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Transformation Pathways towards Sustainable Agricultural Systems –

From Vision to Implementation

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Pictures

Agricultural Systems of the Future (Cover); Liv Merle Kantak (Figure 1); Agricultural Systems of the Future, generated with ChatGPT (Figure 2)

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1 Current Situation

The profound transformation of agricultural systems represents one of the central technological and societal challenges of the 21st century. Climate change, pollution, loss of biodiversity, increasing scarcity of natural resources, as well as changes in working conditions, geopolitical instabilities and the resulting pressures on food sovereignty, necessitate fundamentally new approaches to agricultural systems (FAO 2018; IPCC 2019; OECD 2021; Riechers et al. 2021).The visionary funding programme »Agricultural Systems of the Future« (Agrarsysteme der Zukunft, AdZ) of the German Federal Ministry for Research, Technology and Space (BMFTR) directly addresses these complex demands. Within this framework, agricultural systems are being conceptually re-examined and strategically re-designed. The programme unites formerly eight, now six interdisciplinary and transdisciplinary research consortia that jointly develop technology-driven, ecologically sound and socially sustainable solutions for the agricultural systems of tomorrow[1].

2 Future View

With »Agricultural Systems of the Future«, which was launched in 2019, the BMFTR motivated the investigation of viable alternatives to linear (incremental) improvements of conventional agricultural systems. Therefore, the participating consortia combine expertise from the fields of technology, ecology, economics and social sciences to allow interdisciplinary and disruptive approaches. From 2019 to January 2022, a joint future vision for internal strategic alignment and coherent external communication of all participating AdZ consortia was developed in dialogue with external specialists[2]. It visualizes the joint AdZ vision of a transformation towards a sustainable, fair and responsible agricultural sector that focuses on people and the environment. The content of the vision has since been updated and is now widely used in public debate (e.g., as part of the DAFA German Agricultural Research Alliance[3]).

The shared vision is the development of fair, resilient and responsible agricultural systems that place equal emphasis on human well-being and environmental integrity[4]. This vision deliberately transcends purely technological solutions; instead, it aspires to a holistic re-design of future agricultural systems. The anticipated transformation is captured in the initiative's forward-looking conceptual framework, depicted in the future view of »Agricultural Systems of the Future« (Fig. 1).

[1] https://agrarsysteme-der-zukunft.de/en/consortia/overview
[2] https://agrarsysteme-der-zukunft.de/ueber-uns/zukunftsbild-und-transformation
[3] https://www.dafa.de/foren/strategisches-forum/
[4] https://agrarsysteme-der-zukunft.de/en/about-us/vision-and-mission

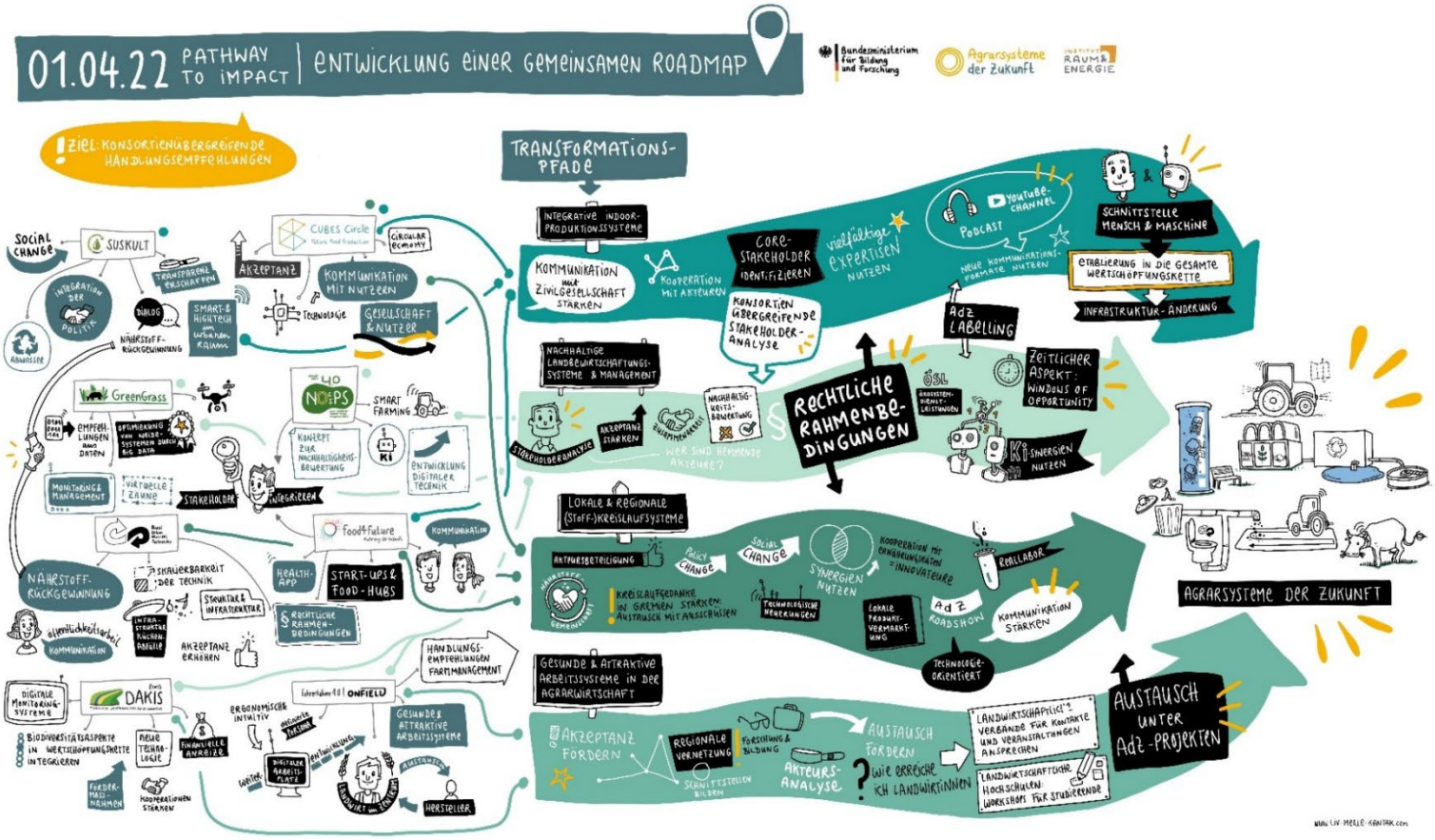


Figure 1: From vision to transformation of »Agricultural Systems of the Future« – Enabling disruptive invention through connected, circular, and integrated system approaches.
Reference: Liv Merle Kantak

3 Transformation Pathways as a Joint Roadmap for Transfer

To implement the vision, all consortia of the »Agricultural Systems of the Future« identified and defined overarching transformation pathways in a workshop series entitled »Pathway to Impact« from 2022 to 2023. The basis for this was a synoptic survey and analysis of transformation theories and transformation concepts (internal working paper) as well as the exchange at international conferences (Global Bioeconomy Summit 2020; International Conference on Sustainability Transitions IST 2021, 2022). The 2022 workshops introduced key approaches in transformation research, and the series continued in 2023, building on earlier results and the consortia's activities to identify potentials for inter-consortia exchange and cooperation. In a two-stage process, shared topics for the transformation pathways of »Agricultural Systems of the Future« were defined[5], outlining both consortium-specific and collective contributions to agricultural transformation as well as the intended output, outcome and impact. Four transformation pathways were defined (Fig. 2).

[5] https://agrarsysteme-der-zukunft.de/en/about-us/future-image-and-transformation

Figure 2: The four transformation pathways of »Agricultural Systems of the Future« – Bridging the gap: From fundamental research to application.
Reference: Agricultural Systems of the Future, generated with ChatGPT

These transformation pathways bridge the gap between cutting-edge scientific research and effective knowledge and technology transfer. They enable a coherent progression from fundamental research and initial prototypes toward viable technological applications and social practices. Our current focus is on translating scientific insights into practical applications, exploiting technological and economic opportunities and thereby actively contributing to the development of sustainable agrifood systems. At the same time, it must be clearly emphasized that the transformation of agricultural systems requires not only a collective scientific, but merely societal responsibility. Lasting success can only be achieved through sustained cooperation among science, industry, civil society, administration and policy. »Agricultural Systems of the Future« demonstrates that systemic and technology-oriented research combined with transdisciplinary co-design and co-creation provide a robust and future-proof foundation for this transformation.

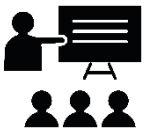
It should be noted that the transformation pathways developed within »Agricultural Systems of the Future« represent only a subset of the many possible pathways toward systemic change (cf. Stark et al. 2022; Veivåg Helseth et al. 2025; de Castro et al. 2025). While this programme concentrates on the re-design of agricultural systems, related areas of action – such as the entire food sector – must also be considered, for which additional transformation pathways have been proposed (e.g., the 11 pathways of actions of the European Commission's Food 2030 Initiative 2023). This plurality of potential transformation pathways enables the deliberate selection of complementary, parallel transformation pathways that can be adapted to local, regional, or (inter)national contexts, thereby maximizing synergies and minimizing trade-offs wherever possible.

4 Platform for Systemic, Interdisciplinary and Transformation-Oriented Research

»Agricultural Systems of the Future« is closely aligned with current developments in science and research policy. We are already putting into practice what the German Science and Humanities Council (Wissenschaftsrat, WR) outlines in its most recent position paper (2024): namely, the implementation of systemic, interdisciplinary, transdisciplinary and transformation-oriented research within agricultural, food and nutritional sciences. Within »Agricultural Systems of the Future«, we are actively operationalizing the strategic fields of action identified by the German Science and Humanities Council for guiding this research domain toward a sustainable future direction:

Research – All consortia of »Agricultural Systems of the Future« have been conducting systemic, interdisciplinary and transdisciplinary research since the beginning of the funding (2019/2020). The German Science and Humanities Council even explicitly refers to the funding programme »Agricultural Systems of the Future« (see WR 2024: 31) as a good example of systemic and transformation-oriented research as well as transdisciplinary approaches.

Research Infrastructure – Pilot plants and living labs have been developed by the AdZ consortia and are already connected with existing research infrastructures. They leverage regional innovation capacities and connect science with society.



Education – »Agricultural Systems of the Future« is active at various educational levels for capacity building and attracting the future generation of experts for shaping sustainable agrifood systems: from the school sector (for example with the Junior Engineer Academy[6]) to joint teaching (lecture series involving all consortia of »Agricultural Systems of the Future«).

Science Communication and Policy Advice – All AdZ consortia are engaged in science–society interaction by using a broad variety of communication formats and integrative schemes. These activities are designed not only to disseminate research outcomes but also to foster dialogue and mutual learning of all involved actors in the transformation of agrifood systems. The central coordination office of »Agricultural Systems of the Future« supports and connects these efforts, facilitates synergies across consortia, and develops complementary formats to ensure inclusive and sustained engagement with all relevant stakeholder groups.

5 Setting the Strategic Course Today for a Future Worth Living

The transformation pathways developed in »Agricultural Systems of the Future« primarily aim to redesign agricultural production to advance them into sustainable, resilient, and environmentally friendly operational systems. At the same time, these pathways create options to strengthen ecosystem services, thereby supporting biodiversity, soil health, ecological restoration, and reforestation and economic viability. The AdZ transformation pathways are intentionally aligned with national strategies (Hightech Agenda, Future Strategy for Research and Innovation) as well as European frameworks, including the European Green Deal and the new EU Strategy for a Competitive and Sustainable EU Bioeconomy.

[6] https://www.telekom-stiftung.de/aktivitaeten/junior-ingenieur-akademie

We also emphasize that sustainable agricultural production must always be considered in close conjunction with sustainable consumption—specifically in the sense of healthy, equitable dietary patterns as outlined in the Planetary Health Diet (Rockström et al. 2025) and consistent with the Leibniz position on Sustainable and Resilient Agrifood Systems (SARAS) (Hunecke et al. 2025). This includes implementing the operational goals for food system transformation proposed by the Food System Economics Commission (Ruggeri Laderchi et al. 2024), namely: achieving healthy diets for all, ensuring strong and sustainable livelihoods throughout the food system, protecting intact ecosystems and restoring degraded ones, and enabling environmentally sustainable production practices across the entire agrifood system. Furthermore, these efforts must be embedded within a coherent global agricultural and trade policy framework that reflects internationally agreed objectives for biodiversity conservation, climate protection, and food security (Böhning-Gaese et al. 2025).

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