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Guest editor: Marcel Loewert

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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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Extended Editorial

Marcel Loewert *, Hannes Utikal **, Janine Heck ***

Transform the European process industries: A multi-level perspective

1 Introduction

Scientists have long recognized that anthropogenic actions cause emissions that have drastic consequences for the global climate and their warnings are increasing (IPCC, 2023). At the same time, a strong economy has always been necessary for prosperity and security. How could climate protection and economic success be reconciled at the same time? To bring together these apparent opposites presents one of the greatest challenges of our time.

For decades, experts all over the world have been developing technologies that make renewable electrical energy widely available and that convert this energy efficiently into other forms of energy such as heat and chemical energy carriers. Processes are constantly being improved and, in addition to business figures, the carbon footprint is now making its way into the minds of actors along the value chains.

This special issue of the Journal of Business Chemistry, celebrating the first anniversary of the successful event "4th International Workshop on Innovation and Production Management in the Process Industries (IPM2022)", highlights the opportunities that collaboration, open communication and seizing new business opportunities bring to the European process industries.

2 The Transformation: A multi-level and interdisciplinary challenge for industry and academia

The 4th International Workshop on Innovation and Production Management in the Process Industries (IPM2022) was convened at industrial park Höchst in May 2022 with the overall theme "Transform the European Process Industries". Founded in 1863, the industrial park has a long history of transformation and the shifts to renewable energy and raw materials will determine its future. Therefore, it presents a perfect setting to bring together representatives from academia and practice and discuss the transformation of the European process industries. IPM2022 was the fourth edition of an international workshop series focusing on process industries with over 70 participants. The workshop was organized by the cluster Process4Sustainability in collaboration with the Institute of Business Administration (University Münster), Mälardalen University and the Association for Chemistry and Economics (VCW). Previous workshops took place in Sweden, France and Australia.

The workshop aimed at

- reflecting on scenarios about the development of the process industries in Europe after the Russian war,
- highlighting the systemic nature of the challenges in the areas of energy and raw material transformation taking recent geopolitical developments into consideration,
- discussing new business models and technologies,
- exchanging best practices,
- strengthening the international network of professionals researching management issues in the process industries.

The upcoming transformation of the economy as well as society can be understood as socio-technical transformation and to shed light on different dimensions of transformation, the workshop took a multi-level perspective.

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Technical, social, regulatory, and economic aspects and their interaction must be considered. The workshop offered academia and industry-related presentations covering the system, company as well as innovation, and production management level.

2.1 The big picture – transformation at system level

Policy has set the goal for industry to become GHG neutral and the process industry in Europe wants to switch to non-fossil energy and raw materials. However, many challenges in the implementation exist. The solutions that can be deployed vary in different regions and industries. Thus geographic, regulatory as well as market developments play a role in designing the respective transformation pathways. Selected topics included, among others, hydrogen and bioeconomy. Due to concentrated hydrogen demand and different potentials for renewable energy generation, regional imbalances are to be expected. High demand will be mainly in regions with steel and chemical industries as well as densely populated centers while production sites are predominantly planned near the North Sea coast. This gives the topic of infrastructure for transporting hydrogen an important role. With a view to the switch to non-fossil raw materials, bioeconomy represents an important lever in the transformation. It opens up renewable resources as additional raw materials. Residual and waste streams can also be used in this context. Political decisions also have a significant impact on the transformation of the process industries and can accelerate or block it. Therefore, an effective policy mix is crucial. How it could be designed is currently still under discussion.

Articles in this issue that address the system level are:

- "The chemical industry as a key player for climate protection: Learning experiences from cooperation with developing countries and emerging economies" by Detlef Schreiber and Paola Bustillos
- "The role of hydrogen in the process industries – implications on energy infrastructure" Florian Ausfelder, Luisa Fernanda López Gonzalez, and Eghe Oze Herrmann
- "Turning point(s) ("Zeitenwende") and new multipolarity: Is the industry in Germany declining into insignificance?" by Jürgen Vormann
- "An active systemic industrial policy for climate-neutral process industries in Europe" by Stefan Lechtenböhmer

2.2 Company level

Embedding sustainability in a company´s strategy is increasingly critical for meeting investor, consumer and regulatory demands. However, incremental changes are not sufficient for a transformation toward a climate-neutral company and new business models need to be established. This raises the questions of how such a company transformation can be managed, and the developed strategy implemented. At the workshop, companies presented their ideas and approaches to increasingly close resource loops.

Nonetheless, recycling products that were not designed to be recycled still poses significant challenges, or in some cases is simply not yet possible. Likewise, the much-discussed approach of using CO_2 as a feedstock is still a long way from large-scale application.

Articles in this issue that address the company level are:

- "DATA – a sustainable performance accounting framework for SMEs. From macro planetary boundaries to micro economic Sustainable Earnings Before Interest and Tax (SEBIT)" by Steven Geschwindner, Toni Eser and Stephan Haubold
- "Sustainable industrial area management: Using the materiality analysis at a multi-stakeholder industrial park to align activities" by Bernd Winters
- "Responsible use – the social license-to-operate: A business approach towards sustainability in chemicals & materials" by Wolfgang Falter and Herwig Buchholz

2.3 Innovation and production management level

The transformation to a climate-neutral process industry needs new ideas, as "business as usual" would result in missing climate targets. The rapidly changing economic environment is also pushing companies to continually adapt products, services, and processes. Technology and innovation management, therefore, has the task of securing the company's success in the long term. Monitoring regulatory developments helps to identify new opportunities and threats at an early stage. The workshop especially

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focused on carbon capture and utilization. Here, the carbonate looping process represents a promising option to capture CO_2 from waste-to-energy plants burning e.g., municipal solid waste. Additionally, a Power-to-Methanol technology for decentralized applications that captures CO_2 from point sources and converts it, was presented.

An article in this issue addressing the innovation and production management level is Koteshwar Chirumalla´s, Thomas Lager´s, and Mikael Ankerfors´ research paper "Exploring sustainability integration and expected outcomes of a digitalized product innovation work process for non-assembled products".

3 Transformation is location-specific: the industrial park Höchst as an innovation campus

As one of Germany's largest chemical and pharmaceutical sites, the industrial park Höchst considers itself as a dynamic "innovation campus" that thrives on innovative ideas. With its roughly 90 tenant companies and 22,000 employees, the industrial park is an important location for shaping the transformation process of industrial production and innovation.

As a 4.6-hectare industrial site with a diversity of manufacturing and research companies, the industrial park – along with Infraserv Höchst, its site operator – is committed to efficiency and resource conservation. This not only makes for an economically successful operating model, but also shifts the focus to environmental issues that are inextricably linked to the future of the industrial park and the entire chemical and pharmaceutical industry. The chemical industry has a tremendous responsibility to society. On the one hand, it is responsible for a large share of greenhouse gas emissions. On the other hand, it has the knowledge and innovative edge needed to further the energy and mobility transition as well as the quest for energy efficiency and resource conservation.

Experts at the industrial park are aware of this huge corporate social responsibility. Optimizing energy efficiency in roughly 120 production facilities as well as continuously improving the eco-footprint of the entire site are firmly enshrined in the corporate strategy of Infraserv Höchst, the site operator responsible for supplying energy to the companies located on site. This is particularly evident in its recent investments and major projects.

3.1 Highly efficient infrastructure for complex processes

Infraserv Höchst generates electricity, supplies gas, water, heat, cooling and raw materials and runs a sophisticated waste management system. The industrial park hosts a stable network that creates synergies and streamlines complex processes with its efficient infrastructure consisting of 983 kilometers of power lines, 478 kilometers of supply lines for utilities, 375 kilometers of pipelines for all kinds of materials and 184 kilometers of water lines.

Widespread closed loop recycling and extensive use of co-generation at the Höchst site make it possible to extract the most from industrial processes and raw materials. By-products from manufacturing companies are processed and recycled at other facilities within the park. Waste heat from production and incineration plants is fed into the site's utility grid. The industrial park is also home to Germany's largest biogas plant, while a waste-to-energy plant incinerates high-calorific-value, pre-sorted components of municipal and commercial waste and supplies the resulting energy to the rest of the site. The site's strength also lies in the combined strength of its tenants, who, with their pooled resources and precisely coordinated processes, can operate more sustainably and cost-effectively together than on their own.

3.2 Scale up of promising innovations

Infraserv Höchst and the companies based at the park have been modeling sustainability for years, developing strategies for CO_2-free chemical production and processes.

Different projects explore how to reduce the industry's carbon footprint. For example, there are ways to reintroduce CO_2 and other by-products of chemical production back into the manufacturing cycle. Infraserv Höchst and the Provadis School of International Management and Technology have joined forces with partners from Finland, Italy and Germany in a European Union-funded project to answer one key question of carbon capture and utilization: Is it possible to industrially produce hydrocarbons from CO_2 that would otherwise escape into the atmosphere? Hydrogen and CO_2 generated in a biomethane upgrading plant– which are abundantly

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available at the industrial park – are fed into a pilot plant and converted into non-petroleum-based mineral oils and waxes, which serve as precursors for making products such as paints, varnishes or solvents. These solid hydrocarbons were synthesized in a microstructured Fischer-Tropsch reactor developed by one partner, INERATEC.

Following this successful demonstration, INERATEC decided to build the world's largest pioneer plant for the power-to-liquid production of synthetic fuels and e-chemicals at the industrial park. The facility will produce around 4.6 million liters of synthetic fuel from up to 10,000 metric tons of biogenic CO_2 per year.

3.3 Collaboration with start-ups and university spin-offs

Attracting and collaborating with start-ups is a key element of the strategy. The industrial park Höchst supports the entire chemical industry value chain, from research to pilot plants to commercial-scale production. Start-ups play a critical role in this ecosystem – they create innovative solutions and upscale them by using the infrastructure that is available at the park.

Innovation projects involving hydrogen energy are also being developed at the industrial park. The expansion of the park's hydrogen infrastructure is progressing steadily. A publicly accessible hydrogen fueling station for cars, trucks and buses has been part of the infrastructure since 2006. Some of the park's internal buses have been running on hydrogen since 2017. By 2030, the entire bus fleet is expected to consist of hydrogen-powered buses. There has also been a hydrogen fueling station for trains at the northern edge of the industrial park Höchst since 2022. About 14 hydrogen-powered trains operated by the regional public transit operator can fill up there each day. They are replacing diesel-powered trains on regional routes and thus avoid CO_2 emissions.

3.4 Success factor: A thriving innovation eco-system

The chemical industry develops solutions for energy, sustainable mobility and many other areas of life. Innovations in these fields are typically the result of cross-industry, cross-disciplinary collaborations. Actively managing the connection between the different complementary actors is thus a key success factor for the transformation of the industry and the future of value creation within the planetary boundaries. In this process, industrial parks may act as an "innovation campus": they bring the infrastructure, customers and the relations to regulatory entities to the table and allow innovators to rapidly scale-up their solutions in an industrial setting.
Based at industrial park Höchst, the cluster Process4Sustainability (P4S) - a network of companies in the process industry, research institutions and innovation partners - supports companies in the transformation process. It translates the goal of CO_2 neutrality for individual companies in their specific context, offers access to expertise and facilitates knowledge exchange.

4 Content of this special issue

This special issue includes on the one hand articles based on academic and industrial presentations at the 4th IPM workshop, on the other hand, additional articles suitable for the topic were submitted. Table 1 gives an overview about all articles.

Koteshwar Chirumalla´s, Thomas Lager´s, and Mikael Ankerfors´ article "Exploring sustainability integration and expected outcomes of a digitalized product innovation work process for non-assembled products" investigates the status of the integration of sustainability and digitalization in innovation processes. An explorative survey focusing on six sectors of the process industries shows that companies consider sustainability and digitization to be top strategic priorities, but often have difficulties implementing these approaches operationally. Moreover, the survey reveals that companies are further advanced in integrating sustainability aspects into product development processes than in digitizing product development. Here, especially the digitization of customer and product information has high potential to change innovation processes.

The article "DATA – a sustainable performance accounting framework for SMEs. From macro planetary boundaries to micro economic Sustainable Earnings Before Interest and Tax (SEBIT)" by Steven Geschwindner, Toni Eser and Stephan Hauboldintroduces an approach to monitor if a company´s activities are within the planetary boundaries. The first part of the article outlines the approach step by step: First, indicators, baseline targets, and organizational targets are defined. Afterwards, the actual environmental

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impact (e.g., greenhouse gas emissions) and the target value are compared. Finally, the indicator obtained is monetized. The approach is then applied to the University for Applied Sciences Fresenius as an example.

The third article, entitled "The chemical industry as a key player for climate protection: Learning experiences from cooperation with developing countries and emerging economies" by Detlef Schreiber and Paola Bustillos shares experiences from the Climate Action Program for the Chemical Industry (CAPCI). The authors first shed light on the connection between the chemical industry and climate change before introducing the conceptual approach of CAPCI. On the one hand, the program provides stakeholders and decision-makers with the knowledge needed to mitigate greenhouse gases in chemical production. On the other hand, it supports activities in the focus countries of Argentina, Ghana, Peru, Thailand, and Vietnam. The authors describe a broad range of concrete activities that are conducted. Finally, they highlight the importance of cooperation and knowledge sharing, especially with developing and emerging economies, to achieve a transformation of the chemical industry on a global scale.

In his article "Sustainable industrial area management: Using materiality analysis at a multi-stakeholder industrial park to align activities", Bernd Winters shares his experiences in applying materiality analysis to multi-stakeholder sites. As this method usually refers to one company, it needs to be adapted to transfer it to multi-stakeholder sites. After setting the scene by describing the involved actors at industrial park Höchst, where especially the cluster Process4Sustainability deals with sustainability-related topics, the article focuses on the process perspective, and the individual steps are described in detail. The article closes by describing the advantages and possible limitations of the presented approach.

Florian Ausfelder, Luisa Fernanda López Gonzalez, and Eghe Oze Herrmann discuss in their article "The role of hydrogen in the process industries – implications on energy infrastructure" the interdependency of infrastructure built-up and implementation of new processes for ammonia production. Here, the production of hydrogen, which today is mostly fossil based, is the most intensive step in terms of emissions. Several alternative pathways for ammonia production, taking into account infrastructure requirements for the transport of gases (natural gas, hydrogen, or carbon dioxide) are compared. Additionally, infrastructure requirements for electrical transmission for an average ammonia plant are considered. Finally, the authors emphasize that industrial transformation and infrastructural development need to be considered jointly to prevent delays.

The first commentary "Responsible use – the social license-to-operate: A business approach towards sustainability in chemicals & materials" written by Wolfgang Falter and Herwig Buchholz criticizes the predominant focus on unwanted environmental effects and social costs in sustainability discussions in the chemical industry. The authors argue for a stronger consideration of the benefits of chemicals and propose to enlarge the current product focus (Cradle-to-Gate) by a use focus (Gate-to-Cradle). Sustainable chemistry finally results from the interplay of both elements.

The other two commentaries, "Turning point(s) ("Zeitenwende") and new multipolarity: Is the industry in Germany declining into insignificance?" by Jürgen Vormann and "An active systemic industrial policy for climate-neutral process industries in Europe" by Stefan Lechtenböhmer reflect on how an effective industry transformation could be implemented. Both articles emphasize and agree about the great importance of constructive cooperation between industry, politics, and society. However, the two authors have different views on the concrete design of the industry transformation. Jürgen Vormann´s commentary summarizes a speech held in December 2022 at the Frankfurt Industry Evening, Chamber of Industry and Commerce. He pledges a balanced consideration of all three pillars of sustainability as he perceives a dominance of the topic of climate in the current discourse and sees the industrial base in Germany as endangered. He emphasizes the importance of free markets and the power of market mechanisms to overcome current challenges. The commentary closes by outlining ten basic rules for a successful transformation of the economy. Stefan Lechtenböhmer, on the other hand, sees a transformative industrial policy which requires an active role of the state as indispensable. He outlines six closely interlinked pillars for the development of such an industrial policy: 1) Directionality, 2) Taking a system perspective, 3) Creating markets, 4) Building capacity for governance and change, 5) International coherence and 6) Considering necessary technology or market exits and their impacts.

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Table 1 Overview about the articles and the levels that they address.

Article / Level	System level	Company level	Innovation and production management level
“Exploring sustainability integration and expected outcomes of a digitalized product innovation work process for non-assembled products”			X
DATA – a sustainable performance accounting framework for SMEs: “From macro planetary boundaries to micro economic Sustainable Earnings Before Interest and Tax - SEBIT“		X	
“The chemical industry as a key player for climate protection: Learning experiences from cooperation with developing countries and emerging economies”	X		
“Sustainable industrial area management: Using the materiality analysis at a multi-stakeholder industrial park to align activities”		X	
“The role of hydrogen in the process industries – implications on energy infrastructure”	X		
“Responsible use – the social license-to-operate: A business approach towards sustainability in chemicals & materials”		X	
“Turning point(s) (“Zeitenwende”) and new multipolarity: Is the industry in Germany declining into insignificance?”	X		
“An active systemic industrial policy for climate-neutral process industries in Europe”	X		

5 Workshop survey

The workshop delegates were a mixture of academic scholars, industry professionals, and representatives from related organizational bodies, all with a profound knowledge of different aspects related to the transformation of the process industries. Thus, the following presentation of the results from workshop delegates can be regarded as “top-of-the-mind” viewpoints from a variety of “informants” (Barrett and Oborn; 2018; Kumar et al., 1993). Workshop delegates were introduced to the questionnaire on the morning of the second day, and they received ample time to respond to the questionnaire before participating in the subsequent round-table discussions.

The workshop inquiry investigated the importance of different managerial challenges related to transformation of the process industries towards CO_2-neutrality. The challenges are categorized into the following areas: strategy, digital transformation, product and process innovation, and manufacturing. The participants were asked to rate the importance of all areas using a Likert scale, where 1 equals “not important” and 5 equals “very important.” In total, 32 workshop delegates responded to the questionnaire. The complete questionnaire can be found in the appendix.

The ten highest rated managerial challenges related to the transformation of the process industries identified by the participants are presented in order as a top-ten list:

1. Strategy: Redesign of a company’s energy and raw material mix: defossilization of energy and raw materials

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and the interdependencies between the two

2. Strategy: Sustainable business model development: integrate the triple bottom line (profit, planet, people) systematically in corporate strategy making
3. Product and process innovation: Regulation as driver for innovation in product and process innovation (e.g. EU taxonomy, green finance, sustainable supply chain regulation)
4. Product and process innovation: Impact Assessment: Assess the environmental and social impact of new products and processes (life cycle assessment; technological readiness levels; social readiness.
5. Manufacturing: Exit from existing technologies (e.g. coal- or gas-based technologies)
6. Product and process innovation: Regional ecosystems: Manage and develop a regional ecosystem for having access to renewable energy, new feedstock, H_2 and CO_2-infrastructure and new markets
7. Strategy: Long-term transformation in times of potential short-term disruptions: handle ambiguity and contradictions
8. Manufacturing: Developing and fostering sustainable innovation cultures in production-oriented industrial operational environments.
9. Digital transformation: Digitalization for sustainable development: Develop and implement e.g. digital product passports; cross-company and cross-industry data base for CO_2 and raw material related data
10. Product and process innovation: Cross-sectoral learning: e.g. chemical industry learns from steel industry in the fields of innovation and technology management

The highest ranked topical area is from the strategy category, which is about the redesign of a company's energy and raw material mix, namely the development of a defossilization strategy which addresses the interdependencies between the two as well. In fact, of the ten topical areas, three belong to strategy category, which shows the criticality of this area for the companies in the process industries. Four aspects, on comparatively lower ranks, stem from the category of product and process innovation such as the importance of regulation as a driver for innovation, the technological impact assessment or the organization of innovative ecosystems and cross-industry learning. Two manufacturing related topics made it into the top ten list such as the process of exiting from established technologies and the development of sustainable innovation cultures. From the category of digital transformation, only one aspect was among the top ten (Digitalization for sustainable development: Develop and implement e.g. digital product passports; cross-company and cross-industry data base for CO_2 and raw material related data).

5.1 Transformation Strategy

In the year 2022, participants attributed the highest importance to the managerial challenge of redesigning a company's energy and raw material mix: the defossilization of energy and raw materials and the interdependencies between the two. Given the variety of open issues – from a lack of fossil-free energy to the low technology readiness of low carbon technologies and a regulatory environment in flux, this challenge was seen as most important. In addition to this more technological challenge, experts highlighted on the second rank in this category the importance of integrating

Table 2 Category "strategy"

Description	Rank in the category	Mean
Longterm transformation in times of potential short-term disruptions: Handle ambiguity and contradictions	3	3.9
Sustainable business model development: Integrate the triple bottom line (profit, planet, people) systematically in corporate strategy making	2	4.2
Redesign of a company's energy and raw material mix: Defossilization of energy and raw materials and the interdependencies between the two	1	4.4
Societal alignment: Design collaboration processes for the cooperation with public policy makers and civil society	4	3.7

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the triple bottom line (profit, planet, people) approach in corporate strategy-making to develop sustainable business models. Balancing short-term requirements and long-term transformation goals simultaneously, handling ambiguity and contradiction was ranked number 3 (long-term transformation in times of potential short-term disruptions: handle ambiguity and contradictions). The design of collaboration processes for the cooperation with public policy makers and civil society was seen as the management challenge with the least importance in this category. Technological, managerial, and on a lower level of importance stakeholder management issues are thus seen as topics with relevance for designing and implementing transformation strategies towards CO_2-neurality.

5.2 Product and process innovation

The category "product and process innovation" encompasses four aspects in the questionnaire (table 3). The topic with the highest importance is the handling of regulation as driver for innovation in product and process innovation (e.g. EU taxonomy, green finance, sustainable supply chain regulation). Practitioners highlighted during the round table discussions the challenges in observing regulatory developments and in creating corresponding products and process innovations early on. On rank 2 the topic "Impact Assessment: Assess the environmental and social impact of new products and processes (life cycle assessment; technological readiness levels; social readiness level)" was seen as a challenge with significant importance, too. It was underlined in the discussions, that theory and practice would have to evolve in order to support encompassing and standardized impact assessments as today a variety of concepts would compete leading to a lack of transparency in the market. Regional ecosystems were seen as a mean for having access to renewable energy, new feedstock, H_2 and CO_2-infrastructure and new markets. The management of these ecosystems were ranked third in the category. Participants acknowledged as well the value of cross-sectoral learning in the fields of innovation and technology management but attributed a comparatively lower importance to this issue.

5.3 Manufacturing

The category "manufacturing" consists out of four aspects: Participants assigned the highest priority to the management challenge "Exit from existing technologies (e.g. coal- or gas-based technologies)" (table 4). It was underlined that the economic business case for existing assets and technologies was typically favorable compared with investments into new low carbon processes and assets (unless new technologies receive public subsidies or are due to regulatory or market requirements). On rank two in this category, the management challenge of "developing and fostering sustainable innovation cultures in production-oriented industrial operational environments". Broadening the criteria for evaluating innovations and working in cross-disciplinary teams were seen as relevant challenges here. On rank three, the "redesign of the global manufacturing network (de-globalization)" was mentioned. The relevance of this aspect varies from industry to industry and depends on

Table 3 Category "product and process innovation"

Description	Rank in the category	Mean
Regulation as driver for innovation in product and process innovation (e.g. EU taxonomy, green finance, sustainable supply chain regulation)	1	4.2
Impact assessment: Assess the environmental and social impact of new products and processes (life cycle assessment; technological readiness levels; social readiness levels)	2	4.1
Regional ecosystems: Manage and develop a regional ecosystem for having access to renewable energy, new feedstock, H_2 and CO_2-infrastructure and new markets	3	4.0
Cross-sectoral learning: e.g. chemical industry learns from steel industry in the fields of innovation and technology management	4	3.8

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Table 4 Category "manufacturing"

Description	Rank in the category	Mean
Redesign of the global manufacturing network (de-globalization)	3	3.5
Timing of new technologies: Identify and assess the readiness of a new low-carbon technology and time the best moment for the implementation	4	3.4
Exit from existing technologies (e.g. coal- or gas-based technologies)	1	4.1
Developing and fostering sustainable innovation cultures in production-oriented industrial operational environments	2	3.9

geopolitical developments as well. The participants attributed the lowest importance in this category to the "Timing of new technologies: Identify and assess the readiness of a new low-carbon technology and time the best moment for the implementation" – in the discussion it was underlined that this topic would not have a high urgency in the year 2022 as the majority of companies would not focus on applying technologies with a low technology readiness level but would focus more on developing the overall transformation roadmaps.

5.4 Digital transformation

The category "digital transformation" consists out of two items (table 5). Participants identified the topic of "Digitalization for sustainable development: Develop and implement e.g. digital product passports; cross-company and cross-industry database for CO_2 and raw material related data" as important. As CO_2-related data form the basis for all company- and value-chain related transformation pathways, the digital infrastructure was discussed as a crucial pillar for the development and implementation of effective and efficient transformation strategies. The concept of industry 4.0 (item: Digital transformation: Industry 4.0: Manage company digital transformation in the process-industries for improved product quality and production flexibility (including e.g. digital twins, predictive maintenance)) was less seen as cornerstone of the transformation towards CO_2-neutrality by the participants even though there are synergies and overlaps between both topics.

6 Outlook: Focus topics and the need for collaboration between academia and practice

The transformation of the European process industries towards CO_2-neutrality by 2050 is a highly complex endeavor in very dynamic geopolitical and economic environments. Technologies need to be developed, infrastructures need to be built, markets need to be transformed – this fundamental change required cooperation between academia, business, society and policy.

The workshop has shed light on some of the most important managerial challenges (figure 1).

1. The defossilization of a company's energy and raw materials mix is the dominant challenge for companies in the European process industries (A.SPIRE, 2021;

Table 5 Category "digital transformation"

Description	Rank in the category	Mean
Develop and implement e.g. digital product passports; cross-company and cross-industry data base for CO_2 and raw material related data	1	3.8
Industry 4.0: Manage company digital transformation in the process-industries for improved product quality and production flexibility (including e.g. digital twins, predictive maintenance)	2	3.4

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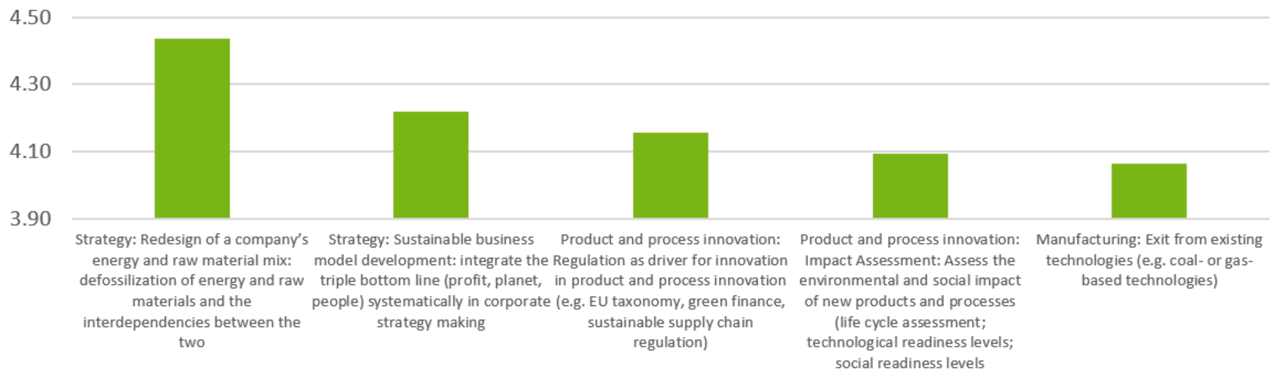

Figure 1 The five highest-ranked topical areas in the workshop inquiry (own representation)

Cefic, 2023; Chemistry4Climate, 2023; Utikal and Loewert, 2022). Science is needed not only to advance technological developments but as well to support companies' decision making processes in the light of contradictions and ambiguity. Technology roadmaps and scenarios as well as conceptual support in the design of the transformation process once the different levers for defossilization are identified will help to support managers in their practical decisions.

2. Developing sustainable business models which take into account economic, ecological and social aspects in a systematic manner and try to quantify all related costs and benefits can be seen as a complement to the technology-oriented development of transformation pathways (Schaltegger et al., 2016; von Delft and Zhao, 2021). From a research perspective, the conceptual challenges for having this encompassing view of business activities are significant: they include concepts of integrated accounting of economic, ecological and social impacts as well as the development of more complex strategy concepts (Geschwindner et al., 2023).

3. Regulation (e.g. EU taxonomy, green finance, sustainable supply chain regulation) must be seen as core driver for innovation in the European process industries. From a business practice perspective, one main challenge is to observe the developments in this field (sensing the opportunity) and to develop suitable business models (seizing the opportunity) (Durand et al., 2019; Velter et al, 2020). Especially for small and medium sized companies, it is very difficult to identify early on the opportunities related to regulation (Cefic, 2023). Business associations play a crucial role in creating transparency about upcoming regulations and companies of all sizes need to actively design their innovation eco-system.

4. The impact assessment - assess the environmental and social impact of new products and processes – is still seen as a challenge for management practice (Falter and Buchholz, 2023).

5. Ex-novation – the exit from existing technologies (e.g. coal- or gas-based technologies) – is as important as innovation if the EU climate goals are to be reached (Lechtenböhmer, 2023). Analyzing this topic requires to distinguish between multiple perspectives and interests from companies, shareholders and financial institutions and policy makers alike. Integrating findings from those different perspectives and research streams remains a major challenge for designing economically and ecologically viable transformation paths.

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Appendix

IPM 2022: Transform the European Process Industries towards CO_2 neutrality: Survey

How important are the following topics for the transformation of the process industries towards CO_2-neutrality? (1 = Not important, 5 = Very important)

Strategy

1. Longterm transformation in times of potential short-term disruptions: handle ambiguity and contradictions. (3.9)
2. Sustainable business model development: integrate the triple bottom line (profit, planet, people) systematically in corporate strategy making. (4.2)
3. Redesign of a company's energy and raw material mix: defossilization of energy and raw materials and the interdependencies between the two. (4.4)
4. Societal alignment: Design collaboration processes for the cooperation with public policy makers and civil society. (3.7)

Digital transformation

1. Digitalization for sustainable development: Develop and implement eg digital product passports; cross-company and cross-industry data base for CO_2 and raw material related data. (3.8)
2. Manage company digital transformation in the process-industries for improved product quality and production flexibility (including e.g. digital twins, predictive maintenance). (3.4)

Product and process innovation

1. Regulation as driver for innovation in product and process innovation (e.g. EU taxonomy, green finance, sustainable supply chain regulation). (4.2)
2. Impact Assessment: Assess the environmental and social impact of new products and processes (life cycle assessment; technological readiness levels; social readiness levels). (4.1)
3. Regional ecosystems: Manage and develop a regional ecosystem for having access to renewable energy, new feedstock, H_2 and CO_2-infrastructure and new markets. (4.0)
4. Cross-sectoral learning: e.g. chemical industry learns from steel industry in the fields of innovation and technology management. (3.8)

Manufacturing

1. Redesign of the global manufacturing network (de-globalization). (3.5)
2. Timing of new technologies: Identify and assess the readiness of a new low-carbon technology and time the best moment for the implementation. (3.4)
3. Exit from existing technologies (e.g. coal- or gas-based technologies). (4.1)
4. Developing and fostering sustainable innovation cultures in production-oriented industrial operational environments. (3.9)

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Research Paper

Exploring sustainability integration and expected outcomes of a digitalized product innovation work process for non-assembled products

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Sustainability and digitalization are currently strategic priorities for manufacturing companies to be globally competitive, and one option is to incorporate these aspects in a company product innovation work process; the topical area for this study. An exploratory inquiry has been conducted with nineteen global manufacturing companies in six sectors of the process industries, including the chemical industries. The findings indicate that the case-companies already have come far on the road in institutionalizing sustainability aspects in raw material selection, process technology development and product design. However, the study discloses a need for a more in-depth understanding how best practices and tools in a more systematic approach can make sustainability an integral part of the work process. The case-companies have not yet come far on their journeys with respect to digitalization of their product innovation work process, but particularly stress the importance of digitalization of customer and product information.

1 Introduction

For all manufacturing industries, and in particular companies in the process industries being suppliers of commodities, functional products, or both, sustainability and digitalization are currently top strategic priorities to continue to be a globally competitive and sustainable organization (Chen et al., 2020; Neef et al., 2018; Shang and Zhang, 2022; Ukko et al., 2019). Sustainability is of importance and of growing urgency to companies (Kaplinsky and Morris, 2018), and environmental innovations give opportunities to respond to concerns over the depletion of natural resources, and the use of raw materials with negative environmental impacts (Yu et al., 2016). Moreover, Industry 4.0 offers the potential for increased automation and flexibility in production, thus digitalization is driving new process innovations (Blackburn et al., 2017; Iansiti and Lakhani, 2014). The opportunities create a need for process innovation processes to consider the integration between individual equipment, connected smart devices, dynamic software systems, smart logistics systems and suppliers (Horváth and Szabó, 2019). However, the transition to digitalization and sustainability requires new strategies, work processes, organizational structures, operation modes, and capabilities (Chirumalla, 2021; Sehnem et al., 2021). Consequently, company product innovation must in the future in an inclusive operational mode both individually and conjointly consider product innovation in the perspective of both sustainability and digitalization (Lichtenthaler, 2021).

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The cluster of process industries spans the industrial sectors, Mining and Metals Industries, Mineral and Materials Industries, Chemicals and Petrochemical Industries, Pulp and Paper Industries, Food and Beverages Industries, Generic Pharmaceuticals, Steel and Utilities (Lager, 2017a). For a formal definition of process industries, see Appendix A. An important aspect on product innovation, related to the difference between companies in the process industries and in other manufacturing industries, is that products delivered from them are non-assembled products principally serving business-to-business (B2B) customers (Frishammar et al., 2012). Not only are they often intermediate actors in long industrial supply/value chains, but their product innovation is also strongly intertwined with process technology development and raw material characteristics (Lager and Blanco, 2010a); both aspects may influence company advancement and inclusion of both sustainability and digitalization. Since product innovation and renovation is a strong strategic company concern (Rothwell and Gardiner, 1985), such activities are usually administered as a formal work process (Melan, 1992), often in a format of a Stage-Gate decision model (Cooper and Sommer, 2016), preferably within a framework of business process management (Jeston and Nelis, 2018). Such a continually improved and customized work process adapted to company operational and product-market conditions, driving development and delivery of new or improved products on the market, therefore constitutes an important intangible asset and a dynamic capability (Teece, 2009). In particular, it impacts the way a company design products and production system such as product innovation work process e.g. (Hallstedt et al., 2013).

Current insights identify the important role that pilot, and demonstration plants can play in creation of sustainable production technologies (Hellsmark et al., 2016), which underscores the necessity for an early integration of raw material properties and production technologies in innovation. Pujari et al. (2004) thus conclude that environmental activities should be incorporated in the front end of a work process and include an analysis of the lifecycle impacts of products and production. In sum, from initial selection and use of environmentally acceptable raw materials and ingredients, use of sustainable energy efficient (fossil free) production technologies, and ending up with recyclable products and packaging, companies in the process industries can play an important role in circular economy founded upon a holistic view on the total product innovation work process (Lager and Simms, 2023).

Smart manufacturing forms a key component of Industry 4.0, but such considerations are still rarely linked to product development and are not yet captured in product innovation work processes. Yet, within the process industries the interlinkages between raw materials, production processes and the final product necessitates a consideration of digitization in the design of an improved product innovation work process. Moreover, and during recent years, there has been growing interest to integrate the two mega trends of sustainability and digitalization to exploit the potential interdependencies or cross-fertilization effects (e.g., (Aksin-Sivrikaya and Bahattacharya, 2017; Chen et al., 2020), and some researchers have already begun to discuss concepts like “digitainability” (Lichtenthaler, 2021) or “smart circular economy” (Kristoffersen et al., 2020).

Hence, there is a need to further the understanding on how digitalization and sustainability could individually and jointly provide competitive advantage in industrial companies, and in the design of a product innovation work process. Moreover, not only is research on the product innovation work process for non-assembled products scarce (Lager and Bruch, 2021), but how sustainability and digitalization perspectives could be more integrated in company work process design is not yet well-addressed and understood. This study is aiming to close this gap, and in an exploratory survey mode of inquiry to informants in nineteen global manufacturing companies in six sectors of the process industries, to develop a preliminary framework for the inclusion and integration of sustainability and industrialization in an enhanced work process for non-assembled products.

This exploratory study is one out of several “key research areas” within a broader research initiative and project, focusing on innovation work processes for non-assembled products in the process industries (Lager and Simms, 2023). The general research question for the total research project is: What are the main building blocks, incorporated concepts, and related constructs of a generic “structural process model” intended to serve as a guiding template for company design or reconfiguration of a formal innovation work process for the development of non-assembled products? Following this general research question, the study addresses the following research questions:

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RQ1. *How far have companies in the process industries come with regards to securing sustainability considerations in their product innovation work processes for non-assembled products?*

RQ2. *How far have companies in the process industries come in digitalization of their product innovation work processes for non-assembled products?*

The article is organized as follows: First, and in a frame of refence the process industries are presented, a generic model for the innovation work process is introduced and sustainability and digitalization related to work process design are reviewed. The research design, selection of case-companies and the deployment of the research instrument are then presented. Afterwards, the empirical findings are presented, and in the discussion a preliminary agenda for further research is proposed. Finally, research limitations and management implications are given together with conclusions.

2 Frame of reference

There are a number of potential strategic and operational activities to pursue in order to institutionalize the areas of sustainability and digitalization in corporate life, and one avenue to follow is to integrate both perspectives in the company product innovation work process.

2.1 Introducing the "family" of process industries and its product innovation intricacies

There are a number of manufacturing characteristics related to the process-industrial material transformation system from incoming raw materials to finished products, that define the process-industrial production and operational environment (Lager, 2017a), see Figure 1.

In a Resource Based View (Barney et al., 2001), the asset-intensive production process and the reliance on raw material from suppliers or from captive supplies differentiate the process industries from other manufacturing industries. In some sectors, company start-up and development have relied on the availability of company-owned raw materials or the access to well-secured raw material resources (Lager and Blanco, 2010b). Furthermore, the specification of incoming materials determine the selection of the design of the production system but generally influence product quality as well (Samuelsson et al., 2016). Such idiosyncrasies have important consequences with regard both to sustainability and digitalization in the process industries.
Being producers of commodities, functional products or both, successful product innovation depends on an understanding of the chain-like structures of companies in the process industries (Tottie and Lager, 1995), and a company position within such complex supply/value chains will critically influence product life cycle assessment. Furthermore, whilst product innovation in assembly-based industries is transferred from the R&D organization to the

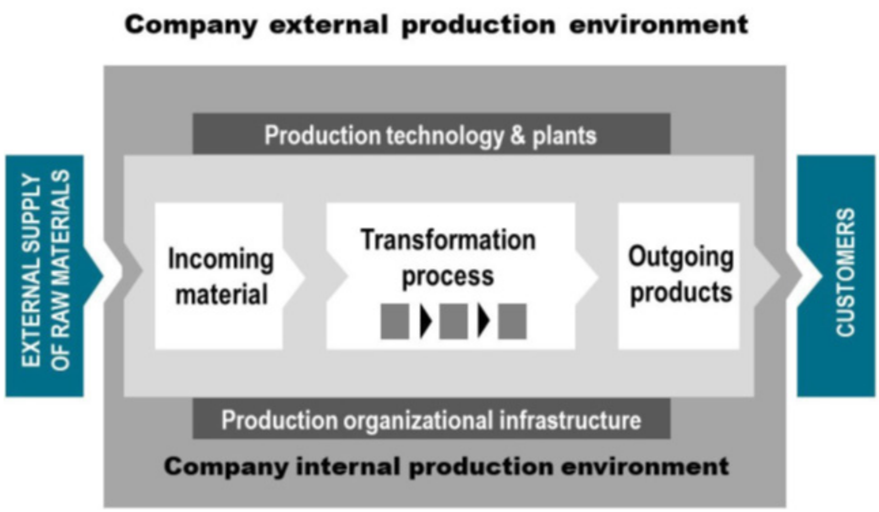

Figure 1 A simplified structural model of the production system in the process industries (Lager, 2019; Lager et al., 2017).

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manufacturing organization when the product design is ready after prototyping (Lakemond et al., 2013), innovation of non-assembled products in the process industries focuses on early experimental work in laboratories or pilot plants (Frishammar et al., 2014). Moreover, an interdependency between product and process innovation is often necessary for successful product innovation (Lager, 2002b) in many process-industrial sectors, and Reichstein and Salter (2006) argued that they should be regarded as "brothers" rather than "distant cousins". A fact that also will influence sustainability perspective integration in the different phases of the product innovation work process.

2.2 Formal work processes and a generic "structural process model" for the development of non-assembled products - a point of departure

A formal structured and delineated explanation of how work should be accomplished, clarifying ownership and process users, process input and output, decision structures and checklists, is usually denominated a "formal work process" (Andersen et al., 2008; Lager et al., 2010; Melan, 1992). Such formal work processes allow new employees to familiarize with company best practices and enable seasoned practitioners to develop and accumulate new knowledge for enhanced work process execution. However, such formal processes are rarely designed to meet future company needs, because they have gradually emerged over longer periods with regards to more circumstantial operational challenges. Cooper and Kleinschmidt (1986) early depicted a product innovation work process as a number of Stages separated by Gates as decision points, from idea to product launch; the Stage-Gate product innovation process. Further research by Cooper (1994b) and other scholars (Bower and Keogh, 1996), suggest that such work processes should be more flexible and adaptable to different project characteristics (Cooper and Sommer, 2016).

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). Even if Cooper and Edgett (2012) have demonstrated that an efficient Stage-Gate process drives business performance, the model has been criticized for lack of iterative loops. In spite of doubts raised by Eisenhardt and Tabrizi (1995) with regards to the model's inflexibility (Unger and Eppinger, 2009), a visual shared model of the product innovation work process must be admitted to be a success factor in product development (Cooper, 1994a; 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 and empirically tested (Lager and Simms, 2023), 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 (Lager et al., 2023) to industrialization in post-product innovation, the integration of product innovation and process innovation must be executed in a rather iterative fashion. The product development phase contains the activities of "test marketing" and "process testing" when advanced process test-work also give samples for test marketing with customers. In consequence, the further development of a product concept into a final product design is thus actually the undertaking of a further development of an associated process concept into a final process design and production set-up.

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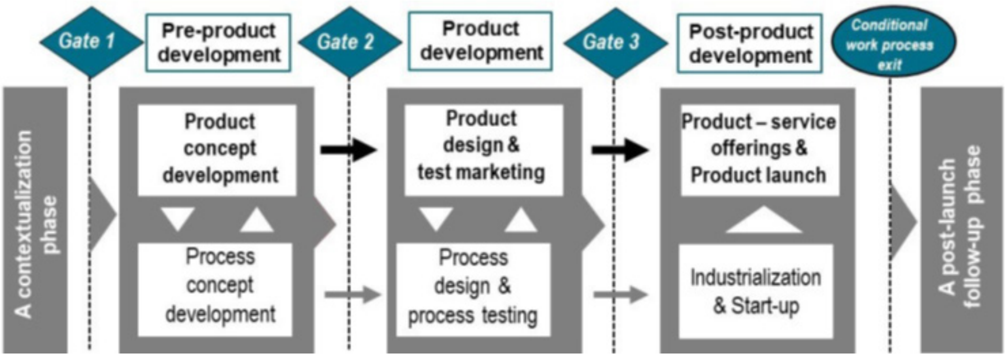

Figure 2 A generic "structural process model" for company design of a product innovation work process for the development of non-assembled products, adopted from Lager and Simms (2023)

2.3 Sustainability and digitalization in the perspective of process-industrial product innovation and work process design

2.3.1 Sustainability perspectives

Cheng and Shiu (2012) classified innovations as organizational, product, process and within the process industries the latter two are interconnected and provide a possibility for sustainability improvements. Environmental innovations, incorporate a variety of innovation types throughout the innovation's lifecycle (De Marchi, 2012; Kemp, 2010), and innovations are of a significant importance in a process industry context. Process industries can play a crucial role in a 'cradle-to-cradle' approach to innovation founded upon effective use of raw materials, sustainable production processes, and a reduced consumption of fossil fuels (e.g. (Eppinger, 2011)). With respect to manufacturing, approximately thirty percent of global energy usage and CO_2 emissions are attributed to manufacturing industries (International Energy Agency, 2007), of which the process industries constitute a considerable part.

In a study of key elements for implementing a strategic sustainability perspective in the product innovation process in a large manufacturing company, Hallstedt et al. (2013), concluded that: "currently there is a very strong focus on technical aspects and business opportunities of product concepts being explored, but very little consideration of the sustainability implications of these concepts". Moreover, a more proactive approach from purchasing is desired with regards to materials for new products, and their stronger involvement in the product innovation work process. Brockhaus et al. (2019) conclude that the issue of how companies effectively make sustainability considerations an integral part of their new product development process (NPD) still remains elusive. In order to avoid the fallacy of "trickle-down" product sustainability, they advocate that true codification of sustainability in NPD goes far beyond simply adding auxiliary sustainability goals for products and institutionalizing product sustainability as a NPD target equal to "traditional" targets. Nevertheless, they fail to deliver more substantial guidelines how to further administrate such a process. In a study of German consumer goods manufacturers, Petersen (2021) observe that human factors like competences and attitudes have a decisive impact on product innovation, when sustainability considerations are to be integrated as an extra layer of product requirements, and hard-to-make decisions on tradeoffs. In sum, and in spite of the very large number of publications related to the development of sustainable products (Thomé et al., 2016), there are still a surprisingly few publications related to HOW sustainable perspectives could be integrated into formal product innovation work processes in general, and for non-assembled products in particular.

2.3.2 Digitalization perspectives

Industry 4.0 incorporates technologies that enable automated and digital manufacturing and can furthermore include digitization of the company's supply chain (Oesterreich and Teuteberg, 2016). Increased use of internet and cloud technologies, sensors, and machine learning in a manufacturing environment (Sung, 2018), can facilitate and open up new avenues for production in extended

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communication in-between objects, machine learning and autonomous robots (Valenduc and Vendramin, 2016). Smart Manufacturing, which is one component of Industry 4.0, consists of integrated manufacturing systems that are able to meet the demands of the plant itself, supply networks, and customer needs in real time (Kusiak, 2018).

Several researchers describe how advanced digital technologies can play a role in product- and process innovation in the process industries. In the process industries, Qian et al. (2017) examined digitalization for realizing four goals in firms' production and operation: agility, high efficiency, environmental sustainability, and safety. Through the continuous adjustment and optimization of the processes online, digital technologies aim to improve processes' flexibility and reliability, maximize the yield, and improve the product quality and maintenance practices (Branca et al., 2020). Herzog et al. (2017) emphasized that smart sensor technology, combined with advanced digital models, as well production planning and control systems provides quality improvement and production cost reduction together with process flexibility along the entire production value chain. Porter and Heppelmann (2015) described that a series of existing digital technologies may facilitate disassembly as well as the taking back and reuse of structural steel components, thereby improving resource efficiency and opening up new business paradigms. Hakanen and Rajala (2018) found that IoT-enabled material intelligence with a digital identity can effectively support trace-and-track items with detailed properties information, enabling a number of services using AI that facilitate the product usage in cross-organizational collaboration. Moreover, Chirumalla (2021) investigated how digitalization can support process innovation work processes from dynamic capabilities perspective and proposed sensing, seizing, and reconfiguring dynamic capabilities for digitally-enabled process innovation. The study found four key enablers for digitally-enabled process innovation, including infrastructure and methodological definition, preparation for predictive and analytical readiness, proactive management practices, and plan for a digital matureness for each function and department.

Further, several researchers presented insights on the impact of digitalization for innovation process in general. Marion and Fixson (2021) examined the transformation of the innovation process by using digital tools and found that digitalization not only affect output and process efficiency, but they also lead to rearrangement of the entire innovation processes, enable new configurations of people, teams, and firms. Further, innovation processes are gradually being compressed with the use of digital technologies, anticipating, and enhancing the phases in which customer feedback is gathered and employed (Agostini et al., 2020). Additionally, Aaldering & Song (2021) indicated that not all process industries can be regarded as laggards in terms of incorporating digital capabilities. "Biotechnology", "Pharmaceutical", "Food and Beverage", "Energy" and "Oil and Gas" demonstrated a higher IT-affinity, thus presenting themselves as digital leaders within the process industries. They also confirmed that each segment of the process industries has adopted a unique pathway towards unlocking digital transformation opportunities.

Unlike in discrete manufacturing industries, companies in process industries generally contain multiple mutually coupled processes in production systems, making digitalization difficult to realize (Qian et al., 2017). Gao et al. (2019) identified challenges facing firms in the metals and mining industry, including the inability to change, goal ambiguity, poor applicability of technologies to current processes, and external constraints. Therefore, adopting digitalization remains a concern for many firms in process industries, and the potential of many data sources remain unexplored by firms, particularly those related to developing new processes (Hakanen and Rajala, 2018). Yuan, Qin, and Zhao (2017) examined the oil and petrochemical industry and found that smart manufacturing should combine information, technology, and human ingenuity to bring about a rapid revolution in the development and application of manufacturing intelligence as well as improve agility, flexibility, productivity, and quality.

2.3.3 Perspectives on sustainability integration and digitalization

A recent international survey revealed that 96% of 765 decision makers in 12 industrial segments acknowledge that digitalization is essential for achieving sustainability objectives and increase their investments in advanced digital technologies (IntelliSurvey, 2021). Hence, one can observe that many industrial companies as well as technology providers such as ABB, Ericsson, and Siemens are defining sustainability strategies and targets to reduce annual CO_2 emissions in their overall operations. However,

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Chen et al. (2020) found that digitalization in manufacturing contributes positively to environmental sustainability by increasing resource and information efficiency. They, however, stressed that applying Industry 4.0 technologies throughout the product lifecycle also cause negative environmental burden due to increased resource and energy use, as well as waste and emissions from manufacturing, use, and disposal of the hardware.

2.3.4 Methodologies and tools for sustainability integration and digitalization in product innovation

Since the use of methodologies and tools have demonstrated improved company performance (Thomke, 2006; Nijssen and Lieshout, 1995), the use of methodologies for product innovation is one avenue to follow (Nijssen and Frambach, 2000; Lager, 2005). However, it is important not only to consider methodology selection and company organizational solutions for making them sustainable (Day, 1993), but furthermore, to secure that they are able to address critical sustainability needs in the future (Hallencreutz et al., 2020; Deleryd and Fundin, 2020). In a study of methodology selection for sustainable product development (SPD), Buchert et al. (2017) selected 29 methods for SPD, but in the plethora of methodologies related to sustainability assessment and product innovation, process industrial idiosyncrasies must be considered and how they can be employed as supporting instruments for the product innovation work process. One methodology that combine both digitalization of customer and product information with an integration of sustainability requirements in product design is Quality Function Deployment (Akao, 2003; Mizuno and Akao, 1994). As one of the most commonly used methodologies in product development Puglieri et al. (2020), reviewed 29 alternative QFD approaches for product ecodesign, with respect to the inclusiveness of environmental requirements and operational requirements. Because of the need for a more structured approach in the merging of general customer requirements on new or improved products with the emerging large number of sustainability related requirements a large number of hybrid QFD methodologies are surfacing (Ocampo et al., 2020). In the use of the well-proven QFD methodology for the development of non-assembled products (Lager, 2019), and in the development of a "House of Sustainability" (Rihar and Kusar, 2021), the further employment of the methodology for process-industrial applications could be of interest to explore.

3 Research design

In this discovery-oriented project, an abductive research approach was considered appropriate, since such an approach can lead to new insight about existing phenomena by examining them from a new perspective (Kovacs and Spens, 2005). Whilst inductive research primarily tries to generalize research findings to a larger population, an abductive research approach predominantly aims to understand new phenomenon (Alvesson and Sköldberg, 2009). One important characteristic of abduction is the process of iterating between theory and empirical evidence (often called "theory matching"), when data collection and analysis generally overlap (Dubois and Gadde, 2002). The problematization of the topical area in this study was not mainly driven by gaps in the literature but by a need for new knowledge in both practice and theory (MacCarty et al., 2013: p. 945). After an initial review of the general literature related to work processes and product innovation work processes in particular, the literature related to the key research areas of sustainability and digitalization were afterwards successively reviewed alongside with the empirical analysis – a procedure suggested by Dubois and Gadde (2002: p. 559).

Research results are sometimes presented in a wise that it is hard to figure out if the findings are prescriptive (normative) for what a company should aim at, or if they are only descriptive and just a snapshot of company "state-of-affairs" of a topical area; a problem well presented by Cobbenhagen et al. (1990):

On the one hand we find descriptive models which merely answers the question, why are we the way we are. The manager … "will in most cases merely take note of this announcement, and just think: So what? Normative ideas and models, on the other hand provide a direction towards which an organization must proceed in order to innovate successfully."

However, the descriptive element in innovation management, as an applied science, is likely to be of more importance than in basic research (Foellesdal et al., 1990). Even if some

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parts of the questionnaire in this study and in the total project contain questions of a more descriptive nature, the majority of questions are of a normative, problem-solving kind, inquiring about informants' advice on how to further improve the performance of a product innovation work process for non-assembled products.

3.1 Deployment of a in a survey mode of inquiry

The population of interest for this study is the process industries worldwide, and the selected study population comprised selected companies from the "family" of process industries, as defined in Appendix A; the level of analysis is the product innovation work process. In reference to Patton (1990), the use of a non-probability sampling strategy was selected in this study. Since, the credibility of such a purposeful sampling strategy is dependent on a clarification of criteria deployed in the selection process, the following guidelines were used in this study:

- Focusing on a subgroup of companies with similar contextual conditions within the manufacturing industries, only companies belonging to the "family" of process industries were selected. The sampling could in this respect be categorized as homogenous sampling (Henry, 1990).

- It was additionally also of interest to disclose any possible idiosyncrasies among different sectors of the process industries. In this perspective the company selection could also be categorized as heterogenous sampling (Henry, 1990); in search of diverse conditions within the total group.

In sum, the selection process could thus be described as "stratified purposeful strategy" (Patton, 1990). Palinkas et al. (2015) recommend selecting individuals or groups that are especially knowledgeable about or experienced with the phenomenon of interest and have the ability to communicate experiences and opinions in an articulate, expressive, and reflective manner. The final individual criteria for case-company selection was world-leading companies, located in different countries, and possessing process-industrial characteristics.

Thirty companies were invited through an e-mail with an attached presentation of the total research project. Of these companies, 20 agreed to participate in the study, and 19 ultimately provided responses. The companies belonged to the following sectors: Chemical Industries (five), Steel Industries (five), Forest Industries (five), Food & Drink Industries (two), Mineral Industries (one) and Packaging Industries (one). In the selection of case companies, the Chemical, Steel, and Forest Industry sectors were targeted to create three sub-groups to identify possible within and between sectoral (dis)similarities. The case-companies have registered offices in Sweden (four), Finland (two), Denmark (one), Germany (two), Switzerland (two), USA (one), Brazil (four), Chile (one) and Japan (two). To ensure the case-company firm desire for anonymity, each company's name, production data and country affiliation is not disclosed in our results. The companies are world-leading global corporations within their industry sectors, and many are major players in the marketplace. In the view of the supply/value chain, some companies are both upstream and downstream operators, and some cover the total supply/value chain from in-situ raw materials to end users. Only the two companies in the Food and Drink industries have mainly B2C customers, while others have primarily B2B customers.

3.2 Case-company informants and the deployment of the research instrument

In this study, the participating individual experts in the case-companies are called "informants", satisfying an early definition by Yin (1994: p. 84),

"*In some situations, you may even ask the respondent to propose his or her insight into certain occurrences and may use such propositions as the bases for further inquiry. The more a respondent assists in this latter manner, the more that the role may be considered one of an "informant" rather than a respondent.*"

Wagner et al. (2010) have elaborated the concept of "key informants" as:

"Key informants report their perceptions of these constructs, rather than personal attitudes or behaviours. In this respect, informants need to be distinguished from respondents who give information about themselves as individuals."

The group of company representatives in this study can thus be viewed as "multiple informants" since their answers often are grounded in their intimate knowledge also about similar

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sectoral conditions outside their own company (Samuelsson and Lager, 2019; Wagner et al., 2010). The informants were thus asked to contribute with their answers to several close-ended and complementary open-ended questions in a questionnaire something which could be looked upon as the informants' pre-conception of the subject matter.

The use of a questionnaire was considered appropriate for the study aims and the difficulties associated with collecting information from geographically dispersed companies, combined with few opportunities for in-person meetings with company representatives during the COVID-19 pandemic, and favored the development of a detailed and comprehensive questionnaire as a research instrument. In crafting the questionnaire, close-ended questions were developed and complemented with related open-ended questions. The draft first questionnaire was pilot tested by one industry professional and an academic scholar to improve the formulation and clarity of the questions. The final questionnaire was converted into an electronic document, which enabled the informants to respond and provide comments online. With the questionnaire, the informants received an additional document explaining the aim of the research project, practical information, and recommendations. The selected mode of answering the questionnaire varied; most often, one or two informants were chosen, while in some cases the questionnaire was answered in a group session. After case-companies agreed to participate, the questionnaire and instructions were sent to the contact person. This article will be submitted for publication and will afterwards be sent to the informants, post publication.

As a final perspective on methodological use and the generalization of research findings, the informants were asked to answer both close-ended and complementary open-ended questions in the questionnaire as "judges" of new and industrial concepts-in-use (Barrett and Oborn, 2018). The statistical analysis of the quantitative ordinal data (a five-point Likert ordinal scale was used) was not intended to be deployed in any kind of statistical generalization of the findings. The intension was afterwards to do a cross-case analysis of the combined quantitative and qualitative information from the informants in an analytical mode of generalization (Yin, 1994, p.30), but not to do an "in-depth" investigation of each case-company's work process in a customary case-study approach.

4 Empirical findings

Due to space limitations, all original questions and in the questionnaire are presented in this section, and the full questionnaire is not appended. Comments from informants are presented, and each sentence ending with sector specification represents a comment from a separate company. Comments from the three main industry clusters Chemical, Steel and Forest are sometimes separated. Two slightly different formats has been used and some questions, associated results, and comments from informants are presented in running text, while others are presented in tables labeled Q.X.

4.1 Sustainability perspectives on the product innovation work process in a process-industrial context

The informants were initially asked a number of questions (see Table 1, Q.1 – Q.4) related to sustainability integration in the product innovation work process in view of raw material selection, production process technology, and finished products.

The informants were afterwards asked (Q.5): What is your company's current opportunities and flexibility in raw material selection in the perspective of the raw material's environmental impact? On a five-point Likert ordinal scale (1 = Very limited; 5 = Very high) the mean value was 3.7 (S.D. 1.3; Skew – 0,5). The sectoral distributions are further illustrated in Figure 3.

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Table 1 Sustainability perspectives on the product innovation work process for non-assembled products.

Question No.	Answer			Comments from informants
	Mean	Std. dev.	Skew	
(Q.1) To what extent does your product innovation work process consider and ensure a low environmental impact of selected raw materials and ingredients for a new or improved product? (1= Not at all; 5 = Very much)	4.4	0.9	- 1.6	***Raw materials that have environmental impact are excluded in product development (Chemical)****; Quality & Price is our main concern (Steel); We focus development on renewable sources, compostable, recyclable, biodegradable (Forest); We are looking into all touchpoints to become more sustainable as a company (Food & Drinks); We are integrating this, based on our own priorities and customer demands (Packaging)*
(Q.2) To what extent does your present product innovation work process ensure a low environmental impact of the selected production technology for a new or improved product? (1= Not at all; 5 = Very much)	4.2	0.9	- 0.5	***Only in some cases, production technology can reduce the environmental impact of products. (Chemical); A main driver for our development work (Chemical);*** *Everything we launch must fit with the energy balance at the production unit (Forest); Sustainability is main Unique-Selling-Point for us (Forest); Our focus is primarily on the product and materials at this time (Packaging)*
(Q.3) To what extent does your product innovation work process consider and ensure a low environmental impact and recyclability of a new or improved product? (1 = Not at all; 5 = Very much)	4.1	1.1	- 0.9	***Balancing recyclability and product functionality is a difficult issue (Chemical); We have a recycling platform including mechanical and chemical recycling (Chemical);*** *To change production processes to avoid hazardous elements is ongoing (Steel); It varies a lot between product groups. It's part of our process, but knowledge gaps are limiting factors (Steel); I believe we should find ways really early in the process (Food & Drink); This is the key selling point of paperboard packaging (Packaging)*
(Q.4) To what extent does your product innovation work process consider and ensure recyclability of a new or improved product packaging solution? (1 = Not at all; 5 = Very much)	3.9	1.3	- 1.0	*We do work with packaging and recyclability, but it's not part of our innovation process (Steel); This is already in place (Food & Drink)*

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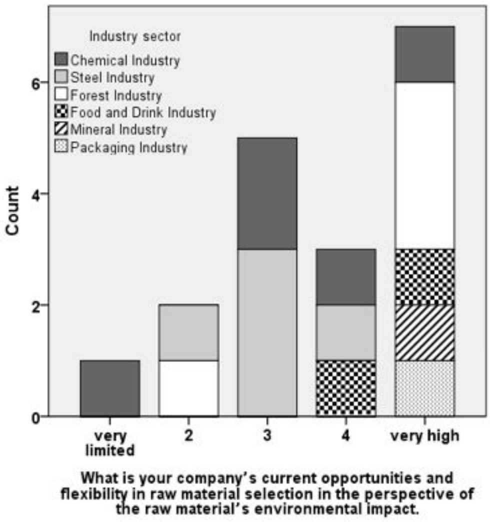

Figure 3 (Q5) Company flexibility of raw material selection in the perspective of raw material environmental impact.

Comments from informants were:

- The flexibility is not very limited due to the purchase of multiple raw materials (Chemical); The main recurring "raw material" considered here is electricity (Chemical)
- Many of the processes allow very few possibilities for flexibilization in raw materials selection (Steel); Current and potential flexibility varies a lot between products and processes (Steel)
- We mainly work with raw materials from renewable sources that are recyclable (Forest); Our raw material is based on sustainable managed forests (Forest)
- Key focus area for the company (Food & Drink); We are working a lot with new materials and natural chemicals (Packaging)

It must first be noted that it was inquired about raw material flexibility with regard to environmental impact. In that respect the high figures for companies in the forest industries and related comments indicate that the high figure on flexibility is more related to different kinds of raw materials, since many companies solely rely on captive raw materials; a similar comment is related to the Mineral Industries. *The bimodal distribution could partly reflect the fact that companies in the Chemical Industries usually are positioned as intermediaries in long, and often complex supply chains from in-situ raw materials to customer end-users.* In a similar vein the low figures for companies in the Steel Industries is most likely related to the same situation.

The informants were further inquired if ensuring sustainability perspectives in the product innovation work process as presented in questions Q1 – Q4 in Table 1 with regard to the total production system could be of value to introduce and deploy in an improved product innovation work process (Q.6). The average YES figure for all individual areas were 83 % with a rather even distribution between the different areas.

In a final question related to the area of sustainability, the informants were inquired (Q.7): At what stage do you consider sustainability issues within your product development work process? The answers were:

- *Throughout the total work process **15***
- *Beginning during the Pre-development phase **1***
- *When the Development phase begin and throughout **1***
- *When the Post-development phase start **0***
- *For the moment not at all **0***

Comments from informants further emphasized the overall high importance of this area: It's starting to be a question with its own headline (Steel); As sustainability is a central theme of our company, this is always on top of our minds (Forest); It's a key focus area for the company and will continue to be so (Food & Drink); Increasingly our projects are driven by these considerations. Materials use by customers is often dictated by sustainability (Packaging).

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A preliminary synthesis

A preliminary synthesis of the research results reveal that the area of sustainability among case-companies is of an overall high importance. A strong majority of all case-companies answered that sustainability should be introduced in an enhanced product innovation work process and as such not only as early as possible but throughout the total work process.

The figures and comments display that sustainability considerations already are in focus in product innovation and in company product innovation work processes, but in "gate to gate", "cradle to gate" or even "cradle to grave" perspectives, raw material, process technology, and product intertwinement in the process industries put severe demands on how the different aspects could be integrated, and how to configure the overall work process. ".

4.2 Digitalization of the product innovation work process

After the inquiry on sustainability perspectives, the informants were initially asked a number of questions (see Table 2, Q.8 – Q.11) related to digitalization of the product innovation work process. The questions, ratings and related comments are presented in Table 2.

The sectoral distribution how far case-companies have come in the digital transformation of their product innovation work process (Q.8) is illustrated in Figure 4.

The sectoral distribution to what extent the case-company present product innovation work process considers and ensure digitalization of customer and competitive product information and data (Q.10) is illustrated in Figure 5.

A preliminary synthesis

The preliminary findings (Q.8 mean value 2.9) indicate that the case-companies not yet have come far on the road to institutionalize digitalization in their product innovation work processes, and comments from informants like "we are on our way", "not yet a focus", and "it is not a current priority" illustrate this state-of-affairs. In reference to Figure 4, and comments from informants in the Steel Industries could indicate some sectoral differences. With regards to the use of supporting tools for work process digitalization, the importance rating of this area is high (Q.9 mean value 4.0), but the general nature of the comments indicates a low awareness and present use of such instruments. Case-company present digitalization of customer and competitive product information and data (Q.10 mean value 3.5) follow the low estimates in Q.8 and comments like "we recognize the importance of this matter, but concrete measures have been delayed", and "would like to implement more agile ways of working". The sectoral distribution in Figure 5 shows a rather scattered picture of present "state of affairs". In reference to the final question related to integration of supply chain members, comments indicate an area that relate to previous Q.11 and digitalization of customer data. In sum, the preliminary findings show that in spite of a general consensus that this area is of interest to further pursue, case-companies have not yet come far on their digitalization journey in this area.

4.3 Expected outcomes from a digitalized work process

Finally, the informants were asked to rate a number of potential expected outcomes of a digitalized product innovation work process.

The proposed expected outcomes and the importance ratings of the informants are presented in Table 3, and sectoral distributions are further illustrated in Figure 6 and Figure 7.

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Table 2 Digitalization perspectives on the product innovation work process for non-assembled products.

Question No.	Answer Mean	Std. dev.	Skew	Comments from informants
*(Q.8) **How far have you come** in the digital transformation of your current product innovation work process? (1 = We have not started yet; 5 = It is already totally transformed*	**2.9**	**0.8**	**0.2**	*We have already taken some initiatives and many more are on the way (Steel); We are only the very early stages yet (Steel); Not yet a focus! Efforts were being directed to existing production lines and new investments (Forest); We have focused on digitalization efforts on the production side of our operations (Forest); Just completed the transformation of the innovation work process (Food & Drink); **We are on our way** (Food & Drink); It is not a current priority (Packaging)*
*(Q.9) How important is digital transformation and **the use of digital supporting tools** for improving your product innovation work process performance? (1 = Not important; 5 = Very much)*	**4.0**	**1.2**	**- 1.2**	*Fast and easy access to information is one of the strongest tools for innovation (Steel); For the moment not, but when in place it'll hopefully be a help (Steel); There is awareness, but very limited resources and focused activities (Steel); It will most probably become important. (Forest); Strong impact on the time to market and cost! (Food & Drink)*
*(Q.10) To what extent does your present product innovation work process consider and ensure the **digitization of customer and competitive product information** and data? (1 = Not at all; 5 = Very much)*	**3.5**	**1.3**	**- 0.6**	***We recognize the importance of this matter, but concrete measures have been delayed (Chemical)**; Not making the process data available to everybody is important since that's core businesses and not to be shared (Steel); We have the supporting tools, but not more than that so far (Forest); Would like to implement more agile ways of working (Food & Drink).*
*(Q.11) To what extent could digitalization of your current product innovation work process better enable the **integration of supply chain members** in your company product development? (1 = Not at all; 5 = Very much)*	**3.6**	**1.1**	**- 0.1**	*Very low integration is needed between the product development and supply chain departments (Steel); Considering internal supply chain members (Steel); A trend! Having digitalization and digital remote access help to improve solutions, processes monitoring, closer follow up of product development (Forest); Could definitely be of value (Food & Drink); It would offer more opportunities, but this is not a current focus for us. We are currently prioritizing sustainability issues (Packaging)*

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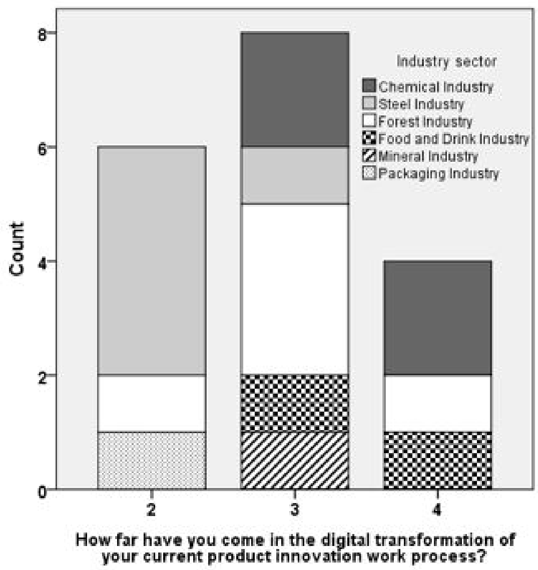

Figure 4 (Q.8) Case-company digitalization maturity with regards to the product innovation work process (unselected categories are not displayed).

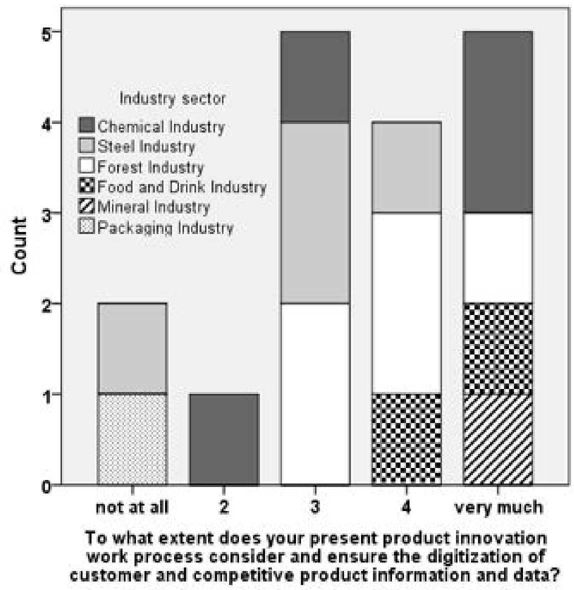

Figure 5 (Q.10) Case-company digitalization of customer and competitive product information and data.

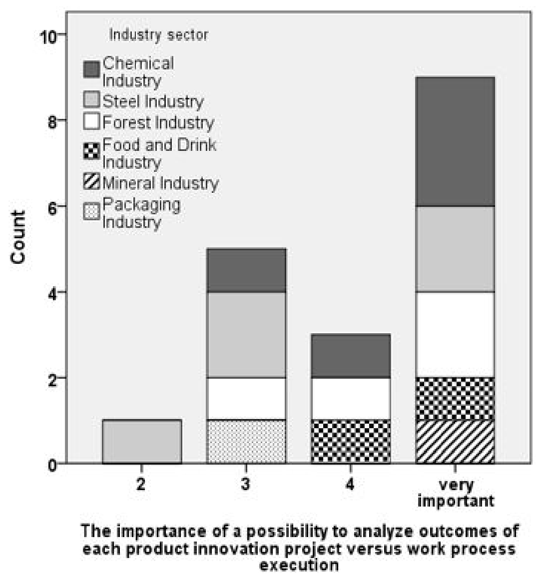

Figure 6 (Q.17) A possibility to analyze outcomes of each product innovation project versus work process execution (unselected categories are not displayed)

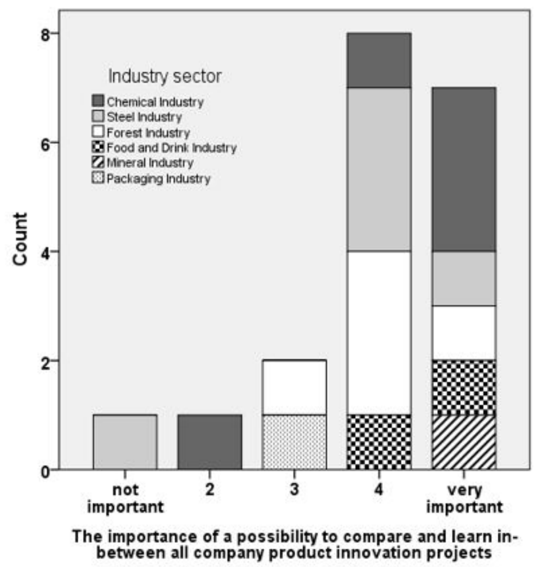

Figure 7 (Q.14) A possibility to compare and learn in-between all company product innovation projects

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Table 3 Company importance ratings of expected outcomes of a digitalized product innovation work process. The different topical areas are re-grouped in ranking order of number of fives.

Question No.	Expected outcome from a digitalized product innovation work process	1 = not important; 5 = very important					Mean (SD); (Skew)
		1	2	3	4	5	
Q.12	Digitalized customer information in general		1	3	5	10	4.3 (0.9); (-1.0)
Q.17	A possibility to analyze outcomes of each product innovation project versus work process execution		1	5	3	9	4.1 (1.0); (-0.6)
Q.13	A digitalized platform of knowledge for “next generation” product development projects		2	1	7	8	4.2 (1.0); (-1.2)
Q.15	An instrument for organizational learning about company best practice product innovation		1	2	8	8	4.2 (0.9); (-1.0)
Q.14	A possibility to compare and learn in-between all company product innovation projects	1	1	2	8	7	4.0 (1.1); (-1.4)
Q.16	An instrument for adapting the product innovation work process to project complexity			5	7	7	4.1 (0.8); (-0.2)

A preliminary synthesis

In view that the case-companies have not come far in the digitalization of their product innovation work processes, the overall high ratings of all six potential expected outcomes indicate that digitalization of the work process is considered to be an activity of strong company importance and usefulness. Since the informants were introduced to a number of general, but most likely rather novel areas of work process advantages, one can assume that the figures represent “top of mind” ratings of the somewhat new perspectives.

Out of six proposed expected outcomes from a digitalized product innovation work process, digitalized customer information rated highest (4.3) on a Likert five-point scale. However, the corresponding question in Table 2, on how well digitalization of customer and competitive product information already is considered in the work process, got a comparatively low rating figure (Q.10 mean value 3.5), which was supported by informant comments like “we recognize the importance, but concrete measures are delayed”, and “would like to implement more agile ways”. The combined information creates a benchmarking perspective with a high importance rating but a present low capability, creating an incentive for companies to pursue such an activity.

In general, proposed potential expected outcomes from digitalization were commonly given high importance ratings including areas like an instrument for best-practice organizational learning, learn in-between product innovation projects, and a possibility to analyze outcomes of each innovation project versus work process execution. The sectorial distributions (see Figure 6 and Figure 7) show a surprisingly large spread within sectors, and no sector idiosyncrasies are distinguished.

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5 Discussion and a preliminary agenda for further research

5.1 Theorizing sustainability and digitalization in the perspective of the product innovation work process for non-assembled products

In Figure 1, the process-industrial production system is introduced, distinguishing the indirect transformation process in the process industries from an assembly-based process in other manufacturing industries. The intimate coupling between raw materials, process technology and delivered product properties in the transformation process, pinpoint the importance of conjointly consider sustainability aspects in all three areas from ideation to product launch. In Figure 2, the generic model of the product innovation work process for non-assembled products depicts a proposed integrative operational mode in between product innovation and process innovation, throughout the total work process from ideation to market launch.

In conclusion and in a process-industrial context, sustainability aspects should not only be included in the development of product concepts during the pre-product development phase, but also included in the development of the related process concepts (including raw material concepts). 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 or reconfiguration of the related production process. In sum, and with regards to the forementioned issues and the empirical findings from Q.7 on sustainability integration in the total work process, a very early and in-depth consideration of sustainability aspects during pre-product development is recommended, as illustrated in Figure 8. In reference to the importance of digitalization of customer and product information (Q.12), digitalization of the work process should incorporate work process phases from contextualization and further extended into the post-launch follow-up phase.

From the perspective of digitalization, and even if some companies in the process industries already have come far on their digitalization journeys (Chirumalla, 2021), the area of digitalization of the product innovation work process is still in need of further clarification and guidelines (Marion and Fixon, 2021), and the findings in this study confirm this "state of affairs". The proposed different expected outcomes from a digitalization of the product innovation work process can from another perspective be regarded as "drivers" for such an activity. The high rating figures of all expected outcomes thus constitutes a clear indication that a digitalized work process should be high on a company improvement agenda because of the strategic importance of a well functioning product innovation work process. Furthermore, the proposed expected outcomes are pointing out that technology related issues are not of a primary importance for the digital transformation of a product innovation work process but rather the organizational change, learning, and management aspects. In consideration of this view, earlier researchers adopted People, Process and Technology dimensions (Yuan et al., 2017; Sjödin et al., 2018) to holistically analyze the impact of digitalization on innovation, which can be a way forward in further research. Moreover, in this direction, the proposed simplified conceptual model could provide a foundational basis to make a further detailed analysis on how to integrate digitalization aspects in all phases of product innovation work process. As emphasized by Aaldering & Song (2021), each sector of the process industries can adopt a unique pathway towards digital transformation, which also is a suggested analytical perspective for future research.

The topical area of integration of sustainability and digitalization was not included in the questionnaire, but the two areas were addressed in an inclusive manner indicating a potential association. As illustrated in the simplified conceptual model, both sustainability and digitalization could contribute and complement the product innovation work process from different angles, which could provide a unique competitive advantage. It is of interest to further explore when and how these two mega trends support and substitute each other in the product innovation work process to understand potential interdependencies and cross-fertilization effects.

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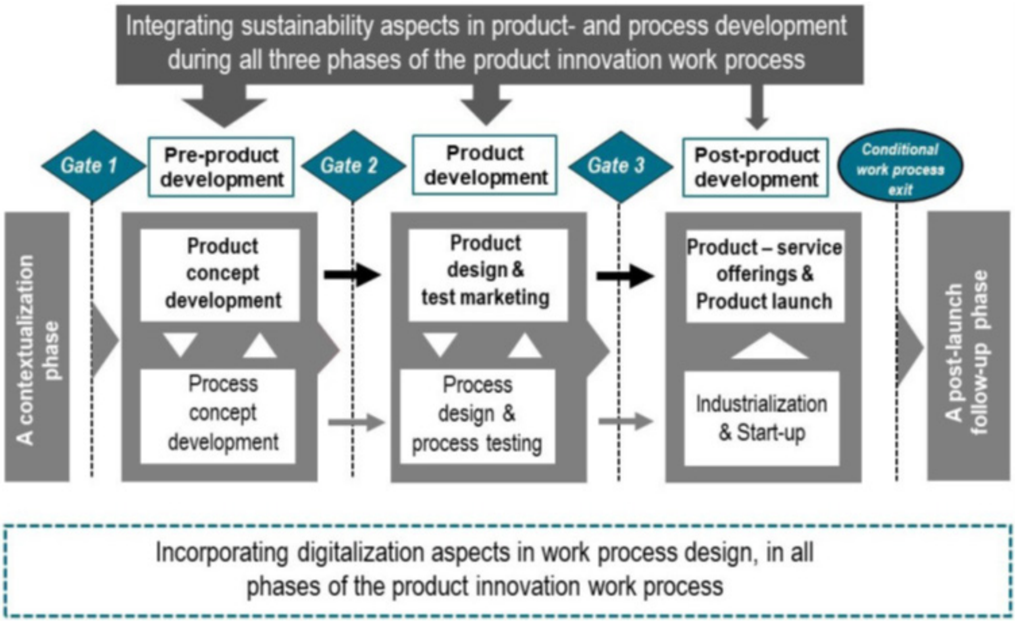

Figure 8 A simplified conceptual model of sustainability integration and digitalization of the product innovation work process for non-assembled products.

6 Theoretical contribution, research limitations, and management implications

In use of the theoretical lens of Dynamic Capabilities (Teece, 2009; Teece and Linden, 2017), integration of sustainability and digitalization perspectives in the product innovation work process for non-assembled products have been explored. According to Teece (2009: p. 48), such capabilities are mainly associated with managerial processes:

… there is much management can do to simultaneously design processes and structures to support innovation while unshackling the enterprise from dysfunctional processes and structures designed for an earlier period.

In this study, a generic "structural model" of the product innovation work process for non-assembled products was selected as a point of departure and platform for the inquiry. In reference to the above quote, incorporating sustainability and digitalization aspects in a company product innovation work process crave such dynamic capabilities, since their proper integration will most likely not only require new incremental operational procedures, but possibly even more radical strategic and organizational solutions for a well-functioning work process. In reference to the scientific utility of a theoretical contribution (Corley and Gioia, 2011), this study provides the following contributions.

First, the study focuses on the integration of both sustainability and digitalization in the product innovation work process, which is still an unexplored area in the process industries, and the study thus contributes to the emerging discussion of "digitainability" (Lichtenthaler, 2021) or "smart circular economy" (Kristoffersen et al., 2020). Even if it was not inquired HOW sustainability and digitalization activities could support each other in this explorative study, it provides the perceptions and the status of nineteen global manufacturing companies from six sectors of the process industries, including a simplified conceptual model of sustainability integration and digitalization of the product innovation work process for non-assembled products. We believe that this study provides a preliminary outlook on the process-industrial context regarding the integration of two mega trends of sustainability and digitalization in the product innovation work process.

Second, six "expected outcomes" (potential "drivers" for such an endeavor) specifically related to a digitalized work-process were initially developed and introduced to the informants. Their high rating of all outcomes, demonstrate their process-industrial relevance irrespective of sector belonging. However, the generic nature of the expected

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outcomes could make them of potential interest also for company use in other manufacturing industries.

Third, the preliminary findings indicate that companies in the process industries already have come far in consideration and ensuring that sustainability perspectives are taken into account in their present product innovation work processes. 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 Food and Drinks Industries, dependent on their position in the supply/value chains. Even if this exploratory study did not further inquire HOW sustainability aspects were institutionalized in the case-companies, general comments from informants indicate, that a more systematic mode of introduction of sustainability aspects could be of interest to develop and pursue.

A final, but minor contribution is the "conceptual model" presented in Figure 8, which in a rather simplistic manner could function as a "trigger" for company further delineation and inclusion of both sustainability and digitalization aspects in the product innovation work process. The conceptual model can contribute and provide a point of departure for further research in the area of product innovation work process design for non-assembled products. The question HOW sustainability and digitalization activities could support each other, was not further inquired in this study, since this is in need of an in-depth case-study approach. Because the importance of digitalized customer and product information scored highest out of all expected outcomes, and that the importance of using supporting tools in the digital transformation of the work process also scored high, highlight the potential use of the QFD methodology. As an instrument for combining general customer requirement on a product and specific sustainability requirements "House of Sustainability" (Rihar and Kusar, 2021), with digitalization of customer and product information (Lager, 2019), this could be one out of several supporting methodologies for an enhanced product innovation work process.

The use of a well-defined questionnaire supports the reliability of the research findings. With respect to the validity of the research results, the combination of both quantitative and qualitative information from experts in the specific topical area demonstrates the study's construct validity. With regard to the external validity and the generalization of the research findings, the theoretical findings from the study population could presumably be generalizable to a well-defined population of interest (the process industries) (Meredith, 1998: p. 450). The reliance on single informants from the companies is a limitation of the case study methodology. Nevertheless, the cross-case analysis based on the amalgamation of quantitative and complementary qualitative case-company information is argued to be robust, and a foundation for an analytical generalization of the research findings (Yin, 1994).

In the perspective of present low digitalization maturity and on-going activities with regard to digitalization of the product innovation work process, and in view of the high rating of potential outcomes and magnitude of company potential benefits from such a digitalization, the preliminary findings should incentivize companies to accelerate the digitalization of this area and take advantage of already available tools and methodologies.

7 Conclusions

Manufacturing industries are considering sustainability and digitalization as a top strategic priority, but it is generally experienced that they sometimes have difficulties to embrace these approaches in an operational mode, and the product innovation work process could therefore provide a central arena for companies in the process industries to anchor and integrate sustainability and digitalization aspects within their organizations. However, not only is research on the product innovation work process for non-assembled products scarce, but how sustainability and digitalization perspectives could be more integrated in company work process design is not yet well-addressed and understood. The purpose of this study is thus to explore current perceptions in companies in the process industries with regards to integrating sustainability and digitalization aspects in their product innovation work processes. Involving informants in nineteen global manufacturing companies in six sectors of the process industries, sustainability, and digitalization integration in the innovation work process for non-assembled products has been explored.

The preliminary findings indicate that the case-companies already have come far in institutionalizing sustainability perspectives in raw material selection, process technology development and product design. However, the study further discloses a need for a more in-depth inquiry and

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understanding on HOW alternative operational best practices and tools in a more systematic approach can make sustainability an integral part of this work process. The empirical results further demonstrate that the case-companies not yet have come far on their journeys with respect to product innovation work process digitalization. The case companies rated all proposed potentially expected outcomes high in such digitalization, and in particular digitalization of customer and product information should incentivize companies in the process industries to put this topical area higher on their digitalization agenda. The paper contributes to the growing interest how to integrate the two mega trends of sustainability and digitalization and concepts like "digitainability" and "smart circular economy" in product innovation work process for non-assembled products. The preliminary findings and proposed simplified conceptual model could provide a good foundational step for further discussion on sustainability integration and digitalization of the product innovation work process for non-assembled products. Further, the paper fulfills the need of further understanding on how digitalization and sustainability could individually and jointly provide competitive advantage in industrial companies, through a design of an enhanced product innovation work process.

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Appendix A Product innovation in the process industries

An intentional definition by Lager (2017a) has been selected in this study:

"The process industries are the portion 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 relatively continuous flow pattern."

A number of industrial sectors have been selected from all manufacturing industries which are included in the statistical classification of economic activities in the European community (NACE, 2006). The following sectors are thus included in the cluster of process industries (NACE codes in parentheses):

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

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Practitioner´s Section

Steven Geschwindner *, Toni Eser ** and Stephan Haubold ***

DATA – a sustainable performance accounting framework for SMEs. From macro planetary boundaries to micro economic Sustainable Earnings Before Interest and Tax - SEBIT.

The present article introduces a framework for Small and Medium Enterprises (SMEs) to measure, monetise, integrate, and manage their sustainability within the limits of the planetary boundaries. This innovative approach aims to enable SMEs to transparently depict, monitor, and manage their transformation towards a fully sustainable business model based on key performance indicators. Using an exploratory process, an accounting framework (hereafter referred to as DATA) was developed involving projecting science based targets onto a company and subsequently associating them with a company-specific monetary value. In the examples of the University of Applied Sciences Fresenius in Idstein (hereafter referred to as HSF) and an additive-producing company from the south of Germany, findings show that it is feasible for SMEs to establish a Sustainable Accounting System with a manageable effort providing a comprehensive economic result in the form of Sustainable Earnings Before Interest and Tax (SEBIT). Currently, the EFRAG (European Financial Reporting Advisory Group) as well as the ASCG (Accounting Standards Committee of Germany) amongst others are discussing and developing reporting standards that will lead to integrated financial sustainability reportings. DATA represents a method for chemistry SMEs, amongst others, to prepare for the upcoming monetary reporting standards and to take sustainability management to the next level. This paper contributes to the field of management control systems, sustainability control systems, sustainable performance accounting, sustainable development performance indicators, and science based targets.

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1 Introduction

As part of the economics lecture for chemists during the winter term 2021 at the private Fresenius University of Applied Sciences, the models and theories of Farley and Daly from their ground-breaking book Ecological Economics (2010) were presented. In this book, they make it very clear, that assuming we want to preserve our world and secure the well-being of our societies, we need to redefine the goals and evaluation of our economic activities. Organizations will have to account for all resources and impacts necessary to provide their product or service, including those imposed on the planet and its ecosystem services. In a sustainable economy, a company can no longer claim to be successful if it shows short-term profits at the expense of future generations (Elkington, 1999; Raworth, 2018; Steffen, et al.; 2015).

As a result of the very lively discussions with the students, and the fact that currently the EFRAG (European Financial Reporting Advisory Group) as well as the ASCG (Accounting Standards Committee of Germany) amongst others are discussing and developing reporting standards aiming for an integrated financial sustainability reporting, we asked ourselves whether there was a way to include sustainability activities and investments into a financial report. Thus, in early spring of 2022 members of the Department of Business Chemistry came together to discuss, how our university could be a more sustainable organization and how we could prepare ourselves for upcoming sustainability accounting standards. At this moment, it became clear that we had to understand the current level of sustainability as well as the needed level of sustainability according to the planetary boundaries. In order to do so, we needed to integrate the accountants and controlling experts from the start. We therefore invited a colleague from the HSF controlling team to join our research group and agreed that we wanted to transform the current, rather idealistic, mainly qualitative discussions within our organization, into a transparent, quantitative, and standard management issue. The goal was to enable our management to make educated and contextualized decisions based on the following three questions:

1. How sustainable are we as an organization, now?
2. How sustainable should we be, according to the planetary boundaries?
3. How do sustainability measures influence our financial result?

In the weeks to follow, we were searching for a framework that would answer these questions. We were expecting a framework that would transform planetary goals into KPIs that could easily be used by our controlling for our financial statement. Soon, we came across frameworks like Welfare Economics, QuartaVista, and VBA (Value Based Accounting Alliance). However, the first worked with qualitative scores, the second had very much specialized on agricultural organisations making it difficult to generalize and the latter had chosen an approach depending on a definition of impact values of e.g. greenhouse gas emissions (GHG) which in our opinion leaves too much room for endless discussions about said values (Felber, 2018; Lay-Kumar, et al., 2021; Lay-Kumar, et al., 2023).

We, therefore, decided to develop an alternative framework and defined the following five basic criteria:

1. The framework has to be in line with the planetary boundaries.
2. The framework has to be generally applicable to all sustainability standards.
3. The framework has to be easy to understand and easy to apply.
4. The framework has to be adaptable to current and potentially future accounting standards.
5. The framework has to cumulate into a financial KPI, “SEBIT”, Sustainable Earnings before Interest and Tax, that could be compared between organizations and years, respectively.

As a result, we developed an accounting framework called “DATA”. This framework incorporates science-based planetary boundaries into sustainable development performance indicators, and monetises them on a cost-based approach into an accountable value that can be booked into the financial statement. We tested the framework using CO_2 as the sustainability indicator on the HSF itself covering the years 2017 to 2021 and on a SME from the south of Germany producing additives, covering the year 2021. The methodology and results presented were developed at the University for Applied Sciences Fresenius,

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hereafter referred to as HSF, in Idstein, Germany, between September 2022 and February 2023.

2 Method

The development of the DATA framework was based on the prior work of Lay-Kumar et al. (2021) and their Four-Phase Framework as presented in Figure 1.

Define

In the Define phase, all sustainability-related activities of the company are defined, along with the basics for the subsequent Assess phase. For this purpose, a framework is chosen that defines the domains of sustainability, such as the ESG framework (Haberstock, 2019). The definition of subdomains is derived from the Tier Two-Indicators of the User Manual for the Sustainable Development Performance Indicators, Authentic Sustainability Assessment (ASA) (Yi et al., 2022). Finally, the data for each indicator in the company is collected and analysed for a one-year period, as depicted in Figure 2.

Governments have introduced milestone targets towards absolute sustainability that we will call relatively sustainable. A company is considered relatively sustainable when it stays within the allowed milestone target for the current reporting year, for example, in terms of meeting GHG emission targets set by the Paris Agreement or the German Climate Protection Act (KSG).

First, we have to define a so-called baseline target (BT) according to a or b:

a. **Science-BT**: The planetary or regional baseline targets, also known as science based targets (SBT), are provided by laws, standards, and regulations such as the Federal Climate Protection Act, GRI, SDG, Science Based Target initiative, or the Paris Climate Agreement, which seek to transfer scientific findings on sustainability into necessary actions required.

b. **Best in Class-BT**: In those cases where official entities do not provide planetary or regional baseline targets, an alternative definition of the Baseline Target can be established based on the "Best-In-Class"(Mittelstaedt, 1992) approach, using nationally or globally collected statistics, referred to as the Best in Class Based Target (BCBT).

Second, we have to break down BT to the specific target of our organization. Therefore, we need to define what kind of organization we want to analyse. We generally discriminate between service companies and production companies.

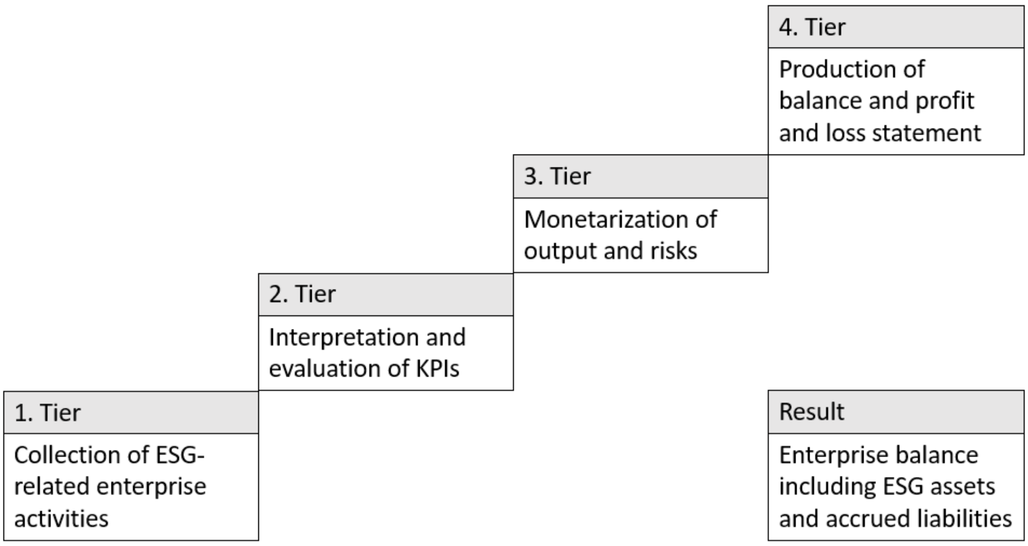

Figure 1 Author's representation of the procedural model based on Lay-Kumar et al. (2021) for creating a comprehensive monetary balance sheet. Deviating from the original model, we have adjusted the stages and labeled them as Define, Assess, Transform, and Account - DATA, and made relevant content adaptations.

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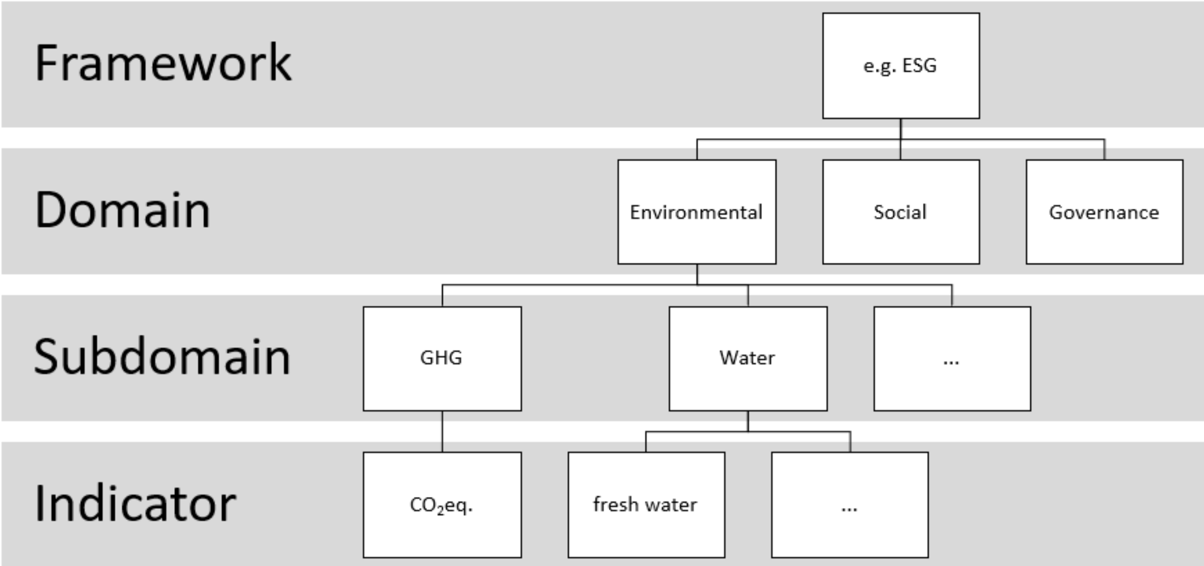

Figure 2 Required Definitions in Phase 1. "Domain" refers to pre-defined domains such as "Environmental", "Social", and "Governance" in the context of ESG (Haberstock, 2019). The "Subdomain" includes indicators such as "Water", "Greenhouse Gases", "Energy", and "Waste" etc. The "Indicators" would then further specify, like "Fresh Water", "Grey water", "Wastewater", etc.

Define an Organizational Target depending on the type of company.

c. Service companies: The calculation of the SBTO (Science Based Target of Organization) for a service company is done using the "headcount" method, which calculates the SBTO of the company from the BT considering the population of the country where the operation is located, the full-time equivalents of the company, and their average tenure in the company (see Formula 1) (Wang, Hopeward, Yi, McElroy, & Sutton, 2022, S. 1191).

$$POP_{e,f} = \frac{T_f[h]}{365 * 24\,[h]} * n_{FTE}$$

$POP_{e,f}$ = Population equivalent of facility
T_f = (Average) time spend by a full time equivalent at facility
n_{FTE} = Number of full time equivalents at facility

Formula 1 Calculation of the headcount or population-equivalent of an organization assumes, that the budget of an indicator i available to a person is allocated to the organization in proportion to the time said person spends in the organization. In Germany, based on our own calculation, this corresponds to approximately 1,720 hours per FTE (Full-Time Equivalent) per year. This represents a proportion of 19.63% of the total hours in a year (8,760 hours).

The SBT of an indicator i in the base year t per capita ($SBT_{i,t,p.c.}$) is calculated by dividing the $SBT_{i,t}$ of the corresponding country (c) by the population of that country, as shown in Formula 2.

$$SBT_{i,t,p.c.} = \frac{SBT_{i,t,c}}{n_c}$$

$SBT_{i,t,p.c.}$ = Indicator related Science Based Target in reference year per capita
$SBT_{i,t,c}$ = Indicator related Science Based Target for resepective country
n_c = Population of respective country
c = Country

Formula 2 The calculation of the Specific Science Based Target per capita ($SBT_{i,t,p.c.}$) for the HSF is based on the Science Based Target (SBT) for Buildings set by the Federal Government, denoted as $SBT_{i,t,c}$ (Bundesregierung, 2019).

The SBTO for the indicator i for the respective year t and facility f can be calculated by multiplying the specific population equivalent with the per capita SBT of the corresponding indicator for the reporting year, as shown in Formula 3.

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$$SBTO_{i,t,f} = POP_{e,f,t} * SBT_{i,t,p.c.}$$

Formula 3 Calculation of the Science Based Target for a specific facility according to its headcount.

d. The calculation of the Organizational Target (SBTO) for a production company can be based on a variation of the headcount method, taking into consideration the SBT or BCBT of the sector and the number of employees in the corresponding sector, as shown in Formula 4.

$$SBT_{i,t,p.c.} = \frac{SBT_{i,t,s}}{n_s}$$

$SBT_{i,t,p.c}$ = Specific Science Based Target in reference year per capita of facility

$SBT_{i,t,s}$ = Specific Science Based Target for resepective sector

n_c = Number of employees of respective sector in full time equivalents

s = Sector

Formula 4 Calculation of the facility-specific Science Based Target per capita of a specific sector.

The SBTO of indicator i for the corresponding year t is calculated by multiplying the full-time equivalents of the company $n_{f,t}$ for facility f with the per capita SBT of the sector ($SBT_{i,t,p.c.}$), as shown in Formula 5.

$$SBTO_{i,t,f} = n_{f,t} * SBT_{i,t,p.c.}$$

f = Facility

Formula 5 Calculation of the Science Based Target for a specific facility $SBTO_{i,t,f}$ according to its number of employees $n_{f,t}$ in the year t.

Since the emissions and employment data for the sectors in Germany are well documented, the corresponding SBTO or BCBTO can be easily researched and calculated with minimal effort.

For the investigated case of HSF, the company was defined as a service provider, and the SBTO of HSF was calculated based on the SBT for the “Buildings“ sector. The underlying assumption is, that while employees are spending time at their workplace, they are not emitting CO_2 at their private homes at the same time. Emissions from commuting employees towards and from their working places were excluded. Scope 1 and Scope 2 Emissions were cumulated in one position by choice and can be accounted for separately. The definition of two boundaries between the three sustainability sectors, referred to as Sustainability Sector thresholds (ST_1 and ST_2) between “not sustainable“ and “relatively sustainable“ (ST_1), and between “relatively sustainable“ and “sustainable“ (ST_2), was based on the ASA Handbook (Yi, et al., 2022).

Assess

The linkage between Indicator i, the respective BT, and the SBTO or BCBTO is established using Sustainable Development Performance Indicators, also referred to as SDPIs. The SDPI for Indicator i at facility f in year t is calculated as the actual GHG emissions at the site in the given year, A [t], divided by the SBTO for GHG at the site during period t.

$$SDPI_{i,t,f} = \frac{A_{i,t,f}\ (i)}{SBTO_{i,t,c,f}\ (i)}$$

$SDPI_{i,t,f}$ = Sustainable Development Performance Indicator

t = Corresponding year

i = Specific indicator (e.g. CO_2)

c = Country

f = Facility (e.g.$HSF_{Idstein,Germany}$)

A = Value of indicator i (e.g.number of tonnes of CO_2)

Formula 6 Calculation of the Sustainability Development Performance Indicator for a specific Indicator (e.g. CO_2) and year. The SDPI represents the ratio between the actual e.g. emission of the organization A and the Science Based Target for the facility of the organization, $SBTO_{i,t,c,f}$.

The Sectoral Threshold ST_1 is defined as an SDPI value of 1. For example, if the GHG SDPI value is 1, it means that the company has emitted as much GHG as allowed according to the SBTO or BCBTO defined for that year. On the other hand, ST_2 is defined with an SDPI value of 0. This indicates that the company either did not emit any GHG or achieved net-zero emissions through appropriate compensation measures in that year, as shown in Formula 6 and Table 1.

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Table 1 Traffic light System in line with ASA (Yi, et al., 2022).

Metric of $SDPI_{i,t}$	**Unsustainable**	**Rel. Sustainable**	**Sustainable**
$SDPI_t$	$SDPI_t > 1$	$SDPI_t \leq 1$	$SDPI_t \leq 0$
(Ratio of actual Company to target e.g. GHG emission in year t)	Meaning: organisation's emissions are not yet sustainable	Meaning: organisation's emissions are within current interim SBT	Meaning: organisation's emissions are within current absolute SBT

This definition of sustainability allows for a rough classification of the company into respective sustainability sectors. However, an accurate financial assessment of the company's success is not yet possible using only non-monetary indicators. To achieve this, the SDPIs need to be monetised in the next step.

Transform

To monetise indicator i in the reference year t, we have introduced a Monetisation Factor (MF) based on the Quarta-Vista approach (Lay-Kumar et al., 2021). The MF is multiplied by the specific monetary cost (SMC) associated with a particular indicator i, resulting in an accountable value (AV) that may need to be booked as either value creation or risk provision, depending on the algebraic sign. The MF is equal to 0 when the SDPI value is 1 or $ST_1(1) = 0$, indicating that the interim SBT has been met. There is no value creation or risk provision at this point. At the transition from relative to absolute sustainability, the Sustainability Gradient (SG) is defined. Up to now, there is no rule on how big or small the sustainability gradient should be. Therefor the definition of the SG is totally up to the organization. However, it is to be expected, that governments will instruct on the SG an organization will be allowed to apply. The SG can take on a value ≥ 0. Therefore, $ST_2(0) = SG \geq 0$. The SG represents the slope of the linear Monetisation Function, from which each MF(SDPI) can be calculated, as shown in Formula 7.

$$MF\,(SDPI_{i,t,f}) = -SG_{i,t,f} * SDPI_{i,t,f} + SG_{i,t,f}$$

MF = Monetarisation factor
$SG_{i,t,f}$ = Sustainability gradient
$SDPI_{i,t,f}$ = Sustainable Development Performance Indicator

Formula 7 The calculation of the Monetisation Factor (MF) for Indicator i in the reference year t depends on the SDPI value. A linear relationship is initially assumed as the simplest assumption, although other functions are also possible and may be interesting for the desired steering effect. An SDPI value > 1 results in a risk provision, while an SDPI value < 1 leads to a corresponding value creation. Since negative emissions can be generated in the case of, for example, CO_2, the SDPI can also become negative, accordingly.

The MF in % represents the proportion of the SMC of an indicator that the company can credit as activated own performance and value creation, or book as expense and risk provision. The corresponding absolute Accountable Value of indicator i in the reference year t is then calculated as shown in Formula 8.

$$AV_{i,t}\,[€] = SMC_{i,t}\,[€] * MF_{i,t}$$

AV = Accountable value
$SMC_{i,t}$ [€] = Specific monetary cost
MF = Monetarisation factor

Formula 8 The calculation of the accountable value (AV) involves multiplying the Specific Monetary Cost (SMC) associated with Scope 1 and Scope 2, such as energy procurement, with the Monetisation Factor (MF).

Account

The accounting of the accountable values is conducted in accordance with the legal regulations of the respective country. As the present study was conducted in Germany, double-entry bookkeeping was based on the Commercial Code (HGB) for companies subject to mandatory bookkeeping, as well as the standard chart of accounts (SKR04) provided by DATEV, which complies with the

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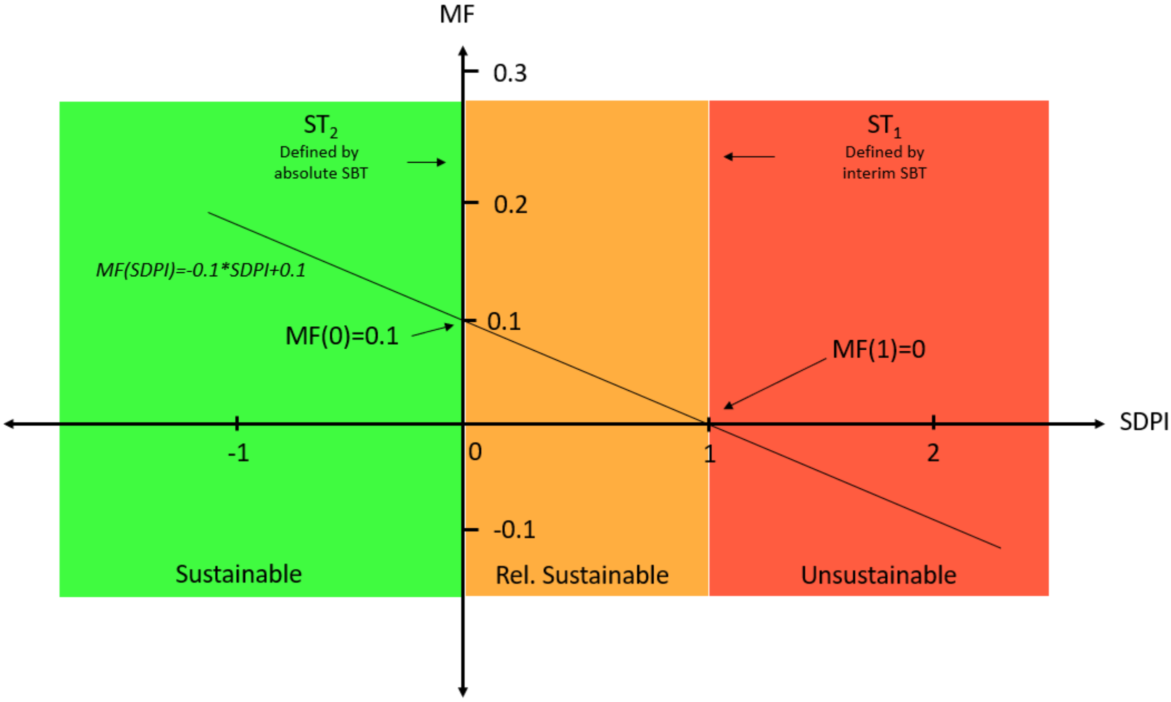

Figure 3 Illustration of the relationship between MF as a function of SDPI for GHG emissions of HSF in the year 2021, with $SDPI_{(CO_2,2021)}$= 8.39 and MF = -0.74, falling outside the displayed range. The Sustainability Gradient was defined as 0.1 or 10%. The Sustainability Thresholds, ST_1 and ST_2, are also depicted, representing the transitions between the sustainability sectors of "sustainable" to "relatively sustainable" with MF(0), and from "relatively sustainable" to "unsustainable" with MF(1).

requirements of the Bilanzrichtlinie-Umsetzungsgesetz (Directive Implementation Act). Environmental benefits, such as reducing specific GHG emissions below the SBTO, are recorded as revenue under "Other capitalized own work" in the income statement (GuV) and recognized as a sustainable intangible asset in the "Self-created intangible assets" section of the company's balance sheet. The asset is amortised in the income statement through "Amortisation of intangible assets and property, plant and equipment" over the appropriate period, which must be determined specifically for SDPI. If the SBTO is exceeded, it is recorded as an expense in an account within "Other operating expenses" in the income statement and recognized as "Other provisions" in the balance sheet. These risk provisions remain until the generated risk, i.e., climate change, is stopped or until corresponding positive measures by the company allow for dissolution in a corresponding amount (Lay-Kumar, et al., 2021; DATEV, 2023). However, since SEBIT is not currently anchored in national accounting regulations, it can only be used for trend analysis and internal control purposes of the SDPI.

The SEBIT would be finally calculated as shown in Formula 9:

$$SEBIT_t = EBIT_t + \sum AV_{i,t}$$

Formula 9 The general calculation of SEBIT involves adding the EBIT to the sum of all AV for the reporting period.

3 Results

Case 1: Production company

An international chemistry SME specialized on the production of additives, has a production site in the south of Germany employing 95 people in 2021. The Scope 1 and Scope 2 Emission of CO_2 was 3,071 t (A). Using formula 2 we calculated the SBT for chemical/pharmaceutical (c/p) industry (isolated emission data for chemical industry were not available) by multiplying the sectoral industry target from the KSG 2021 (182 Mio. t CO_2) by the share of the emissions of the c/p-industry in 2021 (26.3%): SBT = 47.8 Mio. t CO_2 (2021). To calculate the SBTO (formula 4 and 5) of the south German facility we divided the SBT by the number of employees in the c/p-industry in 2021 (0.4945 Mio.) and multiplied the result by the number of employees at the south German facility (95): $SBTO_{relative}$ = 9,182 t CO_2.

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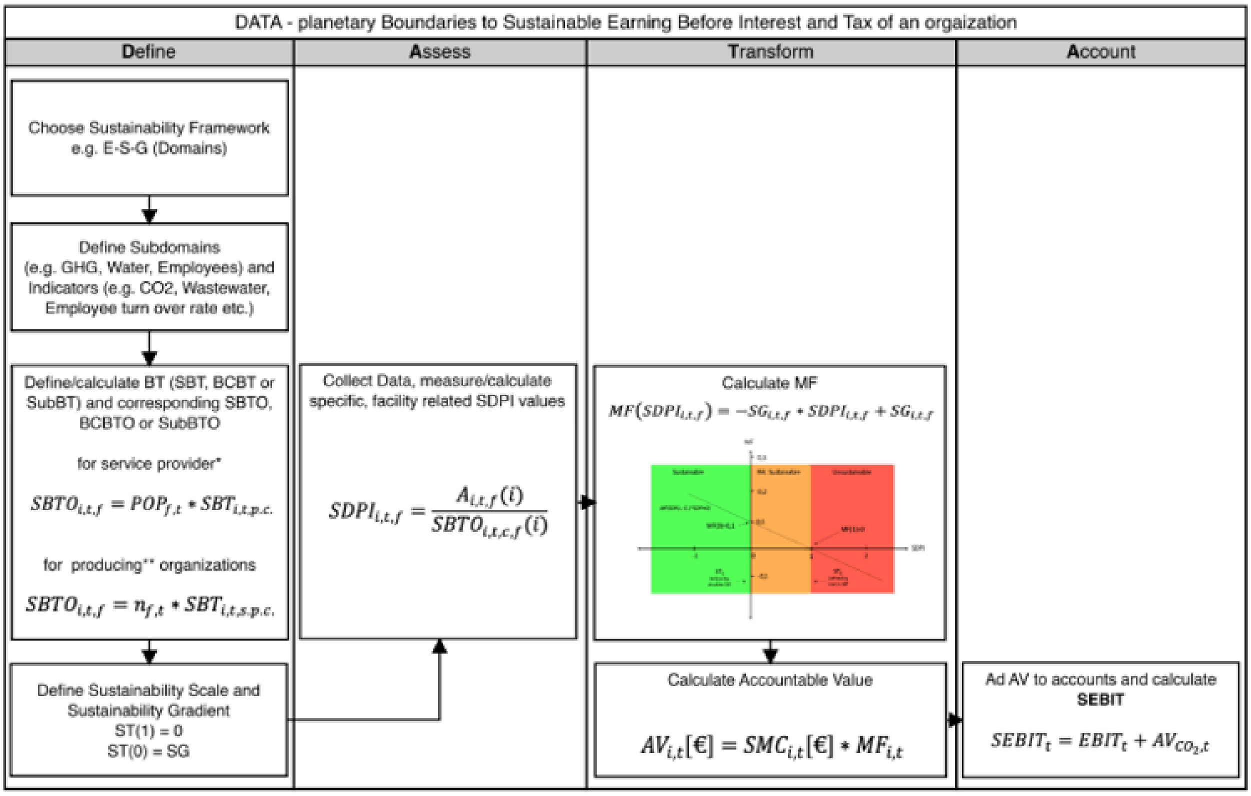

Figure 4 DATA process diagram for the creation of SEBIT. BT = Baseline Target, SBT = Science Based Target, BCBT = Best in Class Based Target, POP = Population Factor, n = Number of Full Time Equivalents, ST = Sustainability Threshold, SG = Sustainability Gradient, SDPI = Sustainability Development Performance Indicator, A = Measured Amount of Indicator, SBTO = Science Based Target of Organisation, f = Facility.

Using formula 6 we then calculated the SDPI by dividing A (3,071 t) by the SBTO: $SDPI_{rel.}$ = 0.33. A SDPI < 1 proves relative sustainability (table 1).

We then tested for absolute sustainability by using a global SBT of 3 t CO_2 emission per capita (Friedlingstein, et al., 2022). With a German population of 83.2 Mio. the SBT of Germany was 249.6 Mio. t CO_2 in 2021. To find the absolute sustainable SBT of the c/p-industry we calculated the share of the c/p-industry emissions on total emissions in Germany (6%) and multiplied them with the SBT of Germany: SBTc/p-industry = 15 Mio. t CO_2 in 2021. The SBTO would therefore be 15 Mio. t CO_2 divided by 0.4945 Mio. people employed in the c/p-industry multiplied by the employees (95) of the south German facility: $SBTO_{absolute}$ = 2,882 t CO_2. The $SDPI_{abs.}$ was then calculated by dividing A (3,071 t CO_2) by $SBTO_{abs.}$: $SDPI_{abs.}$ = 1.06 showing the South German facility to be close to absolute sustainability regarding its CO_2 emissions.

Since relative sustainability is the current goal of the German government, we decided to continue with the $SDPI_{rel.}$ to monetise the findings. To receive the accountable value for the CO_2 emissions we had to define a Sustainability Gradient (SG) as in formula 7. However, since there aren't any regulations in place, we decided to incentivise zero emission with 10% and the achievement of the relative emission goal of 9,182 t CO_2 with 0% of total CO_2-related cost, respectively. This definition leads to a MF-function as in formula 7:

$$MF(SDPI) = -0.1 * SDPI + 0.1$$

And in the case of the SDPI = 0.33 to a monetarization factor of 0.066. With a value of total CO_2 related cost of the south German facility of 1,197,882 € the accountable value would be 79,060 €. As a result, the SEBIT would be SEBIT = EBIT + 79,060 €. Since this value can be interpreted as an investment into a non-tangible asset, we suggest depreciating the value on a straight-line basis over 5 years.

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Case 2: Service provider

For the HSF data from the years 2017 – 2021 were available leading to the following results shown in Table 2:

The significant increase of the SDPI for the years 20/21 compared to 2019, being the last year before the pandemic, is attributed to the low utilization of HSF buildings, coupled with an almost unchanged energy consumption. This analysis does not consider the fact that the energy consumption of both employees and students in their own buildings and residences has increased during the same period, due to longer daily stays and intensive internet usage during work or lecture hours. The SEBIT for HSF would exemplarily be SEBIT = EBIT – 172,198.14 € in 2021.

4 Discussion and conclusions

Using the examples of the GHG emissions of HSF at the Idstein campus from 2017 to 2021 and the CO_2 emissions of a SME from the chemical industry, we have demonstrated that DATA produces a plausible and transparent SEBIT. This allows management to contextualise its economic results within planetary boundaries and capture the actual success, considering all "costs" and impacts. Since there is currently no legal obligation to monetise a company's sustainability-related activities, the creation of SEBIT serves as an internal tool for managing its sustainability goals, only. The results of the chemical industry SME show, that paying an enhanced price for renewable energy sources can be recompensated by incentivising CO_2 emissions that are below the current science based targets. They also show that there can be a rather large gap between relative and absolute sustainability factors. For future works, further data needs to be included and more Sustainability indicators to be defined.

Table 2 The results of the company evaluation for the HSF for the years 2017 - 2021 regarding CO_2 emissions show a clear deviation from the SBT as indicated by the SDPI. The SEBIT is adjusted accordingly by adding the AV value. POP = Population Equivalent Factor, which includes employees and students. SBT = Science Based Target, SDPI = Sustainable Development Performance Indicator, MF = Monetisation Factor, SMC = Specific Monetary Cost, AV = Accountable Value.
*SBT-HSF was calculated using the headcount method, with the emissions target for the buildings sector in the Federal Republic of Germany serving as the calculation basis (Wang, Hopeward, Yi, McElroy, & Sutton, 2022, S. 1191).

	2017	2018	2019	2020	2021
SBT CO_2 Emission of Buildings in Germany [Mio.t]	127	124	121	118	113
n Germany [Mio.]	82.79	83.02	83.17	83.16	83.24
POP equivalent HSF	97	97	97	26	26
SBT CO_2 Emission of Buildings in Germany p.capita [t]	1.53	1.49	1.45	1.42	1.36
CO_2 Scope 1+2 [t CO_2]	348	365	293	280	299
SBT-HSF* [t CO_2]	148	144	141	37	36
SDPI	**2.35**	**2.53**	**2.09**	**7.52**	**8.39**
MF	-0.13	-0.15	-0.11	-0.65	-0.74
SMC [€]	229,370.57	225,736.53	224,908.05	211,831.90	233,052.16
AV [€]	**-30,940.06**	**-34,543.82**	**-24,408.58**	**-138,022.34**	**-172,198.14**
Cos/t CO_2	-88.91	-94.64	-83.31	-492.94	-575.91

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For HSF Table 2 shows that there were significant increases in CO_2 emissions in 2020 and 2021. The $SDPI_{2020}$, CO_2 worsened from 2.09 in 2019, the last year before the pandemic, to 7.52 in 2020 and 8.39 in 2021. This indicates that despite the reduced use of the buildings by the HSF employees and students during the pandemic, HSF was not able to effectively reduce its CO_2 emissions. For future works, more refined data needs to be monitored and more sustainability factors to be defined.

The Sustainability Gradient influences the monetisation factor, by determining the degree to which the SDPI will be accounted for as value-enhancing or -reducing. The subjective definition of the Sustainability Gradient currently makes it impossible to compare different companies with each other using the SEBIT. In contrast, SDPI indicates whether a company is operating within the sustainable, relatively sustainable, or non-sustainable range, and therefore is already suitable for comparing sustainability performance among companies within a sector. By using SDPI, we avoid the monetary valuation of individual ecosystem services or socio-economic activities, which continue to pose challenges. Once legally established, monetisation can steer entire sectors of the economy in a certain direction without the need to introduce new taxes. Market mechanisms are only relevant within planetary boundaries. Beyond said boundaries, there can be no market without destroying the basis of life on the planet.

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Practitioner´s Section

Detlef Schreiber*, Paola Bustillos**

The chemical industry as a key player for climate protection: Learning experiences from cooperation with developing countries and emerging economies

This paper is directed to stakeholders from the private sector, public institutions, civil society, and academia that have to do with the production and use of chemicals or climate change, be it in a direct form or indirectly in advisory institutions, research, or government and regulatory bodies. It is meant as a contribution to the discussion on the nexus between chemistry and climate change, presenting the chemical industry as a key sector for building pathways towards climate neutrality. The findings presented in this paper are based on the learning experience of an international cooperation project with developing countries and emerging economies, named Climate Action Programme for the Chemical Industry (CAPCI) (ISC3, 2023). It seeks to inform and inspire the reader on potentials of the chemical industry for implementing GHG mitigation strategies and contributing to achieve climate targets. Furthermore, it shows possibilities for the transfer of knowledge and experiences between industrialized countries and developing or emerging countries as well as south-south collaboration. As chemicals production and use are characterized by international value chains with a growing share of developing countries and emerging economies, international cooperation and knowledge sharing are crucial drivers for enhancing their successful transformation.

1 Introduction

Chemicals are omnipresent in our modern economies as well as in our daily lives. Over 350,000 chemicals or substance mixtures are currently registered for commercial use – and this number continues to rise. They are essential for manufacturing nearly all industrial products, from automobiles and electronics to household goods and textiles, as well as materials needed for developing renewable energy and sustainable mobility solutions. At the same time, however, the chemical and petrochemical industry is highly energy and carbon-intensive, accounting for around 10 percent of the world's final energy demand (World Business Council for Sustainable Development, 2018) and 7.4 percent of the global greenhouse gas (GHG) emissions when considering emissions directly controlled by the companies (scope 1) as well as those associated with purchased electricity, heat or steam (scope 2) (Intergovernmental Panel

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on Climate Change, 2022). While chemical production is one of the top-three industrial sectors in terms of GHG emissions, along with cement and steel, it is also a major source of innovative solutions and materials for decarbonizing other sectors such as energy and transport. Tapping the entire potential of the chemical industry to advance mitigation and low-emission technologies is crucial for effectively tackling climate change (World Economy Forum, 2021).

On the other hand, the chemical industry is in a unique position to develop technologies and products that can mitigate climate change, enhance circularity and advance sustainability. Innovations in chemistry have the potential to transform entire value chains and reduce GHG footprints, for instance via energy-saving and emissions-reducing technology and materials. Some of the relevant economic sectors and actors include building and construction, energy, transportation, consumer goods, and individual consumers (International Council of Chemical Associations, 2019). The transformation to a low-carbon chemical industry requires action through several pathways, including technological and political solutions as well as smart organizational structures (European Commission, 2023). It also requires agreement and commitment on the part of governments, as well as industry and other stakeholders, guided by the conviction that a climate-neutral chemical industry can be achieved (VCI, 2019; VCI, 2022). A position paper of the International Council of Chemical Associations representing the global chemical industry (International Council of Chemical Associations, 2021) provides some promising starting points. It sets out a vision that the chemical industry can indeed become climate-neutral if certain conditions are met.

The German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) has established the Climate Action Programme for the Chemical Industry (CAPCI) in the framework of the International Climate Initiative (IKI) to help address these challenges in the cooperation with developing countries and emerging economies. CAPCI is executed by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and operates in collaboration with global partners such as ICCA and the Paris Committee on Capacity Building (PCCB) of the UN Climate Secretariat. With a focus on raising awareness and building capacity, CAPCI helps identify and unlock the potential held by the chemical industry in mitigating climate change and driving innovation.

While most multinational chemical companies do have their organizational units dealing with environmental and climate issues or sustainability questions in general, smaller companies, especially in developing countries and emerging economies very often lack knowledge about climate aspects associated with chemicals production and use. Nevertheless, many of these countries have recently raised the ambitions of their climate objectives as defined in their Nationally Determined Contributions (NDCs) (United Nations Environment Programme, 2021), and some of them, including CAPCI partner countries such as Thailand and Vietnam, have even committed to achieving climate neutrality by the middle of the century. As a result, they are revising their national climate policies and developing specific mitigation strategies that need to address all relevant emission sectors – including the chemical industry.

2 Conceptual approach and main activities

The conceptual approach of CAPCI responds to the great need for knowledge and capacities. The activities pursued by CAPCI follow a two-pronged approach and include both, country-specific and more general topic-specific knowledge-sharing measures at the global level. First, the programme provides stakeholders and decision-makers with information, applied knowledge, and best practices regarding GHG mitigation opportunities in the production and use of chemicals, through international webinars and side events, the establishment of an online knowledge base with best practices for mitigation in the chemical sector, publications, and training concepts. Second, it supports activities in selected developing and emerging countries aimed at better understanding the connection between the chemical industry and climate change as well as implementing measures for reducing related GHG emissions.

As the structure of the chemical industry differs from country to country and companies also show different levels of progress in terms of low-carbon practices, CAPCI does not promote a defined technological blueprint but considers the entire menu of mitigation technologies. They range from low-cost options such as measures for increasing energy and resource efficiency, while reducing losses, to more complex solutions such as shifts to renewable energy sources or the application of Power-to-X solutions or carbon capture

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and use (CCU) etc. One best practice from Germany that generated much interest among the partner countries was the use of chemical parks as so-called Verbundstandorte (Weber, 2022), in which inter-linkages between different plants and companies at these parks lead to impressive synergies and optimisation in energy and resource flows. The parks contribute to a local circular economy and thereby significantly reduce GHG intensity.

2.1 Cooperation with partner countries

CAPCI supports selected partner countries, particularly with knowledge, information, training and action-oriented capacity building regarding climate protection in the production and use of chemicals. To identify the initial pilot countries, CAPCI reviewed the chemical industry landscapes, chemical industry GHG emissions, energy mixes, NDCs and collaborative UNFCCC initiatives across numerous GIZ partner countries (International Sustainable Chemistry Collaborative Centre ISC3 et al.). Based on these criteria as well as the formal expression of partner interest and a favourable cooperation landscape, the countries ultimately identified were Argentina, Ghana, Peru, Thailand and Vietnam. CAPCI's main partner organisations in these countries are the ministries of environment and industry as well as the associations of the chemical industry.

2.2 Stock-taking, information-sharing, and stakeholder dialogue

In each country, CAPCI supported activities of stock-taking, information, awareness creation and discussion on the nexus chemistry – climate change. The first step in these efforts involved baseline studies that shed light on the landscape of the chemical industry of each country for mapping the structures and challenges of the chemical industry, in order to provide guidance for tailored measures aimed at GHG reduction to be developed.

CAPCI then organised national stakeholder dialogues in collaboration with national partners from government and private sector as well as academia and civil society to generate further insights into the national chemical industry while also identifying needs and gaps for capacity building for each country. At the national stakeholder dialogues, the participants recognised that the chemical sector is an important factor in relation to climate change as well as broader national sustainable development agendas.

The stakeholder dialogues together with the baseline studies helped to identify challenges, priorities, needs and gaps for capacity building among stakeholders from the private, governmental, and academic sectors related to the chemical industry and climate protection. Their results also serve as a guidance for follow-up activities with a focus on building capacities for climate change mitigation in the chemical industry which represents a crucial pre-condition for identifying and leveraging successful pathways toward greenhouse gas mitigation in the partner countries.

2.3 Developing capacity and training trainers

CAPCI's capacity building programme started with an online training-of-trainers course (ToT), designed and elaborated together with the consulting company HEAT GmbH. It is accompanied by extensive training materials and addresses the different political, economic, methodological, and technical aspects of the nexus "chemistry – climate change" in a broad manner while particularly catering for the needs and gaps, identified in the baseline studies and national stakeholder dialogues in each of the partner countries. In the ToT, that extended over a period of seven weeks, a diverse group of 30 participants from the five pilot countries acquired knowledge about the nexus between the chemical industry and climate change. An online platform called "atingi" (atingi CAPCI) was used for the course which included a number of exercises, quizzes, and a final exam.

The target audience for the training course included representatives from government institutions and the private sector, particularly professionals from the chemical industry with prior knowledge regarding climate policies as a prerequisite. One of the expected outcomes of the course was for participants to be enabled to serve as trainers of subsequent capacity-building activities in partner countries with support from CAPCI. Through this approach, the course turned participants into knowledge multipliers and agents of change for the topic of climate change mitigation and sustainable chemical industry.

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2.4 Study visit

Aiming to further deepen knowledge, CAPCI organised in 2022 a study tour in Germany for a group of experts from the partner countries and particularly for participants from the training-of-trainers course. This study programme included a visit to ACHEMA the big trade fair for the chemical sector. The participants also visited two chemical parks to gain insights into the advantages of chemical parks as "Verbund sites" that leverage energy and resource efficiency along with circular business models. These site visits gave experts from the pilot countries the opportunity to learn on-site about options for creating synergies between chemical processes and plants while enhancing circular economy and GHG mitigation.

2.5 Developing roadmaps towards climate-friendly chemical production

Based on the national baseline studies, the stakeholder dialogues, and the capacity building measures CAPCI aims to support practical measures for efficient greenhouse gas mitigation in the chemical industry. One more general element is the development of roadmap studies, specific to the chemical sector, that show different scenarios and options for mitigating greenhouse gas emissions and ultimately proceeding on the pathway towards climate neutrality, in accordance with the NDCs. It is important to note that each country and industrial sector has to identify and define its own pathway or long-term strategy that responds to the specific structures, conditions, and challenges, though existing roadmaps and strategies can provide valuable inspiration and orientation (World Business Council for Sustainable Development, 2018; ICCA ,2019; VCI, 2019; World Economic Forum, 2021).

2.6 Side events and international webinars

A set of international activities of CAPCI are carried out in parallel with cooperation measures with partner countries. In addition to a web-based knowledge base of best practices, factsheets, and other information materials, CAPCI organized together with the ICCA and the PCCB of the UN Climate Secretariat international webinar series for information and discussion on the important relations between chemicals production and use and climate change. CAPCI engaged representatives from chemical companies and associations as well as from science and research, focusing on sharing knowledge, networking and raising awareness. The topics addressed range from policies over innovation to best practices from the industry.

CAPCI also organised side events at international conferences, such as the conferences of parties of the UN framework convention on climate change (CoP 27) in November 2022 in Sharm El Sheik, Egypt, or the "Triple CoP´s" of the Basel, Rotterdam and Stockholm Conventions in Geneva in June 2022. Special emphasis was given to the important issue of how to enhance synergies and avoid trade-offs between international efforts for tackling climate change and those for ensuring the safe management of chemicals and waste.

3 Main results and learning experiences

The above-described activities have created a good basis for further cooperation, including information and training materials, best practices, and networks of interested partners as well as multiplicators and trainers. In collaboration with national associations and government partners, CAPCI supports diverse country-specific capacity-building measures executed with help from trainers that have taken part in CAPCI's ToT course on Sustainable Chemistry and Climate Change. This includes designing different training modules for consultants, chemical company staff, and political leaders to help them identify mitigation options as well as specific strategies and roadmaps for their country.

The programme partners in Argentina have already started to define a roadmap for their chemical industry, with CAPCI providing support for carrying out a technical study and organizing dialogues with all relevant stakeholders about effective and realistic pathways toward mitigation in the chemical sector. Thailand as well as Ghana also prepare studies for the development of roadmaps for their respective chemical industry.

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Among the most striking learning experiences, it can be noted that partners from the chemical industry as well as from government institutions joined CAPCI cooperation activities with great interest and gave to understand it as coming at the right moment. As one representative of a chemical association put it: “CAPCI is very welcome, because we have become aware that we need to do more in the area of climate change”. On the other hand, the support of the ICCA was very important for CAPCI because it opened doors to focal points in the national chemical associations. These are not only crucial partners; they also generally have long-standing experiences with the Responsible Care programme; and there are signs that climate-related training and awareness-building could at least partially build on the established structures and mechanisms, thereby linking climate protection with chemicals management.

Furthermore, all countries are requested to regularly raise the ambitions of their NDCs; especially when mitigation objectives are risen or even a climate-neutrality commitment is made, this causes a dynamic to include all relevant sectors in respective GHG abatement efforts. Interestingly, the chemical industry was often not in the focus of national mitigation strategies, though they belong to the three most GHG-intense industrial subsectors, accounting for 7.4 % of global GHG emissions (scope 1 and 2). The potential of the chemical industry to contribute to tackling climate change is in many countries not well known and is often under-estimated. One reason for the under-estimation of the sector’s climate relevance may be the fact that the methodology for establishing national emission inventories usually attributes most of the chemical industry’s GHG emissions, particularly those generated by fossil fuel burning, to the emission sector energy.

The implementation of CAPCI so far has shown that the chemical industry has an important role to play in tackling climate change, not only in mitigation of its own significant GHG emissions and implementing innovative solutions in areas such as circular economy, renewable energy, and green hydrogen. It is also an important provider of solutions for decarbonization or “defossilization” of other sectors. Information, awareness creation, knowledge sharing, and capacity building remain important tasks.

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Practitioner‘s Section

Bernd Winters*

Sustainable industrial area management: Using the materiality analysis at a multi-stakeholder industrial park to align activities

This case study is intended to show how multi-stakeholder industrial sites can form a first common framework for sustainable development. The paper presents the application of the materiality analysis approach to a multi-stakeholder industrial park in Germany. The challenge of a multi-stakeholder industrial area is to align activities of different companies within the park and to respond to the expectations of heterogenous external stakeholders. The case study will answer the following questions: 1) How do I identify the key sustainability issues from the internal perspective of the companies involved? 2) How do I find a common denominator for the different companies in the industrial park as a whole? 3) How do I derive the relevant SDG-related aspects for joint stakeholder communication? Benefits and challenges of the method are described and recommendations for the application of the concept are shared.

1 The context and challenge: Sustainable development at multi-stakeholder industrial areas

Founded in 1863, Industriepark Höchst in Frankfurt am Main nowadays is home to some 90 chemical and pharmaceutical companies that conduct research, development and production on site. It is one of the largest industrial parks in Europe, and new companies continue to settle here. It is further developed by the individual companies year after year with investments in the millions. The total investment since 2000 has been around 8.0 billion euros. More than 120 production plants are operated here (Infraserv GmbH & Co. Höchst KG, 2023). In 2023, the headquarters of most companies are abroad, namely France (company Sanofi), USA (company Celanese), Japan (company Kuraray) or Switzerland (company Clariant). The site is managed by Infraserv GmbH & Co. Höchst KG (company Infraserv Höchst) Infraserv Höchst also has a wholly-owned subsidiary private education provider (company Provadis with its private university of applied sciences, Provadis Hochschule).

All companies on site have their individual climate strategy – but most of these company climate strategies are global in nature and not specific to the industrial site Frankfurt. At the same time, the municipality of Frankfurt has acclaimed the goal of being climate neutral by 2035. A goal that can’t be reached without close collaboration among the different players in the region.

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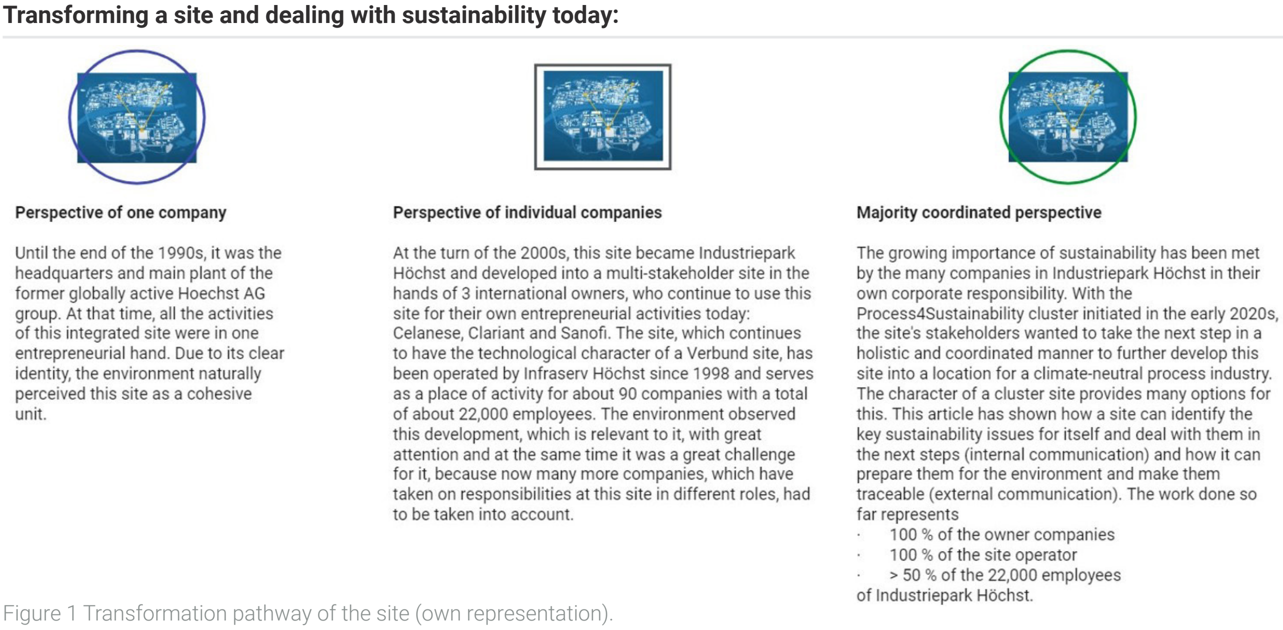

Figure 1 Transformation pathway of the site (own representation).

Against this backdrop, a structure for regional collaboration among a variety of stakeholders was initiated in 2019, the cluster process4sustainability.eu. It is a cluster for climate neutral process industries in Hesse and is co-funded by the different industrial companies, the state of Hesse, and the European Union alike. The following text describes the mission and vision of the cluster:

"Europe wants to become CO_2 neutral - as early as possible, but by 2050 at the latest. This goal requires a fundamental transformation of the economy and society. The process industry and its partnerships are central to the success of this transformation: together, we can develop new markets through innovative solutions, save energy and raw materials, replace fossil CO_2 sources, and increasingly also use CO_2 as a resource.

The Process4Sustainability cluster - a network of companies in the process industry, research institutions, and social innovation partnerships - wants to proactively shape this transformation process. We translate the major goal of CO_2 neutrality concretely for individual companies and the specific local conditions.

We want the transformation to succeed.

Based at Industriepark Höchst, we offer companies practical knowledge about the levers of CO_2 neutrality, new markets, and innovative business models. We create future markets by connecting solution providers with the relevant demanders.

We see ourselves as a partner for business, science, politics, and society on the road to climate neutrality and are supported by the Hessian state government and the European Regional Development Fund." (Provadis Hochschule, 2023)

The cluster is managed by Provadis Hochschule, through the Center for Industry and Sustainability. This cluster office ensures fruitful collaboration by defining, planning, and implementing the work packages. A steering committee as a decision-making body finds and decides on the activities proposed by the office.

The cluster pursues two major goals, (a) the identification and implementation of an economically viable transformation pathway for the industrial park and the process industries in Hesse, and (b) the definition of a collaboration pattern between the industrial park and the key external stakeholders from the fields of business, academia, society, and politics.

The following text will focus on the second topic and describe the activities of a working group focusing on "Identifying and dealing with the key sustainability issues of the Industriepark Höchst".

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2 Finding common ground: Sustainability materiality analysis

2.1 The concepts: Materiality analysis and SDGs

The core challenge of the cluster at the multi-stakeholder industrial park (Unido et al., 2021) was to create a shared understanding of the sustainability-related challenges of the industrial site (Accenture and EPRI, 2023; Cefic, 2023). The industrial site consists of the regional entities of large global corporations with their respective sustainability strategies; at the same time, these regional entities are perceived by neighbours and regulators as a joint entity. This perception of the industrial park is presumably still shaped by its history as the headquarters and main plant of one global company (Hoechst AG).

A variety of concepts can be used to identify sustainability-related topics for an organizational entity. One widely used concept is the materiality analysis (Sailer, 2020; Jenker et al., 2020; Nill and Severtih, 2018; Bertelsmann Stiftung, 2016; Stierl and Lüth, 2015), typically used by an individual company: "The company discloses which aspects of its own business activities have a material impact on aspects of sustainability and what material impact the aspects of sustainability have on its business activities. It analyzes the positive and negative impacts and indicates how these findings are incorporated into its own processes." (RNE, 2023). The core idea of this concept is to identify the expectations of the external environment towards the organizational entity (outside in analysis) and to contrast these expectations with the impact and requirements of the own organizational entity towards the external environment (inside out analysis).

Selecting this concept was the result of a joint decision process of a variety of parties: The selected concept needed to (1) be easy to handle, (2) be compatible with existing company-specific concepts, (3) be easily understood by external stakeholders and (4) allow the integration of existing external information.

The participating companies expected answers to the following questions:

- Inside out: What do the companies jointly demand from society and policy makers? Where do the companies have common interests? Which interests are company-specific? Who might take the lead on a specific topic?
- Outside in: What are the expectations of external stakeholders towards the site in its entirety (in contrast to expectations towards an individual company)? Who are core external stakeholders and how should we work with them?

For communication reasons, it was decided to apply the Sustainable Development Goals (SDG) (GRI et al., 2015; Nill et al., 2017; Kaminski-Nissen and Bongwald, 2022; United Nations, 2023; VCI, 2020) for framing the sustainability-related challenges and expectations. This global initiative of the United Nations (UN) is widely used by a variety of regional stakeholders and provides the necessary legitimacy and connectivity for the industrial park's messages. Other sustainability issues that did not align with the concept of the SDGs were not considered in this project in the first instance. These two core concepts, the materiality analysis, and the SDGs, are used by many local companies, which in turn are part of globally active corporations: They apply the materiality analysis in their corporate reports and the SDGs in connection with their sustainability communications via their headquarters. This approach thus immediately found the necessary support from the cluster members. As part of the materiality, these internal stakeholders (international companies) were integrated with their corporate requirements in a way that is appropriate for the site, thus preparing the ground for an exchange with external stakeholders.

The aim of the project is not to develop a reportable materiality analysis for the industrial park, but to use the work described above to identify the key sustainability issues for our industrial park and prepare them for external communication with our stakeholders.

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2.2 A multi-step process with feedback loops

A materiality analysis generally refers to a company. It focuses on the sustainability impact of the corporate strategy and at the same time involves the various stakeholders of the company, who in turn exert an influence on the company. Basically, this approach can also be applied to a site, even if it does not have a uniform corporate strategy for all the companies located there. A site with all the companies located there will cause sustainability impacts in its entirety and at the same time be considered by various stakeholders.

So how did we specifically go about adapting the approach of a materiality analysis to a multi-stakeholder industrial site with around 90 companies?

Relevant goals of this work package were to create a shared picture of the relevant sustainability issues for the Industriepark Höchst and to link these to the SDGs.

Description of our process:

(1) Identifying

The Industriepark Höchst is one of the major "industrial agglomerations" in FrankfurtRhineMain and faces a wide range of expectations from different stakeholder groups (e.g. the city of Frankfurt, the state of Hesse, citizens' initiatives). The first objectives were to survey the expectations of these stakeholders and to assess the potential influence of the stakeholders on the business. The definition of the field was done based on an in-depth desk research (1) on potential methods, approaches, and/or regulations and (2) on procedures of other locations and companies in the region and (3) on the actions of companies located at Industriepark Höchst. On the one hand, the cluster evaluated sustainability reports of the international and reporting companies. On the other hand, in the case of the non-reporting companies, benchmark comparisons were carried out and corresponding proposals were derived. Furthermore, the results were discussed both bilaterally and multilaterally with the companies and subsequently approved. In addition, extensive desk research was conducted. With the help of expert interviews with national and European chemical association institutions (Chemie³, cefic), industry standards and activities of other large chemical sites (e.g. BASF, Currenta and Chemelot) were analysed. In addition, companies and institutions from the region (e.g. Fraport, Mainova, City of Frankfurt) were observed. As a result, a long list of 132 sustainability topics was compiled. The result was a comprehensive picture of the most important sustainability topics of the companies involved, which had been derived by reviewing sustainability reports or other sources, materiality analyses and SDG communications.

(2) Prioritising

In the next step, in the "prioritising" phase, all the essential topics of the individual companies were brought together and clustered into common overarching topics that were prioritised to obtain a comprehensive picture of the essential topics of the industrial park. This extensive material enabled the development of a first draft of a materiality analysis for the Industriepark Höchst. The outcome of this phase was the prioritisation of the essential topics of the industrial park based on the individual companies. Related to this, a list of 101 topics resulted; redundant aspects were eliminated and the availability of the operationalisation of the aspects was checked.

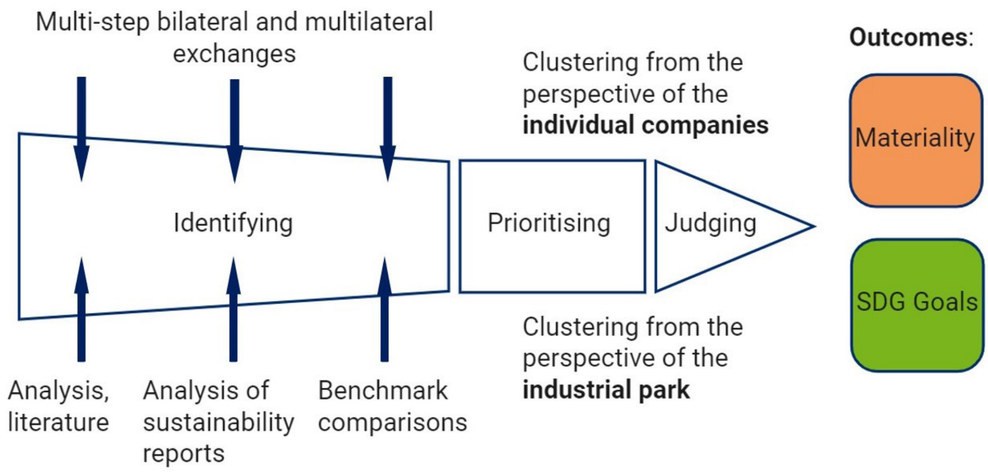

Figure 2 Process and steps towards the outcomes (own representation), 2023.

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(3) Judging

The findings of the "prioritising" phase were discussed in a series of cluster workshops with multiple sustainability experts from different cluster companies. In various exchange formats with the companies involved in the cluster, the specific material sustainability issues for Industriepark Höchst were identified. The objective of this phase was to decide on the central sustainability topics of the industrial park which should be communicated externally. These will be expressed by the corresponding SDGs, which are to be reinforced by tangible projects of the individual companies in the industrial park. The summarized topics were to (1) be relevant to the different external or internal stakeholders and (2) to be potentially influenced by the respective stakeholder groups. As a result, 22 topics were identified and summarized in a coherent catalogue of topics for the materiality analysis.

(4) Outcomes

The next step was to link the identified sustainability issues with the corresponding sustainable development goals. The goal here was to group the issues in a way that matched existing definitions and criteria — in order to structure the cluster's internal and external communication activities. The results of our work were presented and discussed first in smaller and then in increasingly larger circles of companies at Industriepark Höchst.

As a result, SDG-related communication activities were achieved. The developed framework was shared with the various companies at the site. It was possible to publicly present the SDGs and suitable sustainability projects that pursue these SDGs with concrete corporate activities on Industriepark Höchst's sitewide web portal for the first time Sustainability | Industriepark Höchst (https://www.industriepark-hoechst.com/).

The SDGs at Industriepark Höchst and in Process4Sustainability

SDG	Definition	Examples	SDG	Definition	Examples
3 GUTE GESUNDHEIT UND WOHLBEFINDEN	Ensure a healthy life for all people of all ages and promote their well-being	▪ Insulin from Sanofi ▪ Covid-19 vaccine ▪ Other products of the site companies	9 INDUSTRIE, INNOVATION UND INFRASTRUKTUR	Build resilient infrastructure, promote broad-based and sustainable industrialization, and support innovation	• Industrial park at the cutting edge of technology • Industrial Park as Innovation Campus • Cluster: Exchange formats
7 BEZAHLBARE UND SAUBERE ENERGIE	Ensure access to affordable, reliable, sustainable and timely energy for all	▪ Key task of Infraserv ▪ Coal phase-out ▪ H2 filling station ▪ Cluster: Examination of the possibilities of renewable energy	12 VERANTWORTUNGSVOLL KONSUMIEREN UND PRODUZIEREN	Ensure sustainable consumption and production patterns	• Industrial park as the epitome of the circular economy • Hydrogen trains; phosphorus recycling • Cluster: Chemical recycling
8 MENSCHENWÜRDIGE ARBEIT UND WIRTSCHAFTSWACHSTUM	Promote lasting, broad-based and sustainable economic growth, full and productive employment and decent work for all	▪ 22,000 well-paid jobs ▪ Large trade tax payer in Hesse	13 HANDELN FÜR DEN KLIMASCHUTZ	Take immediate action to combat climate change and its effects	• Commitment to CO_2 neutrality 2045 • Cluster: Collaboration for transformation path
			17 PARTNERSCHAFTEN FÜR DIE ZIELE	Strengthen means of implementation; global partnership for sustainable development.	• Cluster: Close cooperation with regional players • International exchange of experience

Figure 3 Defined SDGs for the Industriepark Höchst, Provadis Hochschule, 2022.

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This first overview can be understood as a first-generation SDG concept for the industrial park. In the future, this picture will be updated by integrating the perspective of further cluster partners, further external stakeholders' views and in the light of technological, societal and environmental developments. Furthermore, in a new generation, in addition to the activities, concrete common goals, that the industrial park wants to achieve, could also be defined. Consequently, a status and/or progress report would fit in.

3 Conclusion

The adapted materiality analysis for multi-stakeholder industrial sites can be used to identify and deal with the essential sustainability issues in an aggregated and coordinated way; the described process has helped the companies based at the Industriepark Höchst in different ways:

- Better understanding among peers: Through the described process, companies know more about each other and can thus learn from each other and identify or work on joint sustainability projects - projects that would possibly demand a greater effort for each individual company. Particularly in the last few years, there have been numerous challenges (including shortage of skilled workers, COVID-19 virus, fragile supply chains, Russian war in Ukraine, energy crisis) combined with increased regulatory demands (EU Taxonomy) the collaboration can be of great benefit, especially for SMEs (joint learning, joint testing, more substantial and faster implementation in the community and in the own company). This improved mutual understanding may also promote constructive dialog when it comes to larger new investments or new settlements onsite.

- Joint external communication: A common understanding of the cluster companies enables coordinated joint external communication - be it with the neighbours or with the relevant public bodies (community, city, state) leading to an improved societal acceptance and support.

- Preparation for reporting (EU Taxonomy): Cluster companies can access a wide variety of methods and regulations in order to select a specifically suitable common approach for the development of the key sustainability topics. By taking stock of the relevant methods and regulations, the cluster work can support the company's internal preparation for the upcoming reporting duties.

At the same time the following limitations need to be taken into account:

- Sustainability issues change over time: These issues will be subject to change as a result of internal developments at individual companies - new ones will be added, existing ones will undergo modifications, and others will disappear, as they will have become less important or will have been replaced by solutions through new decisions or will no longer be allowed as a corporate activity due to external requirements and regulations.

- Sustainability communication needs to change over time: As developed here, external sustainability communication can be framed in relation to the Sustainable Development Goals. Here, too, changing requirements of internal and external stakeholders will either necessitate adjustments in breadth (additional SDGs) and/or in depth (more comprehensive reporting on the projects addressed), or new reporting options will lead to new concepts in communicating with stakeholders.

- Industrial site's activities complement company specific activities: Site-related activities do not replace the efforts of each individual company to formulate its own sustainability strategy and thus achieve the set corporate goals and meet regulatory requirements. The added value in the additional cooperation of different companies within an agglomeration has been the focus of this article.

For our concerns at Industriepark Höchst, the described approach has proven to be effective. Every other entrepreneurial agglomeration (business park, industrial region or similar) must define a context-specific approach. Developing this context-specific approach for this industrial park requires the close collaboration of all relevant stakeholders, the discussion of their interests and goals in order to create a site-specific sustainability roadmap that complements the individual company strategies.

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Practitioner's Section

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The role of hydrogen in the process industries – implications on energy infrastructure

The industry sector is a significant consumer of energy and emitter of greenhouse gas emissions. Within this sector, the highest energy demand and emissions are caused by the process industries due to the need to chemically transform feedstocks and raw materials into basic chemicals and materials. New processes that include the use of renewable energies along the value chain are necessary. For the case of ammonia production, several technical process options to produce the required hydrogen feedstock are in principle available to adapt existing European ammonia plants. Each possible technical plant configuration has a significant impact on the respective infrastructure required. The size of the impact is calculated for hydrogen production using the following process options: water electrolysis onsite (with continuous and fluctuating electricity supply) and offsite, conventional production with CCS, and methane pyrolysis. Each of these technical options can only be applied if the respective infrastructure ensures a secure supply. This interdependency between infrastructure built-up and process options limits the speed and type of implementation of new technical options.

1 Introduction

Anthropogenic greenhouse gas emissions from fossil fuels are the main culprit for climate change observed after the onset of industrialization. Significant contributions come from the energy and industry sectors as well as transport and households. The industry sector was responsible in 2021 for 166.7 EJ, which corresponded to around 38 % of the overall energy consumption of 439.1 EJ (IEA, 2022), and emitted 9,136 Mt CO_2, which amounted to around 25 % of the global CO_2 emissions of 36,639 Mt CO_2. Most of the energy consumption and emissions are caused by the so-called energy- and emission-intensive process industries, i. e. iron and steel, chemicals, non-ferrous metals, pulp and paper, cement, glass, and ceramics.

The common foundation of these industries is the chemical and physical transformation of raw materials and feedstocks into basic materials for downstream processing and manufacture. The actual transformation itself is the most energy-intensive step. Therefore, industrial transformation towards a goal of greenhouse neutrality can only be successful if the central processes of these industry sectors are addressed by new and more sustainable alternatives. Additionally, these industries are governed by economy of scale and their existing processes are highly energy efficient. The required chemical and physical transformations have a significant thermodynamic energy demand therefore these industries will remain large energy consumers, albeit

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their processes need to change to allow renewable energy carriers rather than fossil ones. Furthermore, besides technical challenges, new processes based on renewable energies tend to be significantly more costly than existing processes based on fossil fuels.

In most cases, direct electrification might not be suitable and indirect electrification will play a significant role. Not necessarily will the new processes follow the same economy-of-scale or efficiency gains. In some cases, these new processes might actually consume more energy than existing ones. More importantly, however, the industrial transformation will proceed over some time in which old and new processes compete.

Hydrogen is a universal energy carrier that can fulfill different functions in the energy system. It can also be used on the merits of its chemical properties, especially within energy intensive industries, most notably in iron & steel production and the chemical industry. However, implementing hydrogen technology in the process industries has a significant impact on the required energy and feedstock infrastructure to the extent that existing infrastructures becoming obsolete, need to be significantly expanded or even new infrastructure needs to be built.

Ammonia production is second of the largest chemical processes in existence, only surpassed by the production of high-value chemicals, especialle ethylene, and propylene. It is also the largest hydrogen consumer globally. Current global production reaches 184 Mt/a (IFA, 2023) in 2021. Its product is indispensable for chemical fertilizer production as well as an entrance vector for other chemical value chains. It is also a significant contributor to greenhouse gas emissions, estimated to be responsible for 1.3 % of overall global emissions (IEA, 2021). These emissions originate from steam reforming of natural gas, autothermal reforming, partial oxidation, or gasification of feedstock to generate hydrogen for subsequent Haber-Bosch synthesis. A previous study investigated the impact of ammonia production options within the trilateral region (Ausfelder et al., 2020) between Belgium, the Netherlands, and Germany. It identified possible infrastructure requirements as a major aspect shaping industrial transformation.

2 Main Part

A study funded by Fertilizers Europe was carried out by DECHEMA (Ausfelder et al., 2022) to establish the greenhouse gas mitigation potential for the European ammonia production up to 2030 by substituting hydrogen production in existing plants in Europe with suitable alternative processes. The following analysis is based on this study.

Ammonia production in Europe is almost entirely based on natural gas as feedstock. Around two thirds of ammonia production is used to produce nitrates, one third goes into urea production. The latter requires some of the CO_2 from the steam reforming step as input to react with ammonia.
There are several process options to convert existing ammonia plants towards less greenhouse gas intensive ammonia production. To which extent a given option is feasible for a given site depends strongly on the overall process configuration at the site, e. g. if the downstream processing is urea or nitric acid production.

Since the emission-intensive step is the production of hydrogen from natural gas or other fossil feedstock, hydrogen needs to be provided in a less greenhouse gas intensive way. There are several possible pathways for substituting the current ammonia production with processes that generate less greenhouse gas emissions.

Hydrogen can be co-produced with oxygen via water electrolysis. Depending on the electricity used, it can be labelled green when only renewable electricity is used. If photovoltaics or wind turbines are used, the result is in general a fluctuating and intermitting production of hydrogen. It is labelled yellow when grid electricity is used, which allows for continuous production but with specific emissions according to the electric grid energy mix.

Electrolytic hydrogen production can be done onsite or off site. Whichever solution is chosen, it has a significant impact on the infrastructure requirement: enhanced electrical connectivity for the former, new hydrogen transport infrastructure for the latter.

Substituting up to 10% of grey hydrogen of existing ammonia production by green hydrogen is assumed to be compatible with current existing production plants.

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Low-emission hydrogen can also be generated in conjunction with carbon dioxide capture and storage (CCS) as so-called blue hydrogen. Ammonia is a special case for blue hydrogen since the conventional ammonia production requires separation of CO_2 from hydrogen anyway, i. e. the capture process is already part of the overall process design. Currently, process CO_2 is used for urea production, sold for external uses, e. g. in the food industry or just released to the atmosphere.

With respect to blue hydrogen and ammonia, rather than having the CO_2-capture and storage process and transporting hydrogen to the ammonia plant, it is more compatible with the existing industrial infrastructure to produce hydrogen onsite and transport the captured CO_2 to its storage place. Therefore, converting a hydrogen transport problem to a CO_2-transport challenge, insofar as a CO_2-infrastructure to a CCS site would enable ammonia production with limited interference to make use of blue hydrogen.

Finally, methane pyrolysis offers another pathway for hydrogen generation from natural gas without releasing greenhouse gas emissions in the process. Turquoise hydrogen is produced together with solid carbon and without CO_2 being released to the atmosphere.

Notwithstanding any site-specific constraints in relation to up- or downstream processes, it is important to realize

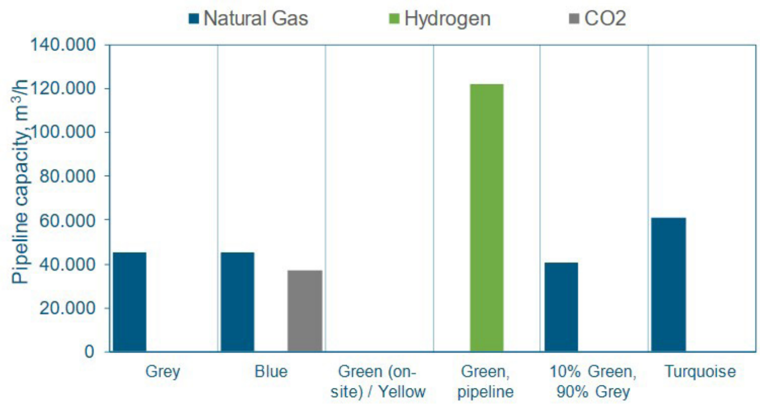

Figure 1 Infrastructure requirements for transport of gases for an average ammonia plant. “Grey” displays the natural gas infrastructure demand for an existing conventional plant, “Blue” displays the infrastructure demand for natural gas and the removal of CO_2, “Green (onsite)/Yellow” doesn’t have a specific infrastructure demand for gases, “Green, pipeline” demands a hydrogen pipeline, “10 % Green, 90 % Grey” has a very similar demand for the natural gas supply as the conventional process, “Turquoise” has an increased demand for natural gas due to the lower hydrogen production per unit natural gas compared to steam reforming.

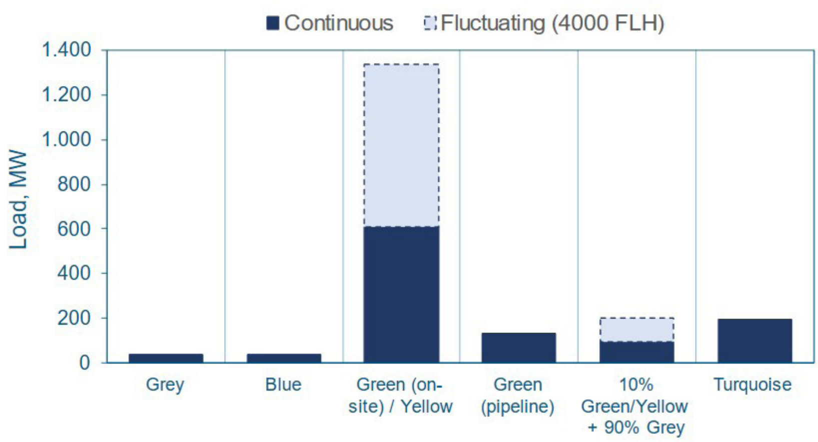

Figure 2 Infrastructure requirements for electrical transmission for an average ammonia plant. “Grey” has a small demand, mainly for compression, as it is the case for “Blue”. “Green (onsite)/Yellow” has a significant demand for the electrolysis which increases for a fluctuating supply (light blue) as well as to operate the air separation unit and compressors, which is also required for the “Green, pipeline” option. “10 % Green/Yellow, 90 % Grey” has a higher demand due to electrolysis which also increases in case of fluctuating supply (light blue), “Turquoise” has an increased demand due to the energy required for the pyrolysis.

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that any option requires its own infrastructure configuration to be applied at the site to guarantee security of supply and thereby a vital precondition for production. These infrastructure requirements differ both qualitatively as well as quantitatively from the demands of the existing European ammonia plants.

For comparison, infrastructure demands are calculated for an "average European ammonia plant" with a production capacity of 500,000 tNH_3/y. An overview of different process configurations and the required infrastructure is shown in figure 1 for gases and in figure 2 for electrical transmission.

Existing grey ammonia plants have a significant demand for natural gas and are usually connected to the natural gas transport grid. Electricity demand is secondary since the main process is based on natural gas and electricity is required for compression, pumps, process control etc.

In case of a transformation towards using blue hydrogen, produced onsite as detailed above, an additional CO_2-pipeline is required with the volume transport capacity of around 80 % of the existing natural gas connection. There is no significant change in the required electric load.

Completely replacing current hydrogen production with electrolysis onsite via continuous renewable (green) or grid (yellow) electricity supply would make the natural gas supply obsolete but require an 18-fold increase of the existing electrical connection.

If fluctuating (4,000 full load hours) renewable electricity instead of continuous electricity is used, the capacity factor for the electrical connection rises to 39.

Offsite production of hydrogen can be supplied by a dedicated hydrogen pipeline with a volumetric capacity of around 2.7 times the existing natural gas pipeline, while 4 times the electricity of the conventional process will be required, specifically to power an air separation unit to provide nitrogen.

Turquoise hydrogen requires both, an expansion of natural gas pipeline capacity by around a factor of 1.3 and expansion of electrical capacity by a factor of 6 compared to the existing plants.

3 Summary and Conclusion

Ammonia production is globally one of the most energy- and emission-intensive industrial processes. There are several less emission-intensive technical process alternatives available for both, greenfield and brownfield implementation. In comparison to existing ammonia plants, these technical options require either significant expansion of existing infrastructures, construction of new infrastructures and may render obsolete some existing infrastructures.

Possible industrial transformation of the European ammonia industry therefore not only depends on technical options for more sustainable processes but crucially on the availability of infrastructures. Both the choice of options to implement and the speed implementation is interdependent and limited by infrastructure development, which in turn determines the mitigation potential of the industrial transformation.

While the chosen example of ammonia production might be especially striking through the size of an average ammonia plant, the basic challenge is similar for all energy- and emission-intensive industrial processes within the process industries. Industrial transformation and infrastructural development are critically interdependent and need to be considered in conjunction.

From the perspective of a given industrial site, investment decisions on new processes will depend crucially on the expected local infrastructure development. On the other hand, transformation of the main industrial processes leads to such a significant change in energy and feedstock infrastructure demand, that it needs to be addressed proactively by the site operator responsible towards the respective infrastructure providers to allow a smooth and efficient transition and to avoid delays or involuntary production shutdowns.

There is also a risk of decohesion within the European Union or even within member states as a function of infrastructure development since new infrastructures might not be available at all production sites at the same time.

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Commentary

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Responsible Use – The Social License-to-Operate

A business approach towards sustainability in chemicals & materials

Chemicals & materials are key ingredients in food, health, housing, mobility, communications, leisure, and many more applications. Especially polymers have enabled material welfare for large societal groups since the middle of the 20th century until today. The unwanted side effects of chemical & material mass production and consumption are visible in form of waste, emissions, resource consumption, human & environmental toxicity, land use, and reduced biodiversity. The industry has adopted the UN 2030 agenda for Sustainable Development (UN-SDG, UN Global Compact), the Paris Agreement to reduce greenhouse gas emissions (COP 21) and supports the aims of the European Green Deal (Chemicals Strategy for Sustainability) towards a safe, resource efficient, circular, low-carbon society.

In line with those targets chemical & material companies increasingly decarbonize energy generation, lower resource consumption across operations and global value chains, reduce waste and emissions, and prevent harm to humans and the environment throughout the entire life cycle. They report on their environmental and social achievements and invest in green technologies. Irrespective of those activities to make chemicals and materials "greener", the image of the chemical industry stays poor and partly even worsens. Chemistry is associated with "artificial/ synthetic", "toxic", "pollution" and "dangerous". This has been true for a long time and there is probably not much to do about it. What is new is the fact that the chemical and material industry increasingly loses support also by their own customers. Take for instance the cosmetics industry, which explicitly excluded chemical cosmetic ingredient producers from their initiatives to define what sustainable and green cosmetics should be.

So how did it happen that the chemical and material experts are increasingly excluded by their customers to define a sustainable future? We believe it is the too narrow product scope. The chemical industry has based its sustainability charter and activities on the principles of Responsible Care. Responsible Care was introduced in 1984 and is today the guiding principle for the industry globally to achieve environmental, social, safety, and do no harm goals that reach beyond legal requirements (License-to-Operate"). The product scope of Responsible Care is "Cradle-to-Gate", starting with raw materials and energy through supply chain and production to the factory gate of the chemical or material company. It also includes end-of-life treatment, be it disposal, burning, or recycling. This is fully reflected in the sustainability activities and reporting of the companies.

The application and use of chemicals & materials ("Gate-to-Cradle") are not explicitly addressed. The pure product focus of Responsible Care disregards other mechanical, biological, physical, or other chemical and material solutions a user may consider. We see this narrow product focus as a fundamental shortcoming and a missed opportunity for the industry to gain more social acceptance.

The Cradle-to-Gate ("footprint") approach looks at the unwanted environmental and social costs in the production and supply chain of a chemical or material, but not at the social benefits of chemicals and materials in use ("handprint"). Minerals, crude oil, air, salt, and other resources are transformed with energy and labor to produce chemicals & materials. There is a social benefit for only a few, directly involved investors and operators, but unwanted environmental and social costs for many. From that

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perspective, the pure production of chemicals and materials is per se not sustainable. This is by the way also the case with most other products and thus not very noteworthy. It explains however the image issue of the industry. Reducing environmental and social costs may help to make products less unsustainable ("greener"), but it will never be able to fulfill "net zero" requirements and thus continue to disappoint expectations, which are probably unrealistic in the first place. Only the use brings social acceptance and benefits that justify or outweigh the unwanted environmental and social costs.

Take for instance smartphones and battery electric vehicles (BEV). They have significantly higher environmental and social costs compared to former blackberries and internal combustion engine (ICE) vehicles, which they substitute. Neither factual environmental and social costs nor scientific decision criteria from cradle-to-gate, but merely societal acceptance in the gate-to-cradle application define, if it is responsible to use those products or not.

In the case of smartphones, more than 1.2 billion people (c. 15% of the global population) decided to buy a new one last year and BEV sales rose to 7.8 million (c. 10% of global passenger car production) in 2022. Society has implicitly decided that the many more benefits and functionalities of a smartphone compared to a blackberry or the lower net operating costs and lower local emissions of BEVs compared to ICEs justify the higher financial, as well as environmental and social, product costs. With chemicals & materials it is a bit more complicated than with smartphones and BEVs, but in principle, it is the same.

A first complication is that chemicals and materials are often building blocks that have multiple applications and uses. Epoxy resins for instance are produced from toxic precursors. It is probably very responsible to apply epoxy resins under controlled conditions and use them to make windmill rotors larger and more efficient, car coats more scratch and park decks more oil resistant. On the other hand, there may be better alternatives than using the same epoxy resin to coat the inside of beverage cans or drinking water containers. The companies in the chemical & material industries and their associations are however generally organized by products and technologies. Another current example are PFAS and fluorinated polymers. There are probably sustainable applications, like catheters, 5G equipment, semiconductors, lithium ion batteries and green hydrogen electrolysis cells, where it is very difficult or impossible to find adequate substitutes. But there are other applications, like make-up, lipstick, frying pan coatings and outdoor rain protection, where less performing substitutes are good enough to do the job without the unwanted side effects. They want to utilize their assets and thus have a strong incentive to sell their products into all application areas that are legally allowed to serve, irrespective of the responsibility in the application and use areas. A second complication comes from indirect sales via distributors, traders or agents. Routes-to-market are often not very transparent and it is not always clear, who the final user really is.

Another complication is the fact that the societal acceptance of what are responsible or not so responsible uses varies by groups as well as countries or regions and over time. Some societal or regional groups accept the use of nuclear energy, the capturing and storage of carbon dioxide or the use of blue or turquoise hydrogen as a sufficient contribution to climate change and sustainable businesses. Other groups require a complete ban of fossil hydrocarbons, both as a source of energy generation and feedstock, or the active removal of carbon dioxide from the atmosphere or the extensive use of green hydrogen to couple transportation, heat, and industrial sectors. How should industry deal with those partly conflicting and changing societal sustainability demands?

Complaining about an increasingly volatile, uncertain, complex, and ambiguous business environment does not help. Responsible Use of chemicals and materials should be done as a complementation of Responsible Care, not as a substitute. The process and steps of Responsible Use are the same as with Responsible Care, but the scope is enlarged from Cradle-to-Gate (product focus) by Gate-to-Cradle (use focus) and thus covers Cradle-to-Cradle (responsible products for responsible use along a value ring), see figure 1.

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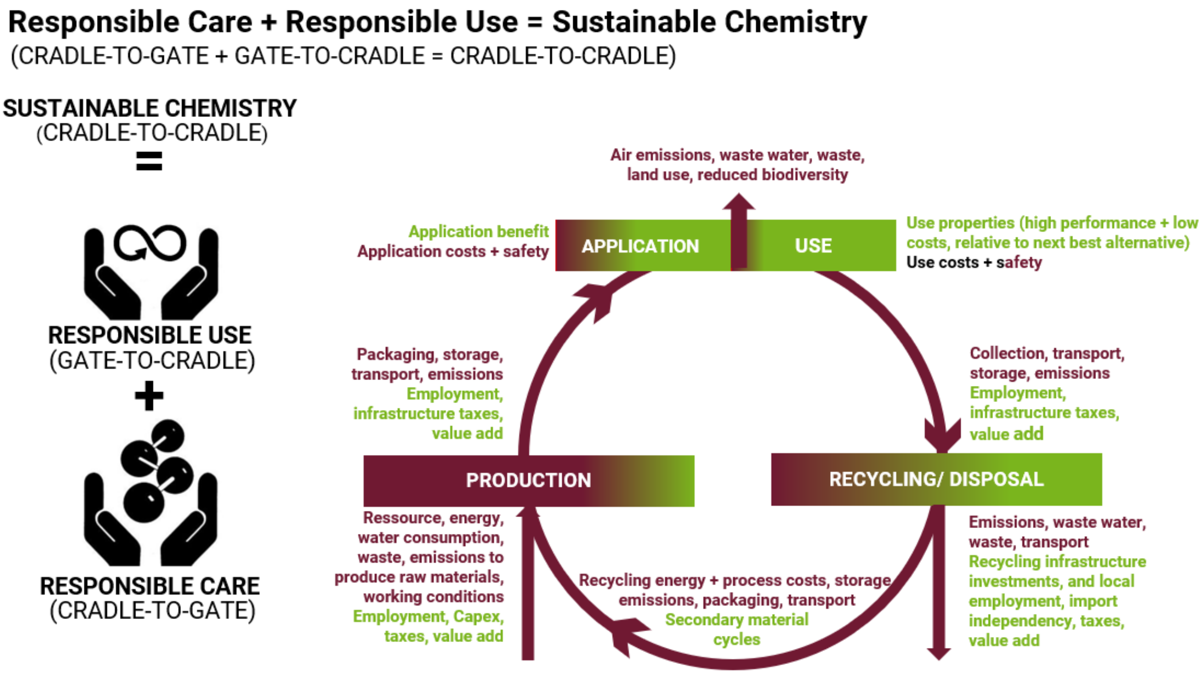

Figure 1 Sustainable Chemistry, source: https://ELCH-consulting.com.

The additional Gate-to-Cradle "Responsible Use" part needs to cover all relevant uses of a given chemical or material in order to fully understand the risks and opportunities. Chemical & material companies and their distribution partners should implement Responsible Use in three sequential steps:

1. Regulatory compliance

Protecting regulatory License-to-Operate to stay in business

Fulfilling national and regional ESG requirements is the required minimum activity to stay in business. Those requirements cover non-financial reporting, supply chain transparency, greenhouse gas emissions, distribution permits, etc. Larger chemical & material companies are already fully covering those aspects at least Cradle-to-Gate, but small and medium-sized companies are often reluctant and should consider the deadlines, especially on non-financial reporting (CSRD, ESRS), supply chain transparency (supply chain due diligence law, TfS, EcoVadis) and EU taxonomy (REACH/ CLP). Regulatory compliance is often carried out along ISO 14001 (Environmental), 26000 (Social) and 37000 (Governance) standards, but it should go beyond current product stewardship and Responsible Care of a chemical & material. It should explicitly cover the Responsible Use of chemicals & materials. Understanding regulatory compliance issues of chemical & material users and their alternative problem solutions is important to understand fully, what is needed to stay in business. This may already confront managers with some unpleasant truths. Think for instance about a fine chemical that is used to reduce blood pressure and at the same time it is an active ingredient used in pesticides to kill insects. In the latter use it will be soon forbidden in some application areas and countries. In one application the fine chemical is the best problem solution with high responsible use and in another it may soon no longer been sold.

2. Financial impact

Achieving Social License-to-Operate by managing ESG- and diminishing sustainability-risks

Double materiality is the standard approach to managing ESG risks and opportunities. Inside-out the impact of the business on the environment and society is mirrored against the outside-in financial sustainability impact on the business. This is largely done for products with the consequence of easily ignoring or overemphasizing risks and opportunities. Doing the same for all relevant applications and uses helps to get a more balanced profile about the ESG- and

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sustainability risks and opportunities and their material and immaterial financial impact short, medium, and long-term on the specific applications and uses of the product.

Understanding this in detail is needed to maintain a competitive position and secure financial performance in an increasingly volatile, uncertain, complex and ambiguous environment, where greenwashing is the norm rather than the exception. Let´s assume a morally and ethically acceptable use. When there is no better technical and/or commercial solution to fulfill this specific needed application and use, then this is the sweet spot for the specific chemical or material. This is what the chemical and material industry should focus on and encourage customers to use. At the same time, they should not be shy to discourage or even ban applications and uses, where there are better alternatives and they should actively fight against no use and misuse. This can build trust and create additional sustainable businesses.

3. Business opportunities

Social License-to-Lead by offering societally preferred sustainable businesses

This is about taking an inside-out perspective to solve sustainability challenges better than competitors and other problem solutions. This allows for higher positive sustainability outcomes, enlarged product opportunities, more efficient, measurable environmental and/or social impact, preferred by various stakeholders. This is about being better and faster than competitors to effectively solve sustainability issues of key stakeholders, typically customers. This often comes with new technologies, solutions, and approaches that help to reduce environmental and/or social costs. Timing is often the key to be ready just in time to capture the opportunities of the regulatory framework (CO_2-prices, taxes, duties, bans, incentives, subsidies, …) and the customers‘ willingness to pay for more sustainable solutions. Those companies that properly differentiate structural sustainability trends from mere greenwashing hypes or green fashions and those that are neither too early nor too late in capturing the business potential of sustainability needs will successfully grow sustainable businesses and take market shares from their peers.

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Commentary

Perspectives on an effective design of industry transformation

Jürgen Vormann

Turning point(s) ("Zeitenwende") and new multipolarity: Is the industry in Germany declining into insignificance?

The following text summarizes a speech held, at Frankfurt Industry Evening, Chamber of Industry and Commerce Frankfurt am Main/Germany on December 13, 2022. The author acted as CEO at Infraserv GmbH & Co. Höchst KG for 18 years. Infraserv Höchst is the operator of the industrial park at Frankfurt-Höchst, a vibrant R&D and production site for the chemical and pharmaceutical industry. At the same time, Jürgen Vormann was responsible for a variety of regional and national organizations and has been outlining the interest of the manufacturing industry towards regional, national and international policymakers. In his final official speech as CEO, Jürgen Vormann underlined the importance of constructive cooperation and mutual support between industry, politics, and society and pledged for a well-balanced policy mix which at the same time has to aim for economic, social and environmental targets to secure a strong industry in Germany and Europe. He fears that current climate change-related arguments would prevail in the public discourse and that this orientation might endanger the industrial base in Germany.

The topic of my speech today, formulated as a question, is: "Turning point(s) and new multipolarity – is the industry in Germany declining into insignificance?" With my remarks on this topic today, I can and will share only some of my thoughts on this question; I would like to provide some food for thought and an input for a public discussion, which is overdue and unfortunately only slowly gaining momentum. A comprehensive treatment of the topic would certainly go beyond the time frame of this evening.

Why have I chosen this topic? Because, in my view, it is of great importance for Germany and in particular for the industry in this country!

The overall argumentative context is quickly described: For the first time since the end of World War II, a war takes place in Europe. And already in the run-up of Russia's invasion of Ukraine, in the fall of 2021, the energy markets were anticipating a possible war since the annexation of the Crimean peninsula and the occupation of territories in eastern Ukraine in 2014. Due to the great dependence of Europe, (and Germany in particular), on oil and above all gas supplies from Russia, due to low gas storage levels in early 2022 and against the background of a politically poorly planned and even more poorly implemented "energy turnaround" of the German federal government, the prices especially for natural gas have literally exploded in the meantime.

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This has led to a significant deterioration in the competitive position of - especially energy-intensive - German and European companies. Energy-intensive production facilities were temporarily shut down or downsized, e.g. in some areas of metal production (production in October 2022: -14% yoy 2015) and the chemical industry (production in October 2022: -22% yoy 2015).

The short-term consequences are disruptions in the local value chains, which will lead to supply bottlenecks – to name a few: e.g. for flocculants and precipitants for drinking water production, precipitants for wastewater treatment, and urea for pharmaceutical synthesis and ad-blue production. These short-term product shortages are painful enough. In the medium to long term - and this is far more dangerous for Germany and Europe - this development is deteriorating the competitiveness of significant parts of the industry in Germany, threatening energy intensive production facilities and thus the stability of value chains and the safety of jobs in this country. Even more serious: there is a risk of future investments being made in other regions of the world. The consequences of such a development for the German and European economic structures - and the social systems that are based on these - can hardly be overestimated. To make things even worse, the demographic development in the coming years, a paralyzing regulatory framework in conjunction with a slowly working bureaucracy in Germany and Europe will further accelerate this development!

So much for the woodcut-like arguments put forward in recent months by some subsectors of the industry, especially from the chemical industry. I personally share this pessimistic assessment, and I, therefore, see a real danger that a significant part of the industry in Germany is on the verge of being sidelined. Mind you, I am quite deliberately using the term “industry in Germany“ here; I am not necessarily talking about the “German industry,“ as long as it is internationally positioned with regards to its development opportunities in other parts of the world, outside Germany and possibly also outside Europe. I am firmly convinced, however, that a German industry, which loses its competitiveness in Germany and thus weakens its home base, will in the long term lose its competitiveness and its independent entrepreneurial identity in the global context.

What is the objective of my remarks today?

Today, I would like to take a step back, block out the media cacophony of the year 2022, the discussions about “the Scholz-whammy” and “double whammy“ and take a look from a somewhat greater distance and with a much longer industry perspective on the future.

On the one hand, I would like to describe what I consider as some of the major structural challenges - and their causes - our country in general and the manufacturing sector in particular are facing.

At the same time, I want to outline starting points and generally applicable rules for change processes which, in my view, can help correcting mistakes made in the past and avoiding undesirable developments in the future.

What challenges do we face today - and why are we standing here?

The word chosen as the “German word of the year 2022” is “turning point.“ I can assure you that a few weeks ago, when I was formulating the topic for my speech today, I had no insider information from the jury of the German Language Society. I chose this word for the title theme deliberately, and I also use it in the plural, because I am convinced that when we talk about “longer periods of history that are characterized by unifying features“ (at least this is the definition of the term “era“ in Wikipedia), we will not only find “the one“ or “the dominating“ connecting characteristic which defines an era; during the last eight decades - since the end of World War II - we have to consider a whole series of important developments that in my opinion have led or will lead to profound paradigm shifts, thus determining fundamental changes of or even within an era.

Allow me today to single out three distinct developments, that are of particular importance from my point of view:

1. The renewed disintegration of the world into several power blocs:

At the end of World War II, the world was clearly divided into two large camps. The “West“ under the leadership of the United States and the “East“ under the leadership of the Soviet Union were clearly defined as politically, economically, and above all militarily organized power blocs; China and other parts of the world initially played a subordinate role. But even in this phase of history, which superficially lasted until the

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fall of the Iron Curtain in 1989/1990, new centers of power emerged, which have also been clearly visible for some time now: China, which will soon become the world's largest country by GDP and which is already a world power - both under economic and military aspects; and India, soon to be the world's largest country by population. The countries of the European Union have created a supranational structure aiming to gain economical and political synergies to bring sufficient "weight" to the scale internationally. The "turning point", proclaimed by the German chancellor in the wake of Russia's illegal invasion of Ukraine is, in my opinion, at most to be subsumed here as a subcategory of the developments after the fall of the Iron Curtain and the proclaimed "end of history" (Francis Fukuyama); in the light of human history and human psychology, only naïve politicians (of those mainly German) were to believe this as being true.

In the history of mankind, questions of power almost always had an economic component - and economic questions are always also a question of power. In this context and against the background of the current socio-economic developments in the European Union, I believe, that Europe needs to urgently re-answer the "systemic question". The answer to this question will not only have a decisive impact on the success or failure of the desired transformation of the German and European economy, but it will also determine Europe's political and economic competitiveness on the global level between the different power blocs - not to mention our military strength, which at the moment is highly questionable and currently predominantly dependent on the United States!

The systemic question that we must ask (and answer!) is: Do we continue to trust in the power of market mechanisms – i.e. Adam Smith's "invisible hand" and the statistical "power" of many market participants - as the most effective and efficient form of a search process? Or: Do we give ourselves over to the illusion, that a few "know-it-alls" - be it in politics and/or in business - know better than the "many" market participants, who have to prove themselves in competition? China is building - not at least against the background of the success of its rapid economic catch-up process of the past five decades - on increased central control of the markets. The United States of America, in general, follow the principles of a free market economy, whilst at the same time they start stimulating the transformation of its economy with a protectionist touch and enormous state subsidies under the Inflation Reduction Act.

And we (German) Europeans? The EU Commission produces many glossy slides with a vision of a "European Green Deal", and visionary solutions are being presented on paper for concepts and measures to meet the challenges in climate protection, taxonomy, energy supply, industrial policy, distributive justice, compliance, and other "Sustainable Development Goals". And whilst the economic feasibility of the presented visionary concepts are still unproven and the required financing of the necessary transformation measures is more than questionable, the EU at the same time already starts to detail draft regulations for the transformation of the European economy which – if put into effect – will result in an overwhelming and non-value-added bureaucracy. In one word: the "rule of law" will thus be substituted by even more and even more complex rules and regulations. This contributes little to nothing to an economic added value for Europe, but it will at least keep European consultants and lawyers in business.

2. The end of limitless growth

Resources are scarce for humans as their needs are fundamentally unlimited. For thousands of years, human demand has had to adapt to the natural supply and be it through distribution battles in which human victims had to be mourned. In the face of a still rapidly growing world population, there are few reasons to believe that these fundamental mechanisms have changed nor that they will change soon. At the latest with the beginning of the industrial revolution, however, not only the scientific discussion about the economics of supply and demand and the options and limitations of satisfying human needs had started; due to advances in science and technology, the references to the finite nature of certain natural resources were receded into the background. Medical and technical developments enabled sustained and strong population growth, which even picked up in pace after the end of World War II. In the wake of this development, the general public only became aware of the "Limits to Growth" through a report of the Club of Rome published in 1972. This - in my view necessary – discussion however has since then met with a strong response especially in the economically far-developed, aging, and largely saturated Western societies – a fact that in my opinion is worth being examined with the scientific tools of psychology. With reference to Abraham Maslow, I assume at first glance, that humans, whose existential needs like food, clothing, and security are satisfied, rather focus on their individual needs or their need for self-realization and soon

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start neglecting the fact, that for an ongoing satisfaction of existential needs the basis hereto must not be destroyed.

Interestingly, the discussion in media and politics about sustainability and conservation of scarce resources for some time now primarily focuses on the question of CO_2- emissions and their consequences - keyword: global warming. Against the background of the aforementioned, this is likely due to the fact that significant stakeholder groups in our society for reasons of either/or fear and/ or ideology articulate a "personal concern" in combination with a "sense of urgency" i.e., they create an alarmist mood which - transported via media - then can be used to build up political pressure to overcome initial resistance against these ideas. I do not want to be mistaken: I, too, consider man-made climate change as a challenging and rather urgent problem; however, after reading all the IPCC reports on climate change of the past years, I am also convinced that the world will not end in the next 20 to 30 years due to climate change. And in view of the still unsolved problems of war and hunger in today's world, even several decades of a socio-economic transformation process towards sustainability and climate protection seems to be a rather ambitious period for the solution of such a monumental task. At the same time, I am firmly convinced that we can achieve what I consider a sustainable development of our economy and our society. In this context, we must also work hard towards a significant reduction of CO_2-emissions; however, we should not commit economic suicide for fear of ecological death.

In the still emerging economies of Asia and in the US economy, which for decades is characterized by a rapidly shrinking middle class and significant trade deficits, it will be decided whether sustainability and climate protection will have the same importance as they do here in Germany and Europe. In a saturated society like ours, it is easily forgotten that in other regions of the world, there is still the "fight for daily bread". By introducing overly ambitious rules and regulations, we risk to undermine and to destroy our today's and tomorrow's basis of our economic existence. Just take Venezuela as a negative example: Venezuela was in the 1970s (and still would be today) one of the richest countries in the world due to its oil wealth. Visit Venezuela today, and you might get a sense of how quickly an ideologically motivated policy can lead to the destruction of a country's business model.

3. Energy supply is a key issue for competitiveness and sustainability

The adequate and reliable supply of useful energy at competitive prices has always been one of the key factors for successful industrial development. At the beginning of the industrialization of the Western world, the question of the availability of primary energy sources was dominating. Over many decades of industrial development, the focus more and more shifted towards competitive energy costs and energy prices on a national and later also international basis.

The conversion of fossil energy sources into useful energy contributes significantly to CO_2-emissions into the atmosphere. Thus, beginning in the 1960s, the scientific discussions on "social cost" and the "internalization of external (environmental) effects" started, which finally led to CO_2-reduction efforts by the introduction of CO_2-emission certificates with a positive price and thus a cost. This concept follows a market economy approach and, if applied globally, would not only avoid distortions of competition but also, in the Smithian sense of the "invisible hand" of the market, it would have effective and efficient steering effects for the reduction of greenhouse gas emissions. In Germany – and in my opinion for primarily dogmatic reasons – we are already the famous "step further forward" within the framework of the German and European climate protection targets: As of today, we have in fact a general ban on the burning of fossil fuels – the German coal phase-out is agreed and signed, with natural gas already being "next in line" in the current political discussions. It cannot be ruled out that even the current German and European legislation will already put the industry in Germany on the economic sidelines today; a permanent sidelining however will lead to economic decline - unless we succeed in finding new, sustainable, redundantly available energy sources, which are, at the same time, competitive on an international scale. However, there are still high hurdles to overcome here:

Starting with the question of which technologies are not only technically feasible but also commercially competitive, to the question of their societal acceptance, to questions of appropriate and rapid approval procedures, timely technical implementation, and financial viability:

In view of the multitude of these transformation challenges, and given our ever-increasing sustainability targets, we in

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Germany already should have progressed much further in the implementation of individual transformation steps. Instead of finally getting down to tackle the challenges and establishing and implementing a technically and commercially valid long-term transformation strategy in a spirited manner, we Germans are merely running behind the foreseeable failure to meet our climate protection targets, and almost all German politicians are trying to compensate for this only by permanently tightening the targets. A competent and responsible acting legislation looks different. And - see my comments above - competent, responsibly acting German and European policymakers would not lose sight of their global competitors but would adapt their own transformation expectations in terms of content and timing accordingly.

I would like to use the following picture for your imagination, to illustrate the dramatic nature of the current developments in German and European energy policy: Imagine that you are a professional skydiver, ready to jump the plane. This time, however, you will have to refrain from wearing a parachute due to its questionable sustainability. But in hope (and firm belief?), that by the time you are about to hit the ground, you will have found a more sustainable, technically functional, affordable, and acceptable alternative to your parachute, you boldly jump out of the airplane! I consider myself to be a courageous person, who is fundamentally confident about the future – but I nevertheless would not make the "leap" under these circumstances; I would not yet dare to "jump" under these conditions.

What is to be done?

Based on what I have said so far, I would like to conclude my keynote speech by attempting to outline ten basic rules for a successful transformation of our economy. I will keep these basic rules very brief and, incidentally, look forward to discuss these proposed rules with you.

1. Courage and confidence as a basic attitude!

An optimistic, confident basic attitude is the best guarantee for the development and testing of concepts for the future that can outlast the day and are made for the people. This also includes having the courage to be clearly visible and audibly in the discussion on these concepts for the future and to stand up for one's own opinion in a public, if necessary contentious, discourse - a quality not always widespread between industry leaders in view of today's media environment. Courage and confidence are also helpful in coping with doomsday scenarios, true to Luther's motto: "If I knew that the world would end tomorrow, I would still plant a little tree today!"

2. Intellect instead of dogma!

We should use our minds instead of traditional and possibly dogmatic thought patterns. However, this requires us to critically question ourselves and, if necessary, to be able to admit one's own mistakes or misconceptions. In conjunction with Rule No. 1, this basic rule almost completely describes the principle of enlightenment - namely, man's enlightenment from self-inflicted immaturity: Dare to use your own mind - and act accordingly!

3. Realism instead of naivety!

Let us look at the world as it is - and not as we would like it to be. A realistic view on where we stand today should help us to identify real problems, to perform a solid root cause-analysis and to deriveproper and feasible possible solutions to these problems. This rule also holds true in the evaluation of people, negotiating partners, and even nations and their interests and behavioral patterns.

4. Numbers, data and facts instead of beliefs!

Numbers/data/facts should be the basis for every decision. Beliefs or assertions without facts should play no role in decision-making. Alarmism must be avoided in any discussion.

5. Balance of objectives instead of a "blinkered view"!

There is usually more than one objective to be pursued in processes of change and transformation. When it comes to far-reaching changes, it is necessary to balance the justifiable objectives of the various stakeholder groups for reasons of acceptance. Against this background, we should also view the first "Ampel"-coalition at the federal level in Germany as an opportunity - even if not everyone likes everything in this context.

6. Develop several fault-tolerant options for action!

Don't put all your eggs into one basket, and also think the

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unthinkable. This rule maintains the necessary flexibility of action, it leads to risk diversification and reduces fatal surprises.

7. Focus instead of bogging down!

We must make complexity "manageable". In the age of "Dynexity" – i.e. dynamically evolving, complex issues - it is crucial to focus. Less is more - this also applies to legislation: We need less legislation but better, i.e., simpler, more transparent, clearer rules, which correspond to common sense and which, in the event of a dispute, can be decided quickly without everlasting nitpickings on legal subtleties.

8. Think global - act local!

This applies to few issues as much as to the issue of climate change. If there are no transparent, well-coordinated, and comprehensible regulations and agreements in this field on an international level, everyone will lose out in the long run. In this respect, the establishment of the G7 Climate Club is an important first step in the right direction.

9. Let's trust in the power of the market mechanism!

Different concepts for the future should be tested in competition according to the rules of the market economy, true to the motto: "The better is the enemy of the good." Incidentally, this requires entrepreneurial courage and the willingness to accept the risk of failure in the market!

10. There is nothing good - unless you do it!

If the German and European economy is to be successfully transformed, we must all, as stakeholders in Germany and Europe, put an end to the cacophony of ever-increasing goals and objectives and instead move towards coordinated action on a subsidiary basis. This will not happen by itself, this will not happen through bureaucratic action - it will only happen on the basis of a mutually accepted, balanced system of objectives; and it will only happen when strong, visible, and credible leaders – both in politics and in the industry - lead this transformation process boldly and courageously!

Ladies and gentlemen, thank you very much for your attention. I am looking forward to further discussions with you!

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Commentary

Perspectives on an effective design of industry transformation

Stefan Lechtenböhmer

An active systemic industrial policy for climate-neutral process industries in Europe

To achieve climate neutrality, as envisaged in the Paris Agreement and the European Green Deal, the energy-intensive process industries play a key role. However, shifting their energy base to non-fossil sources and to reduce non-energy related emissions, is a major challenge. For this transformation to succeed, new forms of cooperation between industry, society and politics are needed. Next to a policy mix including marked-based instruments (e.g., the ETS), faster planning processes and public investments in infrastructure are necessary. Moreover, policies should as well accompany "ex-innovation" processes. An active systemic industrial policy for climate-neutral process industries in Europe

Introduction

Process industries are key to achieving climate neutrality and circularity. The most energy-intensive industrial processes are the transformation of raw materials such as ores, limestone, sand, oil and gas into basic materials such as steel, cement, plastics, aluminium, glass, etc. These processes are physically linked to high energy demand, which is the main reason why the steel, cement and chemical industries alone directly emit about 20% of global CO_2 emissions, plus significant indirect emissions, e.g. from electricity consumption.

Their high and, to a large extent, unavoidable energy demand places the processing industries at the centre of all efforts to achieve climate-neutral industrial production. The European Green Deal, with its ambition to fully implement the Paris Agreement and make Europe the first climate neutral continent, therefore puts a strong focus and pressure on these industries to shift their energy base to non-fossil sources and to take significant measures to avoid non-energy-related process emissions, e.g. from cement, glass and lime production. For the petrochemical industry, this means not only decarbonising its energy supply but also shifting its feedstock from oil and gas-based fossil carbon to non-fossil sources, such as plastic waste and biomass. Often these changes will require process industries to move to entirely new, sometimes disruptive, technological pathways - such as hydrogen-based iron direct reduction instead of conventional blast furnaces (Bataille et al., 2018). For European process industries seeking to maintain their technological and environmental leadership as a key unique selling point in their often highly competitive global markets, these challenges to transform their energy base have been made even more urgent by the recent energy crisis triggered by the Russian war in Ukraine. The war has put European manufacturers at a significant energy cost disadvantage to their competitors, with no prospect of this situation being fully reversed in the near future.

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Main part

Against this background, **European process industries are under strong pressure** to transform towards climate neutrality and circularity, which are the most powerful levers to reduce the energy demand of material production.

The transformation of these industries is therefore highly challenging due to their high capital intensity and long investment cycles in plants and infrastructure (Wesseling et al., 2017), as well as their links to public (energy) infrastructure. In particular, the transition from the current fossil energy supply to a future renewable energy supply will only be possible if investments in clean energy and the corresponding infrastructure for the transport of clean electricity and hydrogen, but also the necessary infrastructure for carbon transport and storage, are available.

All of these points make it clear that industrial companies will not be able to make the transformation on their own. They will need strong public support to develop and invest in entirely new technologies, public planning and frameworks to accelerate clean energy supply in a timely manner, and to create more circular value chains. In all these crucial areas, new stakeholders from different sectors, as well as customers and the general public, will need to be involved to make the transition possible. In short, an active, integrated climate industry policy with a clear strategic focus on climate neutrality and circularity is indispensable, which means: streamlining and supporting the forces of markets and innovation systems by combining them with broader societal actors.

However, industrial policy or a strong role for governments has long had a protectionist/conservationist focus. Only recently has there been a call for an active systemic rather than traditional industrial policy for the transition to climate neutrality. This is consistent with a similar evolution in innovation policy, which has shifted from a goal of supporting all types of economic development to more mission-oriented and transformative goals (Nilsson et al., 2021).

A transformative industrial policy focused on emission-intensive basic industries requires above all systemic innovation, which requires an active role of the state and a targeted technology policy. According to Nilsson et al. (2021), such a policy should be based on six closely interlinked pillars:

1. Directionality, to create a very important certainty of direction with regard to climate neutrality and resource efficiency. This can be achieved through political goals and strategies, but also through infrastructures, and should always be based on participatory processes, as only strategies with broad social support can create the necessary stable framework conditions in the long term. The main elements of such a policy for directionality are:

- Rigorous emissions trading, climate change legislation and industrial strategy, as well as strategies on hydrogen, carbon management, circularity and the future design of the electricity market, are essential approaches that must work together to provide the necessary direction, and this requires a common mission for climate neutrality and resource efficiency - as set out in the European Green Deal.
- Innovation support and market introduction of the necessary technologies and infrastructure through targeted instruments such as climate protection contracts.
- Targeted and broad participation through activating instruments, ranging from more regional actions such as the IN4climate.NRW initiative involving industry, science and government in the heartland of the European manufacturing industry, to a national "industry consensus", which should aim at enabling a broad understanding of the challenges of the transformation, but also of the important role of a climate-neutral industry for the sustainability transformation. This understanding is important both for the acceptance of the necessary infrastructure and investment and as a basis for the future recruitment of motivated skilled workers, e.g., in STEM professions.
- Finally, all this needs to be embedded in relevant European policies and instruments, as an industrial strategy ultimately needs to be understood and supported on a pan-European basis.

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2. Knowledge creation and innovation for industrial transformation should promote whole-system innovation and learning, in addition to mission-driven technological innovation and the acceleration of its market readiness.

- The key strategies of electrification, hydrogen economy and carbon management can only be successful if they are considered in a holistic and integrative way and therefore require an active role of the state and a wise integration of societal actors.
- In addition to socio-technical aspects, this systems perspective should also take into account dimensions of sustainability in an integrated manner in order to be successful.
- Examples of such approaches are participatory scenario processes, such as those carried out for the NRW Climate Protection Plan (Lechtenböhmer et al., 2015), or the multidisciplinary research programme of the IDRIC in the UK.

3. Today's market structures have been created - with strong government influence - in parallel with the structures of fossil-based industries. The paradigm shift towards climate neutrality now requires a corresponding transformation of core markets and the creation of new ones. This applies both to markets for renewable energy and to the creation of markets for ‚green' industrial products, e.g., through standards or quotas to stimulate demand, based on setting definitions for ‚green' products and processes.

4. Building capacity for governance and change.

- Climate change mitigation has been primarily an energy policy issue (and to some extent a housing and transport policy issue). Industrial decarbonisation is a very new area that requires appropriate institutional capacity at all levels of governance, not only for adoption processes. In particular, its high technical and economic complexity and its close links with resources, innovation, foreign trade and geopolitics require the creation and development of specific institutional structures and expertise in policy and administration.
- Such an institutional component, linking different policy areas, should play a central role in the Industrial Strategy and related strategies.

5. International coherence is particularly necessary for industrial transformation, as there is a strong need for international coordination in addition to global climate and trade agreements.

- International coordination is needed both to mitigate the problems of global commodity markets for the transition, and to build new international partnerships that enable developing countries to leapfrog to clean industrial structures rather than replicate un-sustainable fossil development patterns and to seize the development opportunities offered by often abundant renewable energy and resources (Hermwille et al., 2022).
- In addition to existing initiatives such as the Glasgow Breakthroughs, Mission Innovation, LeadIT and the Industrial Deep Decarbonisation Initiative, sectoral climate clubs (e.g. an international steel club) can be fruitful approaches to internationally coordinated policy.
- Just Energy Transition Partnerships, concluded with South Africa and currently being negotiated with Indonesia, could be a vehicle to catalyse clean industrial development in the partnership between Europe and developing countries.

6. Finally, it is important to take action on the downside of the transition: An industrial strategy should also take into account necessary technology or market exits and their socio-economic impacts in an integrated way.

- Industrial transformation will entail structural changes in certain companies, industries and particularly regions. In addition, in a more climatefriendly world, challenges will arise from better production conditions in other regions of the world where, for example, large and cost-effective renewable energy potentials can be tapped. This „renewables pull" effect could trigger industrial relocation ("green leakage") (Samadi et al., 2023).
- Like coal mining, process industries are often spatially concentrated and their transformation can have similar consequences and trigger similar resistance. It is therefore important to contribute to the development of instruments and to integrate the reorientation of companies and industrial regions into the industrial strategy. This also applies to employment relationships, collective agreements and codetermination in companies, some of which are threatened by

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transformation. At the same time, the innovative capacity and competence of the industrial workforce can be integrated and used constructively through appropriate integration, which also makes an important contribution to the human capacity and expertise required for transformation.

Conclusion

The manufacturing industry faces major and unprecedented challenges as it transitions key processes to non-fossil energy and feedstocks. These changes will require new forms of cooperation between stakeholders from industry, society and governments, which can be created by an active systemic industrial policy for the transition to climate neutrality. Such a new industrial policy needs to consist of an integrated policy mix, including a range of market-based instruments such as the ETS, the adaptation of market rules, e.g., in electricity markets, and the creation of new green markets. However, it will also require a strong emphasis on faster planning procedures, public investment in infrastructure, e.g., for new green energy supply, research and subsidies for the market entry of new production processes, as well as active stakeholder engagement policies. Finally, strong policies are needed to accompany the necessary "ex-innovation" processes, especially in heavily industrialised regions, and, last but not least, the creation of strong public institutions.

Such a much more active cooperation between public and private actors is not only challenging, but may also fail, or at least be insufficiently successful, in some areas. Such a risk is particularly daunting given the complexity and urgency of the challenges ahead. The creation of strong and capable (public) institutions, including strong scientific underpinning, and a strong involvement of societal stakeholders, together with flexible policy design, can be means to enable such a new industrial policy to be flexible and adaptable to mistakes. For European companies, particularly those in energy-intensive manufacturing industries, this means a major innovation challenge. In addition to the need to innovate their products and processes and their competitive access to markets, they need to be much more actively engaged with their communities, ranging from their employees to the communities in which they are located to those that need to support infrastructure. This means that companies need to actively develop and focus on their societal value as one of their core outputs and business objectives.

This means that Europe has the opportunity, based on its technological competence and its ability to align market forces with societal goals, to successfully implement an active systemic industrial policy and to lead the transition to climate neutrality and make it a success. The European Green Deal is a bold first step in the right direction.

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