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# Shaping Digital Ecosystems for Sustainable Production: Assessing the Policy Impact of the 2030 Vision for Industrie 4.0

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**Abstract:** How can we effectively shape digital ecosystems for sustainable production in line with the Sustainable Development Goals of the United Nations? The German *Plattform Industrie 4.0* has developed a vision for 2030 entitled "Shaping Digital Ecosystems Globally" with sustainability as one of three key pillars. Based on this vision, three development paths towards a digital, networked and sustainable manufacturing industry of the future were identified and further concretized with corresponding scenarios and business use cases. This article assesses this participatory approach of jointly thinking and shaping futures, with a particular focus on outcomes and policy impacts. A specific focus is placed on the involved and addressed public and private stakeholders, industry and policy sectors, and governance levels. The study shows that the 2030 Vision for Industrie 4.0 is a good example of how broad policy impacts can be achieved by taking a multi-actor, multi-sector and multi-level approach. Based on some practical implications for designing collaborative manufacturing networks in digital ecosystems, the article concludes with a call for collective action towards the Sustainable Development Goals to be achieved by the year 2030.

**Keywords:** Industrie 4.0; digital ecosystems; Sustainable Development Goals; vision; policy impact



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## 1. Introduction

Since the introduction of the term "Industrie 4.0" at the world's leading industry trade fair in Hannover, Germany, ten years ago—igniting the vision of a fourth Industrial Revolution [1]—progress has been made in digitally connecting the shopfloor with the business level within smart factories. The 2030 vision for Industrie 4.0, which was presented by the German *Plattform Industrie 4.0* at the Hannover fair eight years later, focuses on "Shaping Digital Ecosystems Globally" with environmental and social sustainability as one of three key targets [2]. In the context of the looming coronavirus pandemic, the role of Industrie 4.0 solutions for mastering the economic COVID-19 crises and for transforming the industry sector towards a sustainable and resilient collaborative and digitally networked value creation system has been reinforced [3,4]. The close relationship between the Industrie 4.0 Vision and the Sustainable Development Goals of the United Nations has been emphasized, and several scenarios along three development paths towards a digital, networked and sustainable manufacturing industry of the future were pointed out at the Digital Summit of the German government in 2020 [5,6].

Against this backdrop, this article deals with the question of how we can effectively shape digital ecosystems for sustainable production in line with the Sustainable Development Goals. Regarding the effective shaping of future ecosystems, a specific focus is on the question of how we can achieve a broad policy impact with a systematic approach of jointly thinking and shaping futures. To find some answers to these questions, the general approach, outcome and impact of the collaborative vision and scenario-building process of the German *Plattform Industrie 4.0* will be reviewed. With a specific view on the practical implications for collaborative data-driven business models in sustainable and resilient value creation systems, this process of jointly thinking and shaping futures—which Cornish has called "futuring" [7]—will be assessed against the key success factors for broad policy impact of such initiatives [8].

In the following, a participatory approach to *futuring* based on using a multi-actor, multi-level and multi-sector concept in order to improve policy impact in complex systems will be outlined. Subsequently, the German *Plattform Industrie 4.0* will be briefly introduced, with a focus on its structure and organization, illustrating the demand for broad policy impact. Based on this, the process and outcome of the vision and scenario-building process is outlined, with a specific focus on the relationship to the Sustainable Development Goals and with respective implications for realizing collaborative data-based business models in sustainable and resilient value creation systems of the future. Finally, based on a short description of policy measures which have been directly triggered by the 2030 Vision for Industrie 4.0, the impact of these *futuring* activities is assessed and discussed from an innovation policy point of view.

## 2. Participatory Approach and "Futuring" to Improve Policy Impact in Complex Systems

Manufacturing industry in the 21st century is described as a "complex, multi-facetted, highly networked and dynamic sociotechnical system" [9] (p. 34). To achieve broad policy impact in such a complex system, a participatory process of jointly thinking and shaping futures in a systemic approach is required [10]. This is particularly true when it comes to strategic alignment of individual investment decisions to jointly tackle grand societal challenges, such as addressed by the United Nations Sustainable Development Goals (Figure 1).

It is essential for all stakeholders representing the n-tuple helix innovation actors of knowledge-based economies, such as academia, industries or government [11–13], to make well-informed decisions when it comes to major and longer-term investments in Research, Technology Development and Innovation (RTDI). Sharing knowledge in collaborative forward- and outward-looking decision-making processes [10,14] and strategic alignment of public and private investments reduces risks and increases the overall return of future-oriented investments for each stakeholder [15,16].

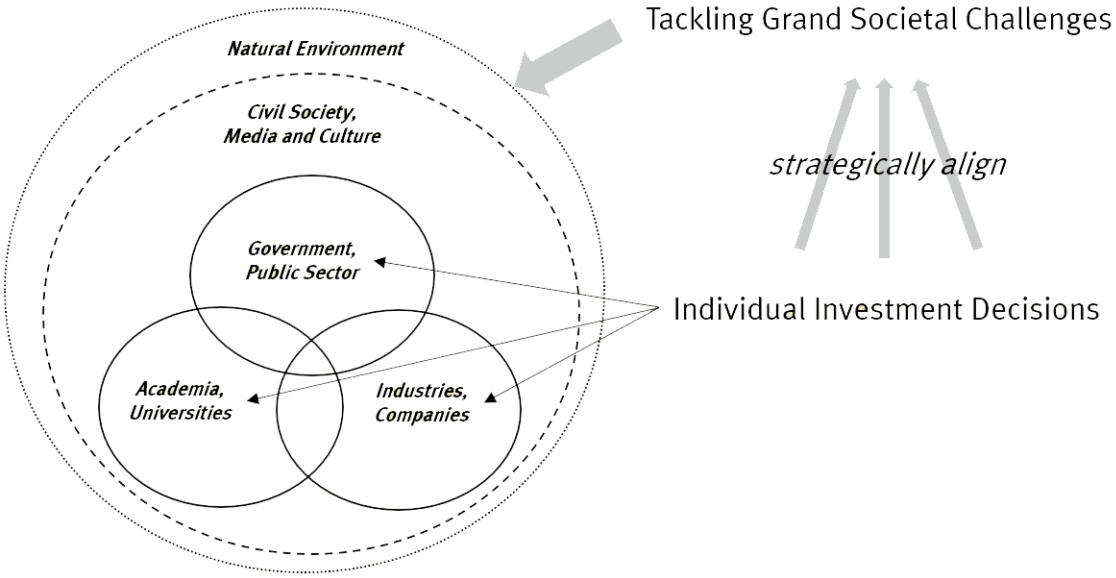


**Figure 1.** Strategic alignment of RTDI investments in a 'quintuple helix' innovation system. Extended illustration based on [12].

As Figure 2 illustrates, effective strategic alignment of RTDI investments needs to address stakeholders from multiple governance levels and representing multiple public and private policy sectors, e.g., from research and education to economic and industry to social and environmental policies. All of the stakeholders need to share a common vision for the future in order to align and synchronize their efforts in the global innovation

landscape, and thus to jointly realize breakthrough solutions for the 21st century's grand societal challenges [8,17].

| Governance Level | Example | Some RTDI related policies, programmes, plans and strategies |
|---|---|---|
| **Supra-National** (inter-/transnational) | **European Union**  | • Priorities of the European Commission including the European Green Deal or EU's digital strategy<br>• NextGenerationEU – Recovery plan for Europe<br>• Horizon Europe – EU's research and innovation programme<br>• Digital Europe programme<br>• A new Circular Economy action plan<br>• ... |
| **National** | **Federal Republic of Germany**  | • High-Tech Strategy 2025 – Strategic framework for RTDI policy<br>• German Recovery and Resilience Plan<br>• Excellence Strategy – Programme to strengthen cutting-edge research and international competitiveness of German universities<br>• Central Innovation Programme for SME<br>• ... |
| **Sub-National** (local, regional) | **German Federated State of Baden-Württemberg**  | • Innovation Strategy Baden-Württemberg<br>• investBW funding programme<br>• Innovation Park Artificial Intelligence Baden-Württemberg<br>• ... |

**Figure 2.** Governance levels with examples of RTDI policies, programmes, plans and strategies.

Mutually communicating and translating visions of future developments and strategic targets between innovation actors from different spheres—e.g., from private business to public administration—is needed in order to provide each stakeholder with the appropriate "frame" for strategically aligned decision-making in a specific context, e.g., market vs. regulation perspective [18]. In the context of the rise of systemic instruments in innovation policy [19], *futuring* has become an important approach as a way of systematically thinking and shaping futures, with a focus on achieving broad policy impact [20].

As Figure 3 illustrates, three key factors for achieving a broad policy impact can be derived from the evaluation of successful participatory approaches to jointly thinking and shaping futures [8,10,15]:

Key Factors for Broad Impact of Futuring Initiatives

| | |
|---|---|
| **Multi-Actor** | **Stakeholder involvement** in a participatory process, taking into account their respective knowledge, incentives and capacities for shaping the future in strategically aligned (and collaborative) actions |
| **Multi-Sector** | **Systemic view** on subject of discussion, integrating all relevant & critical aspects and sectors, i.e. industry, policy, etc. sectors, and with regard to broad "n-tuple" innovation helix approaches |
| **Multi-Level** | **Interdependent governance levels** are addressed to strategically align the efforts – from macro level (supra-/inter-/transnational) down to micro level (regional, local or even corporate governance) |

**Figure 3.** Key success criteria for broad policy impact of *futuring* initiatives.

Accordingly, this article focuses on the policy impact achieved thus far by the 2030 Vision for Industrie 4.0 approach, with a specific focus on addressing:

- Public and private stakeholders (multi-actor)
- Industry and policy sectors (multi-sector)

- Governance levels (multi-level)

## 3. Materials and Methods

This article provides an overview of the recent vision and scenario building process of the German *Plattform Industrie 4.0*, which culminated in the vision 2030 for Industrie 4.0 and subsequently in scenarios and business use cases for ecological transformation with Industrie 4.0. This process of jointly thinking and shaping futures will be analyzed referring to the mentioned policy impact as the key success criteria of *futuring* activities.

The structure and organization of the German *Plattform Industrie 4.0* reflects the high demand for broad policy impact by integrating a wide spectrum of stakeholders with their different skills and competencies (Figure 4). The platform is chaired by the Federal Minister for Economic Affairs and Energy (BMWi) and also includes the Minister of Education and Research (BMBF) and high-ranking representatives from industry, science and the trade unions. Representatives from politics, business, science, associations and unions jointly support and govern the activities of the platform in the steering committee. Over 350 participants from over 150 organizations are active in the platform and contribute with their expertise to the working groups and research council [21]. A specific focus is on international cooperation—the official website currently shows 13 bilateral and multilateral cooperation agreements—and on implementing and transferring Industrie 4.0 concepts.

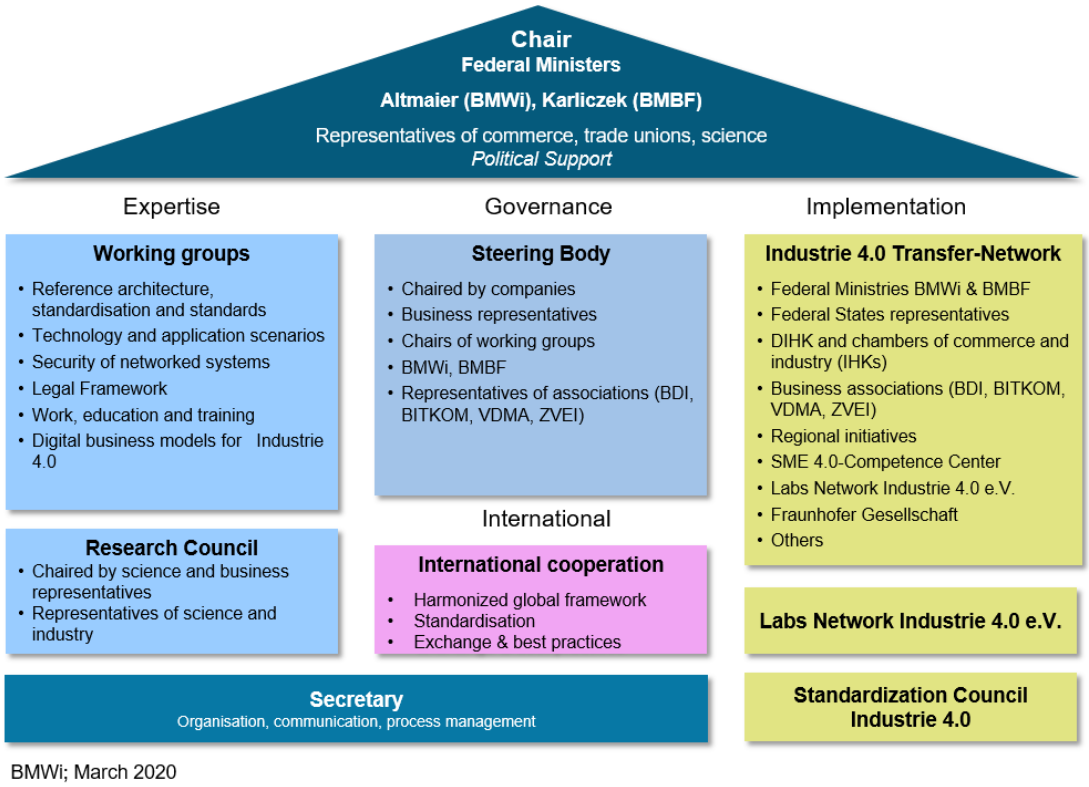


**Figure 4.** Structure and Organization of the German *Plattform Industrie 4.0* [22].

The analysis of the *futuring* process, outcome and impact is primarily based on the review of the more than 200 publications, papers and studies which are made public via the official website www.plattform-i40.de (accessed on 30 June 2021); around 150 items are available in English. The findings of the literature review are complemented by personal experience and conversations with participants in the *Plattform Industrie 4.0*.

In the following, the results of this analysis are presented and discussed. First, the outcome of the vision and scenario building process is briefly described, with a specific focus on the Sustainable Development Goals (SDGs) of the United Nations and particularly on ecological transformation with Industrie 4.0. Second, some implications for realizing

collaborative data-driven business models in sustainable and resilient value creation systems are discussed. Third, the vision and the scenario building process are assessed against the quality criteria for effective *futuring* exercises; finally the results are discussed from an innovation policy point of view.

## 4. Assessment and Results

### *4.1. Vision and Scenarios: Industrie 4.0 Ecosystems for Sustainable and Resilient Futures*

Eight years after the introduction of the term "Industrie 4.0" at the world's leading industry trade fair in Hannover, the German *Plattform Industrie 4.0* presented at the same place the 2030 vision for Industrie 4.0 [2]. This vision has been developed using a collaborative approach, with participation of the six thematic working groups, the research council and representatives of the leading companies, associations including trade unions, and was aligned with the federal ministries involved. With the support of the secretary, a core group finalized the vision which was finally presented at the Plattform Industrie 4.0 Leaders' Dialogue 2019 in Hannover [23].

The vision, entitled "Shaping Digital Ecosystems Globally", underlines the great need for a transformation of industrial production towards resilient and networked sustainable value creation with new forms of cooperation based on open, transparent and secure digital ecosystems. The shared values of "Autonomy–Interoperability–Sustainability" build the key guidelines for implementing the vision (see Figure 5):

- *Autonomy:* The principle of autonomy underpins the importance of self-determination and free scope of action for all stakeholders in a free and social market economy, and it emphasizes the value of diversity and plurality for collaborative value adding business solutions in the emerging digital ecosystems.
- *Interoperability:* Cooperation of stakeholders and a high level of interoperability to which all partners commit and contribute is required in order to ensure networking across companies and sectors. Networked value creation with decentralized intelligence enables increased productivity, sustainability and resilience across the whole system.
- *Sustainability*: Modern industrial value creation unites economic, ecological and social sustainability, and thus ensures a high standard of living. With regard to social sustainability, a focus is on decent work and education as well as on social participation. Climate change mitigation and the circular economy are strategic action fields to realize ecological sustainability.


**Figure 5.** 2030 vision for Industrie 4.0 of the German *Plattform Industrie 4.0* [2].

In the context of the looming coronavirus pandemic, the role of the 2030 vision for transforming the industry sector towards a resilient and sustainable collaborative and digitally networked value creation system has been reinforced [3,4]. Figure 6 shows the relationship between the 2030 vision for Industrie 4.0 and the Sustainable Development Goals (SDGs) of the United Nations. The three strategic action fields of the sustainability pillar of the 2030 vision directly refer to SDGs 8, 12 and 13. SDG 9 is related to the three strategic action fields of the autonomy pillar, particularly in the context of a resilient and secure digital infrastructure as a precondition for future digital industry and innovation.

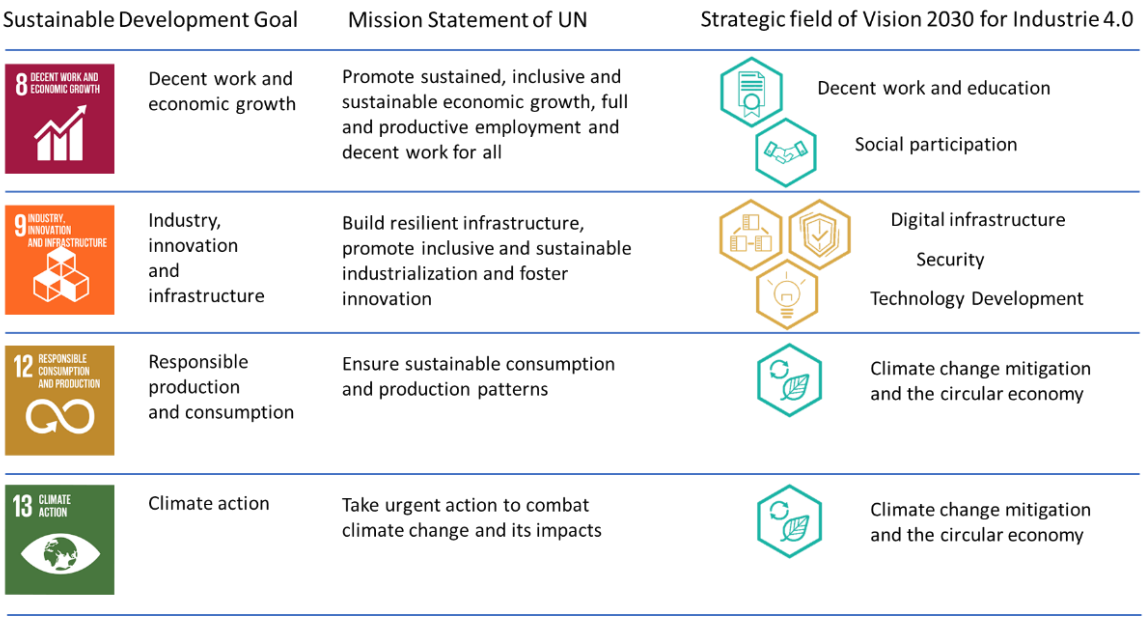


**Figure 6.** Relationship between SDGs of UN and strategic fields of Vision 2030 for Industrie 4.0.

To concretize how Industrie 4.0 can help to realize the SDGs, the *Plattform Industrie 4.0* initiated a sustainability task force which analyzed over 60 business examples [6]. From this analysis, three development paths for shaping the ecological transformation with Industrie 4.0 emerged (Figure 7).

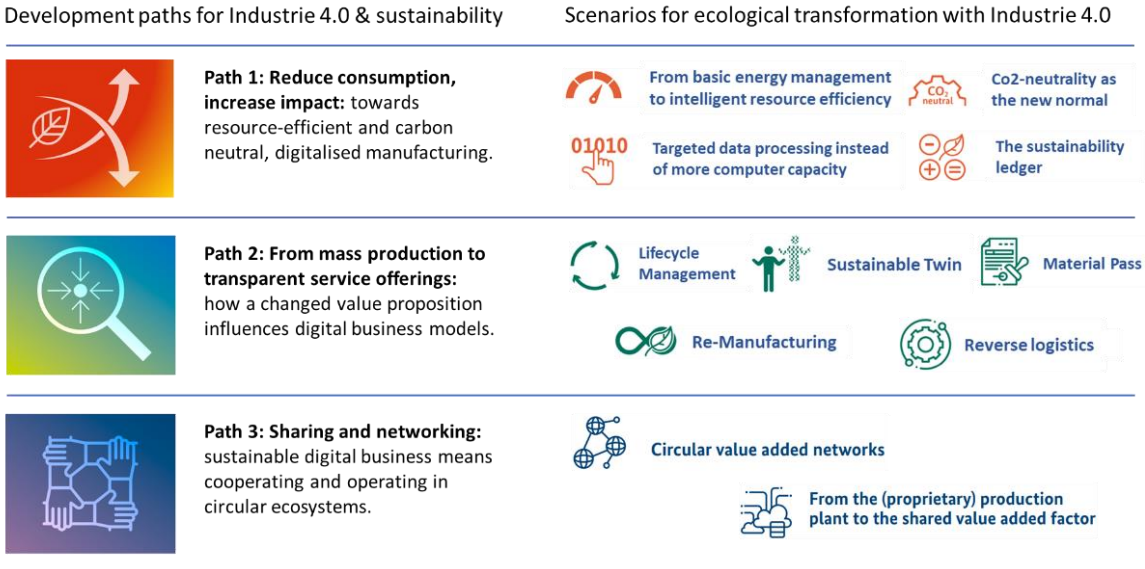


**Figure 7.** Development paths and targeted scenarios for ecological transformation with Industrie 4.0.

For each identified path, the task force outlined specific scenarios for ecological transformation with Industrie 4.0. These scenarios give answers to the question "Where do we want to go?" based on the description of the status quo ("Where are we now?").

Since industry accounted for more than 41% of worldwide power consumption in 2016, the first development path focuses on realizing highly efficient and carbon neutral manufacturing processes. In the scenario "from basic energy management to intelligent resource efficiency", for example, a range of technologies—from smart sensors to Industrial Internet of Things (IIoT) platforms to Artificial Intelligence (AI) based data-analysis services—is described with the goal of realizing $CO_2$-neutral factories. An increasing number of articles in the literature point out how digital technologies such as blockchain [24] and data fusion-based AI algorithms in the IIoT context [25] can contribute to sustainability and long-term resilience in global manufacturing systems [26].

The second development path focuses on the value of digital business services in future circular, as opposed to contemporary linear value chains. Several scenarios describe how transparent and circular value creation systems can be realized with the help of digital twins and related digital product and material passes, such as currently discussed in the context of the European Green Deal and New Circular Economy Action Plan, with the overarching aim of making Europe climate neutral in 2050 [27,28].

Collaboration and sharing as new imperatives for future value-added networks with a focus on circular ecosystems is at the center of the third development path. Here, the scenarios go beyond the typical principles of Circular Economy (longer use, re-use, refurbishment or re-cycling of resources) [29] and refer to an optimized use of production resources in sustainable and resilient value creation systems of the future. The latest report of the World Manufacturing Foundation points in the same direction and gives key recommendations to promote digitally enabled circular manufacturing [30].

In the following, the implications for realizing collaborative data-based business models in respective Industrie 4.0 ecosystems will be outlined and briefly discussed.

### *4.2. Implications for Collaborative Data-Driven Business Models in Industrie 4.0 Ecosystems*

As described above, data sharing and digital services for transparent and circular value creation will substantially contribute to an ecological transformation of industry. Collaborative data-driven business models and digital platforms which orchestrate digital ecosystems—broadly seen and well-known in the consumer markets—are now also emerging in the so-called Business-to-Business (B2B) markets of the manufacturing industry [31,32]. Against this backdrop, the *Plattform Industrie 4.0* has identified several business use cases, three of which will be briefly outlined in the following (Figure 8).

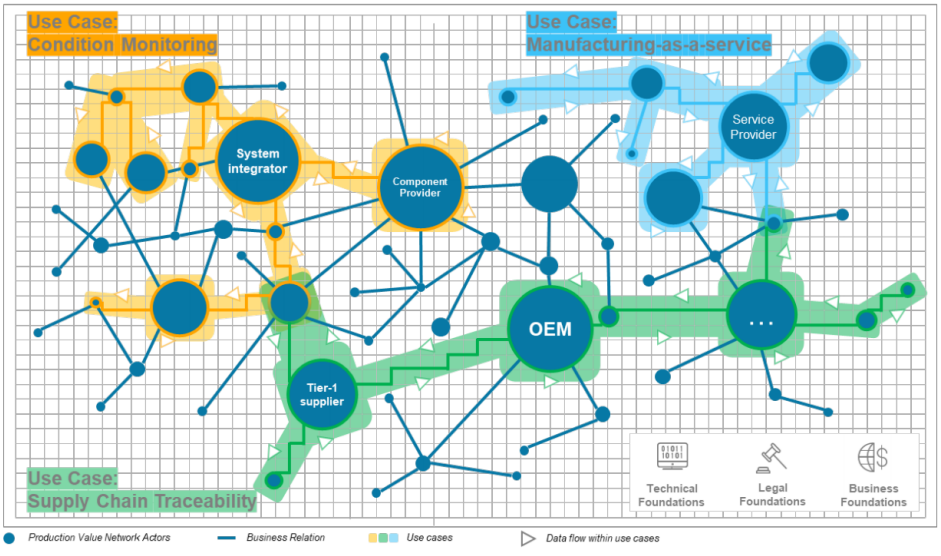


**Figure 8.** Collaborative data-driven business use cases in a Industrie 4.0 ecosystem [33].

The first use case of collaborative condition monitoring and predictive maintenance strives to increasing the life span of production plants, machines and manufacturing components, and thus to empower the inner circle of the circular economy according to the following rule: maintenance and repair first, then reuse, remanufacturing and recycling. For the realization of this use case, various actors such as manufacturing component providers, equipment suppliers, system integrators and factory operators must share their machine data. This requires mutual trust and a trusted environment with sovereignty over owned data and an interoperable, barrier-free technical solution for secured data exchange [34].

The use case of supply chain traceability refers to optimizing ideally circular, cross-company value creation and material flows with the help of digital sustainable twins and related digital product and material passes. Collaboration between private business and public administration is required in this context in order to jointly build and shape the technical, legal and business foundation, and thus to fully "harness the fourth industrial revolution for the circular economy" [35].

The use case of manufacturing-as-a-service aims to optimize the use of already existing manufacturing resources in Industrie 4.0 ecosystems. The initial implementations of this use case can be already seen on the market. Service providers such as the German start-up V-Industry have developed platforms to identify suitable and available machine capacities at contracted manufacturers for placing production orders in a very quick and easy manner [36].

To elaborate these use cases, several barriers for broad implementation of collaborative data-driven business models in Industrie 4.0 Ecosystems can be identified [34], summarized as follows:

- *Lack of collaborative thinking and mutual digital trust:* bilateral market relations are prevalent, combined with a fear of losing data sovereignty and competitiveness.
- *Lack of sustainable and scalable business models*: clear value propositions with a fair share of overall benefit for all market actors in the long term are often not yet seen.
- *Lack of financial resources and skills*: smaller manufacturing companies in particular struggle with the necessary investments and knowledge for transformation.
- *Lack of reliable technical and legal foundations*: secure digital infrastructure with clear standards for sharing data and a supportive legal framework are seen as prerequisites.

To overcome these barriers, the *Plattform Industrie 4.0* has proposed several measures that are currently being implemented by various actors at multiple governance levels involved in various industry and policy sectors. Some of these measures are outlined in the following section as a basis for assessing the policy impact of the platform's vision and scenario building process.

### *4.3. Assessing the Policy Impact of the 2030 Vision for Industrie 4.0*

Regarding the policy impact of the Vision 2030 for Industrie 4.0, several measures have already begun to shape the ecological transformation with Industrie 4.0, and to overcome the identified barriers for broad implementation of data-driven business models in digital ecosystems. In the following, four of the policy measures which have been directly triggered by the vision and scenario building process of the *Plattform Industrie 4.0* are briefly described and placed in the larger context (see Figure 9).


**Figure 9.** Policy measures triggered by the 2030 Vision for Industrie 4.0.

Shortly after presenting the 2030 vision for Industrie 4.0 at the Hannover trade fair, the *European GAIA-X Project* was launched at the German Digital Summit 2019 to set up a federated data infrastructure for Europe, with broad high-level policy support from the beginning [37]. According to the autonomy pillar of the vision 2030 for Industrie 4.0, the aim of this project is to set up a federated data infrastructure "as the cradle of an open, transparent digital ecosystem, where data and services can be made available, collated and shared in an environment of trust" [38] (p. 45). With the broad commitment of many actors from business, science and politics at various governance levels (from national GAIA-X hubs to the international level) and in numerous sectors (e.g., agriculture, finance, health, industry, mobility, smart living) [39,40], this project can be seen as an ideal type of multi-actor, multi-sector and multi-level initiative.

Some months later and with reference to the interoperability pillar of the vision for 2030, Industrie 4.0 companies and associations launched the *Industrial Digital Twin Association (IDTA)* [41]. The aim of this joint initiative is to enable the realization of collaborative data-driven business models such as those described e.g., in the use case of supply chain traceability with the help of digital sustainable twins. It also technically supports the implementation of the Digital Product Passport, which is foreseen for the revised Ecodesign Directive in the context of the Green Deal and New Circular Economy Action Plan of the European Commission. Thus, IDTA strives for shaping future collaborative business by making the digital twin practical for industry through open technologies, in close cooperation with GAIA-X and other initiatives [42].

With its position paper "Creating the DataSpace Industrie 4.0", the *Plattform Industrie 4.0* invited national and international organizations to jointly shape the digital ecosystems with a specific view on sustainable production in the future [33]. Afterwards, some industry-driven associations set up the European Data Spaces Business Alliance [43]. In line with the sustainability pillar of the 2030 Vision for Industrie 4.0 some data-driven business use cases such as supply chain traceability and collaborative condition monitoring and predictive maintenance are expected to be realized with the support of the European Digital Europe program in *Manufacturing Data Spaces.*

As Figure 9 illustrates, all of these measures are interrelated and represent important building blocks for realizing the shared vision of digital ecosystems for sustainable production. In the *lighthouse project CATENA-X*, all of these building blocks are brought together in order to realize a continuous data exchange for all contributors along the automotive value chain and to implement sustainability and Circular Economy or Manufacturing-as-a-Service use cases [44]. This lighthouse project is funded under the German program "Investing in the future of the vehicle industry". In the context of the coronavirus pandemic, the steering committee of the *Plattform Industrie 4.0* presented a paper on "COVID-19 and Industrie 4.0" and asked, in line with Germany's EU Council Presidency motto "Together for Europe's recovery", for joint actions to create the conditions which are required for competitive, resilient and sustainable growth of European industry [3,4]. Among other things, the high-ranking representatives of industry, associations, science and unions demanded complementary investments from politics to create the necessary framework conditions for specific future sectors and industries. As a result of the policy dialogue in the German government, the Federal Minister for Economic Affairs and Energy launched this EUR 2 Billion program as part of the German recovery package [45]. Small and medium-sized enterprises belong to the core target group of this program, with the aim of overcoming the existing barriers on the path towards a sustainable, resilient, collaborative and digitally networked value creation system.

Figure 10 illustrates that all the described measures address and take into account various public and private stakeholders from several policy and industry sectors and from different levels. Even if the *Plattform Industrie 4.0* is a national initiative, cooperation with regional and international partners is part of its DNA. As the common vision shared by CESMII—the US Smart Manufacturing Institute for Digital Transformation—and the *Plattform Industrie 4.0* illustrates, thinking about sustainable and resilient futures with Industrie 4.0 is not only seen as a national or European but as a real global endeavor [46].

| Measure | Aim | Actors | Sectors | Levels |
|---|---|---|---|---|
| **GAIA-X** | set up a federated **data infrastructure** for secure and transparent data exchange and digital trust | members from **industry** and **science** with strong **policy** support e.g., from Germany and France | **10 domains** incl. energy, finance, health, mobility, public sector, Industrie 4.0 & SME or smart living | 15 **national** hubs working together in a **European** association and cooperating in an **international** network |
| **Digital Twin for Product Passport** | use of digital twin for **interoperable exchange of information** across the entire product life cycle | mainly **industry** works on technical implementation in accordance with **public** legislation & regulation | **value chains** affected by the Ecodesign Directive & related to multiple (energy, economic, etc.) policies | **(inter-)national** initiatives on technically implementing the new policy framework from **European** Commission |
| **Data Space for Sustainable Production** | create ecosystems for **new collaborative data-driven ventures** to enable sustainable production | **industry**-driven associations join their forces and cooperate with **public** administration & funding | data spaces for **various verticals/domains** related to data governance, infrastructure, etc. policies | **(inter-)national** use cases & projects based on national & European funding in relation to **European** Regulation |
| **CATENA-X** | create standardized data & information flows along the **entire automotive value chain / network** | members from **industry** and **science** with **policy** support (funding from Recovery & Resilience Plan) | **10 use cases** with partners from different sectors addressing various aspects of collaborative value creation | **national** lighthouse project in the European context (national funding is part of **European** Recovery Plan) |

**Figure 10.** Measures and their impact on multiple actors, sectors and governance levels.

Based on these examples of initiated measures, it is already becoming apparent that the *Plattform Industrie 4.0* could achieve a broad policy impact with its process of jointly thinking and shaping future Industrie 4.0 ecosystems. Assessing this process against the key success criteria for broad policy impact described in Section 2 shows that many stakeholders have been involved with their specific competences and expertise, taking a holistic view on shaping the digital ecosystem, and strategically approaching all the relevant governance levels for support in this endeavor (Figure 11). This multi-actor, multi-

sector, multi-level approach has enabled a broad policy impact, which could be achieved within a relatively short period of time.

| Key Factors for Broad Impact of Futuring Initiatives | | Assessing the 2030 Vision for Industrie 4.0 Initiative |
|---|---|---|
| **Multi-Actor** | **Stakeholder involvement** in a participatory process, taking into account their respective knowledge, incentives and capacities for shaping the future in strategically aligned (and collaborative) actions | ✓ **Broad stakeholder involvement** with …<br>• expertise of over 350 persons from over 150 active organisations in the Plattform Industrie 4.0<br>• iterative discussion of the vision, scenarios, use cases, etc. also with external experts and the broader public<br>• … |
| **Multi-Sector** | **Systemic view** on subject of discussion, integrating all relevant & critical aspects and sectors, i.e. industry, policy, etc. sectors, and with regard to broad "n-tuple" innovation helix approaches | ✓ **Holistic view on shaping digital ecosystems globally** with …<br>• "triple helix" of academia-industry-government relations including the trade unions at the core<br>• integration of economic, energy, education, research, etc. policies in close contact to public administration<br>• … |
| **Multi-Level** | **Interdependent governance levels** are addressed to strategically align the efforts – from macro level (supra-/inter-/transnational) down to micro level (regional, local or even corporate governance) | ✓ **Strategic approach on multiple governance levels** with …<br>• direct impact on national and European policies, programmes, plans and strategies<br>• linking international cooperation at global level with regional implementation at local level (test beds, etc.)<br>• … |

**Figure 11.** Assessing the 2030 Vision initiative against key success criteria for broad impact.

## 5. Discussion and Conclusions

The aim of this paper has been to assess the participatory approach of jointly thinking and shaping futures from the German *Plattform Industrie 4.0*, with a particular focus on the outcomes and policy impact related to sustainable and resilient collaborative and digitally networked manufacturing systems. A specific view was on the involved and addressed public and private stakeholders, industry and policy sectors, and governance levels as they represent the following key factors for broad policy impact of *futuring* initiatives:

- Broad involvement of public and private stakeholders (multi-actor)
- Systemic view of all relevant aspects and industry and policy sectors (multi-sector)
- Strategic approach on all relevant governance levels (multi-level).

Assessing the process, outcomes and policy actions directly triggered by the 2030 Vision for Industrie 4.0, the collaborative vision and scenario-building process of the German *Plattform Industrie 4.0* is a good example of how broad policy impact can be achieved through a multi-actor, multi-sector and multi-level approach.

In this process, many stakeholders participated with their specific competencies and expertise (multi-actor), taking a holistic view toward shaping digital ecosystems (multi-sector), and strategically approaching all of the governance levels relevant for this endeavor (multi-level). Consequently, the stakeholders involved in developing and implementing the shared vision of "Shaping Digital Ecosystems Globally" and its pillars "Sustainability", "Autonomy" and "Interoperability" were able to set up the following actions in mutual strategic alignment:

- Elaborate and provide, with the *sustainability task force*, the strategic knowledge about development paths, scenarios and business cases which is needed for successfully implementing collaborative business models for sustainable production in digital ecosystems or *manufacturing data spaces* of the future ("Sustainability").
- Launch the *European GAIA-X project* to set up the data infrastructure needed for securing data sovereignty, as a precondition for realizing collaborative data-driven business models in a trusted digital environment ("Autonomy").
- Found the *Industrial Digital Twin Association (IDTA)* to make the digital twin practical for industry, which is highly relevant for interoperable exchange of data and informa-

tion in the collaborative condition monitoring, Circular Economy, and Manufacturing-as-a-Service business use cases ("Interoperability").

- Initiate the *lighthouse project CATANA-X* together with stakeholders from the automotive industry, in order to realize continuous data exchange for all contributors along the automotive value chain and implement concrete use cases in a rapidly scalable and expandable data ecosystem ("Shaping digital ecosystems globally").

Of course, the findings of this study are subject to some limitations, as the focus was on assessing the policy impact of a single *futuring* initiative, the vision and scenario-building process of the German *Plattform Industrie 4.0*, and mainly based on secondary data published by the organizers themselves (e.g., via the official website, www.plattform-i40.de (accessed on 30 June 2021)).

The publicly available documents primarily convey the outcomes of the process and do not describe the process itself, e.g., how the process was organized, what methods and techniques were used, etc. Thus, this article was not able to assess the process-related quality criteria ("internal validity criteria") for foresight and futures studies [47], and focused instead on the key criteria for broad policy impact ("external validity criteria") of such activities [20]. To obtain more insight into the "internal validity" of this process, looking, for instance, at the concrete strategic intelligence and sense-making activities which have been used to think about possible futures and identify the prioritized future [48], a more in-depth study with another research design would have been needed.

Regarding the assessment of "external validity", it is not critical that the reviewed secondary data was provided by the organizers of the *futuring* initiative themselves. First, the published documents reflect findings and observations which can also be found in other sources. In some passages, the article refers to corresponding findings in the literature or in other initiatives, such as the World Manufacturing Foundation. Second, the documents reflect the most important views and opinions of the actors who are also partly responsible for the implementation of concrete measures. This is a strong argument for the external validity of the process, as "pragmatic validity [ . . . ] increases if relevant actors are able to use it." [47] (p. 22).

Since the paper focused on a single case and not on a comparative analysis of various cases, the general validity of the results could not be empirically verified in this study. However, the findings of this study are consistent with the results of similar investigations of other *futuring* activities at the regional and European levels [8,10,14]. In addition, they are in line with innovation policy literature, which sees such participatory and systemic approaches as an important instrument for next generation innovation policy [19,49], with quadruple or quintuple innovation helixes for sustainable development [12,13,50].

This article and its findings contribute to current discussions in innovation policy literature and identifies areas where further research is needed. Regarding the currently discussed roles that the state could play in guiding the transformation of complex socio-technical innovation systems [51], the case of the *Plattform Industrie 4.0* illustrates various governance roles. For example, the state acts as a transformation *facilitator* by supporting a policy-oriented process of jointly thinking and shaping futures, including a wide spectrum of stakeholders with their different skills and competencies, in order to strategically align RTDI investments in a complex system. In this case, the Federal Minister for Economic Affairs and Energy (BMWi) and Minister for Education and Research (BMBF) chair the platform, together with high-ranking representatives from industry, science and the trade unions. They also act as *initiators* and *promoters* of transformative policy measures, such as the European GAIA-X project or the program for digital and ecological transformation of the German vehicle industry. Finally, they assume the role of a *moderator* and *enabler* of trans-national political cooperation, as the launch of the European GAIA-X project illustrates [33].

Areas where further research is needed include the question of how to assess the impact of individual *futuring* activities in an "open innovation diplomacy" [52] context with "multi-level, multi-modal, multi-nodal, and multi-lateral configurations" [53] (p. 148),

where the actors are involved in different activities. The study of the vision and scenario-building process of the *Plattform Industrie 4.0* revealed the involvement of key actors in related activities at different levels. Here, further studies on the importance of social capital or trusted networks would be interesting in order to analyze the role of personal relationships—e.g., strong versus weak ties [54]—and to study the role of key persons—e.g., bridging structural holes [55]—in the success and related impact of similar initiatives from different or adjacent communities (e.g., on the national and European levels).

The role of the regional level and of clusters as "local nodes in global value chains" [16] (p. 248) should not be underestimated in this context. This is particularly true when it comes to solving major global challenges which require orchestrated approaches, such as smart specialization strategies with their "entrepreneurial discovery" processes [56], in order to leverage and supplement localized innovation capacities [15,53]. In this respect, regional competence centers or young entrepreneurs and start-ups can play an important role with regard to climate change mitigation and the circular economy [57,58].

In conclusion, the grand societal challenges of our millennium, such as coping with global climate change or with global pandemics caused by increased human pressure on the biosphere, require global and strategically aligned actions taking into account the knowledge and competencies of multiple stakeholder groups and communities. Thus, thinking and shaping futures in a participatory approach that combines political boundary setting with entrepreneurial solution finding and aligns public with private investments is a prerequisite for mastering these grand challenges. As Industrie 4.0 is nowadays seen as a globally widespread issue [59] with close links to tackling the UN's Sustainable Development Goals [6], Industrie 4.0 initiatives all over the world are called to join their forces to achieve the Sustainable Development Goals by the year 2030.

In this context, the findings of this article provide good practices which should be included in upcoming initiatives related to Industrie 4.0 at the regional, national, European or international levels in order to collectively shape the digital ecosystems we need for the ecological transformation of industry on a global scale.

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