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Preliminary remarks

Developments in the 2020s, such as the COVID-19 pandemic, the escalating effects of climate change and the continuing high number of armed conflicts, have further increased the pressures on agriculture and food systems. The creation of a future-proof framework for this sector, which can be brought about only through a fundamental transformation, poses immense challenges and is one of the key priorities of the 21st century.

There is an urgent need for society as a whole to act; alongside many other stakeholders, this includes the scientific community – without which the necessary transformation cannot be achieved. German agricultural, food and nutritional sciences thus face enormous challenges, both now and in the future. The fundamental question is to what extent the German research and innovation system – including the higher education sector – is prepared for this urgent task, given its current focus and existing structures.

The Federal Ministry of Food and Agriculture (BMEL) commissioned the German Science and Humanities Council (WR) to undertake a structural review of agricultural, food and nutritional sciences in Germany and to develop structural and substantive future perspectives for the next decade and beyond. In July 2021 the WR appointed a working group to undertake this task.

Russia's invasion of Ukraine in February 2022 crystallised public awareness of the challenges facing our agriculture and food systems and the corresponding need for action. Ensuing developments provided an extraordinary catalyst for social, political and scientific discourse, which the WR has contributed to in the form of this policy paper. Building on this, it will develop concrete recommendations which are to be adopted by July 2024.

The working group brought together several experts recruited exclusively from abroad who are not members of the WR. In addition to this international body of scientific expertise, a number of stakeholders at global, European and national level were also included. The WR owes them all a special debt of gratitude. The WR would also like to thank other experts from Germany and abroad who have supported the consultation process through hearings and discussions.

This policy paper addresses the contribution to be made by the system of research and higher education to the impending transformation processes, which nevertheless can be achieved only through the endeavours of society as a whole. Thus, the policy paper is aimed primarily at the BMEL, the scientific communities within the agriculture and food sector, higher education institutions (HEI) and non-university research institutions, and research organisations. It is also aimed at political stakeholders at national, European and international level, societal stakeholder groups involved in the complex and vital transformation processes, and citizens who would be significantly affected by its success or (partial or complete) failure.

The WR adopted this policy paper on 21 April 2023 in Leipzig.

Summary

Despite the enormous and constantly rising productivity of **agriculture and food systems**, around one tenth of the world population suffers from chronic hunger and well over one third cannot afford a healthy diet. Furthermore, food production in its current form plays a significant role in terms of exceeding the planetary boundaries, contributing for example to biodiversity loss, anthropogenic climate change and chemical pollution. In view of these problems and the rising global population, the food situation is likely to deteriorate further. Thus, there is an **imperative and urgent need to transform** agriculture and food systems. To this end, this policy paper sets out a **vision** to guide society, science and policymakers.

The WR recognises the **responsibility of science and research to play an active part in these macrosocial transformation processes**. It strongly supports existing efforts by various academic stakeholders in Germany and emphasises the fact that the broad positioning of German agricultural, food and nutritional sciences, their acclaimed disciplinary research and wide-ranging networks in Germany and abroad provide an excellent basis for facilitating transformation at local, national, European and global level. However, a **reorientation** of the entire field – which is severely fragmented in parts – is required, which in turn calls for the rigorous implementation of both a **systemic approach** and a **transformative perspective**. This creates a framework for analysing the complexity of the challenges appropriately and using the results as a basis for developing possible solutions, actions and pathways to transformation. In order to **implement** this reorientation, the agricultural, food and nutritional sciences need to see **structural and procedural changes** which:

1 – support **integration efforts** in the agricultural, food and nutritional sciences – from research, teaching and transfer to (data) infrastructures and digitalisation – to enable data, information and knowledge to be pooled and shared between disciplines;

2 – **create** and develop medium- and long-term **opportunities for participation** so that stakeholders in the publicly funded system of research and higher education can systematically share their research needs with partners from other sectors of society at an early stage, work together on possible solutions and pathways to transformation, and agree on conflicting goals and synergies;

3 – ensure that individual researchers as well as institutions receive due **reputation** and **recognition** for the challenging, resource-intensive and transformative achievements that society so urgently requires, both within and outside the academic system, and;

4 – give **voice and visibility** to the agricultural, food and nutritional sciences **in a national**, **European and global context** so that they can provide well-founded advice to policymakers, engage the public in the transformation efforts and exchange views with academics at international level.

These structural and procedural changes require ideas and commitment on the science and science-policy side, as well as the **targeted use of financial resources** by funders and policymakers, without restricting the ability to conduct independent, knowledge-driven research. On the basis of this fundamental positioning, the WR plans to develop **concrete recommendations for the necessary structural and procedural changes** by 2024.

A. Transformation of agriculture and food systems

A.I POLITICAL CONTEXT

The **need to transform agriculture and food systems** is widely acknowledged, as in many areas they are unable to provide the world's population with an adequate and secure supply of high-quality food and they are a significant contributor to biodiversity loss and climate change. Key transformation objectives are already being addressed in broad sectors at **global, European and national level** through laws, policies and agreements.

First and foremost, among these is the 2030 Agenda for Sustainable Development of the **United Nations** (UN). |[1] The agenda includes 17 ecological, economic and social Sustainable Development Goals (SDGs) which the global community has resolved to implement by 2030. SDG 2 (Zero hunger) is particularly relevant to agriculture and food systems and closely linked to other goals relating to health, climate and the environment. |[2]

The **European Union** (EU) has responded to the need for transformation by developing strategies such as the European Green Deal, the Farm-to-Fork strategy that lies at its heart, and the Chemical Strategy for Sustainability. The EU has also enacted legally binding regulations which call on members to urgently tackle threats caused by climate change – such as threats to food security. |[3] Current crises like the war in Ukraine have served to strengthen the **G7 States**' commitment to "continue [their] work towards sustainable and resilient agriculture and food systems". |[4]

The challenges associated with transformation have been partially addressed by **German government policy**. When the German Sustainability Strategy was updated in 2016, the 2030 Agenda goals were incorporated into a national

|[1] cf. UN, 2015. See: https://sdgs.un.org/2030agenda. All web links in the position paper were last accessed 19.04.2023.

|[2] cf. Valin, H./Hertel, T./Bodirsky, B. L. et al., 2021.

|[3] cf. EU, 2021.

|[4] G7 Agriculture Ministers' Communiqué, 2022, p. 3.

strategy. [5] This provides a framework for various programmes aimed at implementing the global sustainability goals at national level. [6] The German Advisory Council on Global Change (WBGU) in its 2020 flagship report on rethinking land use outlines the critical interactions between climate change, food security and biodiversity conservation and states that: "The pressure to act is greater in the Anthropocene than ever before in the history of humankind." [7] In the 2021 coalition agreement "sustainable agriculture and food systems" [8] are one of the six pillars of Germany's future research strategy. A concept paper on the food strategy published by the Federal Ministry of Food and Agriculture (BMEL) describes food as a key aspect in the transformation to a resource-efficient, climate-friendly and sustainable economy. [9]

In view of the urgent need for transformation, which is already being addressed at political level to some extent, this paper describes the **status quo** of agriculture and food systems worldwide and also takes account of adjacent systems in order to identify interdependencies (cf. A.II). It then sets out a **vision for agriculture and food systems** which are ideally structured in a **future-proof manner** based on four aspects of equal value: (1) environment- and climate-friendly, (2) economically viable, (3) socially acceptable and (4) health-promoting. [10] These four dimensions are mutually dependent and by no means mutually exclusive. **Objectives** for **societies** in transition are described first; from these, objectives are derived for national **science** and **science policy** (cf. A.II).

A.II THE NEED FOR TRANSFORMATION

The **food value chain** encompasses production, processing, trade and consumption (farm-to-fork, plough-to-plate). Each of these stages also entails transport, intermediary trade and warehousing aspects as well as other upstream services, ranging from the production of fertilisers to food waste recycling, for example.

[5] cf. The Federal Government, 2021.

[6] This includes the National Programme for Sustainable Consumption (cf. BMUB/BMJV/BMEL, 2018), which was revised in 2021 (cf. Die Bundesregierung, 2021), and Zukunftsstrategie ökologischer Landbau (cf. BMEL, 2019). Dating even further back are the Nationale Strategie zur biologischen Vielfalt (cf. BMUB, 2015) and the Protein Crop Strategy (cf. BMEL, 2020). The Climate Action Plan 2050 (cf. BMUB, 2016) also contains guidelines for a sustainable agricultural framework.

[7] WBGU, 2020, p. 21.

[8] Social Democratic Party of Germany (SPD), Alliance 90/The Greens and the Free Democrats (FDP), 2021, p. 18.

[9] BMEL, 2022b, p. 2.

[10] Agriculture and food systems are future-proof if negative (and potentially irreversible) ecological, economic and social effects are avoided during the production of healthy food while also considering the needs of all present and future generations of humankind. This understanding can be traced back to the discussion on sustainable development undertaken in the wake of the Bruntland Report of the World Commission on Environment and Development in 1987 (cf. WCED, 1987) and the UN Agenda 21 adopted in 1992 (cf. UNCED, 1992). The three-dimensional model (ecology, economy and social, cf. Deutscher Bundestag, 1998) established in this context is at odds with other models which distinguish between one- and multi-dimensional models (cf. Michelsen, G., 2012, pp. 62-66). In the context of agriculture and food systems, whose primary function is the production of healthy food as the basis of human life, health constitutes a fourth dimension which sits alongside ecology, economy and social affairs.

Numerous stakeholders are involved in adding value through this multitude of activities. | [11] This results in a **high level of complexity** that is both **efficient** and **problematic**. For example, increased productivity means that a section of the world's population can now access a wide range of different foods at affordable prices all year round, and yet there is less arable and grazing land per head of population. | [12] Indeed, most people in the Global North can afford to eat meat on a daily basis. The problem, however, is that value creation in the 21st century is accompanied by the use of pesticides and chemicals and often lies in the hands of a few global corporations, e. g. in the fertiliser sector. | [13] Furthermore, the range of food on offer is increasingly characterised by a growing proportion of highly processed foods encouraging nutritional habits which – differentiated by socio-economic status, gender and other traits – contribute to an unhealthy diet.

Against this backdrop, agriculture and food systems in their **present form** cannot provide the global population with an adequate and secure supply of high-quality food, while at the same time they are further accelerating climate change and environmental degradation (also to their detriment). Although food production has increased significantly in relation to global population growth, especially since the 1960s, | [14] roughly 700 to 830 million people, around 10 % of the world population, suffer hunger. | [15] At the same time, more than two billion people worldwide are overweight or obese – and the trend is rising. | [16] This **worrying situation** affects Germany too and is likely to become **increasingly critical**. | [17] With the global population expected to reach between nine and ten billion within the next three decades, the demand for food is expected to rise by 55 % between 2010 and 2050, according to current estimates. But the challenge of providing the world's population with an adequate and secure supply of high-quality food cannot be addressed through **production increases alone** without further exacerbating the negative effects on the climate and the environment. | [18] The COVID-19 pandemic and continuing high number of armed conflicts have already compounded the situation and laid bare the vulnerability of our agriculture and food systems to **shocks and crises**. | [19]

| [11] cf. Van Berkum, S./Dengerink, J./Ruben, R., 2018, pp. 10–16.

| [12] cf. https://de.statista.com/statistik/daten/studie/1196555/umfrage/anbauflaechen-und-weideflaechen-weltweit/.

| [13] cf. European Parliament, Directorate-General for Internal Policies of the Union/Venus, T./Drabik, D. et al., 2015, p. 62 f.

| [14] cf. https://www.oecd.org/agriculture/understanding-the-global-food-system/how-we-feed-the-world-today/

| [15] cf. FAO/IFAD/UNICEF/WFP/WHO, 2022; Von Grebmer, K./Bernstein, J./Resnick, D. et. al., 2022.

| [16] cf. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight; FAO/IFAD/UNICEF/WFP/WHO, 2022.

| [17] cf. WBAE at the BMEL, 2020, pp. 72–102.

| [18] cf. Searchinger, T./Waite, R./Hanson, C. et al., 2019, p. 16.

| [19] cf. Klassen, S./Murphy, S., 2020; Webb, P./Flynn, D. J./Kelly, N. M. et al., 2021; FAO, 2022c; FAO, 2022b; Institute for Economics & Peace, 2022; HIIK, 2022.

Furthermore, **agriculture and food systems** do not exist in isolation; they **interact with other systems** such as climate and environment, economy, social and health. Interactions at the respective interfaces rebound on the systems concerned, producing undesirable side-effects and conflicting goals in many areas. | [20] These **interactions** can be defined as follows:

Climate and environment: The manner of our **food production** has a direct impact on the environment and is currently estimated to account for around one fifth of the overexploitation of groundwater, around one third of soil degradation and around half of biodiversity loss. | [21] This makes it the key driver in **exceeding the planetary boundaries**. | [22] Agriculture and food systems are also a major driver of anthropogenic **climate change**: they currently consume around one third of global energy and generate around one third of global greenhouse gas emissions per year. | [23] In addition, the creation of new agricultural land is responsible for around 90 % of global deforestation. | [24] According to current forecasts, the social costs of global greenhouse gas emissions linked to agriculture alone will run to over 1.7 billion US dollars a year by 2030. | [25]

Economy: The agriculture and food sector is the **world's largest economic sector** and is estimated to employ more than two billion people worldwide. | [26] In **Europe and Germany**, the agriculture and food sector also has a **significant economic impact**, too. For example, in 2020 this sector employed around 29 million people in the EU and around 4.4 million in Germany. | [27] In the agriculture, forestry and fisheries sector alone, gross value added within the EU during this period amounted to around 2 % of the value added from all economic sectors; in Germany, the gross value added corresponded to around 1 % of the value added from all economic sectors. | [28]

| [20] cf. Ericksen, P. J., 2008; Ingram, J., 2011; Ingram, J./Zurek, M., 2018.

| [21] cf. Ingram, J./Zurek, M., 2018, S. 548; see also: Poore, J./Nemecek, T., 2018; Mateo-Sagasta, J./Marjani Zadeh, S./Turral, H., 2018; Westhoek, H./Ingram, J./Van Berkum, S. et al., 2016.

| [22] cf. Campbell, B. M./Beare, D. J./Bennett, E. M. et al., 2017. On the concept of planetary boundaries, see: Rockström, J./Steffen, W./Noone, K. et al., 2009; Steffen, W./Richardson, K./Rockström, J. et al., 2015. The term planetary boundaries can be defined as follows: “Ecological limits that result from the fact that the natural habitats and resources on Earth are finite and require certain periods of time to regenerate. The boundaries and where exactly they run is still the subject of intensive discussion. However, it is undisputed that humankind, and its economic activities, is increasingly endangering the limits of the Earth and with them its own livelihood” [unofficial translation] (BMBF/BMEL, 2020, p. 60).

| [23] cf. Crippa, M./Solazzo, E./Guizzardi, D. et al. 2021; IRENA/FAO, 2021.

| [24] cf. FAO, 2022a, p. XII; for BMEL’s activities in this context, see: Deforestation-free supply chains: agricultural production without forest destruction, https://www.bmel.de/EN/topics/forests/forests-around-the-globe/deforestation-free-supply-chains.html.

| [25] cf. FAO/IFAD/UNICEF/WFP/WHO, 2020, p. 93 and pp. 107–109.

| [26] cf. Gladek, E.; Fraser, M.; Roemers, G. et al., 2017, p. 8.

| [27] cf. Rossi R., 2020, S. 1; BMEL, 2022a, p. 43.

| [28] For the situation in the EU, see https://data.worldbank.org/indicator/NV.AGR.TOTL.KD?end=2021&locations=EU&start=1995&view=chart; https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?end=2021&locations=EU&start=1995&view=chart; for the situation in Germany, see https://data.worldbank.org/indicator/NV.AGR.TOTL.KN?locations=DE;

Social: As a large proportion of the global population makes its living in the agriculture and food sector, the social importance of agriculture and food systems is significant. Around three quarters of people employed in agriculture worldwide live in **poverty** and often face **precarious working conditions** which will only worsen as climate change progresses. |[29] This is one of the greatest challenges facing food security. Women, especially in the Global South |[30], play a major role in food production and yet their access to land, credit, technology and resources is often restricted due to **gender inequality**. |[31] This also applies to indigenous groups and local communities who are often among the **disadvantaged** and particularly vulnerable **social groups**.

When it comes to Europe and Germany, considerable importance is attached to the **structure of rural areas**, which play a vital role in providing cities with water, fresh air and recreational space. The more remote rural areas in particular are suffering from significant population decline, which is further exacerbated by inadequate health provision, poor educational opportunities and lack of transport services. Other factors to contend with are the **mechanisms** which support a **shift in the ownership structure** of agricultural holdings in favour of large corporations and the ever-increasing dependency – globally – on ever fewer suppliers of seed, fertiliser and crop protection products. |[32] These factors risk further compounding the existing **problem of generation change** in agriculture. |[33] Even beyond farming itself, **working conditions** in the agriculture and food sector are **sometimes precarious**, as evidenced not least by recent difficulties in downstream sectors of the food value chain, such as processing and retail. The COVID-19 pandemic has ultimately exposed these structural problems. |[34]

https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=DE. The figures for Germany can be broken down more precisely in terms of the agriculture and food sector (i. e. farming and fisheries, including up- and downstream economic sectors) as follows: in 2020, this sector generated a gross value added of around 188.5 billion euros, which equates to more than 6 % of the value added from all economic sectors, cf. BMEL, 2022a, p. 43.

|29 cf. New Foresight/Commonland, 2017, p. 7.

|30 The terms Global South and Global North have superseded the former ways of classifying the world (e. g. East, West, Third World) and refer – as a relational concept – not to clearly defined geographical areas, but rather to weak or strong economic, political and social positions in the world order (cf. https://gssc.uni-koeln.de/en/the-center/global-south).

|31 cf. Njuki, J./Eissler, S./Malapit. H. et al., 2023.

|32 On the general situation, see International Panel of Experts on Sustainable Food Systems (IPES-Food), 2017; for the situation in the seed sector, see: OECD, 2018; for the situation in the fertiliser sector, see: European Parliament, Directorate-General for Internal Policies of the Union/Venus, T./Drabik, D. et al., 2015, p. 62 f. Germany still has a large number of small- and medium-size plant breeding companies with their own breeding facilities (cf. https://www.bdp-online.de/de/Branche/Kennzahlen/).

|33 cf. Rossi, R., 2020, S. 5; Statistisches Bundesamt, 2021b; Deutscher Bauernverband e. V., 2021, p. 89 f.

|34 For the meat industry, cf. EFFAT, 2020, p. 5 f. (for Europe) and pp. 7–10 (for Germany). In December 2020 the German legislator responded to grievances about working conditions in the meat industry by passing the Occupational Safety and Health Inspection Act (Arbeitsschutzkontrollgesetz), which brings about changes in the law to safeguard workers' rights in the meat industry, including a ban on temporary agency work.

Health: Around 700 to 830 million people worldwide go hungry and around three billion people cannot afford a healthy diet. |[35] For young children in particular, undernourishment and malnutrition can lead to impaired mental and physical development, which in most cases is irreversible. For example, as a result of poor nutrition, around 150 million children below the age of five are affected by growth retardation, while a further 45 million children in this age group suffer from emaciation. |[36] At the same time, more than two billion people worldwide are overweight or obese – and the trend is rising. |[37] This **global constellation of under-, mal- and overnourishment** is described in research as the triple burden of malnutrition. |[38] All three forms of malnutrition occur in Germany. |[39]

Diabetes and cardiovascular diseases are widespread as a result of unhealthy diets. Other diseases such as AIDS, malaria and measles can have a more serious effect on people already suffering from malnutrition. |[40] The **financial burden on the health system caused by malnutrition** is severe: in 2013 the Food and Agriculture Organization of the United Nations (FAO) estimated the global social and economic costs to be around **3.5 billion US dollars** per year; |[41] in Germany alone, around one third of all health system costs are caused by diseases which are directly or indirectly attributable to diet-related risks. |[42] In 2017, diet-related risks were responsible for an estimated 22 % of global adult deaths; |[43] in Germany in 2019, around 14 % of all deaths were linked to an unhealthy diet. |[44] The negative ecological impacts of agriculture and food systems are also increasing the incidence of other diseases – such as zoonoses. |[45]

The description of the status quo of our agriculture and food systems, which are dysfunctional in many respects, lays bare the urgent **need for transformation**. Not only is our ability to supply the world's population with an adequate and secure supply of high-quality food at risk; the agriculture and food systems also have a negative impact on the systems with which they interact (climate and environment, economy, social and health).

|[35] cf. FAO/IFAD/UNICEF/WFP/WHO, 2022; Von Grebmer, K./Bernstein, J./Resnick, D. et. al., 2022.

|[36] cf. ibid.

|[37] cf. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight; FAO/IFAD/UNICEF/WFP/WHO, 2022.

|[38] cf. Labadarios, D., 2005; Pinstrup-Andersen, P., 2007; a 'multiple burden of malnutrition' is an alternative term.

|[39] cf. WBAE at the BMEL, 2020, pp. 72–102.

|[40] cf. Schaible, U. E./Kaufmann, S. H. E., 2007.

|[41] cf. FAO, 2013, p. 5. More recent figures are not available.

|[42] cf. BMUB/BMJV/BMEL, 2018, p. 45.

|[43] cf. Afshin, A./Sur, P. J./Fay, K. A. et al., 2019, p. 1961.

|[44] cf. OECD/European Observatory on Health Systems and Policies, 2021, p. 6.

|[45] cf. Valin, H./Hertel, T./Bodirsky, B. L. et al., 2021, p. 17 f.

A **transformation of the agriculture and food systems** calls for a large number of transformation processes which need to be actively shaped and, at the same time, forms part of an **overall societal change** involving the public and private sector and civil society |[46] alongside science and policymakers.

In order for **science and research** to contribute effectively to the transformation processes and support the change, a **structural (re-)orientation** is required which still allows academic freedom to be preserved. This pertains not only to agricultural, food and nutritional sciences, but also to specialist disciplines which are relevant to the adjacent systems. The task of **science policy** is to facilitate and support this (re)orientation by strategically focussing on the transformation-related challenges and demands facing science and research.

The following **vision** outlines relevant objectives for achieving this at social, scientific and science-policy level in two stages.

First, a notional **ideal of society** to be achieved by 2050 is presented which was developed on the basis of global, European and national agendas, laws, strategies and agreements. The core element of this ideal is climate- and environment-friendly, economically viable, socially acceptable, health-promoting and thus **future-proof agriculture and food systems**, which – where possible – anticipate crises, prepare for them, rapidly overcome them and learn from them, i. e. are resilient.

Societal vision

By the year 2050, the ecological, economic, social and health-related functions of **future-proof** agriculture and food systems carry equal weight worldwide; this reduces food insecurity and ensures that the global population has access to a sufficient quantity of healthy food. In the context of agriculture and food systems, these **four dimensions – the cornerstones of food security –** are given **equal consideration**. Food security is regarded as the global responsibility of humankind.

For a long time now, **conflicting goals** inherent in the system have been continuously monitored and optimally addressed through continuous political negotiation processes involving societal stakeholder groups. Where the systems have changed irreversibly, **societies adjust their behaviour** accordingly.

On this basis and in full awareness of its global responsibility, Germany continually refines its agriculture and food systems through a broad negotiation

|[46] The Federal Ministry for Economic Cooperation and Development defines the term civil society as “the totality of engagement of the citizens of a country – for example, in clubs, associations and diverse forms of initiatives and social movements. This includes all activities which are not-for-profit and not dependent on party political interests” [unofficial translation] (https://www.bmz.de/de/service/lexikon/zivilgesellschaft-14976).

process. Corresponding education and research programmes enable the various **societal stakeholder groups** to **participate** in this process and play an active role in shaping it. Potential structural changes to the systems are reflected on and democratically legitimised through the participatory processes.

Human **consumer behaviour** continuously evolves in a **healthy nutritional direction and environment**. The population increasingly demands high-quality, healthy products, thereby reducing the incidence of malnutrition and associated diseases. The demand for animal products is limited to a level that does not exceed the planetary boundaries. The holistic approach associated with the **One Welfare concept** |[47], which addresses the interaction between the health of humans, animals and the environment within the context of the One Health approach and transcends it to include their well-being, is implemented and encouraged through the well-established culture of sustainable dietary habits.

Food continues to be consumed not only to absorb calories and nutrients, but also to fulfil important **sociocultural functions** – such as eating together. There is a strong awareness of the links between consuming food for nourishment or pleasure and its impacts on health, climate and environment. Following on from the modified consumer behaviour, agriculture and food systems play a part in landscape conservation and in preserving **cultural landscapes** and their multifunctional land use (including the provision of groundwater, bioclimatic regulation and recreation). Society recognises the importance of rural spaces.

In 2050 **production systems** are future-proof in line with modified consumer behaviour. Prevailing ideas about authenticity and naturalness in agricultural production are being re-examined in society and alternative narratives are emerging concerning nature-friendly production systems. The focus lies on **innovative cultivation systems that are adapted to local conditions** and are sustainable, regenerative and environmentally friendly. The associated economic risks are not borne by farmers alone, but financially supported by functional **risk assessment mechanisms**. Processes both in production and across the entire field of agriculture and food systems are continuously improved by means of ecological, social, systemic and technological **innovations** enshrined in rules and regulations. For example, digitalisation can minimise the use of environmentally harmful substances as well as harvesting and processing losses and contribute to efficient cropping.

Food processing systems and the retail sector are structured along diverse lines that reflect **local and regional diversity**. Supply structures are efficiently interlinked at different spatial levels (local, regional, national and global) to encourage **resilience** in agriculture and food systems. For some time now, **food prices**

|[47] "The concept of One Welfare recognises the interconnections between animal welfare, human wellbeing and the environment, with an emphasis on the importance of interdisciplinary collaboration and solutions" (Stephens, T., 2022, p. xiii). For a more detailed definition, see: Lindenmayer, J. M./Kaufman, G. E., 2022, p. 18 f.

for sustainable products have reflected the production, processing, storage and transport costs arising in the food value chain. Nonetheless, they are affordable for all consumers – even those in lower-income groups. When the actual value of food – including the hidden costs – is reflected in this way, and appreciated by consumers, less is wasted.

The economically efficient and competitive agriculture and food sector is **attractive for employees** from an economic and social point of view. Food products and the people behind them within the food value chain receive broad social recognition and appreciation. In the case of farmers, this relates not only to their contribution to food production, but also to material and energy production and climate protection. This is supported by the fact that their work is transparent to consumers.

The food value chain generates reusable by-products whose potential for **nutrient recovery** is exploited in accordance with circular economy principles. Thus, agricultural commodities not only provide a source of food but also contribute to the recovery of energy and material as part of a **sustainable bioeconomy**, which changes the way farmers see themselves. The recovery of material and energy from agricultural commodities, including waste materials, provides an opportunity to replace a proportion of fossil-based resources without significantly impacting on food prices. **Biological resources and waste materials are used efficiently and systematically**, and the manufacturing economy is converted to one based on renewable raw materials. This not only safeguards prosperity but contributes to the regeneration of climate and environment.

This structure puts German agriculture and food systems on a footing that is climate- and environment-friendly, economically viable, socially acceptable, health-promoting and thereby future-proof, enabling them to face up to the **global challenges** in 2050. Due to their high level of functionality, sustainably structured value chain, and resilience, German agriculture and food systems are able to make a substantial **contribution to food security** both in Germany and abroad. Furthermore, they play a part in overcoming the interconnected global crises of the 21st century (species extinction, climate change, war, pandemic and mass migration) and thus safeguarding peace, stability and prosperity.

There now follows a **science and science-policy vision** based on the societal objectives outlined above. At its heart lies the **rigorous implementation of systemic approaches** – underpinned by Germany's existing disciplinary diversity and high-quality science and research – which must be considered a prerequisite for a successful transformation of agriculture and food systems. Since science and science policy act as drivers of social development, they must align themselves with the objectives as quickly as possible to enable the ideal of society to be achieved by 2050.

Science and science-policy vision

The various subsections of the agricultural, food and nutritional sciences interact – on the basis of comprehensive and FAIR |[48] data – to facilitate **integrated research and analysis** of the agriculture and food systems in all their complexity. At the same time, researchers are exploring the interplay between agriculture and food systems and the **interacting (sub)systems**, which include climate and environment, the economy, social and health. Systemic approaches permit academics and their institutions to contribute to the **advancement** of future-proof agriculture and food systems on an ongoing basis, supported by **high-performing specialist disciplines**. They develop their potential through **successful**, needs-driven **inter- and transdisciplinary collaborations** involving stakeholders from other disciplines and partners outside the system of research and higher education. Appropriate consideration is also given to local and indigenous knowledge. Academics continually scrutinise their own actions and have access to proven collaborative models and diverse, sustainably financed infrastructures.

The aim of **higher education and continuing education** is not only to impart knowledge specific to a particular discipline, but also to convey an understanding of **systemic relationships**. Students are introduced to inter- and transdisciplinary ways of working and learn to reflect on the potential and challenges of these approaches so that they can apply them to future professional activities, whether in an academic or a non-academic setting.

Academics at every career stage who use their staff and resources to address systemic issues are **highly valued** – both within and outside the system of research and higher education. They can carry out their work effectively within the legal framework, as the **regulatory processes** – where possible – have been **simplified** by cutting red tape. The **evaluation and reputation system** within the sciences takes rigorous account of their **wide-ranging** work and contributions, which open up different **career paths** in both the academic and non-academic sector.

Scientific publications are **open access** and so can be accessed by all societal stakeholders. High-quality publication bodies that facilitate low-cost publishing have been set up for this purpose. Furthermore, **academics communicate** their research results as soon as they have scientifically robust findings, and also share them appropriately with **non-scientific target groups**.

This enables academics to exchange information with different societal stakeholders, drive innovation and advise political decision-makers as effectively as possible using a theoretical and evidence-based approach. Together with non-

|[48] The ideal model is underpinned by the FAIR Guiding Principles for scientific data management and stewardship, which state that data should be findable, accessible, interoperable and reusable (cf. http://www.go-fair.org/fair-principles/).

scientific stakeholder groups and using **participatory methods**, they identify research needs, define and address problems, seek solutions to conflicting goals coming to light in agriculture and food systems, and find ways of dealing with them. Academics assume **a variety of roles** in **transdisciplinary formats**, including that of moderator or facilitator in participatory formats. There is close cooperation between public and private sector as well as the numerous stakeholders involved, such as higher education institutions (HEI), non-university research institutions, companies and production facilities. **Communication with practitioners** is rigorously pursued to ensure that practical issues are taken into account and scientific findings are successfully transferred to practice.

Science policy effectively promotes the dynamic development of the research and higher education system in a form suited to the challenges of inter- and transdisciplinary research. It is co-ordinated on an **interagency** basis, regularly reviews its funding performance and adapts in response to changing needs. Funding measures are structured so that necessary changes regarding the disbursement of funds can be made during the project, thereby strengthening participatory research. Funding bodies and scientific institutions jointly develop thematic **strategies** regarding the system of research and higher education in the agriculture and food sector and in this way take **responsibility** for its further development. Together, they agree on **flexible forms of collaboration** and essential **innovative (infra)structures**. Science policy facilitates not only research that specifically addresses or considers systemic approaches but also research that offers **wide scope** to pursue innovative and possibly risky research methods beyond any explicit system reference and independently of any direct reference to exploitation. Incentives are available for academics who incorporate transformative ideas into agricultural, food and nutritional sciences.

Stakeholders in the German agricultural, food and nutritional sciences, whose **expertise is in demand internationally**, play numerous active roles in promoting the **transformation** of agriculture and food systems **at European and global level**. These efforts are widely supported by German policy. Academics who engage with the Global South and work **with local stakeholders** to devise solutions tailored to local conditions have access to diverse interagency funding programmes. In this way, Germany, as a leading economic power and major science and research centre, assumes **responsibility in a global context**.

B. (Re-)Orientation of the agricultural, food and nutritional sciences

The urgent need to transform both German and global agriculture and food systems is rooted in their current structure, which is dysfunctional in many respects. Although the systems fulfil many of their functions successfully, they neither ensure that the global population is adequately supplied with high-quality food, nor fully perform their ecological, economic, social and health functions (cf. A.II).

Since agriculture and food systems are closely bound up with adjacent (sub)systems (climate and environment, economy, social and health), a **(re)orientation of the sciences** is required which puts the focus not only on **transformative efforts** but also on **systemic approaches**, as already outlined in the vision (cf. A.III) and described in more detail below (cf. B.I).

Agricultural, food and nutritional sciences in the **German system of research and higher education** are very well positioned to achieve this: their research in many disciplines is internationally recognised and supported by excellent infrastructures; teaching and education is valued in Germany and beyond, and diverse funding structures are available. Expertise in numerous complementary fields brings a **high level of diversity** to agricultural, food and nutritional sciences which, when viewed in the **context of systemic approaches**, **can benefit and be integrated into any transformation** (while serving as a model for other European countries).

The **challenges** and **need for action** in respect of five areas of the **German system of research and higher education** – (1) research, (2) research and data infrastructure, (3) education, (4) transfer and innovation, and (5) science communication and policy advice – are outlined below. The response to them must be underpinned by the need for transformative and systemic approaches (cf. B.II). The development of these areas drew on the **expertise within the working group**, extensive national and international expert **discussions**, and a review of the **scientific literature**. Also included was a **publication analysis** in which the Fraunhofer Institutes for Technological Trend Analysis (INT) and Systems and

Innovation Research (ISI) traced scientific activities in agricultural, food and nutritional sciences from 2011 to 2020. In addition, the answers to the working group's **questionnaire**, which were sent to around 115 agricultural and nutritional science institutions in Germany, were **analysed** in order to obtain a well-founded inventory from the perspective of the HEI and research institutions.

B.I POTENTIAL OF SYSTEMIC APPROACHES

Radical innovations, which in turn necessitate independent, knowledge-driven research, are required to address the enormous challenges and the need for social transformation processes in the Anthropocene era; |[49] **increasing scientific knowledge alone is not enough**. Rather, it is necessary:

1 – to systemically combine existing knowledge obtained mainly along disciplinary boundaries, and different forms of knowledge, and study how complex systems function and interact (systems knowledge);

2 – to pay particular attention to traditional and local knowledge accumulated by rural and indigenous communities and passed down through the generations |[50] (plurality of knowledge forms);

3 – to investigate how collective human action changes in complex systems and how societies can align themselves with the perspective of sustainable transformation (transformation knowledge);

4 – to ensure that the abovementioned forms of knowledge reflect ethical and political principles and values (orientation knowledge). |[51]

Thus, the importance and **potential of systemic approaches** as a means of addressing scientific problems of the Anthropocene are indisputable – especially for **transforming agriculture and food systems**.

Already an internationally established concept, the **food systems approach** is an example of a systemic approach that relates specifically to agriculture, food and nutrition. |[52] It clarifies the key **interactions** both within agriculture and food systems and with adjacent (sub)systems (climate and environment, economy, social and health), thereby revealing the close connections between them. By describing concrete interactions in the form of **drivers** and **outcomes**, it

|49 The term Anthropocene denotes a geological age when the dominance of humans leads to – in some cases considerable – changes in the environment (e. g. climate change) from which is derived humankind's responsibility for the future of the planet (cf. WBGU, 2020, p. 362).

|50 cf. Chianese, F., 2016, p. 5; Pandya-Lorch, R./Baumüller, H./Saleemi, S. et al., 2021, p. 432.

|51 cf. most recently: Renn, J., 2022, especially p. 744 ff.

|52 For example: Ingram, J., 2011; van Berkum, S./Dengerink, J./Ruben, R., 2018; Ingram, J./Zurek, M., 2018.

fosters a closer understanding of them which can play a vital role in the future-proof transformation of our agriculture and food systems. |[53] For all systemic interactions, the relationship between drivers and outcomes can be demonstrated by numerous interdependencies – in this case using the example of food, health and the environment: changes in eating habits (drivers) have a significant impact on health – in terms of both undernourishment and overweight (outcomes). Conversely, changes in environmental conditions, such as climate change (drivers), have an impact on the productivity of agriculture and food systems (outcomes).

Using the food systems approach – as well as other systemic approaches – means that scientific support for transformation not only involves **disciplines relating specifically to food and agriculture**, such as nutritional, food, crop and animal sciences or agro-economics, but also takes into account **disciplinary perspectives** that have a bearing on **adjacent systems** and the transformation process itself. These include human and veterinary medicine, climate research, social sciences, economics and even philosophy and ethnology/anthropology. In this way, academics can identify **potential synergies** and **conflicting goals** both within agriculture and food systems and across system boundaries and develop specific **transformation paths** leading to future-proof agriculture and food systems (taking into account their diverse, cross-system impacts). This leads to changes in our **understanding of the role of science**: increasingly, it functions as a **driver** or **intermediary**, with academics gradually taking on more multifunctional roles. Based on this changed understanding of their role, they no longer regard themselves purely as researchers; they can also supervise, evaluate and moderate, propose innovations and solutions, and communicate ideas on transformation with non-scientific stakeholder groups.

As a result, systemic approaches achieve what individual disciplines alone cannot: disciplinary perspectives invariably describe and address only parts of the problem; in contrast, systemic approaches make it possible to grasp the complexity of the problem across all systems and additionally develop new synthesised findings and courses of action that cannot be achieved in individual disciplines. In this way, science (through exchanging ideas with practice) can influence the systems and their different internal and external interactions and play an instrumental role in shaping the **transformation towards future-proof agriculture and food systems**. |[54]

|[53] cf. Van Berkum, S./Dengerink, J./Ruben, R., 2018, p. 10 f.

|[54] cf. Von Braun, J./Afsana, K./Fresco, L. O. et al., 2023, pp. 923–933.

Although teaching and research are fundamentally the core responsibilities of science, other **scientific performance areas** are increasingly gaining ground. So, in addition to **research** and **education**, three other areas for action within the system of research and higher education are considered below: the increasingly complex and now indispensable **research and data infrastructures**, together with **transfer and innovation** and **science communication and policy advice**. The latter two areas are part of transfer in the broader sense, which describes the interaction of academic stakeholders with partners outside the system of research and higher education in general terms and places special emphasis on agricultural, food and nutritional sciences, which are socially highly relevant. Transfer in the narrower sense focusses on the translation and implementation of scientific findings, as well as their joint elaboration through participatory processes, for example in the form of (corporate) spin-offs and institutional, social and technical innovations. Due to the growing importance of science communication and policy advice, this area is dealt with separately.

In all **five areas**, there is currently an **imbalance** in terms of the **reputation and recognition** of the academic work and contributions associated with them. Although the system of research and higher education currently recognises achievements in research, it does not accord the same level of recognition to the other four areas. They still scarcely figure in our understanding of academic excellence and thus add little value to the careers of scientists in the academic environment. In agricultural, food and nutritional sciences, where all five areas are relevant to a transformation towards future-proof systems, it is especially important to be involved in reforming scientific evaluation and incentive systems, as the Coalition for Advancing Research Assessment (CoARA) |[55] is currently attempting to do.

The differences between the areas discussed below are not always clear-cut; they **complement** one another in diverse ways and are **interlinked by reciprocal bonds**. Consequently, individual aspects cannot always be assigned exclusively to a single area. The order in which they are addressed does not imply any priority.

II.1 Research

Research in the agricultural, food and nutritional sciences is conducted at a high level at institutions of every kind within the German research landscape

|[55] cf. https://coara.eu/.

(universities and the universities of applied sciences, non-university and government department research institutions at national and state level, and privately funded research institutions |[56]). It is characterised by a high level of **methodological and thematic diversity** – from basic research to development. Research in agricultural, food and nutritional sciences will increasingly have to take on more functions to address future issues in the context of transforming agriculture and food systems: specifically, it will have to form the (1) **basis for a systemic understanding** of agriculture and food systems that goes beyond their subdomains and boundaries; encourage (2) the **integration of local and indigenous knowledge** into scientific and public discourse; (3) develop **solutions and strategies for transforming** systems which are currently dysfunctional in many respects and (4) review the **effectiveness** of diverse transformation efforts.

Cooperation and networking: Researchers in some fields have recognised the importance of **systemic approaches** and thus consider agriculture and food systems in the context of **interdisciplinary collaborations** on a case-by-case basis, taking into account interfaces with adjacent (sub)systems (ecology, economy, social and health), as with the One Health approach. |[57] For example, some higher education institutions (HEI) have put in place structures for interdisciplinary collaborations in the form of centralised institutions specifically designed to bring together different disciplines and departments to work on specific topics and projects while enabling them to draw on a stable supply of resources (including personnel). In their current form, **collaborative research projects** appear **sometimes disparate** and restricted to the **individual level**; |[58] In the agricultural sciences, projects in structured collaborative formats, namely the Collaborative Research Centres (CRC/Transregio programme) funded by the German Research Foundation (DFG), have declined in recent years. |[59] Yet precisely such structured efforts are needed to enable the continued rigorous implementation of systemic approaches in the severely fragmented field of agricultural, food and nutritional sciences – especially with a view to transformation processes. The structures required to enable the synthesis of interdisciplinary

|[56] cf. the Research Association of the German Food Industry (FEI), which is jointly supported by science and industry, https://www.fei-bonn.de/.

|[57] The One Health High-Level Expert Panel (OHHLEP) defines One Health as "an integrative and systemic approach to health, grounded on the understanding that human health is closely linked to the healthiness of food, animals and the environment, and the healthy balance of their impact on the ecosystems they share, everywhere in the world" (https://www.who.int/groups/one-health-high-level-expert-panel/members).

|[58] Although good networks have been created between different stakeholders in education, consultancy and research within national borders, there is room for improvement cross-border; only a loose network has been established at national level (cf. European Commission 2022, p. 1850).

|[59] A DFG special evaluation showed a decline in the number of Collaborative Research Centres (CRCs) in agriculture, forestry and veterinary science between 2012 and 2020. This indicates that the discipline is bucking the trend observed for these programmes in life sciences as well as across all DFG review boards.

research approaches and findings that go beyond time-limited formats must also be put in place.

Participation: In view of the challenges facing society as a whole and the action required, there is a need for more systematic sharing of scientific knowledge with all relevant social sectors. **Scientific and non-scientific stakeholders** should **work together** to formulate and address scientific research questions, problems and solutions so that **research in the agriculture and food sector can become more participatory**. There are numerous formats of participation with varying degrees of intensity, |[60] including the co-creation and co-design methods, which are recognised as **transdisciplinary approaches** |[61]: **co-creation** involves all phases of collaborative and transdisciplinary research work, from problem diagnosis and solving to implementation and evaluation; in contrast, **co-design** refers only to the process of cooperative problem-solving once a problem has been diagnosed. Suitable structures are required to enable these and other types of participatory research, i. e. functional **interfaces between science and practice.** Their function is to understand and convey the research need identified in practice. These structures may take the form of specially created **platforms**. |[62] At the same time, when it comes to addressing the research questions associated with these needs, **living labs** |[63] as institutionalised forms of participation can provide an ideal framework for corresponding research involving numerous stakeholders. Academics assume **multiple roles** in this type of co-creation structure: in addition to their research work, they can drive innovation, monitor transdisciplinary work processes or even perform a coordinating role as moderators.

Legal framework: Researchers in agricultural, food and nutritional sciences are subject to diverse legal requirements due to their work with plants, animals and humans. The WR makes a distinction between regulations which (1) make research and development in a particular field fundamentally more difficult, as is

|60 These range from an unilateral (1) information and (2) consultation on an (3) equal or (4) unequal cooperation to an (5) autonomous and competent action of empowered non-scientific stakeholder groups. While the first two levels of participation are regarded as purely mono-directional or mono- or interdisciplinary, the third and above are multi-directional and thus transdisciplinary (cf. Brinkmann, C./Bergmann, M./Huang-Lachmann, J. et al., 2015, p. 11-12).

|61 Transdisciplinarity refers not to science-internal processes where conventional discipline-specific identities are dissolved, but rather to those “where researchers trained in given disciplines work together with non-academic producers of knowledge from companies, associations or civil society, for example” (German Science and Humanities Council, 2015, p. 25).

|62 One such platform is the independent think tank Agora Agriculture. It supports transformative negotiation processes at the interface between science, policy, society and the private sector by producing science-based analyses, facilitating dialogue and highlighting politically feasible solutions (cf. https://www.agora-agrar.de/en/index.html).

|63 According to Schneidewind, a living lab describes a social context in which researchers carry out interventions in the sense of real-world experiments to learn about social dynamics and processes. The idea of the living lab transfers the natural sciences laboratory concept to the analysis of social and political processes. It ties in with the experimental shift in social sciences and economics and has strong links with the concepts of field and action research [unofficial translation] (Schneidewind, U., 2014, p. 3).

the case with genome editing techniques in plants (e. g. CRISPR-Cas) |[64] and those which (2) impose strict licensing requirements on the research, for example relating to animal welfare or access to genetic resources. |[65] Compliance with the respective statutory requirements is a major challenge for researchers. Initiatives by research institutions such as the German Nagoya Protocol HuB |[66] provide support structures to help researchers understand the approval procedures. This type of support is essential. At the same time, it is imperative for research that decisions regarding approval procedures are made promptly and transparently. More research is needed on the impacts of legal frameworks to better estimate their effect.

Internationalisation: Although **agricultural, food and nutritional research** (compared with other disciplines) is often **tied to a specific location** and tends to concentrate on regional and national issues as a result, a growing international focus and corresponding creation of networks (both European and global) can be observed, as illustrated by the rising number of international publications with German involvement. |[67] This collaborative approach is largely driven by individuals. These individual networks have arisen through joint EU projects in which German academics have comparatively little responsibility for coordination. |[68] To increase the exchange of knowledge at European and global level with the aim of bringing about the future-proof transformation of agriculture and food systems, **international networks and collaborations** must be **structurally expanded and institutionalised** – especially in the case of research infrastructures in large institutions. Furthermore, **Germany's global responsibility as a leading location of science and research** must also be considered. German academics should aim to cooperate especially with countries in the Global South, which are often the most severely affected by the negative impacts of climate change and food insecurity. However, their principal responsibility here should not be to further boost productivity; instead, they should focus on encouraging communication and collaboration aimed at **developing regionally and locally adapted solutions** for future-proof agriculture and food systems jointly with local stakeholders, and **integrating traditional and local**

|[64] cf. DFG, 2023.

|[65] In this context, see the Nagoya Protocol on access to genetic resources and the fair and equitable sharing of the benefits arising from their use (benefit-sharing), which came into force in 2014 (cf. Secretariat of the Convention on Biological Diversity, 2011).

|[66] cf. https://www.nagoyaprotocol-hub.de.

|[67] cf. Publication analyses carried out by the Fraunhofer INT and ISI on the development of Web of Science publications in the agricultural, food and nutritional sciences from 2012 to 2020.

|[68] In the Cluster 6 “Food security, sustainable agriculture, marine and maritime research and the bio-economy” of the Horizon 2020 programme, Germany was responsible for coordinating (Partner Role) 12.6 % of the “R&I Projects” (Signed Grants) in which German institutions were involved. In comparison, Spain coordinated 30.4 % of the projects in which Spanish institutions were involved, France 19.0 %, Italy 18.0 %, Denmark 16.5 %, the United Kingdom 16.4 % and the Netherlands 15.6 %, cf. https://webgate.ec.europa.eu/dashboard/sense/app/98dcd94d-ca66-4ce0-865b-48ffe7f19f35/sheet/QCdc/state/analysis.

knowledge accumulated by rural and indigenous communities and passed down through the generations. This knowledge has significant potential to bolster resilience and sustainability in the face of the global challenges. |[69]

Research funding: The **German funding landscape** is extremely **diverse** and features numerous funding bodies. In addition to the German Research Foundation, the EU and several commercial enterprises, funding providers include various foundations as well as government departments at national and state level; in particular, the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry of Education and Research (BMBF) are major funders of agricultural, food and nutritional research. This diverse funding landscape, while welcome in principle, **increases** the need for **coordination between different funding bodies** – against the background of the systemic approach – not only to deal with specific questions, but to adequately address the research needs for the upcoming transformation processes. **Improved cooperation** between funding bodies and federal and state departments is needed if we are to tackle the dysfunctionality that exists in some areas of agriculture and food systems at the level of research funding. In addition to the abovementioned BMEL and BMBF, this should also include the Federal Ministry for Economic Affairs and Climate Action (BMWK), the Federal Ministry of Health (BMG) and the Federal Ministry for Economic Corporation and Development (BMZ). |[70] A coordination database currently ensures that government research projects are co-ordinated and double funding is avoided. However, this level of coordination is insufficient. What is needed – where appropriate – are both **strategic coordination arrangements** which focus on (further) developing the respective funding programmes and **jointly implemented funding programmes** which also take account of the specific requirements of agricultural, food and nutritional research (e. g. growing seasons). The anticipated challenges posed by this type of cooperation must be tackled head-on in view of the urgent need to transform agriculture and food systems and in line with the coalition's pledge to "continue the cooperation between the Federal Government and the Länder for a sustainable science system". |[71] Furthermore, it is important to understand whether – going beyond specific issues – appropriate **funding strategies and instruments** already exist to help stakeholders in German agricultural, food and nutritional research address **cross-sectoral problems** that have a bearing on transformation – and to provide opportunities for international cooperation (beyond the EU).

Need for action: Research must be systemic in its approach if it is to shape transformation processes. This can only be achieved by fostering structural networks between discipline-based research, different institutions and the scientific community on the one hand and non-scientific stakeholder groups on the other, for

|[69] cf. Chianese, F., 2016, p. 5; Pandya-Lorch, R./Baumüller, H./Saleemi, S. et al., 2021, p. 432.

|[70] cf. Wissenschaftsrat, 2023, p. 29.

|[71] Social Democratic Party of Germany (SPD), Alliance 90/The Greens and the Free Democrats (FDP), p. 20.

example through participatory formats. This calls for structures at local, regional, national and international level adapted to the research question as well as corresponding funding strategies and instruments co-ordinated (and if necessary developed) across regional and departmental boundaries.

II.2 Research and data infrastructures

Research and data infrastructures have become increasingly important in recent decades as a prerequisite for knowledge generation, archiving and dissemination through teaching and transfer. Like many other disciplines, agricultural, food and nutritional sciences face many challenges in this area which have yet to be adequately addressed. (1) Firstly, the financing of infrastructures. Often, the (re)**investments** required for continuous renewal – especially in view of accelerating investment cycles – and the increasing **operating costs** can **no longer be financed** from the current basic budget of individual institutions, especially the HEI. |[72] This aspect will be further exacerbated by rising energy costs. (2) Furthermore, there is a **shortage** of permanent positions for **technical and scientific staff**. At present these positions still tend to be funded on a project basis – frequently via federal government funding. (3) **Provisions are not always in place** to ensure that infrastructures are **sustainably available**, for example when the manager or responsible employee leaves as the fixed-term project expires. (4) With regard to data-based work, the **job market** for qualified personnel in this field is increasingly **under pressure** and salary levels in the public sector are scarcely competitive. In addition to these general challenges, **agricultural, food and nutritional sciences** have to contend with **specific challenges**:

Research stations, test facilities and trial fields: Test stations, test facilities and trial fields play a vital role in researching certain questions under real-life conditions. They enable interactions between genotype, phenotype, environment, soil, climate (change) etc. to be investigated under site-specific conditions. They can also perform **key functions** in education and training both in HEI and companies. Individual institutions such as HEI or government research institutions generally have access to such infrastructures – which they sometimes share with chambers or state institutes of agriculture. Energy- and labour-intensive facilities are responsible for a high level of resource consumption, especially in the livestock farming sector. These facilities, some of which have been in operation for a long time and are outdated, had to be **consolidated and restructured** to meet the need for innovation, facilitate cross-disciplinary work and increase efficiency. European and international cooperation is vital to ensure that the best use is made of these facilities. When it comes to trial fields, planning and coordination efforts must be considered transnationally, partly to enable comparative experiments to be conducted under different climate conditions. In view of

|[72] On the fundamental problem of a backlog of maintenance and repairs in the system of research and higher education, cf. Wissenschaftsrat, 2022b.

sharply rising investment and operating costs, **cross-site planning and coordination efforts** are required to make optimal use of research infrastructures, provide sufficient resources to cover the cost of renewal and adopt a multidisciplinary approach. |[73]

Longitudinal studies: **Longitudinal cohort studies** are vitally important in agricultural, food and nutritional sciences, |[74] especially when also considering the interfaces with pathogenesis or health promotion. The German National Cohort (NAKO Gesundheitsstudie/NAKO) is a longitudinal epidemiological study of widespread diseases such as cardiovascular diseases, cancer, diabetes and infectious diseases which has been running since 2014. |[75] The food sector is currently dominated by food-industry studies. There is a paucity of longitudinal studies reporting the effects of less-processed foods on human and animal health. Nutritional habits as a whole must be taken into account, including differences in the respective cultural environments. This raises the question of what other types of (not only epidemiological) longitudinal studies in what other areas will be needed in future to investigate how **aspects of agriculture and food systems interact with adjacent systems** – either in a national, European or international context. |[76]

Collections: Collections play a special role in agricultural, food and nutritional sciences. Natural history collections, gene and species banks, and explicitly, in-situ conservation |[77] preserve plants, plant parts, seeds and cultivars worldwide and act as **insurance for genetic diversity**. They are also used for researching biodiversity and species loss. In particular, digital collection data can be combined with other data, e. g. geo-biodiversity data, to improve our understanding of the Earth system. There are several ways in which collections can help shape the transformation. Having recourse to this diversity provides an important means of developing future varieties that are adapted to climate change and other challenges. Because some collections such as gene and species banks have been destroyed during armed conflicts, an international agreement is needed to determine how to physically **protect** these resources. In addition, they can

|[73] cf. https://emphasis.plant-phenotyping.eu/.

|[74] On the importance of longitudinal studies which can only be facilitated through future-proof field study infrastructures, see Stützel, H./Brüggemann, N./Fangmeier, A. et al., 2014.

|[75] Originally called the National Cohort (NAKO) (cf. https://www.helmholtz.de/glossar/begriff/nako-kohorte/) and started in 2013 with a pilot study (cf. https://nako.de/allgemeines/was-ist-die-nako-gesundheitsstudie/zeitplan-der-nako/). Other countries such as Great Britain or the Netherlands run longitudinal studies which have long been addressing nutritional issues in a broader context (cf. http://www.bristol.ac.uk/alspac/ and https://www.lifelines.nl/researcher/data-and-biobank).

|[76] For example, interactions between the food and health sectors were touched on in the gern study in Germany carried out by the Robert Koch Institute (RKI) and the Max Rubner-Institut (MRI); there are no plans for a follow-up study (cf. Von Schenck, U., 2019).

|[77] In-situ conservation means the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties, cf. UN, 1992, p. 4 (Art. 2).

become places of mutual exchange with societal stakeholders or even places of joint transdisciplinary research.

Data infrastructures and management: Many institutions use existing generic infrastructures to publish and archive research data. To date, **Germany** has only a **few specific**, **standardised infrastructures** for agricultural, food and nutritional sciences. One such example is the BonaRes Repository, which focuses on data from long-term field trials and soil profiles. |[78] Several initiatives have also been developed by the German National Research Data Infrastructure (NFDI). |[79] The FAIRagro concept is a more recent example which focusses on crop-related aspects of agricultural sciences and for which funding has been approved. Agricultural, food and nutritional scientists are also involved in other national initiatives such as NFDI4Biodiversity and NFDI4Health. At European or international level, food and nutritional sciences in particular have recourse to established structures such as ELIXIR |[80] or OMICs databases. |[81] Bearing in mind the need for a systemic approach, agricultural, food and nutritional scientists face the challenge of gathering a **wide variety of highly heterogeneous data** and making it available in an appropriate manner. |[82] This should also include data provided (or that could be provided) by non-academic stakeholders. These data may be derived from farms, which often lack incentives to get involved in scientific projects, as well as from other local stakeholder groups or from indigenous knowledge sources.

In the agricultural, food and nutritional sciences, **individual data management solutions** are currently being pursued at project, faculty or university and institute level at many institutions, especially HEI. Many academics believe that there is a lack of standardised concepts for ensuring the quality of raw data for interdisciplinary use (especially in terms of interoperability and reusability) and the publication of these data (including meta data) while at the same time guaranteeing data protection. This shortcoming creates problems when cooperating with private partners. Similarly, there are insufficient incentives to implement a quality-assured data management strategy that meets international standards (such as FAIR) and is therefore also resource-intensive. Remedying these deficiencies can help raise awareness across the spectrum that the value of data should not be confined to an individual research project. To work systemically,

|[78] cf. https://www.bonares.de/. Further soil research initiatives are provided by the National Soil Monitoring Centre (cf. UBA, 2022, p. 99) in Germany and the EU Soil Observatory (EUSO) at EU level (cf. https://joint-research-centre.ec.europa.eu/eu-soil-observatory-euso_en).

|[79] cf. https://www.nfdi.de/konsortien/.

|[80] cf. https://elixir-europe.org/.

|[81] e. g. https://www.omicsdi.org/.

|[82] In its Roadmap to Research Infrastructures 2021, the Helmholtz Association addresses the challenges of data heterogeneity with TerraNet and Terra-Lab and aims to develop solutions using its research infrastructures, cf. Helmholtz Association of German Research Centers, 2021.

it is essential to share, reuse and re-combine data from researchers from different agricultural, food and nutritional science disciplines as well as adjacent disciplines. Thus “technical, legal, organisational and social aspects of data sharing must be compelling and sustainably regulated” |[83] and appropriate incentives created.

Data access: Data from **long-term trials** can primarily be reused if it is available in **digital form**. Some of the concepts required to digitalise these types of data sets are lacking, as well as the corresponding internal or external funding. Furthermore, researchers often have **no regulated access to public-sector data**, such as those from chambers or state institutes of agriculture. In this case it may be necessary to develop an inter-agency strategy that makes these data available across federal states and institutions.

Need for action: Highly resource-intensive research and data infrastructures require planning and coordination efforts at national, European and international level, underpinned by the progressive expansion of research networks and a transparent assessment of the situation. The aim should be to retain and further develop the various infrastructures and ensure that stakeholders have access to them. This calls for compelling and sustainable rules on data sharing in technical, legal, organisational and social respects.

II.3 Education

Between the 2012/13 and 2020/21 winter semesters student numbers in agricultural, food and nutritional sciences have followed a broadly similar trend to the average across all study areas offered by the German higher education system; at universities they have remained largely stable, while universities of applied sciences have seen a slight rise in student numbers. However, in nutritional sciences and home economics there has been a continuous, pronounced rise in student numbers over the same period (around 40 %). Yet this strong appeal did not lead to a rise in the number of doctorates in nutritional science degree programmes. Rather, the number of **doctorates** awarded – already low to begin with – **declined significantly** up to the 2020/21 winter semester; the same applies to food chemistry. This trend can also be observed to a lesser degree in agricultural sciences. |[84] The absence of well-qualified early-career researchers, including future teaching staff, can be a major obstacle to imminent transformation efforts in academic and non-academic fields. Against this background, even with the prospect of training and further scientific qualifications, the challenges are considerable. Outside the scientific field, certain institutions, such as

|[83] Wissenschaftsrat, 2020, p. 38, unofficial translation.

|[84] Statistisches Bundesamt, 2021a, own calculations.

specialist Länder authorities, are already finding it increasingly difficult to recruit qualified personnel.

Degree courses: In recent years there has been an increase in the number of degree courses which demonstrate a greater awareness of the thematic links between agricultural, food and nutritional science and other disciplines – in both their content and structure – and the conflicting goals within agriculture and food systems. These new courses also cover adjacent disciplines (e. g. economics or political sciences), have a more practical focus and, in this context, explicitly address relevant aspects. However, **attractively designed courses** must also **integrate systemic and participatory approaches** if transformation-related research problems are to be properly addressed. A structural review of the overall curriculum is required to determine how the content of individual subjects relates to or complements one another. Consideration must also be given to **(re)evaluating** the basic and systemic content of **bachelor's and master's degree programmes**. Systemic approaches can be integrated into higher education in various ways, for instance by broadening specialised degree courses with **modules** which take account of the systemic connections within the agricultural, food and nutritional sciences or devising **degree courses** which focus explicitly on systemic approaches. In addition, **digitalisation** and **data-based capabilities** are important cross-disciplinary skills which should be included in the overall focus of these degree courses. The same applies to **field research**, depending on the specific needs of the course.

Graduate and postgraduate qualifications: When considering the qualifications of **young researchers**, it is important to ensure that **systemic connections** receive adequate recognition and that scientists are qualified for transformative tasks in the early stages of their career. **Inter- and transdisciplinary perspectives** on systemic connections that relate specifically to agriculture, food and nutrition, as well as the transformation management requirements, must therefore be incorporated into graduate and postgraduate qualifications to support subsequent work in participatory formats.

Collaborations and practical relevance: Agricultural, food and nutritional science teaching collaborations can be found in all types of institution in **numerous institutionalised forms**. These exchanges are governed by collaborative arrangements which are not only bilateral but may involve a wide range of faculties together with non-university and (mainly federal) government department research institutions. It is this very diversity that makes **applied teaching** and **practical relevance** one of the strengths (specifically for Germany) of working with relevant stakeholders, e. g. from policy and industry. This is especially true of the universities of applied sciences but applied courses can also be found at universities – corresponding to their respective thematic focus. In future, however, practical phases or phases involving project-based research should not only serve to strengthen the applied and practical relevance of the course; they should also give students more opportunities to **experience inter- and transdisciplinary practice** and – given the systemic approach and need for transformation – prepare them for various challenging tasks in agriculture and food systems (with a view to careers within and outside the system of research and higher education). Education in agricultural, food and nutritional sciences could also benefit from more courses involving **project-** and **problem-based learning**: starting from real-life problems (based on relevant vocational fields in the case of project-focused courses), the students would engage in self-directed learning and identify solutions independently, with tutors providing supervision at most. |[85] Practical courses of this nature offered by HEI are not always a **compulsory part of the curriculum.** Consequently, students do not make full use of them at all sites, thereby diminishing the impact of any existing potential.

Internationalisation: An increasing internationalisation of agricultural, food and nutritional science courses can be seen on several levels: for example, courses routinely feature (compulsory) **placements or semesters abroad**, as well as (in some cases, interdisciplinary) **trips to other European countries**. Furthermore, a growing number of international courses (i. e. taught in **English**) can now be found at German universities and universities of applied sciences. It is clear that **expanding the range of international courses** on offer should form part of the strategic focus of both types of institution. In view of the goal of developing a more global focus and strengthening competitiveness in an international context, the existing international programme could be supplemented by collaborative **degree programmes at international level** involving partners from several countries. Appropriate courses, as well as occasional modules or events, would **significantly enhance** the internationalisation of agricultural, food and nutritional sciences. Bearing in mind Germany's responsibility as a centre of science in an international context, the countries in the **Global South** must also be included. Apart from the advantages that a **strong international focus** brings in terms of language, collaborative arrangements and the exchange of personnel, at **content level** it is key to communicating with foreign students and upholding international standards of teaching (and research).

Continuing education and training: The diverse continuing education courses currently available cover a **broad range** in terms of both **form and content** but are mostly aimed at higher education members in the broadest sense (students, postgraduates, graduates etc.). The needs of **other target groups** such as farmers, representatives from industry and commerce, or those working in the development cooperation sector, who are equally relevant in terms of their importance for transformation, are **not adequately addressed**. In this context, a further expansion of the existing range of continuing education courses is needed which also includes non-university students. In Germany the chambers and state

|[85] cf. Wissenschaftsrat, 2022a

institutes of agriculture function as intermediaries between science and practice; as such, academics could help them design their continuing education and training programmes with non-academic stakeholders in mind.

Early-years and secondary education: Agriculture and food systems can only be transformed through the efforts of society as a whole, and aspects of **diet** and **consumption** play an important role in this context. An education programme that is geared towards this and integrated into the (pre-)school curriculum can make a sustainable contribution to **raising awareness** in related areas and support conscious **behavioural changes** – provided that any such changes are firmly embedded in public consciousness and the education system from the bottom up. Foundations and privately funded associations already perform a key role in this context. |[86] The scientific community could contribute by providing even more structural support for the (further) development of suitable **educational approaches** and for the **further training of teaching staff**, and by evaluating their effects.

Need for action: Systemic approaches must be consistently embedded into teaching and (further) education programmes. It is up to individual HEI to determine how they are integrated into the respective curricula at bachelor, master and graduate level – including the targeted integration of participatory formats. In view of the need for global transformation, the internationalisation of study programmes must be accelerated to strengthen the reciprocal exchange of information.

II.4 Transfer und innovation

Extended understanding of innovation: German agricultural, food and nutritional sciences encompass a **broad range of innovation forms**. However, the fact that far greater emphasis has been placed on technical rather than other dimensions (e. g. institutional, ecological, social, systemic) has created an **imbalance**. Furthermore, different forms of innovation are rarely **linked** and assimilated (e. g. socio-technical or socio-economic innovations). This is especially true of innovations at the **interfaces** between agriculture and food systems and their adjacent subsystems (such as climate and environment, economy, social and health). Moreover, greater attention should be paid to **exnovation**, a process which complements innovation and is relevant to transformation processes, but invariably associated with the parallel development of new structures. |[87] Opportunities to assess and monitor innovation and exnovation processes are also needed:

|[86] The Sarah Wiener Foundation's "I can cook!" initiative has trained 20,000 educational specialists and teachers from preschools and primary schools to promote the importance of a healthy, balanced diet (cf. https://ichkannkochen.de/english/).

|[87] Exnovation involves the gradual discarding through long-term processes of practices, products, processes or technologies whose benefits or social acceptance have been lost. They are particularly relevant when socio-technological configurations are no longer accepted by society – especially in the context of negative environmental externalities (cf. Hebinck, A./Diercks, G./von Wirth, T., 2022, p. 1011).

although parameters exist for measuring individual transfer performances, **quantifiable** and **qualitative methods for recording and assessing** the effects of systemic and transformative in- and exnovation processes that also focus on potential risks – which are urgently needed to evaluate funding programmes – are only in the early stages of development.

Transfer and innovation networks: Successful transfer calls for networked structures such as functional ecosystems. These create a framework for continued, **multi-directional collaboration** between all parties which enables research problems to be addressed, knowledge co-created and innovations fostered. Suitable networks also provide an opportunity to promote spin-off companies, and to involve partners from industry and society who were not included previously, such as public authorities or other stakeholders at municipal level, who play a vital role in the practical implementation. Germany already has a number of platforms for this purpose, some of which are well-established, |[88] but **more are needed** and they should be **linked together** where appropriate. Since the rising number and diversity of stakeholders goes hand-in-hand with **rising project-based research effort and resources** (investment of time and money), funding formats and evaluation regimes must take account of the additional cost of participatory research. Another point to consider is that the financial, personnel and time resources of all partners involved in participatory research projects should be integrated into the respective projects in such a way that all parties benefit.

Support programmes: **Provisions that support networking in higher education** range from those provided by research and legal departments to the services of in-house transfer and innovation centres. These bodies act as facilitators of collaboration, for example, for spin-off companies, and occasionally as points of contact for non-scientific stakeholders. Furthermore, **external partners** such as national contact points and transfer agencies offer transfer-related services at federal state and European level for both scientific and non-scientific stakeholders. This broad spectrum of support should be **sufficiently transparent** to leverage existing potential across the entire spectrum.

Funding and regulations: The fact that industry and science apply different performance parameters to the development of innovations is a fundamental problem with major implications for the **planning**, **financing and implementation** of transfer and innovation projects. From a corporate perspective, the **slow overall pace of progress** – due in part to the considerable time and effort spent securing public funding both before and during the planning of large joint projects – combined with **inflexible guidelines** governing the subsequent design of the

|[88] For example, the Innovation Forum for Organic Farming in Brandenburg (Innovationsforum Ökolandbau Brandenburg), which is affiliated to the Eberswalde University for Sustainable Development, is a joint platform for companies and academics which creates the basis for cooperation and the exchange of ideas and experiences (cf. http://innoforum-brandenburg.de/en/home-en/). In the field of nutritional research, the Technical University of Munich's *enable* Cluster provides opportunities for the exchange of ideas for "a broad, inter-disciplinary consortium of academic institutions, industrial, traders and craft enterprises" (https://www.enable-cluster.de/en).

project hamper collaborative work and in particular, transdisciplinary partnerships. This makes collaborative arrangements **unappealing** for many of the stakeholders involved. For financial reasons, this applies particularly to societal stakeholders, small and medium-sized enterprises, of which there are many in the agriculture and food sector (in contrast to medicine), and representatives of the start-up sector. This difficult situation, which is characterised by multiple stakeholders with different requirements, cannot be fully resolved; it can, however, be optimised. What is needed are **flexible funding programmes** with scope for project participants to respond with **agility**.

Skills acquisition: Stakeholders in the German agricultural, food and nutritional sciences have responded selectively to the **specific requirements** associated with the development of innovations and knowledge transfer through a range of provisions that can be found **at diverse levels of higher education**. In addition to seminars and continuing education courses (for example on spin-offs or patent law), these include doctorates with a transdisciplinary focus as well as theses at bachelor’s and master's level. However, academics are faced with the task of estimating and managing as best they can the specific and in some cases highly divergent interests of non-scientific stakeholders and the highly complex nature of (transdisciplinary) work in the transfer sector. For this they need to acquire a variety of skills and knowledge, not all of which, however, are part of the existing educational programme in the transfer sector: ranging from academic, theory-based knowledge pertaining to concrete, real-life operational issues, and the necessary communication skills, to a familiarity with and ability to operate within networks. **Collaborative arrangements in teaching** and **further education programmes** currently meet this broad spectrum of requirements only to a limited extent. For example, greater efforts could be made to share case studies and examples of good practice with academic and non-academic stakeholders in further education training and development programmes.

Need for action: A broader understanding of innovation with a sharper focus on linked and cross-sectoral innovation as well as exnovation is needed to meet the requirements for transformation. In addition to promoting selective innovations (including start-ups), robust networks and long-term collaborations with (non-)academic partners must be established. On the academic side, this calls for the targeted expansion of skills and support structures, and on the funding side, attractive programmes with a high level of flexibility.

Importance of science communication: To ensure that academics are comprehensively supported in their efforts to communicate science, |[89] science communication must be regarded as a natural and essential component of science, **thoroughly understood** and **structurally anchored** in the system. Where, on what levels, and in what concrete form it is anchored is a strategic decision for individual institutions and depends to some extent on their size and structure. Many HEI and research institutions have already established **central departments** which deal with science communication matters over and above their pure public relations work. These may be supplemented by internal communications structures within larger projects, depending on the amount and scope of projects for which third-party funding has been obtained. When it comes to communicating to a wider public, there is a certain imbalance between universities on the one hand and universities of applied science on the other; because of the way they are structured, the universities tend to have more leeway.

Formats of science communication: Traditional **analogue and digital formats** of science communication in the agricultural, food and nutritional sciences include lectures and conferences, videos, podcasts and blogs, and all forms of social media. More dialogue-based or interactive formats are gaining ground as a means of encouraging different stakeholders in agriculture and food systems and in society as a whole to follow the path to transformation, and to accompany them on their journey. The long-established Field Days (Feldtage) |[90] provide one such interactive space where interested farmers can exchange ideas with experts from science and research about their crop-growing experiences. Furthermore, **dialogue-based exchange formats** involving different societal groups and **participatory approaches** which foster mutual understanding are also being trialled in other disciplinary contexts. The **living labs** increasingly found in agricultural, food and nutritional sciences also have a prominent role to play in participatory formats. |[91]

Funding science communication: Science communication is also gaining increasingly attention in the context of research funding. It must be further developed as an **integral part of research funding.** Funding formats should be structured in such a way that it becomes increasingly feasible to report not only to the

|[89] cf. Wissenschaftsrat, 2021.

|[90] Field Days (Feldtage) enable farmers to share information with one another as well as with academics on specific agricultural themes such as seed, crop protection or cropping methods. For example, https://www.landwirtschaftskammer.de/landwirtschaft/ackerbau/feldtag/index.htm.

|[91] Living labs are currently set up on the initiative of different scientific stakeholders. For example, during the proposed establishment of an Innovation Centre for Agriculture System Transformation (IAT) at the Centre for Agricultural Landscape Research (ZALF), the design of transformation in the agriculture and food system will be informed by living labs and new forms of according research. The Thünen Institute is involved in the Living Lab Tellow, where transformation processes are tested in living labs under real-life conditions, as well as in setting up national living lab networks. Efforts by the Senckenberg Society for Nature Research (SNG) to implement Solution Labs are to be mentioned as well (cf. Wissenschaftsrat, 2022c, p. 14 f.).

funder, but to all parties involved, about research methods, procedures and results both during and after the project, so as to disseminate solutions for transforming agriculture and food systems.

Policy advice structures: The scientific advisory councils and government department research institutions at federal and state level already undertake valuable consultation and communication work. However, in view of the need to transform agriculture and food systems, efforts must be made to pool the expertise of different scientific disciplines and voices, consider relevant questions from a systemic perspective and formulate them to ensure effective policy advice and science communication. **Greater synthesis** is needed before this can happen. The establishment of an institutionalised process or a structure that transcends ministerial boundaries could be helpful in this respect. It will also be important for policymakers to increasingly commission studies that address systemic issues. Established structures and forums for policy advice already exist at international and European level. **Internationally**, **Science** or **Knowledge Policy Interfaces** transfer scientific and other (e. g. local or hands-on) knowledge to the political sphere. Examples at **European level** include the European Commission's **High-Level Expert Groups**. Although scientific advisory councils and government department research institutions already provide well-founded policy consultancy, there is no **comparable structure in Germany** to support the upcoming transformation processes. There is no **national advisory board** to oversee the systemic connections, initiate new research projects (also involving non-scientific stakeholder groups), and develop short-, medium- and long-term goals and corresponding pathways to transformation for policymakers at interagency and interstate level.

Skills acquisition: The ability to communicate knowledge and methods in agricultural, food and nutritional sciences not only beyond subject boundaries but system boundaries too can only be ensured through the **appropriate training** of academic stakeholders. While numerous HEI already offer corresponding modules in their agricultural, food and nutritional science degree programmes, the field of **science communication and policy advice as a key competence is yet to be widely established** and **differs greatly depending on the location**. **Continuing professional development and further education** programmes are few and far between and not regarded as a fundamental component of the agricultural, food and nutritional sciences. While science communication requires information and specialist knowledge to be interpreted in such a way that lay people can understand it, in order to be effective, policy advice not only requires this knowledge to be presented in non-scientific contexts, but also demands an **understanding of political processes and methods**.

Need for action: The successful transformation of agriculture and food systems largely depends on policymakers, industry and civil society understanding the complexity of the systems and being willing to fundamentally change their behaviour. Science communication and policy advice structures must therefore be configured at national, European and international level in such a way that – through science-led processes – research findings from different disciplines can be combined, collated and communicated appropriately in a spirit of cooperation.

C. Conclusion

The challenges of the 21st century, which are fast reaching crisis proportions, are alerting the general public to the urgent need to transform agriculture and food systems worldwide. In view of their considerable internal complexity and multiple interactions with other systems, their scientific treatment demands excellent disciplinary research and rigorous systemic consideration in equal measure. On this basis, pathways to transformation can be elaborated and supported, while at the same time identifying intended and unintended consequences. Given the acute nature of the crises, there exists a **high level of willingness** within science, industry, politics and society **to question the orientation and behaviour of individuals and society as a whole** within the context under consideration here, and to develop and implement new visions.

In this policy paper, the WR has drawn up a vision for future-proof agriculture and food systems. It is intended to provide guidance for the necessary transformation processes, which the agricultural, food and nutritional sciences as key drivers – in collaboration with adjacent disciplines – can and should help bring about. This calls for structural changes in the areas of the agricultural, food and nutritional sciences mentioned above and a willingness on the part of scientific stakeholders to examine their work for its relevance to the upcoming transformation processes and, if possible, to relate their work to them. This **position paper identifies the action required** within the system of research and higher education, and especially in the **field of agricultural**, **food and nutritional science** to achieve this.

The WR is convinced that science can make a significant contribution to shaping future-proof agriculture and food systems and that increased efforts are needed in future, which will require coordination at national, European and international levels. At the same time, the WR is aware that such far-reaching transformation processes can only succeed if they involve as many societal stakeholders as possible. On the science side, processes of this nature require **time**, **long-term interagency strategies** which outlast legislative and budget periods, a **transparent and confident exchange of ideas**, and **ongoing collaborations** with different societal stakeholders from politics, public authorities and industry as well as civil society.

On the basis of this positioning and drawing on a survey of German agricultural, food and nutritional science institutions, an extensive appraisal and information obtained during visits to several research areas, the WR will publish its **recommendations** in **mid 2024**.

Appendix

BMBF	Bundesministerium für Bildung und Forschung; Federal Ministry of Education and Research
BMEL	Bundesministerium für Ernährung und Landwirtschaft; Federal Ministry of Food and Agriculture
BMJV	Bundesministerium der Justiz und für Verbraucherschutz; Federal Ministry of Justice and Consumer Protection
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit; Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit; Federal Ministry for the Environment, Nature Conservation, Buildings and Nuclear Safety
COVID-19	Coronavirus SARS-CoV-2
DFG	Deutsche Forschungsgemeinschaft; German Research Foundation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
HEI	Higher Education Institutions
IFAD	International Fund for Agricultural Development
INT	Fraunhofer-Institut für Naturwissenschaftlich-Technische Trendanalysen; Fraunhofer Institute for Technological Trend Analysis
ISI	Fraunhofer-Institut für System- und Innovationsforschung; Fraunhofer Institute for Systems and Innovation Research
OECD	Organisation for Economic Co-Operation and Development
NFDI	Nationale Forschungsdateninfrastruktur; German National Research Data Infrastructure

SDGs	Sustainable Development Goals
CRC	Collaborative Research Centre
UN	United Nations
UNICEF	United Nations Children's Fund
WBAE	Wissenschaftlicher Beirat für Agrarpolitik, Ernährung und gesundheitlichen Verbraucherschutz; German Scientific Advisory Board on Agricultural Policy, Food and Consumer Health Protection
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen; German Advisory Council on Global Change
WFP	UN World Food Programme
WHO	World Health Organization
WR	Wissenschaftsrat; German Science and Humanities Council

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In a one-step process, the drafts prepared by the working groups and committees are discussed in the commissions of the WR and can also be changed if necessary. As a result, the WR is considered the author of the published recommendations, statements and position papers.

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