The three examples show that specialization in the complex start-up scenery is a potential benefit for the entire ecosystem, and the complementary offerings support each other, ideally maximizing the value for the start-up and the entire innovation cluster. The TQ is offering in addition to Fintech start-up support programs also the expertise required for Greentech start-ups in a joint program named h_ventures. This refers to a start-up program that gives first-time founders the knowledge and the connections to build a viable team. This activity for Greentech start-ups is sponsored by the Hesse Ministry of Economics, Energy, Transportation and Housing and powered by Goethe University Frankfurt and TechQuartier, this program was created to empower professionals and students.

Industry sector and companies active in chemistry, white biotechnology, and material sciences

In the RMN area besides specialized VC firms also several company venture funds invest in start-ups or grown-ups (late stage start-ups) mainly when the idea fits with the company strategy and the products or offering is suiting to the portfolio of the parent company. The RMN area is home to several globally active Corporates like BASF, Evonik Industries, or Merck KGaA, which also invest through internal VC Funds. A first example is the Evergreen fund of 250 Mio€ which invests in seed to Series B in e.g., circular economy and decarbonization of start-ups. Another interesting approach is Evonik Industries, a Specialty Chemicals multinational headquartered in Essen, Germany, with operations in Hanau and Darmstadt, both in the RMN area. They also have a cooperate VC arm which makes direct investments into cutting-edge start-ups while also investing in funds like the German HTGF (High Tech Gruender Fond) and other diverse set of technology funds in key geographies and areas

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of interest to Evonik. As a third example for a corporate fund located in the RMN metropolitan area is the strategic corporate venture capital fund of Merck KGaA, with a dual remit of strategic and financial returns. In 2021 the fund available for investment was increased by an additional 600 Mio€ to enable increased and larger investments across the two investment areas of biotechnology and technology. Together the three mentioned companies comprise 55000 employees in the RMN area of the total 306823 employees (18%) in the chemical sector according to the German Federal Employment Agency in 2021 in whole Germany. With regard to revenues the BASF headquartered in Ludwigshafen generated a turnover of 89.4 billion USD in 2021 and was placed at the top 1 world-wide among the chemical companies. The chemical sector is the third largest industry sector in Germany with huge relevance for the supply chains of other large sectors like automotive and mechanical engineering. The number of employees is not directly linked to start-up funding, but the traditional relevance of the chemical sector to the RMN area is important to align corporate and political mindset that a Greentech cluster in this region is self-feeding the existing job machinery if all stakeholders contribute adequately.

Start-ups

The fact that the RMN ecosystem generates start-ups and showing that the actual approach is successful is seen in the annual start-up Monitor 2022 (Kollmann et al., 2022). In 2022 there were 1588 start-ups founded in Germany. Among top 10 ranked German universities the founders had received, with the indicated percentage, their degrees from the following universities: Mannheim with 2.5% (top4), Darmstadt with 1.8% (top6) and Frankfurt with 1.6% (top10).

Interestingly, among all Greentech start-ups investigated in that publication, founders have an educational background in engineering sciences with 29% followed by natural sciences with 11%. In total 40% of all start-ups are technology driven developments (figure 5). The highest educational qualification of the green start-up founders is 36% masters, 18% diploma and followed by 16% PhD and in total summed up that in Germany 86% of all founders have an academic background (Fichter & Olteanu; 2022). Thus, it is evident that for founding a start-up in technical disciplines the proximity to universities and the associated technology transfer units is matter for a successful, functioning ecosystem.

As outlined in figure 5 among founders of Greentech start-ups the key faculties and qualifications are business administration and economics (represented by 41%).

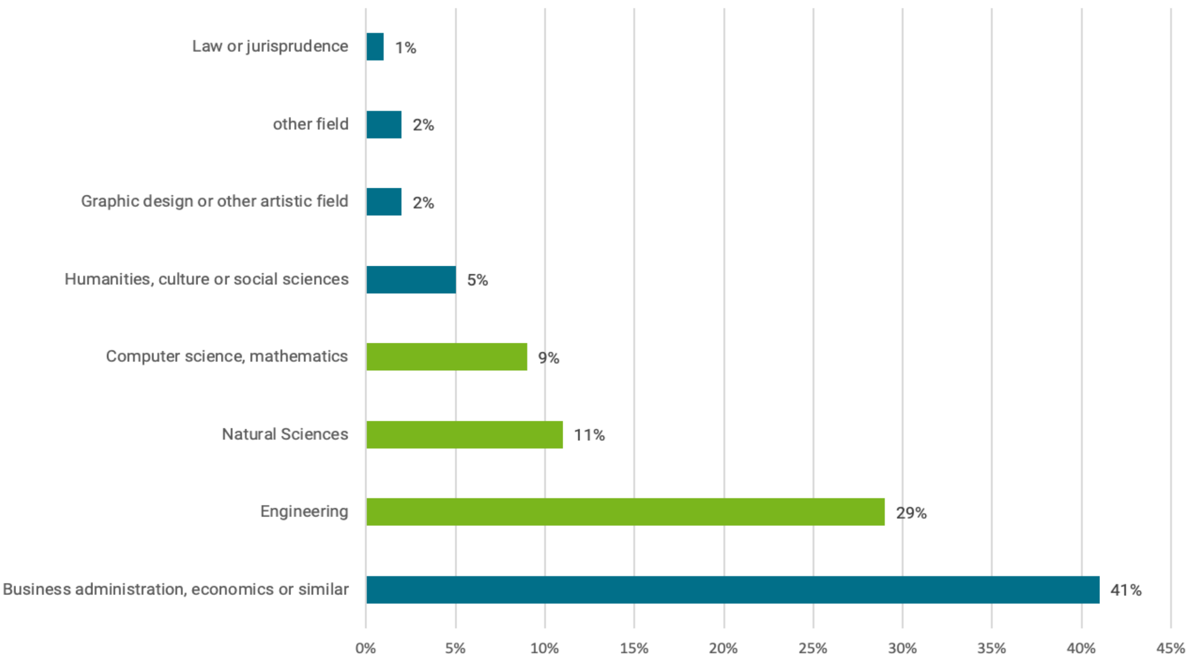

Figure 5 Founders academic degree in Germany for “Green Start-up” (modified from Fichter and Olteanu, 2022). Green bars comprise science, technology, engineering, and mathematics (STEM) disciplines.

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This high percentage is not surprising as in the early phases of getting a business started a lot of activities are business model generation and financial aspects. But to develop Greentech products and solutions it is often even more relevant to have technical ideas (figure 5 grey bars represented by 49%) which are feed into the ecosystem with novel technologies and solutions which requires a decent number of students in science, technology, engineering, and mathematics (STEM) disciplines relevant to develop innovative products and solutions in the Greentech sector. This percentage of founders with technical background are the basis for the Greentech products. The RMN ecosystem would like to lift the absolute number of start-up in Greentech. With the rich plethora of universities in the RMN area, there is no dearth of qualified STEM graduates. The actual question is how to motivate more of them to become entrepreneurs. Taken together the RMN area and its associated universities have 109138 STEM students corresponding to 38% of the total students from the universities listed in table 1. The pool of creative, driven, and energetic STEM students is the technical basis for novel Greentech inventions resulting in novel products and services relevant to generate start-up ideas and built a cluster gaining both regional and international attention.

Founders with an academic degree claim that 64% of start-ups they have founded were independent of any support by an university or research organization (Fichter and Olteanu, 2022). This possibly indicates that starting a business with a non-technical idea requires less technical infrastructure and does not necessarily rely on formal support by universities and associated organizations. 80% of technologically focused Greentech start-ups in Germany were supported by universities and transfer organizations to advance the business idea, business plan, and financing. In total 72% had received support in order to apply for governmental funding like EXIST founders program. For 69% it was deemed crucial to get access to the network of mentors,

Table 1 Universities in the Rhine-Main-Neckar metropolitan area with total number of students in Science, Technology, Engineering and Mathematics (STEM). *numbers are from the annual online reports of the individual universities between 2019 and 2022 depending on the accessibility.

Institution	Location	Students [*]	STEM
Technical University	Darmstadt	24,969	16,325
University Applied Sciences	Darmstadt	16,180	7,119
Goethe University	Frankfurt	43,461	5,957
University Applied Sciences	Frankfurt	15,362	5,006
University Applied Sciences	Fulda	8,438	2,218
University Applied Sciences	Geisenheim	1,812	1,812
Justus Liebig University	Gießen	27,500	7,870
University Applied Sciences	Gießen / Friedberg	17,930	17,930
Fresenius Applied University	Idstein	18,000	2,971
Karlsruhe Institute of Technology (KIT)	Karlsruhe	21,850	12,231
University	Kassel	23,552	9,421
Gutenberg University	Mainz	30,564	6,936
University	Mannheim	11,532	0
University Applied Sciences	Mannheim	5,581	5,581
Philipps-University	Marburg	21,723	7,761
Total		**288,454**	**109,138**

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founders, business angels and others. Around 47% of the start-ups received dedicated support in particular through transfer organizations from the university like Innovation and Technology Transfer Centers and 43% had utilized specific research infrastructure to advance the product TRL in the form of technical equipment and laboratories from the originating university (Fichter and Olteanu, 2022). This indicates a difference between start-ups in term of budget sufficiency needed to develop their idea to a viable market ready product. In the technology disciplines of chemistry, white biotechnology, and material sciences a higher order of magnitude of investment is required. In the RMN cluster best practice sharing with other clusters would be key to improve the financial offerings and funds as a joint effort between the state governments with the associated institutions and VC. Financial support is to keep start-ups afloat before achieving sufficient turnover to become an independent viable business which in turn would be able to contribute to the regional ecosystem.

Discussion

In general, German universities do not produce a significantly rising number of Greentech start-ups despite a decade long effort and the implementation of entrepreneurship professorships. Most graduates still move on towards employment in research, industry or government institutions. To leverage the existing elements in the RMN ecosystem it is important to connect the further elements required to raise the number of successful start-ups in particular those with focus on biotechnology, chemistry, and material sciences for Greentech applications and pave the way for entrepreneurs to be able to choose business building their own businesses as a viable career path.

Our analysis of the stakeholder groups and the supporting infrastructure led to the identification of the following three points to improve from the perspective of Greentech start-ups.

- General RMN Ecosystem requirements for Greentech start-up to form a cluster
- Technology Readiness Levels and Valley of Death
- Innovation infrastructure: From Accelerators and Hubs

RMN Ecosystem requirements for Greentech start-ups

Since a specific evaluation for the RMN area has not yet been published, an analysis of German start-ups was conducted to understand gaps in the RMN Greentech ecosystem, by interviewing 284 start-ups. This led to the identification of key needs to further develop the ecosystem [Zinke, 2018] and is summarized below (figure 6).

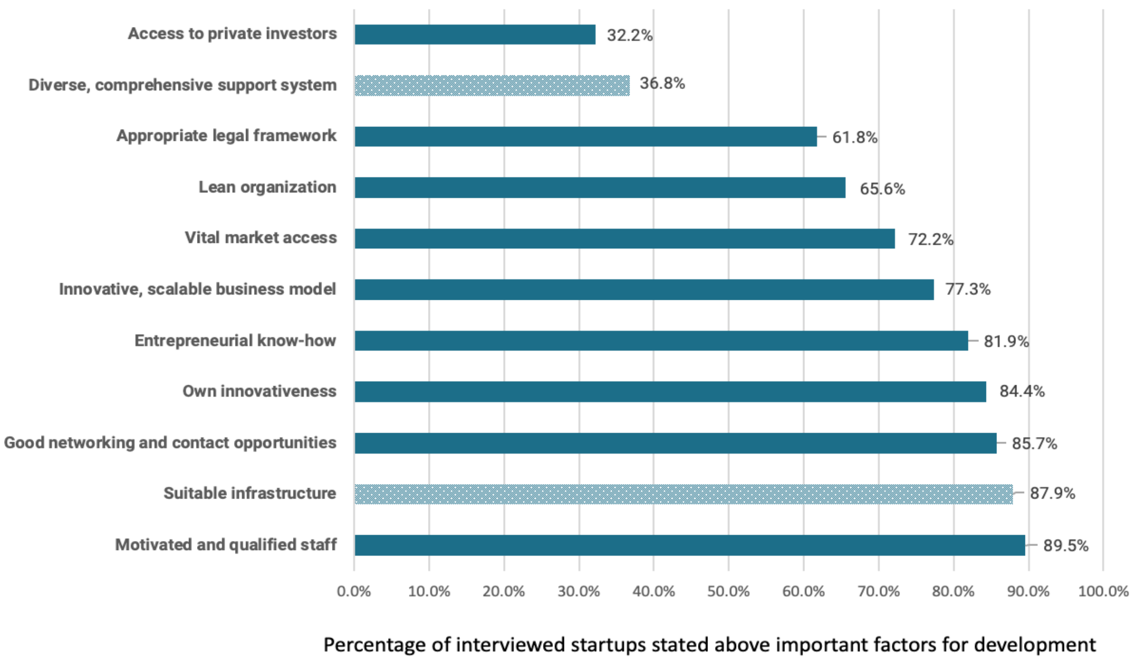

Figure 6 Needs of 284 German start-ups ranked "very relevant" and "relevant" to the question how important the factors listed above are for the own success of the start-up (modified from Zinke, 2018). Grey dotted bars indicate the need for infrastructure and the support required during development including all technical and regulatory aspects.

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In this analysis, of 11 factors ranked as 'relevant' and 'very relevant' two pertained to the need for a diverse and comprehensive support system. This could be addressed through an offer of agile technical coaching for topics from regulatory, safety, scale-up and other technical aspects which are typically not in the focus of university transfer organizations. Furthermore, in the aforementioned analysis, 87.9 % of the start-ups claimed that suitable infrastructure was pivotal for their success. This would hold true especially for founders working in the area of biotechnology, chemistry or material science which requires regulatory compliant laboratories and pilot plants for scale up optimization.

Technology Readiness Levels and Valley of Death

To describe and evaluate the maturity of a technology or product, it is classified using a scale of 9 Technology Readiness Levels (TRL) introduced by the US Department of Defense (Mankins, 2009). The basic assumption of the classification is that a technology element is "critical" if the system being acquired depends on this technology element to meet operational requirements (within acceptable cost and schedule limits). A further assumption is that the technology element or its application is either new, novel or in an area that poses major technological risk during detailed design or demonstration (Mankins, 2009). In the RMN region the support to achieve TRL 4 to 9 especially in terms of infrastructure and funding for chemical, biotechnological and material science related development programs was identified as a gap to be addressed. This included infrastructure and help to start-ups by mentoring, coaching and peer to peer learning to develop the idea to industrial maturity. Further details are published in the White Paper – start-up State Hesse. This gap is regarded as a major risk since failing to address it would mean local start-ups migrating to other regional ecosystems that do provide sufficient infrastructure and help that would result in regional fluctuations. To counter this brain drain, the state government of Hesse is implementing funding programs for Greentech start-ups and their special needs (Kraemer et al. 2022) as one example the above-mentioned h_venture program.

The valley of death theory proposes that there is a key hurdle despite the good start at the initial phases, for new start-ups in the ecosystem supported by the universities and their associated Technology Transfer Centers, where start-ups have been encouraged to new idea creation, to file patent applications and to found new businesses. Especially when applied to the RMN ecosystem but also in other regions in Germany, the number of start-ups is still to improve due the lack of an adequate technical infrastructure mainly related to the higher end of the TRL scale in later development phases especially in technology applications.

With regards to the TRL, academic research focuses on the development at the levels 1 to 4, whereas industry requires products to enter the market at TRL of 8 or 9. Industry is generelly interested to license or incorporate products close to market viability, i.e. at TRLs of 7 to 9, rarely ever at 6. Therefore, TRLs 4 to 6 represent a gap between academic research and moving the development of the technology towards industrial commercialization. This gap is referred to as the technological "valley of death" to emphasize that many new technologies reach TRLs 4–6 and die before having the chance to get picked up for completion. In Germany with more conservative funding of cost intensive product developments like in Greentech the valley of death forms an often insurmountable hurdle for its typically under-capitalized Greentech start-ups. As stated above this should be substantially supported and selected by VC firms and fund for tech products and services. German VC firms are smaller and generally considered more risk averse than their US peers. This results in a more conservative and later stage investment of start-ups by VC firms. These early phases require less capital than the later stages where 90% of the total development budget required in technology intensive developments from TRL 7 and beyond (figure 7) which is brought in by VC firms at the later stage. Along the development path for start-ups there are two critical points in time where financing and technical handover and the required infrastructure determine the success rate of an ecosystem in total. At these timepoints, the VC remains the main driver of innovation by selecting what will be needed and developed into the upcoming markets (Ferrary & Granovetter, 2009) but the technical handover requires in Greentech laboratory and pilot plants to scale and develop products under real conditions in an industrial setting and are often not available as needed.

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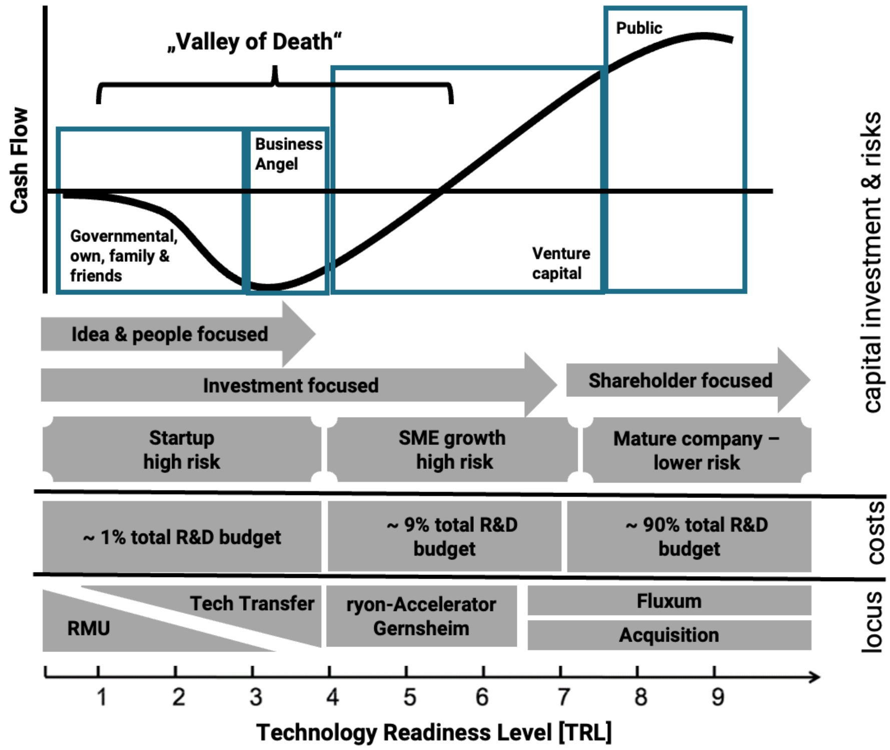

Figure 7 TRL and valley of death: Developments from idea to shelf require in Greentech development substantial R&D invests (costs) and bear typically decreasing risks and an adopted investment strategy (capital investment and risks) along the development phases. In addition, it requires infrastructure along the TRL which is offered from various stakeholders in the RMN ecosystem from early to late phase (locus) and for Greentech it covers the whole value chain (modified from Hirzel et al., 2018) from idea to shelf.

Innovation infrastructure: From Accelerators and Hubs

In the RMN ecosystem, there are several start-up support institutions with different offerings. Hub31, TIZ, Unibator, Research and Technology Transfer Mainz are some examples of additional spin-off units of the RMN universities. These institutions often engage with further partners like chambers of industry and commerce or others. Together with the previously mentioned TQ, HIGHEST and INNOVECTIS, their main focus is to support the start-ups to gain investor readiness and help them successfully applying for funding by business angels, capital firms or governmental support programs. They offer dedicated events around founding firms in addition to the legal framework to set up new businesses in Germany. Further, they offer match making to potential corporates. As mentioned above the RMN ecosystem still requires bridging technical and infrastructure support regarding market and product readiness to close the gap between TRL 3-4 and 7. This requires for STEM – technology start-ups with focus on chemistry, green or white biotechnology and material sciences access to a dedicated laboratory and pilot plant infrastructure. This bespoke infrastructure needed to support Greentech start-ups exists in few regions in Germany but with different technological depth and offering. The general comparison is not made as the supporting institutions do not divulge adequate information about the detailed offering.

To close the technical gap and support start-ups with the infrastructure to achieve the required market and product readiness, the Hessian government represented by the Hessian Trade & Invest (HTAI), the Hessian business and infrastructure bank (WI Bank Hesse), Goethe University Frankfurt, Technical University Darmstadt and Merck KGaA Darmstadt have funded their own technical accelerator (ryon – Greentech Accelerator) located at the Merck KGaA site in Gernsheim (figure 1) as part of the Greentech Park Fluxum. The ryon – Greentech Accelerator combines the laboratory and pilot plant infrastructure combined with a bespoke technical program supplementing the activities provided already in the ecosystem – Greentech Accelerator Gernsheim with focus on agile technical and regulatory coaching and support by experts from academia and corporates. The accelerator is an open innovation forum

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where stakeholders meet to connect, match start-ups and corporates, and is a multiplicator in communication and networking in the RMN Greentech Cluster and beyond. Fluxum, where the ryon – Greentech Accelerator is embedded, is itself an additional element in the ecosystem where small and medium enterprises or grownups with need for place to grow their businesses have a Greentech Park in their vicinity, which allows them to build own buildings according to their needs on a rented area of land with access to existing facilities like industrial wastewater treatment, chemical factory fire brigade, site security, and energy and gas supply. The grownup needs to fulfil criteria to be in line with the guiding Greentech principles on site to enter the final stage of their development across all TRL from idea to market. This finally benefits the entire ecosystem and is a key driver of supporting the ecosystem for examples with jobs and taxes that stay in the region, which in turn works to secures the future economy in the RMN region.

One outcome from summarizing all mentioned aspects is that in Gernsheim, in the geographical center of the RMN metropolitan area, the infrastructure for Greentech start-ups with the need for laboratory and pilot plant infrastructure and the required expertise and technical support is under stepwise implementation. Laboratories are available and will be built to support teams with all necessary required regulations mandatory for safe operating chemical plants or biotechnology laboratories under state law regulations for genetically modified organisms. After founding the ryon – Greentech Accelerator Gernsheim the missing technical infrastructure to support start-ups to bridge from TRL 4 to 7 allows the RMN ecosystem to grow and requires that all stakeholders play in concert and set the basis for a successful Greentech cluster with the main emphasis to lift the potential of what already exists an academic setting embedded in a strong chemical, biotechnology and material science industry cluster.

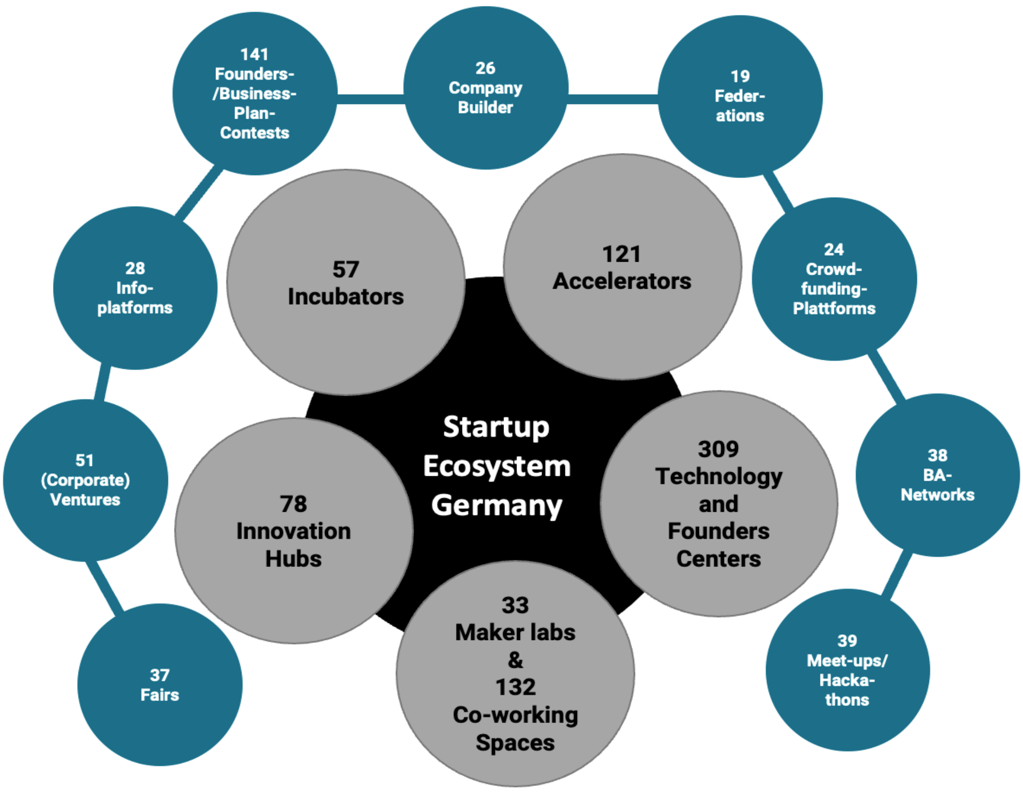

Figure 8 Instruments of the German Start-up ecosystem (modified from Zinke, 2018). The grey inner circle represents primarily the physical infrastructure related offerings from offices to pilot plants plus the ecosystem supporting activities surrounded in blue.

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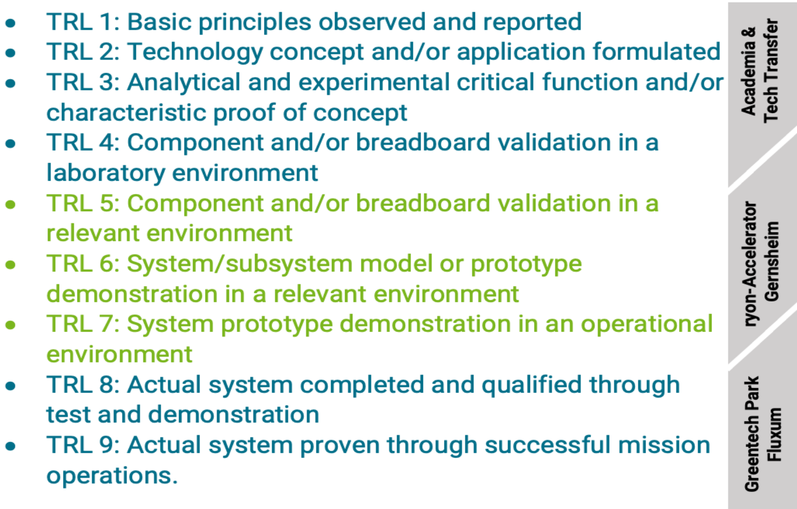

Figure 9 Technology Readiness Levels (adapted from Mankins, 2009) Academic and Tech Transfer units support TRL1-4, ryon-Greentech Accelerator Gernsheim TRL 4-8 and the associated Greentech Park Fluxum the TRL 8-9.

4 Summary

As shown in the capability analysis above, the RMN ecosystem offers Greentech start-ups the entire support chain along all TRL. However, the community of stakeholders especially with focus on developing solutions and services for biotechnology, chemistry, and material sciences are not yet connected as required. This highlights the importance and critical need for such a Greentech cluster where all the stakeholders are brought closer together. Doing so will heighten their ability to support start-up funding, allowing them to grow in the region. It would also allow for harmonized financial programs from private investment, business angels, and firms to cover costs with growing needs later in the TRL development process.

Germany and the global community have developed the need to urgently move to sustainable products and services to manage the climate crisis and offer solutions resulting in more sustainable materials for daily use covering all aspects of life. To support the green transformation, it is important that new ideas become vivid and bring forth novel materials in areas where structures are already in place to help to accelerate this transformation. The Rhine-Main-Neckar metropolitan area has a strong ecosystem comprising all the required stakeholders with relevant preconditions offering goldilocks conditions for such an environment. The time is ripe for the players within Europe to unify to develop the recognition that the region is the chemical, biotechnology, and material science hotspot. Thus, the RMN ecosystem has the potential to become a true global cluster in Greentech with significant impact to improve people's lives for generations to come.

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Author Contributions

Conceptualization, J.v.H.; writing—original draft preparation J.v.H.; writing—review and editing, J.v.H; visualization, JW and JvH.; supervision, J.v.H.; project administration, J.v.H.; and funding acquisition, J.v.H. The author has read and agreed to the published version of the manuscript.

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Data Availability Statement

The data and sources are available from the authors upon reasonable request.

Conflicts of Interest

Joerg von Hagen, Andrew Salazar and Julian Wenzel are associated with Merck KGaA, Darmstadt, Germany.

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