Fraunhofer ISST

The Future of Industrial Value Creation Systems

A Perspective From German Industrial Companies

Contents

DESMA

dormakaba

FIEGE

KOSTAL

KSB

klöckner & co

MURTFELDT

SEW EURODRIVE

thyssenkrupp

VOITH

wilo

Project led by:

Fraunhofer ISST

Fraunhofer IAO

Supported by:

Federal Ministry of Research, Technology and Space

Changes in Industrial Value Creation Systems

How companies are responding to technological, societal and geopolitical upheaval — and how they are seizing new opportunities for staying competitive over the long term

Three Drivers of Change:

1. Digitalization
2. Automation
3. Circular economy

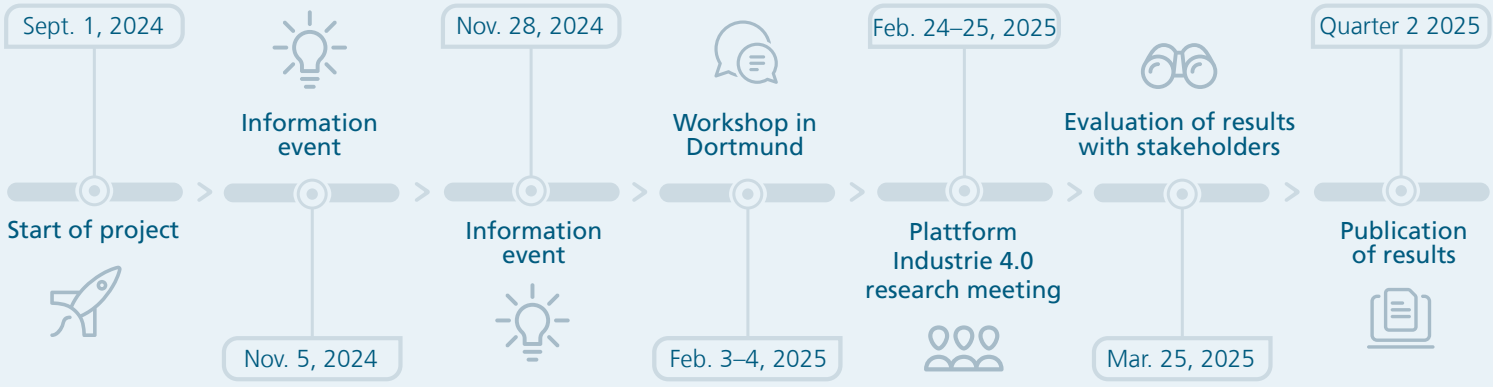
Industrial value creation is in a state of profound change driven by innovations in technology, geopolitical shifts and expectations from society. Increasingly, traditional production processes that follow linear paths are becoming value creation systems that are flexible, densely networked and sustainable.

Challenges and Opportunities

The key drivers of this transformation are digitalization, automation and concepts focusing on the circular economy and sustainable production. They are presenting companies with significant challenges to overcome, but also new opportunities for boosting competitiveness. This is leading to a growing focus on new business models based on resource efficiency, emissions reduction and a holistic view of product life cycles. At the same time, burgeoning technologies such as artificial intelligence and the Internet of Things are creating the right conditions for optimizing production and decision-making processes and establishing more transparency throughout the value chain. On the other hand, geopolitical upheaval — particularly in the context of trade relationships and regulatory requirements — is exerting additional pressure on the formation of global supply chains, resulting in companies turning their thoughts specifically to local production strategies and a strategically diversified supplier structure in a bid to enhance their resilience. Societal expectations are also changing: Consumers are increasingly interested in ethical and sustainable production practices, compelling businesses to go beyond simply being profitable and focus more heavily on social responsibility and environmental sustainability. These changes are requiring corporate strategies to undergo comprehensive adaptations for the sake of ensuring that businesses can achieve long-term success and stay viable into the future. For numerous companies, deciding on the exact form that future value creation systems will take is also a strategic challenge that is fraught with uncertainties about basic regulatory, technological and environmental conditions. At the same time, however, it is clear that companies are increasingly willing to shoulder responsibility and are approaching sustainability requirements as not only an obligation, but also a driver of innovation and differentiation.

Methodological Framework

To achieve a common understanding of future value creation systems and the research questions associated with them, Fraunhofer ISST — working with the support of Fraunhofer IAO and the German Federal Ministry of Research, Technology and Space (BMFTR) — began by staging two information events involving key



The participating companies were involved in the project at different points along the way: Klöckner & Co, KSB, thyssenkrupp, Wilo and one other company took part in the first information meeting (on November 5, 2024). dormakaba, KOSTAL, Miele, Murtfeldt and VOITH were then represented at the second information event (on November 28, 2024). DESMA, dormakaba, Klöckner & Co, KOSTAL, KSB, Miele, Murtfeldt, thyssenkrupp, Wilo and one other company all took part in the two-day workshop on February 3 and 4, 2025. Finally, all the companies whose participation was requested took part in the evaluation of the interim results on March 25, 2025. A total of 14 companies were involved in the process as a whole.

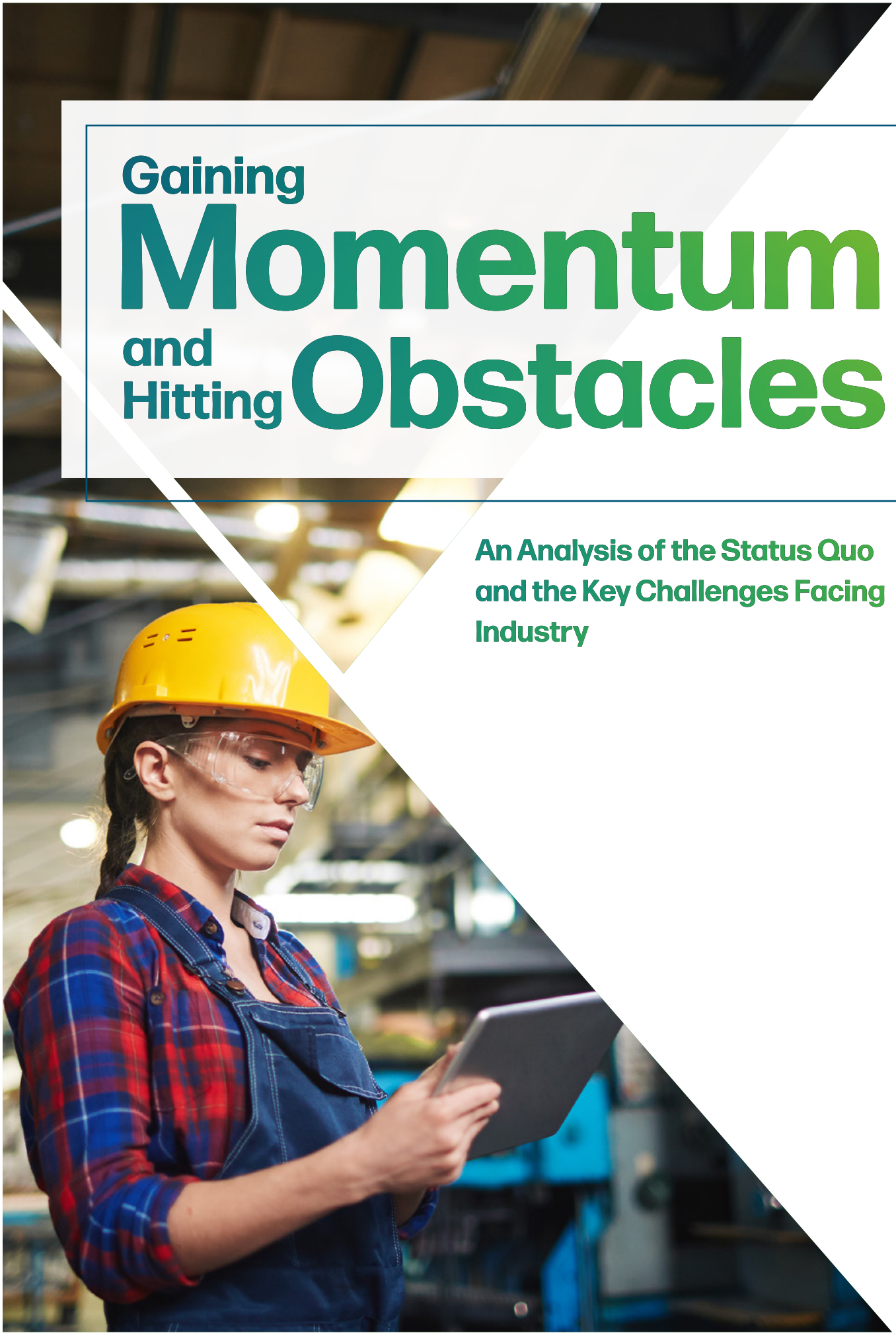
representatives of German industrial companies. The discussions held during these were then used to prepare for a two-day workshop focusing on systematically identifying and outlining the key elements of future value creation systems. The results were considered in more detail in a multi-stage process. To create a starting point with a solid foundation, the workshop participants first outlined the status quo that exists within modern-day value creation systems, working against a backdrop of points that had been raised during the information events. Building on this, they then explored future trends that are set to have an impact on value creation systems. Using a tool called the Future Value Creation Canvas, the participants devised potential scenarios for future value creation systems; these ultimately provided a basis for drawing out key research questions. Methodologically speaking, the process was based on developing thesis statements and forward-looking ideas based on the current state of research and technology, with the addition of a qualitative content analysis aimed at developing a research agenda. An initial opportunity to reflect on the results was provided on February 24 and 25, 2025, in a research meeting held by Plattform Industrie 4.0. This was followed by a meeting involving the project participants on March 25, where a preliminary sketch illustrating the value creation system of the future was evaluated.

Aim and Outlook of This Report

This report summarizes the results obtained from the work that has been conducted to date, and looks at how industrial value creation systems are set to develop in the future from the perspective of German industrial companies. It highlights significant changes that value creation systems will see in the future, and outlines which opportunities and challenges will arise from these. The focus of the report is on technological innovations, new business models and the changing landscape around basic regulatory and societal conditions.

Strategic Challenge

For many companies, shaping future value creation systems is a task that is plagued by uncertainty — but also offers huge potential.



Gaining Momentum and Hitting Obstacles

An Analysis of the Status Quo and the Key Challenges Facing Industry

The Status Quo of Industrial Value Creation Systems

In order to pinpoint the development prospects that may be available for industrial value creation systems, it is essential to start by looking at the position that these systems are currently in, along with the key challenges they face, the factors influencing them and current trends. The sections that follow provide a structured overview of this.

SWOT Analysis for Identifying the Current Situation

A SWOT analysis, looking at key strengths, weaknesses, opportunities and threats from the perspective of industrial companies, was systematically conducted with the aim of assessing the current position that industrial value creation systems find themselves in. The analysis was based on the results of the information events held ahead of the workshop, and illustrates the factors that are particularly important in industry players staying competitive and fit for the future.

Focus on Success Factors and Structural Weaknesses

The key *strengths* demonstrated by today's industrial value creation systems include strong, trust-filled partnerships within existing value creation chains and the outstanding technical expertise possessed by German companies in major industry sectors. Another success factor is targeted application of standards and Industry 4.0 technologies — especially the Internet of Things, which is a huge driving force in making production processes digitalized and efficient. On the international stage, German companies' participation in major European projects also makes them more competitive and strengthens their data sovereignty. The high quality standards that German innovations meet, particularly when it comes to new developments, is another significant competitive advantage. On the other hand, *weaknesses* preventing value creation networks from achieving their full potential present certain challenges. Cultural differences within international collaborations and in corporate cultures internally often create barriers. Additionally, companies often stifle their own potential by using inefficient internal processes and structures when they are trying to be innovative. A lack of resources also makes it difficult to comply with legal requirements, and companies are put at a competitive disadvantage by technology that is lagging behind when compared with global standards. Not only that, but insufficient preparation work as part of internal data management creates obstacles in collaborations, and companies are susceptible to disruptions if they are highly reliant on global supply chains.

Despite these challenges, there are numerous *opportunities* that could aid in the advancement of industrial value creation networks. The development of new business models and services based on data opens up potential for additional value

The SWOT analysis is a strategic tool for evaluating the status quo. It takes a systematic look at strengths, weaknesses, opportunities and threats. Its aim is to make internal potential and external influencing factors more transparent — creating a basis for well-founded strategic decisions.

	Strengths	Weaknesses
Internal factors	■ Strong partnerships within existing value chains ■ Strong expertise in major sectors ■ Application of standards and I4.0 technologies, such as IoT ■ Established major European projects with German involvement, strengthening competitiveness and data sovereignty ■ Quality of (new) developments in Germany	■ Cultural differences as a barrier to continued operationalization ■ Companies sabotage themselves with the internal processes and structures they use in practice ■ Lack of resources for meeting legal requirements ■ Technology lagging behind when compared with global standards ■ Lack of readiness in internal data management, creating an obstacle to collaboration ■ Susceptibility to disruptions in global supply chains
	Opportunities	**Threats**
External factors	■ Development of new business models and services based on data ■ Improved sustainability through optimized use of resources and circular economy ■ Access to new markets/customers through innovative services and the platform economy ■ Promotion of open-source solutions and cross-sector collaboration	■ Growing geopolitical tensions and trade disputes ■ Reliance on global supply chains and raw materials markets ■ Data privacy and security concerns as networking increases ■ Challenges in standardization and interoperability between various systems

Opportunities to be Harnessed

Threats to be Managed

creation. More sustainable and efficient industrial processes can be achieved by optimizing the use of resources and harnessing a circular economy. Innovative services and the platform economy have the potential to reach new markets and customer groups, while open-source solutions make it possible to strengthen cross-sector collaborations and take advantage of synergies.

There are also various *threats* working in opposition to these positive opportunities for development, however. Growing geopolitical tensions and trade disputes may jeopardize the stability of global value chains. Reliance on international raw materials markets represents another source of uncertainty. The world is also becoming increasingly networked, giving rise to more data privacy and security concerns that could have a negative impact on the trust placed in digital solutions. Finally, standardization and interoperability between various systems pose significant challenges: If systems are incompatible, it may be difficult to integrate new technologies and make them operate efficiently.

Trends and Consequences

Based on the strengths and weaknesses that companies already present, and the challenges identified for them, it is clear that industrial value creation systems are in a state of profound change. To develop strategies with a viable future, it is essential to identify key trends early on and categorize the impacts they may have on companies and value creation networks. This process focuses on fundamental questions in areas such as the openness of systems, the intelligent orchestration of complex value creation networks and the future role that employees might have.

Open vs. Proprietary Value Creation Systems

In the past, there were two fundamental approaches that dominated how innovation processes were shaped: *open* and *proprietary* systems. Open systems are based on collaborative, transparent structures in which knowledge is shared, common standards are developed and innovation is encouraged through collaboration. By contrast, proprietary models are based on closed, controlled systems whose hallmarks are exclusive access, confidentiality and patent protection.

Nowadays, the clear line separating the two system types is becoming increasingly permeable (see Figure 1: Trends and consequences in an open vs. proprietary context in the appendix). Since technology-based USPs are often short-lived, international competition is looking for new ways for systems to mark themselves out from the rest. In light of this, companies need to keep developing new USPs — whether they present themselves through sales, marketing, quality or an outstanding user experience. In this context, the principle of openness is becoming increasingly strategically relevant, especially in areas where innovation happens frequently. Openness — in the form of open-source approaches or open business models — can help to reduce development risks, accelerate innovation processes and improve access to external insights. At the same time, it does not make sense to apply an open approach uniformly to every stage that a product goes through. The degree to which openness should be present varies throughout the product life cycle: Proprietary strategies are more appropriate in the early stages, when new developments need to be protected and competitive advantages secured. Later on, when a product has reached maturity and the technological leaps and bounds it is making are becoming less significant, it makes sense to create more open access to the knowledge associated with the product.

Over time, what was once a nugget of gold eventually turns into a commodity — an everyday item that no longer holds a competitive advantage. This dynamic balance can also be seen in approaches to product data and intellectual property. While product data ecosystems are often given open designs in order to encourage compatibility and integration, critical IP elements remain proprietary — resulting in a hybrid model. Companies take an open approach specifically where it encourages innovation, and they exert control where protection is needed. The kinds of open standards that emerge in various sectors also require collaborative processes, something that has an impact on corporate culture. This shift in favor of more openness is urging organizations to move away from silo mentalities and establish a culture of sharing and collaboration. At the same time, there are certain elements of value creation systems that do require confidentiality — although patent registration is not a universal solution in this context. Not only is it bound up with significant costs and time demands, it does not provide a cast-iron guarantee of protection as the effectiveness of intellectual property rights concerning technology may end up being limited by workarounds or protracted testing processes. Clearly, openness and protection are not completely opposing concepts, but rather complementary elements of a differentiated innovation strategy, so the degree to which openness is applied needs to be managed in a way that is sensitive to the context and appropriate for the stage a product is at. The aim in doing this is to harness potential for innovation as effectively as possible, reduce risks in specific areas and ensure long-term competitiveness on the international innovation stage.

Orchestrating vs. Producing Companies

The relationship between orchestration and production is also undergoing changes within today's value creation systems. Although both are already established concepts that present themselves in various forms, a clear trend in favor of orchestrating structures is emerging (see Figure 2: Trends and consequences in an orchestration vs. production context in the appendix), and is being accelerated in particular by increasingly complex products and a growing sense of individualization in highly diversified markets.

Orchestration — meaning coordinated management of services, processes and partners throughout a product's life cycle — is becoming more and more strategically relevant in this setting. It is a development that is being spurred on by the growing demand for tailored, adaptive solutions, something that enabling technologies such as adaptive manufacturing and digital twins have a vital role in meeting. Technologies of this kind make it possible to integrate complex product and process data and respond dynamically to changing market conditions or customer needs.

However, classic production-oriented value creation still has its place, especially when it comes to standardized products. Efficiency, throughput and pipeline-focused processes are at the heart of this approach and have proven themselves to perform particularly well in stable market environments. It is not enough to simply focus on one of these approaches or the other: Instead, the value creation systems of the future will require the two strategies to coexist and integrate in a way that is sensitive to the context in question — that is, based on the product type, solution maturity level and intended business model.

Putting orchestrated value creation into practice does come with significant challenges, however. With so many different platforms currently in existence, there are incompatibility issues, data exchange is difficult and strict demands need to be met in the areas of data security, data quality and data privacy (particularly in the light of the GDPR). Therefore, the efficiency with which a value creation network can be configured and managed largely dictates how successful it is. Against this backdrop, it is clear that companies are increasingly acting as designers and coordinators of complex ecosystems. It is becoming more and more important for them to home in on aspects such as a strategic focus on core areas of internal expertise, the company's vision and the ability to integrate external partners and platforms. Roles such as product owners who act as managers/agents, or orchestrators who are generalists, highlight how conventional approaches to production are transforming into dynamic business models focused on services and networks.

Supervisory vs. Executing Personnel

The growth of digitalization and automation is changing not only the technological foundations underpinning work processes, but also the manner in which people are collaborating with artificial intelligence (AI), robots and internal chatbots. At the heart of this is the question of what role humans will play when they work with AI, robots and internal chatbots in the future — and especially what changes they will see in their job profiles, skill requirements and innovative capabilities.

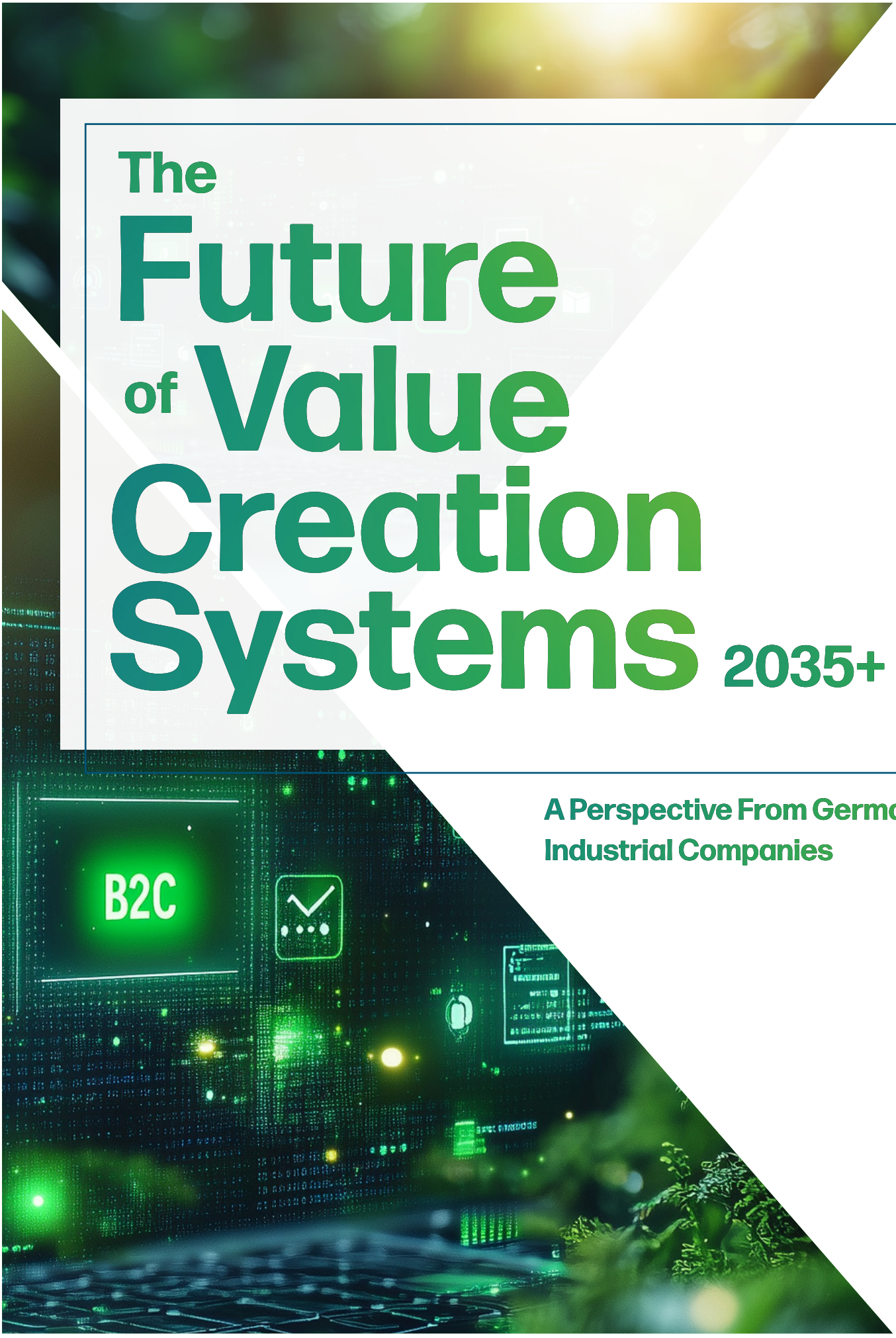
A major trend in this context is collaborations between humans, AI and robots in which executing and supervisory tasks are becoming more and more automated. This is leading to a fundamental shift in the role of humans, who are increasingly acting as coordinators, interpreters and holders of responsibility rather than executing or managing tasks themselves (see Figure 3: Trends and consequences in a supervision vs. execution context in the appendix). As a result, there is a need for humans, machines and AI to be strategically orchestrated so that work processes can run efficiently, safely and in a way that promotes innovation. This transformation is also going hand in hand with a clear shift in the types of duties that employees are expected to perform. The focus of their activities is now moving further toward areas that require insights into people, social skills and strategic thinking. There is also a challenge in ensuring that knowledge is transferred as necessary to automated entities such as AI systems. The ability to communicate knowledge and supply digital systems with information effectively is becoming a key skill.

The introduction of internal chatbots is an excellent example of this development. The employees of the future will need to not only learn how to operate these systems, but also have the ability to scrutinize and validate their outputs through a critical lens. For this reason, putting appropriate onboarding processes and ongoing training in place will be an important organizational task. Another area of tension is emerging due to the decline in operational activities, something that can potentially lead to a loss of practical knowledge. This creates the risk of losing vital practical experience, which can in turn have an impact on innovative strength. Areas such as construction are seeing increasingly less development activity, posing the question of how it will be possible to develop new innovations in the future if people are becoming further and further detached from actually doing certain activities themselves.

The growth of automation is also leading to a potential reduction in expertise levels within technical disciplines, as the role of operational skills is becoming less important. Because of this, companies will need to invest specifically in the technical, social and methodological skills their employees will need in the future — such as the ability to use AI systems effectively, work in an interdisciplinary environment and learn within dynamic settings. What this means is that digitalizing and automating supervision and execution tasks is a challenge that is not just rooted in technology — it needs an organizational and cultural approach above all else.

The Future of Value Creation Systems 2035+

A Perspective From German Industrial Companies



A New Understanding of Future Industrial Value Creation Systems

By considering the status quo and the trends illustrated in this report, we can move toward a new understanding of what industrial value creation systems will look like in the future. Although these systems will continue to include key value creation processes such as product development, production, sales, use and recycling of goods where appropriate, they will also be underpinned by four main concepts.

Role of humans

Humans ***interacting intuitively with autonomous technology*** (such as agentic AI) in a range of dynamically changing roles

Data and AI as foundation

Fully automated data and application landscape, plus ***natural language-based interaction with corporate knowledge*** through consistent use of AI and digital twins

Resource-neutral, circular economy

Complete reuse of resources — a total circular economy — even in the face of significant uncertainty on procurement markets

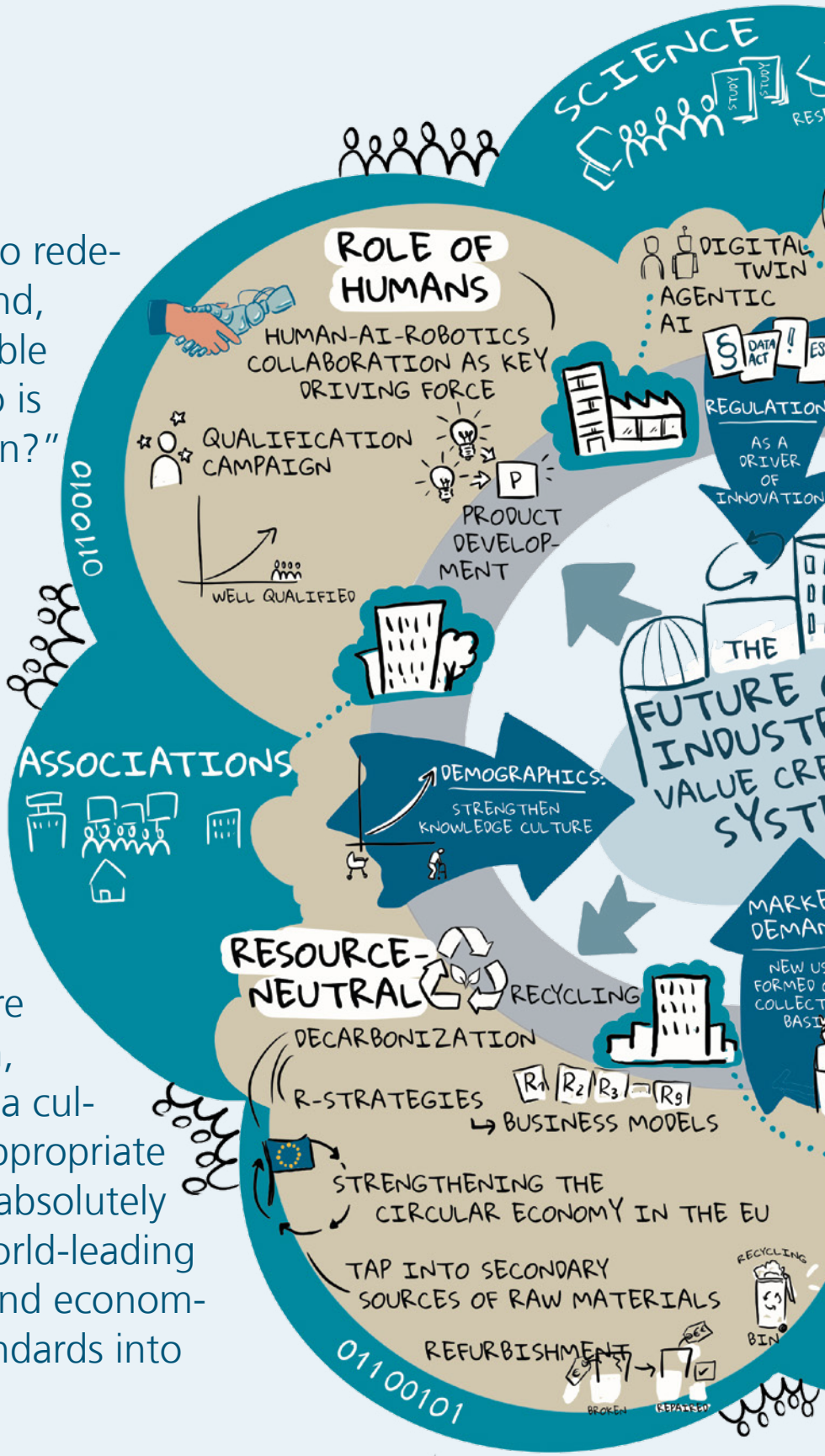
Customer-centered ecosystems

Production companies as ***orchestrators of customer ecosystems*** and, therefore, catalysts of customer innovation

Together, these key design elements will form the basis for a future-proof, adaptive industrial value creation system that is able to adapt flexibly to changing framework conditions (see the image on the next page). The sections that follow will take a closer look at the stakeholders involved in future value creation systems, the effects of the key design elements referred to above and the specific impact of the context in which a system is designed, something which may include demographic or regulatory changes, for example.

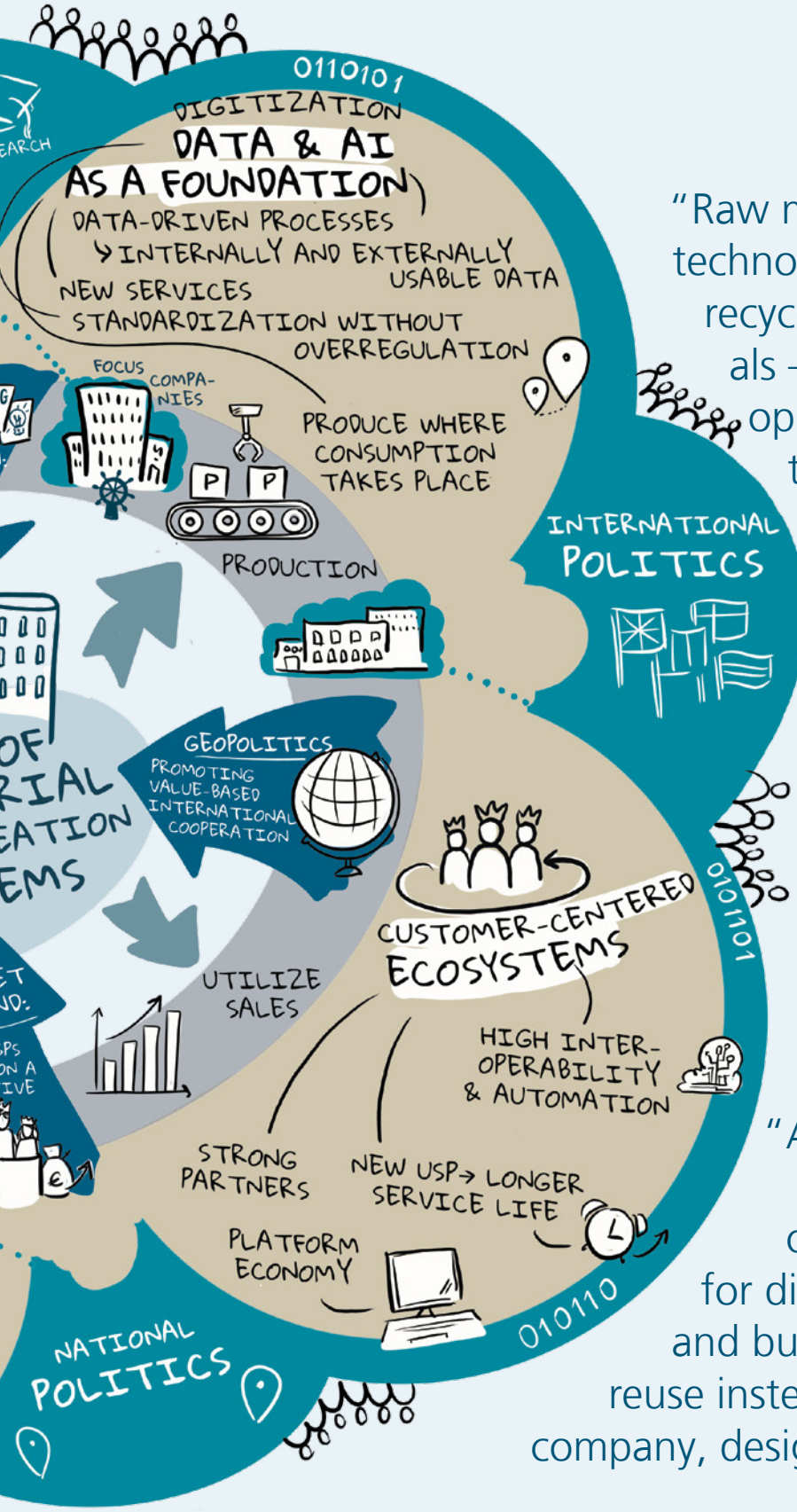
"Humans and AI need to redefine their roles. In the end, who is actually responsible for supervision and who is responsible for execution?"

Karsten Radtke,
thyssenkrupp Uhde



"Clear standards that are conducive to innovation, competitive conditions, a culture of openness and appropriate training for experts are absolutely essential for creating world-leading products. We need to find economical ways of putting standards into practice."

Christian Decker,
DESMA Schuhmaschinen GmbH



"Raw material sovereignty requires technologies that enable complete recycling of strategic raw materials — now, our task is to develop these technologies and use them exactly where they are needed."

Christian Berger, Wilo

"A value creation system that is fit for the future is based on circular principles: design for disassembly, design for repair and business models that focus on reuse instead of waste. How do I, as a company, design a value creation network in a circular economy?"

Thorsten Westermann, Miele

Important Stakeholders

Designing value creation systems with a viable future requires coordination between a number of important stakeholders, each of whom has a different role and set of responsibilities.

Focus Companies are Companies That Orchestrate

- the ecosystems in which customers operate,
- the role that people play in the system,
- how AI and data can be used as a foundation
- and, therefore, entire value creation systems in the future.

Industrial companies have a major part to play in this. They are primarily responsible for putting the key design elements of systems into practice, and they make strategic decisions about the specific features that future value creation models will have. Innovation-driven developments such as integrating data-backed processes, using artificial intelligence and implementing sustainable business models are primarily initiated and advanced by the actions that take place within companies. In this context, companies can act as *focus companies*, taking on a coordinating role within value creation networks and providing a central source of momentum for transformation processes along the entire supply chain. *Industry associations* serve a supporting purpose here, especially when it comes to establishing and practicing cross-sector principles such as the circular economy. They encourage dialogue between companies and provide platforms for developing common standards and initiatives.

International politics also have an impact on what value creation systems will look like in the future. Trade agreements, geopolitical developments and the process of defining global standards and regulations affect the structure of global supply chains, something that in turn has a direct effect on which locations companies choose to be based in. In this context, political stability and international cooperation based on values have a major impact on the stability that economic stakeholders feel when making plans and taking action.

On a *national level*, legal framework conditions and strategies developed on the basis of industrial policy affect the direction in which industrial value creation systems develop. Governments lay the foundations for innovation, competitiveness and sustainability by providing funding, regulation and strategic programs. In this context, political governance measures hold a significant role in achieving societal and environmental objectives within industrial processes.

Finally, *science* is a key contributor to the development of value creation systems. Applied research and technology innovations provide fresh momentum for boosts in efficiency, sustainability and digital transformation in industrial production. The insights gained from these areas lay the foundations for evidence-based decision-making processes, and make it possible to keep adapting existing systems to changing conditions.

Key Design Elements

The value creation system of the future is based on four key design elements.

The first concept is known as the *resource-neutral, circular economy*, which relies on the principle of complete resource circulation. Instead of new raw material consumption, this model focuses on preserving, reusing and regenerating existing resources within closed cycles. Its aim is not just to avoid waste, but to eliminate the consumption of new raw materials altogether. With intelligent product design, digital traceability and industrial collaborations in which competitors act as partners, it is possible to feed products, components and materials through circular usage loops several times over. Easy disassembly, repairability and reusability are systematically factored into this concept right from the design stage. Additionally, digital systems make it possible to track resources seamlessly throughout their entire life cycle, allowing the circular system to be managed and optimized with precision. In this setting, companies are no longer isolated — they operate within circular ecosystems where the production waste from one business provides valuable input materials for another. There is also a fundamental shift in the role of end consumers, who no longer engage in linear consumption and instead are active users in collective, service-focused usage models such as sharing, leasing or product-as-a-service. Over the long term, the resource-neutral, circular economy aims to achieve more than just environmental sustainability — it also has its sights set on economic resilience, support for innovation and social justice. It marks a paradigm shift toward a responsible economic model that is fit for the future.

As indicated in the description of the resource-neutral, circular economy concept, customer relationships are set to look fundamentally different in the value creation system of the future. One-off, specific interactions will be replaced with ongoing, dynamic relationships functioning within ecosystems that are networked across sectors and companies. Production companies will act as orchestrators of complex customer networks and provide platforms on which customers, partners and even competitors can work together to create added value. This will lead to *customer-centered ecosystems* with a high degree of personalization, where individual customer needs will be addressed using data-based services. This development marks a paradigm shift in how businesses deal with customers, moving the focus away from one-time instances of selling products and toward long-term relationships, collaborative solution development and a common goal of sustainable use. Customers will become active participants in service portfolios, with their requirements feeding directly into design, production and service development processes. This new approach to industrial value creation will produce resilient systems that have the ability to learn — and can respond flexibly to external changes and encourage ongoing innovation.

Another element at the heart of value creation is a fully *data-driven information system* that can achieve new standards of transparency, agility and efficiency by harnessing artificial intelligence, agent systems and digital twins. All key data points drawn from everything ranging from product use to logistics and environmental conditions are recorded, analyzed and fed into intelligent decision-making processes.

In this context, artificial intelligence is no longer simply an analytical tool supporting the process, but rather a proactive partner that accompanies the entire value chain. It allows reliable forecasts to be made and resources to be allocated dynamically during the planning stage, automatically generates optimized product variants during the design stage, looks after predictive maintenance and adaptive process control during production, and provides support for creating personalized services and automated communication processes during customer interactions.

Digital twins make it possible to simulate scenarios with precision and identify risks, bottlenecks or inefficiencies early on. They are a vital tool in continuously optimizing processes and products throughout their entire life cycles. Combined with agent-based systems that are able to act and cooperate autonomously, they result in a self-regulating, learning system that responds flexibly to changes and keeps improving all the time.

This far-reaching level of digitalization makes it possible to achieve a complete understanding of value creation in real time, allowing efficiency to be leveraged in various ways and creating scope for developing ongoing, sustainable customer relationships of the type described previously.

In spite of these advancements in automation, *humans* remain key players in value creation and will continue to shape systems and define their purpose. However, their role is also undergoing significant changes. As humans, AI and robots take an increasingly collaborative approach to interaction, the duties that they are required to fulfill are changing. More and more routine activities are being taken on by intelligent systems, leaving humans to contribute their specific skills in areas involving creativity, critical thinking and social and communicative interaction. In this new landscape, humans will be orchestrators of technological processes and build bridges between technical systems and human needs. Not only will they remain an integral part of value creation, but the future will continue to see them provide direction, values, normative guidance and a sense of responsibility.

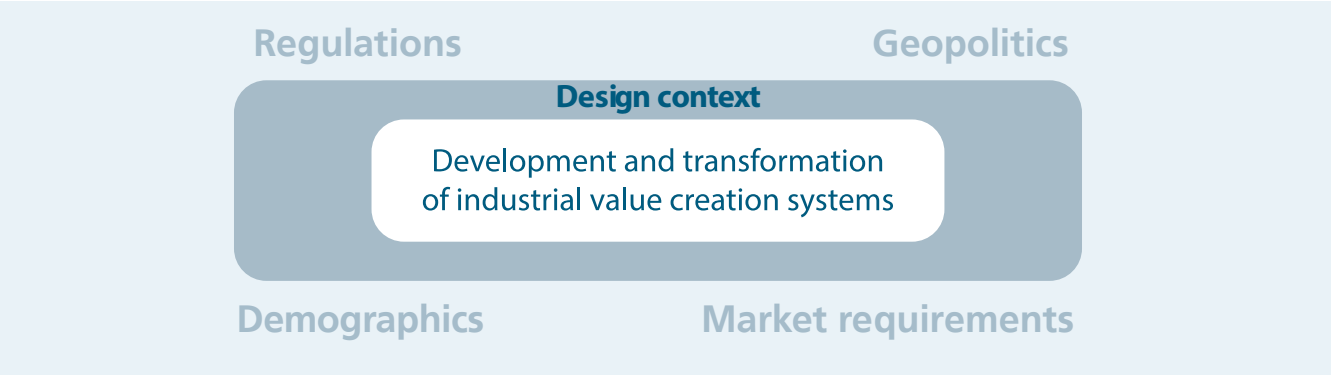
When considered in relation to the key design elements presented in this section, the trends discussed in "Trends and Consequences" can be interpreted as pivotal design options that have a significant influence on both the structural features of value creation systems and how they operate. This opens up different areas in which the various stakeholders involved have room to act:

Those with a part to play in ecosystems have to decide how open to make the value creation system and identify a suitable compromise between two sides: one involving a high level of interoperability and decentralized cooperation, and the other involving closed, more tightly controlled environments. The strategic focus of the value creation system will continue to be a key source of conflict, centered on the question of whether the system needs to concentrate primarily on coordinating and networking processes (orchestration) or on direct physical production of goods and services. This decision is strongly related to the role of the focus company, which can act either as an orchestrating hub within a digital ecosystem or as a producing stakeholder with vertically integrated processes. In turn, this ties closely into another area of tension surrounding how to balance supervision of activities and execution of activities within the value creation system. Although AI-supported technologies are increasingly capable of monitoring, analyzing and optimizing processes, executing activities is still the preserve of humans or machines, depending on the context.

Where its key design elements are concerned, the value creation system of the future will have various options available in order to strike the right balance. It will be a dynamic system with the ability to create flexibility within the design elements that have been defined for it, and will be able to keep adapting to changing requirements in technology, market economics and society. This adaptability will allow stakeholders to respond to new challenges in the design context outlined in the next section, and to optimize their positions in the ecosystem in line with their strategic focus and the resources available to them.

Design Context

The design context establishes the outer framework within which industrial value creation systems are able to develop and transform. There are four main areas that define this context: regulations, geopolitics, demographics and market requirements.



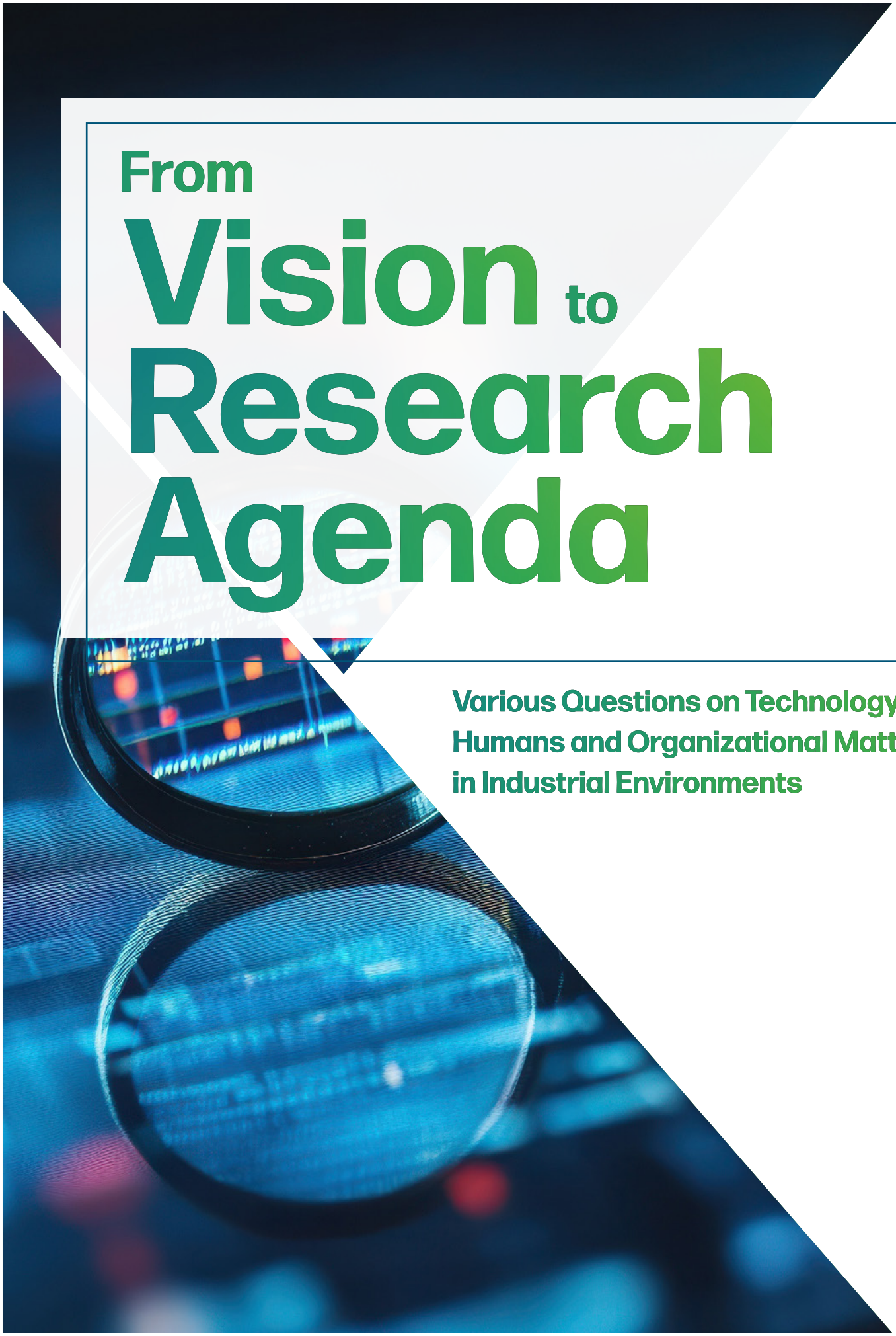
Regulations are of major consequence because legal and normative conditions have a direct impact at a variety of levels in industrial value creation. Legal standards and provisions affect product development, for example, by establishing certain safety, sustainability or quality requirements that have to be met. At the same time, regulatory stipulations have an impact on process design by encouraging companies to engage in resource-efficient practices — although they also create a risk of overregulation. Additionally, the need to keep adapting business models to national and international guidelines requires outstanding agility. In this context, regulations may create restrictions, but they may also be drivers of innovation.

Geopolitics are another factor with significant influence. Political stability, international relationships and economic cooperation have a major say in the locations where companies choose to be located and in global networks focused on industrial value creation. Production decisions are increasingly being made on the basis of fundamental geopolitical conditions such as secure supply chains and access to markets and raw materials. International trade agreements and political relationships also influence sales strategies and value propositions. The strategic decisions that companies make increasingly have to take political parameters into account. In this context, it is becoming ever more important to foster values-based international collaborations as a means of ensuring stable and resilient global value creation systems.

Demographic developments have an impact on both supply and demand in industrial processes. In particular, demographic shifts and an aging population are leading to changes in consumer needs and a growing lack of qualified experts. As the knowledge possessed by members of the workforce keeps changing and evolving, specific measures that will help them acquire certain skills are needed. In light of this, an essential condition for making industrial value creation systems future-proof is developing and promoting a company-wide culture of expertise at the micro level and targeted educational content in our educational facilities at the macro level.

Market requirements have a direct impact on the design of future value creation systems. Customer needs are increasingly moving toward individualized products, high levels of interoperability and end-to-end automation. These demands are leading to a greater focus on customer-centered ecosystems that extend beyond the boundaries of companies. At the same time, new USPs are emerging through long-lasting, resource-efficient products, for example, or platform economies that favor collective innovations over benefits that exist solely within a single company. Because of this, the ability to develop and implement USPs of this nature on a collaborative basis is becoming a key competitive advantage.

From Vision to Research Agenda



Various Questions on Technology, Humans and Organizational Matters in Industrial Environments

Determining Research Questions

The insights we need today in order to take industrial value creation to the next level — and how we can identify specific areas in need of research on that basis.

The process of designing new value creation systems produces a variety of questions (including research questions) on subjects such as integrating digital technologies, the sustainability of production processes and changes in work and organizational structures. There are also fundamental questions on how value creation is distributed, new forms of collaboration and impacts on existing business models. The participants in the workshop mentioned earlier on completed a structured template as a way of systematically collating all these questions. This approach recorded not only the questions themselves, but also where the responsibilities for each of them were thought to lie and how urgent they were believed to be.

As the "Important Stakeholders" section outlines, it is not only industrial companies that have a key role to play in future value creation systems — politics (both national and international), associations and the scientific world do as well. Where urgency was concerned, the participants had the opportunity to indicate whether a research question should be addressed within the short term (< 1 year), medium term (< 3 years) or long term (< 5 years). The results show that most of the research questions were considered to be relevant within the short or medium term. The information below presents the research questions that were identified in order of urgency.

Core Regulatory Issues

- Inconsistent ESG criteria
- Lack of transparency in certification processes
- Lack of standardized evaluation models

In the short term, successfully transforming industrial value creation systems will require not only technological innovations, but — most importantly — consistent regulatory framework conditions, circular business models and a strategically coordinated approach to collaboration that extends beyond the boundaries of companies.

Out of 21 research questions in total, 14 are considered to require urgent action. The questions primarily relate to three subject areas: framework conditions, technologies and organizational matters.

The area of *framework conditions* brings up the question of how regulatory requirements can be made more flexible and incorporated into effective incentive schemes for encouraging sustainable practices in specific aspects of industry. Focal points in this area include strategies for increasing raw material recovery in the recycling process and identifying strategically relevant raw materials. Discoverability and recoverability of these materials in existing products are also pertinent themes in this context. Additionally, a point that remains unresolved is what overall impact various approaches have when compared with one another — for example, how recycling, repair and new purchases each perform in terms of environmental, social and economic efficiency. This is accompanied by the question of how environmental impacts relate to social performance and to legal framework conditions in value creation networks. The aim is to conduct a well-founded analysis of the potential impact that these approaches have and the scope for collaboration they provide in an industrial context.

Where *technologies* are concerned, we are seeing reflections on the role of artificial intelligence and other digital solutions in the value creation system of the future. Discussions are being held on the specific areas of application in which AI should be encouraged as a way of providing effective support in the transformation that is taking us toward a circular economy. The accessibility and usability of new technologies are also being considered, especially as information systems such as ERP or MES solutions become simpler.

In the area of *organizational matters*, there is the question of which stakeholders should be responsible for managing and orchestrating value creation networks, and which systemic framework conditions are required in order for this to take place. The question of how companies can design circular value creation structures is also being explored, with concepts such as design for disassembly and design for repair at the forefront. Additionally, discussions are taking place on potential incentive-based systems that would encourage industrial reuse and, ideally, would make it possible to do away with measures that are purely regulatory in nature.

Short
Need fo
< 1

Table 1 provides a structured overview of the questions raised in the workshop with a short-term timeline. Two research questions emerge as particularly pressing here. The first relates to the long-term transparency and governance of ESG regulations. This focuses especially on issues to do with institutional foundations, standardization of ESG criteria and the introduction of independent monitoring and evaluation mechanisms. The aim is to create reliability in the regulatory landscape in order to establish more security for companies when they are making plans and ensure that sustainability goals relating to society are met over the long term. A significant issue in this context is the lack of objectivity present when

ESG criteria are being rated. The underlying data and rating processes are neither transparent nor consistent in many cases, resulting in situations where one and the same company may receive significantly different ESG scores. To date, there has also been a lack of mandatory integration of ESG regulations into internationally established and standardized certification processes. This makes it more difficult to compare ratings and reduces how trustworthy they are. Additionally, social and governance-related aspects in particular are frequently overshadowed by environmental criteria, leading to imbalanced sustainability performance ratings. This problem is exacerbated by a lack of access to clearly defined and measurable KPIs, making it more difficult to develop effective management and control mechanisms. These deficiencies jeopardize the reliability that regulations aim for and hinder the ability to put effective ESG governance into practice on a sustainable basis.

t-term
r Action
year

Another major concern for industrial companies is creating resource-preserving value creation networks that extend the life cycle of products and close material cycles. In this area, the second key research question is targeted at the structural and strategic realignment of industrial processes in the context of sustainable economic systems. The concepts of design for disassembly and design for repair are at the heart of this, playing a key role in how circular business models will be put into practice. These approaches are introduced as early on as the product development stage and aim to design products that can be easily disassembled, repaired, reused or recycled at the end of their lives.

However, putting these design principles into practice is associated with various challenges. To take one example, there is still a lack of widely standardized directives and sector-specific standards that enable systematic integration into existing product development and production processes. Additionally, developing circular value creation networks requires close coordination with suppliers, service providers and disposal partners, presenting many companies with organizational and logistical obstacles. Not only that, but the transformation in the direction of a circular economy also implies that business models will need to undergo profound changes. While traditional models are mostly based on linear consumption behavior and selling new products, circular approaches make it necessary to develop new value creation strategies such as product-as-a-service and leasing or sharing models. This shift inevitably requires investment and cultural changes within a company, and also assumes that regulatory incentives will be in place and that the market will be accepting of these models. Another problem is the lack of economic appeal in services based on repairs or take-back, particularly in cases that do not have appropriate pricing models or incentive structures in place.

Considering the above, developing circular value creation networks is an integrative process that requires not only technological innovations and strategic adaptations within companies, but also institutional and political support mechanisms.

Elements of Circular Business Models

- Design for reuse & repair
- Modularization & disassembly
- Reverse logistics & digital traceability
- Collaboration throughout the value chain

Challenges in Education Structures

- Lack of interdisciplinary education
- Few links between technology & economy
- Dwindling enthusiasm for technology
- Slow responsiveness to new skill requirements

In the medium-term timeline shown in Table 2, there are seven research questions with a significant need for action. These also address key challenges in the areas of framework conditions, technologies and organizational matters — challenges that need to be tackled as part of the move toward a value creation system that has a viable future.

In the area of *framework conditions*, the role of the education system is particularly prominent. The question here is what a future-oriented education system in Germany needs to look like in order to meet the complex requirements presented by the transformation taking place in industry and society. This includes strengthened interdisciplinary skills and a revival of general enthusiasm for technology among society. Promoting education in technical subjects, breaking up discipline-specific silos and finding new ways to communicate innovation skills are vital approaches for ensuring long-term innovative strength and competitiveness.

Where *technology* is concerned, the focus is on what role humans play in their interactions with artificial intelligence. As digital systems advance rapidly, we are increasingly being faced with the question of whether humans continue to have control over AI applications or whether more and more of these tasks are being delegated to machines. Determining this requires a critical look at the impacts on decision-making structures, responsibilities and the design of human-centered systems. At the same time, there needs to be an in-depth analysis of whether technological solutions for fully recovering strategically important raw materials are already in place or still need to be developed. Investigations are also being conducted into how AI can be used in specific areas along the entire value chain as a means of boosting efficiency — through intelligent forecast systems, automation or data-based support systems for making decisions, for example.

In the area of *organizational matters*, the focus is on setting the structural aspects of future value creation networks on a new course. This comes with a debate over the extent to which local or regional value chains are economically viable and which structural, political or infrastructural barriers are currently standing in the way of transformation. There is also a strong focus on the question of whether high recycling rates are a necessary condition or a possible consequence of the structures involved in this case. The social impact of future value creation systems is another aspect that is being given attention. An inclusive, fair transformation process means breaking down existing barriers and developing targeted measures for encouraging social integration. The aim is to make social implications a core element of the system design and take an active approach to shaping them.

During the workshop, a key priority for the participants was to tackle a technology-related question that considered the current status of recycling strategically important raw materials — such as rare earths, lithium and cobalt — and the technical opportunities available for recycling them. These materials are vital for key technologies in the fields of energy, digitalization and mobility. In the context of geopolitical dependencies, volatile markets and a growing demand for these resources, recovering materials from end-of-life products is becoming increasingly strategically important.

Mediu
Need fo
< 3 y

For many of these raw materials, there are already recovery technologies available in principle: Metals such as aluminum, copper, gold and nickel in particular have established recycling processes that are used in industrial settings. However, recycling rare and critical raw materials in practice is still being met with significant technical and economic

challenges. Many of these materials exist in complex compound structures or are present in very low concentrations in products, making recovery an elaborate, energy-intensive and often financially unappealing process. Another problem stems from the lack of consideration that the product design process gives to the raw material recovery processes that will take place later on. Without specifications or standards focused on design for recycling, it is not feasible to recover many raw materials in practice — even if the technology to do so exists in theory. Deficiencies in collection and disassembly infrastructures, plus inefficient return logistics, are also putting obstacles in front of raw material recovery processes. While there are some initial solutions available, they are not extensive enough to cover all strategically important raw materials, nor can they be scaled economically. With a view to the future, research will need to focus on how recovery technologies can be further developed and made accessible to a larger market.

m-term
r Action
years

Developing new technologies, such as those designed for recovering raw materials, requires a certain degree of enthusiasm for innovation. However, the workshop participants observed that open attitudes toward technological progress are on the decline in Germany. For this reason, they considered it particularly important to spark renewed interest and engagement in this area.

This research question is primarily focused on a key issue in education and innovation — namely, the decline in enthusiasm for technology and interest in engineering and science professions in Germany. Despite technological innovations playing a vital role in competitiveness, sustainability and societal transformation, the workshop participants observed that young people in particular are becoming increasingly detached from technical fields.

At the same time, overcoming the main challenges that the future will bring relies on more than just technical expertise: It also means forging connections between technical disciplines and issues present in society, the environment and the economy. It is not enough to train a narrow focus on isolated subjects in the education system — instead, we need an integrative education strategy that encourages interdisciplinary cooperation but still allows for technical qualifications that explore their disciplines in depth.

In particular, this presents higher education facilities with the challenge of developing new teaching formats and study structures that not only impart technical knowledge in a way that is practical and relevant to societal issues, but also create scope for cross-disciplinary thinking. With a view to the long term, we need education and science policy that strengthens interdisciplinary and cross-sector collaborations, develops technical education in a way that is appropriate for the modern age and maintains a level of education in engineering and science that is in-depth, methodically precise and at an excellent standard. This research question explicitly addresses the need to identify structural and cultural framework conditions that create space for and encourage a renewed feeling of enthusiasm for technology. A driving force behind this will be the development of education processes that pique interest in technology at an early age, maintain this interest over the long term and feed it into specific career paths.

Enabling Structural Transformation

New value creation systems need flexible organizational structures. Putting down local roots, cross-regional collaboration and dismantling institutional barriers are vital strategic elements of successful transformation.

A New Pathway Defined by Industry

Highly complex, dynamic and networked

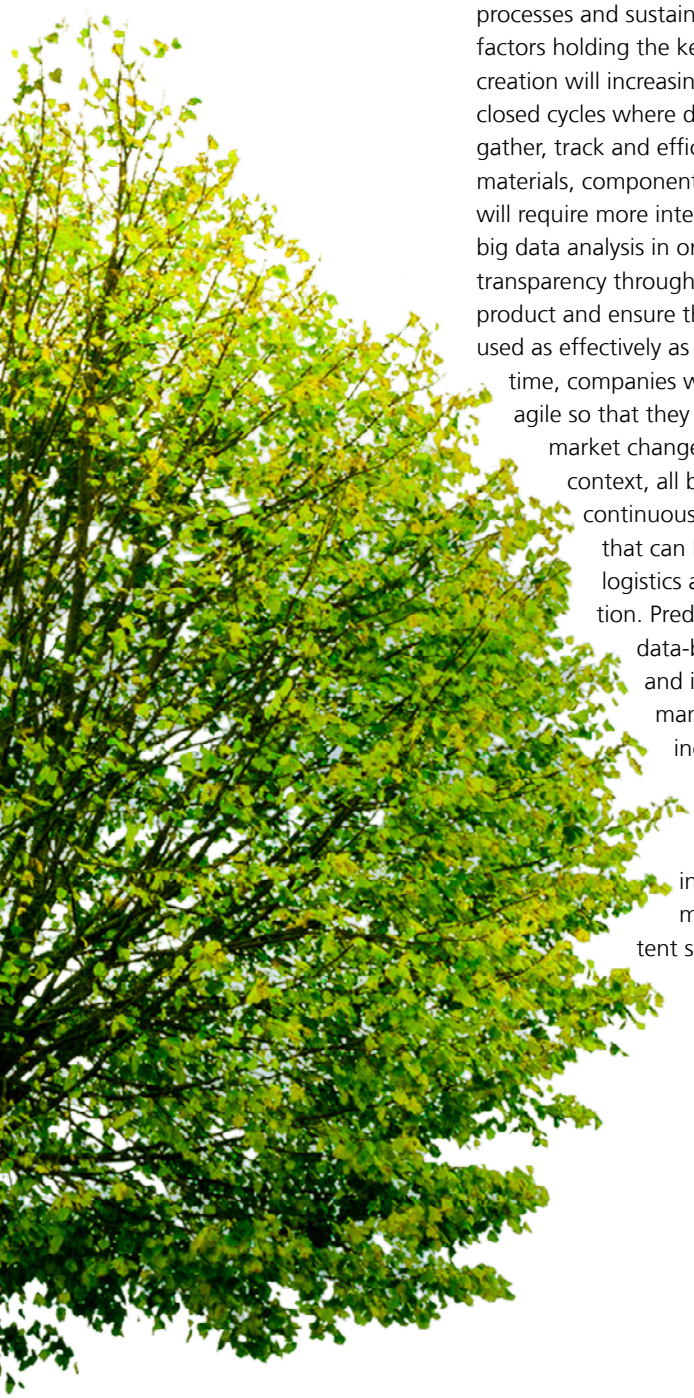
Conclusion and Outlook

The hallmarks of the value creation system of the future will be dynamic design, growing networks and increasing complexity. Technological innovations, environmental requirements, geopolitical shifts and societal expectations are leading to fundamental changes in the framework conditions within which the economy operates. To ensure transformation is successful and sustainable, it is essential that both internal and external key factors are systematically incorporated into strategic plans.

Today

As discussed in the "The Status Quo of Industrial Value Creation Systems" section, *today's value creation systems* are marked by a conservative attitude toward implementing data-supported services, and a mechanistic corporate culture that curbs innovation and flexibility within organizations. Companies often operate within rigid structures that make it difficult to adapt to changing market requirements. At the same time, a more flexible operational approach would mean unstable supply chains, as short-term changes in production or procurement have the potential to fuel uncertainty throughout the value chain. Another major issue is the difficulty in adapting products to dynamic market conditions. Despite changing customer requirements and developments in technology, many products remain largely unchanged, something that weakens the ability to compete in a globalized environment. On top of all this, there is the challenge of training and educating technical specialists in a way that is appropriate for the current times, and ensuring they have the right skills to use new digital business models — all while fierce price wars put pressure on margins in international markets. Fragmented regulation also makes it difficult to create long-term plans. Variations in national and international requirements lead to uncertainties that prevent strategic decisions from being made and curb investments in innovative value creation structures. Alongside these aspects, companies are facing growing competition between pay-per-use business models and traditional flat-rate services, requiring new strategic decisions to be made. Design for reuse and recycling is also becoming a more important factor to consider. Companies are increasingly being required to deal with sustainable product concepts so that resources can be used efficiently, regulatory requirements can be fulfilled and environmentally conscious customers can have their expectations met. For this reason, the transformation process in value creation systems requires not only innovations in technology, but also a shift in business models, corporate cultures and plans for implementing regulatory framework conditions.

Tomorrow



In *future value creation networks*, digital processes and sustainability will be the main factors holding the keys to success. Value creation will increasingly be structured in closed cycles where digital technologies will gather, track and efficiently reuse or recycle materials, components and products. This will require more integration of IoT, AI and big data analysis in order to create enhanced transparency throughout the life cycle of a product and ensure that resources are being used as effectively as possible. At the same time, companies will need to become more agile so that they can respond to dynamic market changes more rapidly. In this context, all business processes will continuously generate usable data that can help improve production, logistics and customer interaction. Predictive maintenance, data-based business models and intelligent supply chain management will take on an increasingly central role.

The competition landscape will also change: While products will increasingly be expected to maintain a globally consistent standard of quality, the focus of competition will shift further toward factors such as service quality, innovation capabilities and sustainability. Companies will no longer need to make themselves stand out through their technological expertise alone — instead, they will increasingly do so through collaborative business models and strategic partnerships in value creation networks. These networks will allow resources to be used more efficiently, accelerate innovation processes and strengthen resilience in the face of external disruptions. Another central element of future value creation models will be a heightened awareness of cost-effectiveness and a reduction in waste. Digital technologies will make it possible to optimize production processes, minimize material usage and manage energy consumption with precision. At the same time, it will be essential for companies to apply their individual strengths in more specific areas so that they can carve out strategic positions for themselves within value creation networks. Industrial value creation as a whole will be characterized by closer integration of digitalization and sustainability in the coming years. Companies that make early investments in data-driven processes, resource-friendly business models and strong network partnerships will remain competitive over the long term.

Key Factors

There are several *key factors* driving forward the shift from isolated, rigid structures toward networked, data-driven and sustainable value creation models. Despite advancements in automation and digitalization, the *human* factor will remain essential — although there will be fundamental changes in the world of work. Digital assistant systems, artificial intelligence and networked production processes will change not only workflows, but also the requirements that will need to be met in the area of employee skills and qualifications. With this in mind, companies are being faced with the challenge of providing their workforces with continual training and establishing new learning formats in order to play an active role in successfully shaping the digital transformation. At the same time, factors such as work satisfaction, a guaranteed supply of experts and attractive working conditions will play increasingly important roles in maintaining innovative strength and competitiveness over the long term. Although machines and algorithms will be able to take on many tasks in the future, humans will remain indispensable sources of creativity, decision-making power and responsibility. Stakeholders in future value creation systems will be encouraged to involve their workforces in the transformation process early on, provide ongoing skill-building opportunities for them and strengthen them through employee-first corporate cultures. This will bring the strengths and potential of employees to the fore exactly where needed and help maintain sustained success in the transformation process.

Another key factor is the strategic significance of *collaborations between businesses.* Pooling resources, expertise and technologies enables companies to not only act more efficiently, but also make innovation cycles shorter and harness synergies in specific areas of complex value creation networks. This is particularly evident when it comes to customer relationships as a key design element of value creation systems. For some time now, collaborations have been free from the constraints of classic supplier relationships and partners within the same industry — instead, we are increasingly seeing cross-sector and cross-stakeholder alliances that provide access to new technologies, business models and markets, especially in the context of digital platforms and a sustainable circular economy. In order to do their part in making the transformation process successful, all stakeholders are being called to question conventional ways of thinking, be open to new types of collaboration and work collectively on sustainable solutions with a viable future. Active, cooperative action is essential for making the shift away from isolated structures and toward resilient, networked value creation systems.

Technology skepticism and a lack of digital infrastructure in Germany continue to present significant obstacles in the process of transforming value creation systems. Many companies are hesitant to invest in disruptive technologies due to uncertainties surrounding economic viability, cybersecurity and compatibility with existing systems. This may result in these companies suffering a competitive disadvantage over the long term. To counteract this, companies are being urged to make proactive assessments of opportunities in technology, initiate pilot projects and invest specifically in digital skills and infrastructure.

Unclear, fragmented regulations within the EU are also placing companies on a more uncertain footing when it comes to planning. Variations in national specifications and complex approval procedures make it more difficult to scale digital business models and engage in cross-border collaborations. As a result, companies are being required to plow more resources into compliance and legal adaptations, slowing down innovation processes and increasing costs. Against this backdrop, political decision-makers urgently need to harmonize basic regulatory conditions, draw up clear guidelines and encourage innovation-friendly structures at European level. The area of applied science also has to play its part in implementing standards in a way that is compatible with corporate practices. The worlds of business, politics and science must work together to create the right foundations for a digital, sustainable economy that is focused on the future.

Conclusion

As industrial value creation systems undergo transformation, all the stakeholders involved in the process are being faced with complex questions and far-reaching challenges. However, they are also having significant opportunities opened up to them. The move away from traditional, often rigid structures in favor of networked, data-based and sustainable value creation models requires much more than new developments in technology. It also demands profound changes in corporate cultures, in strategic partnerships, in basic regulatory conditions that align with practice and — most of all — in training and education for technical experts. Every stakeholder needs to do their specific part in actively shaping the transformation process, ensuring that competitiveness can be maintained over the long term in an increasingly dynamic global environment.

What is particularly worth highlighting is that companies want to play a proactive role in the value creation system of the future and orchestrate customer ecosystems in order to bring sustainably produced new products to the market. Applied science needs to establish the right technologies and basic conditions for ESG criteria and other regulations that will apply in the future so that companies can achieve the level of self-efficacy they require."

Prof. Boris Otto,
Project Manager and Institute
Director at Fraunhofer ISST

Appendix

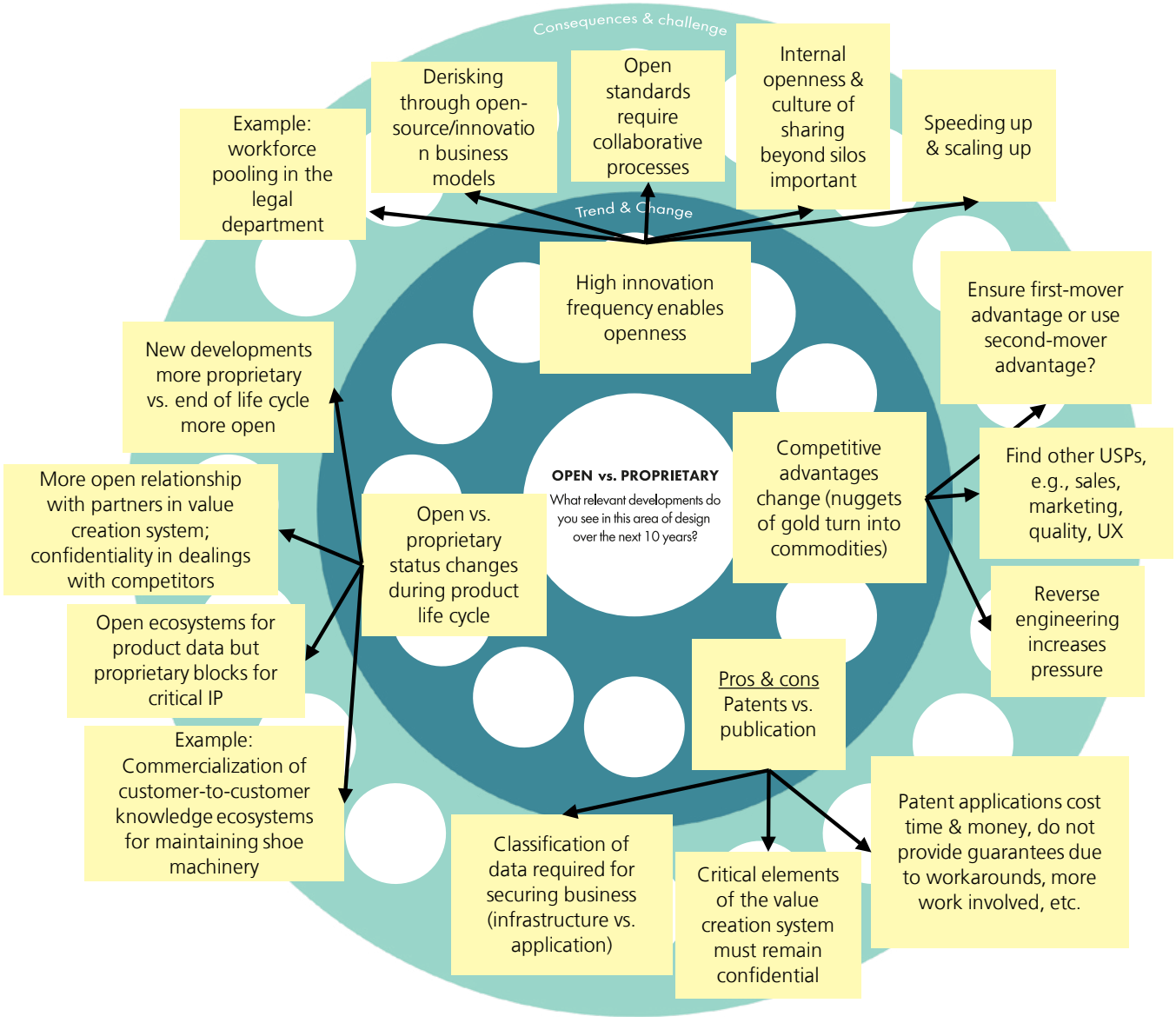


Figure 1: Trends and consequences in an open vs. proprietary context

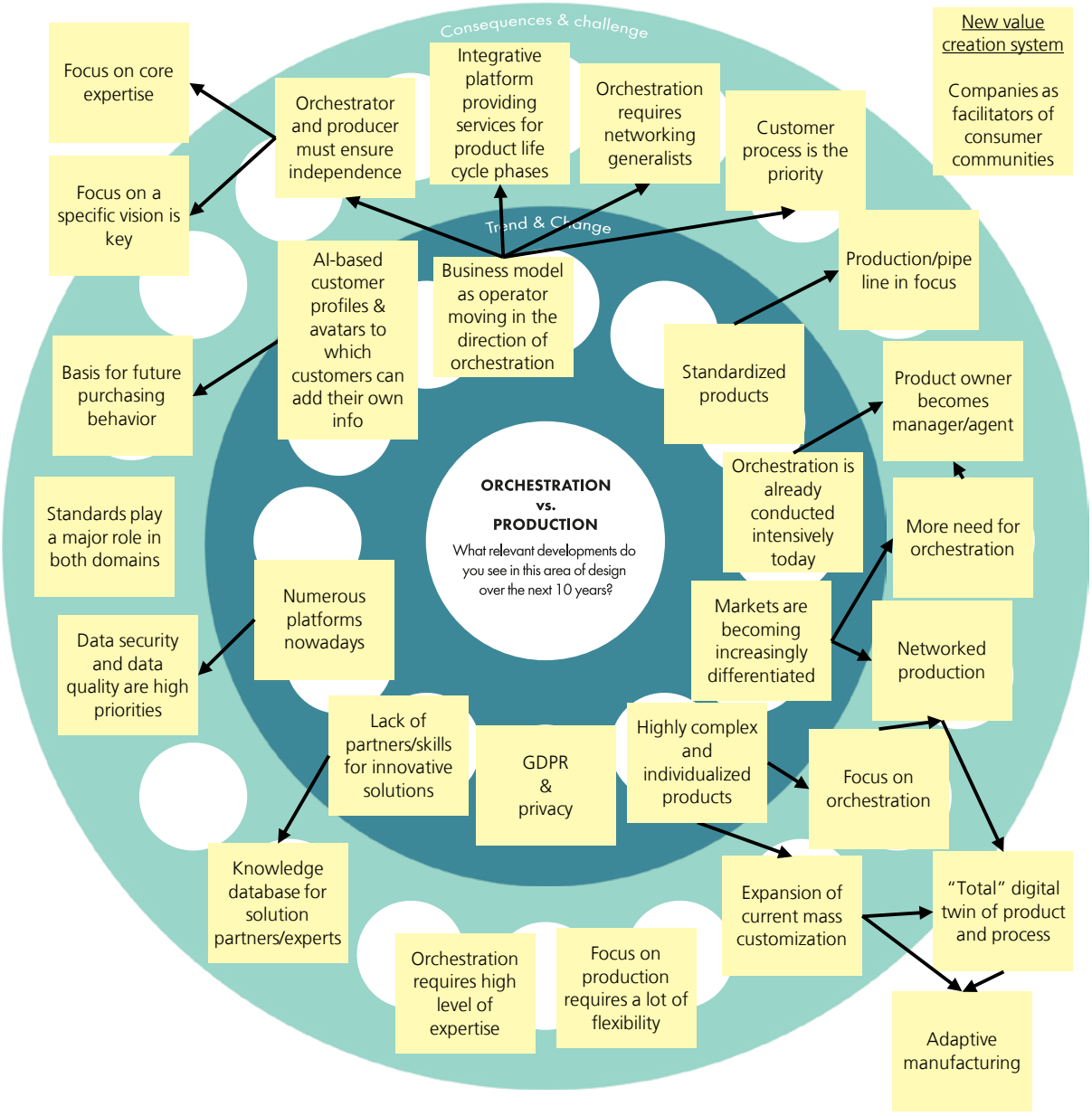


Figure 2: Trends and consequences in an orchestration vs. production context

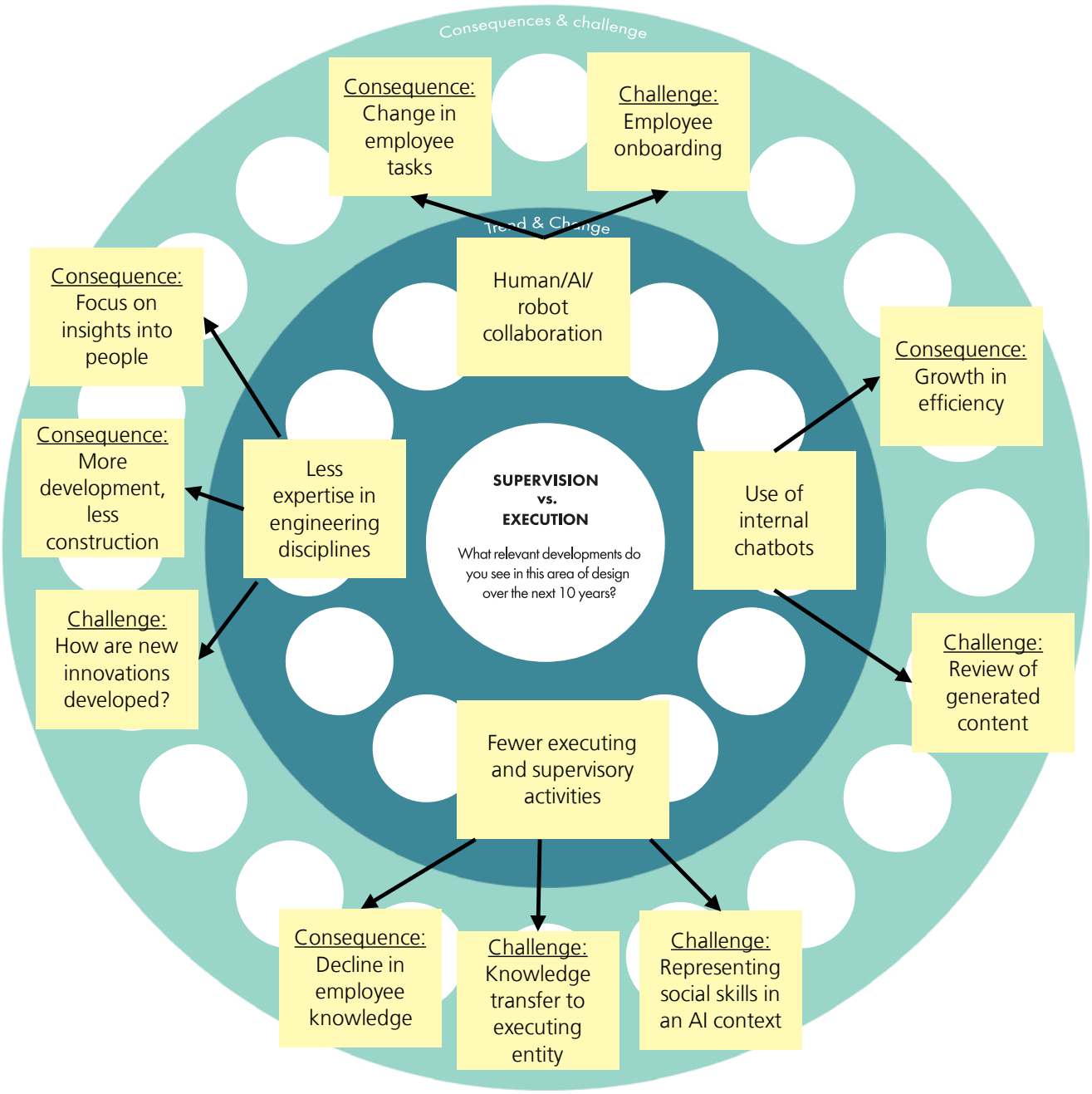


Figure 3: Trends and consequences in a supervision vs. execution context

Topic	No.	Question	Aimed at
Framework conditions	1	Can regulations be streamlined and redefined as incentives and objectives?	International politics National politics Companies Science
	2	What is the raw material yield in recycling today? – Recycling Yield – How can it be increased?	National Politics Science
	3	Which raw materials are strategically important?	International politics
	4	Findability of defined strategic raw materials in products on the market: Where can I find these raw materials/in which products?	International politics National politics Associations Companies
	5	Recycling vs. repair vs. replacement: What is the overall balance from raw material to end product? Is recycling really that good (environment, social issues, economy, jobs, economics, creation of demand, innovation, further development of technology, etc.)?	Science
	6	How do we evaluate the advantages of a better environmental balance compared to poorer social performance? LCA must be completely objective.	International politics National politics Associations Companies Science Technology experts
	7	How should value creation systems be structured in order to be legal (antitrust law, etc.)? Are they still helpful? Do they still solve challenges? How open/collaborative are companies really when it matters?	Companies Science
Technology	8	Which specific AI fields within the overall value creation system need to be addressed in order to accelerate the transformation?	National politics Companies Science
	9	How do we make new technologies accessible?	National politics
	10	How can information technology systems (ERP/MES) be simplified so that they are easy to use?	Companies Science
	11	How can evaluations, such as condition monitoring, be standardized so that they can be used plug-and-play (AI data lake)?	Companies Science

Table 1: Research questions with a short-term need for action *(continued on next page)*

Topic	No.	Question	Aimed at
Organization	12	If the goal is value creation systems, who/how/based on what motivation can and should control/orchestrate them? With what goals? How can WCS be controlled/orchestrated? What systemic requirements are necessary for this? Where should they come from? E.g., standards (in many cases much more difficult to define/set up than originally thought).	International politics Companies Science
	13	As a company, how do I create a value-added network in a circular economy? Design for disassembly? Design for repair? Are new business models emerging/are existing ones changing?	Associations Companies Science
	14	What incentives could be created to promote reuse in industry more strongly without imposing regulations?	National politics Companies Science

Table 1: Research questions with a short-term need for action (continued from previous page)

Topic	No.	Question	Aimed at
Framework conditions	15	What could/should Germany's education system do to overcome the challenges that the future will bring?	National politics Companies Science
	16	How do we spark enthusiasm for technology in Germany again? How do we create links with specialist disciplines?	Science Education
Technology	17	Deep dive: humans AND AI or just AI? Impact of exponential growth in AI applications on the role of humans in value creation systems: Who will be supervising whom? What role remains for humans?	International politics National politics Associations Companies Science Social sciences
	18	Are there already technologies in place for recycling all strategically important raw materials from products?	Science
	19	How can AI provide efficient support for companies in the context of value chains?	Science
Organization	20	Transformation to future value creation systems: Do local/regional value chains make sense? Are they economically viable? What is standing in their way? Is the recycling rate a condition or a consequence?	International politics National politics Associations Companies Science
	21	Value creation system design: impact on people! What obstacles exist? How do we remove them?	International politics National politics Associations Companies Science

Table 2: Research questions with a medium-term need for action

Contact

Fraunhofer ISST

Fraunhofer Institute for Software and Systems Engineering ISST
Speicherstrasse 6
44147 Dortmund, Germany
www.isst.fraunhofer.de

Prof. Boris Otto
boris.otto@isst.fraunhofer.de

Philipp Hagenhoff
philipp.hagenhoff@isst.fraunhofer.de

Lea Krammer
lea.krammer@isst.fraunhofer.de

Fraunhofer IAO

Fraunhofer Institute for Industrial Engineering IAO
Nobelstrasse 12
70569 Stuttgart, Germany
www.iao.fraunhofer.de

Prof. Katharina Hölzle
katharina.hoelzle@iao.fraunhofer.de

Felix Bickert
felix.bickert@iao.fraunhofer.de

Benjamin Schneider
benjamin.schneider@iao.fraunhofer.de

Photo credits