GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

Fraunhofer
ISI

Innovationen in der Bioökonomie in traditionellen Sektoren am Beispiel von drei Innovationslinien zu Fleischanaloga (TRADINNOVATION)

Förderkennzeichen 031B0783

Ort: Karlsruhe

Datum: 30.6.2023

Status: Abschlussbericht

Impressum

Ausführende Stelle und Projektleitung

Fraunhofer-Institut für System- und Innovationsforschung ISI

Breslauer Straße 48, 76139 Karlsruhe
Dr. Bärbel Hüsing, baerbel.huesing@isi.fraunhofer.de

Verantwortliche Autorinnen und Autoren

Dr. Bärbel Hüsing, baerbel.huesing@isi.fraunhofer.de;
Dr. Miriam Bodenheimer, miriam.bodenheimer@isi.fraunhofer.de;
Dr. Pia Niessen, pia.niessen@isi.fraunhofer.de;
Alexander Schwarz, alexander.schwarz@isi.fraunhofer.de

Bildnachweis

Deckblatt: shutterstock.com/dropStock

Zitierempfehlung

Hüsing, Bärbel; Bodenheimer, Miriam; Niessen, Pia; Schwarz, Alexander (2023): Innovationen in der Bioökonomie in traditionellen Sektoren am Beispiel von drei Innovationslinien zu Fleischanaloga (TRADINNOVATION). Abschlussbericht. Karlsruhe: Fraunhofer-Institut für System- und Innovationsforschung ISI

Veröffentlicht

Juni 2023

Hinweise

Das diesem Bericht zugrundeliegende Vorhaben wurde mit Mitteln des Bundesministeriums für Bildung und Forschung unter dem Förderkennzeichen 031B0783 gefördert. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt bei den Autorinnen und Autoren.

List of Content

List of tables

List of figures

List of abbreviations and acronyms

Abbreviation	Explanation
B2B	Business to business
BMBF	Federal Ministry of Education and Research
BMEL	Federal Ministry of Food and Agriculture
BMWK	Federal Ministry for Economic Affairs and Climate Action
bn	Billion, 10^9
CM	Cultivated meat
EFSA	European Food Safety Authority
EU	European Union
IBMA	Insect-based meat alternative
IS	Innovation system
LEH	Lebensmittel-Einzelhandel (food retail)
LGH	Lebensmittel-Großhandel (food wholesale)
MA	Meat alternative
Mio.	Million, 10^6
PBMA	Plant-based meat alternative
R&D	Research and development
TIS	Technological innovation system

1 Summary

A growing world population and increasing prosperity are leading to rising demand for animal-derived food and meat. However, expanding conventional agricultural livestock farming would increase its negative effects on the environment, climate, animal welfare and human health and compromise the urgently needed sustainability transition of the agro-food sector. Meat alternatives are being developed as a potential solution. They mimic meat products in appearance, taste, texture, and cooking practices, but do not rely on traditional livestock farming.

We investigated the innovation systems (IS) of plant-based meat alternatives (PBMA), insect-based meat alternatives (IBMA), and cultivated meat (CM) from the interdisciplinary perspective of innovation research and the multi-level perspective of transformation research. Research questions were:

- How can the innovation systems for PBMA, IBMA and CM be characterized, what are their strengths and weaknesses in comparative analysis?
- How do the meat alternative innovation systems interact with one another?
- How does the incumbent dominant regime of the livestock and meat sector interact with the emerging niches of meat alternatives?
- Which recommendations can be derived for the further development of the meat alternative innovation systems and for harnessing their potential contribution within a protein transition in the agro-food sector?
- What can be learnt from this analysis for innovation, exnovation and transformation processes in other traditional sectors?

The comparative analysis of the innovation systems showed that they are in the formative phase. The PBMA innovation system is the most developed regarding the number and type of actors, networks, entrepreneurial experimentation and market formation. Although a substantial number of different PBMA products are readily available to consumers, PBMA are still a niche with production volumes and sales of less than 2 % of the meat market. The legitimacy of PBMA is highest of all meat alternatives studied: PBMA conform to food law and do not require a market authorization. PBMA acceptance by consumers is highest of all meat alternatives. However, improvements in price, product quality and variety are required to move the innovation system into the growth phase.

The starting situation in the IBMA innovation system some years ago was comparable to the PBMA innovation system. However, entrepreneurial experimentation with IBMA was not successful, mainly for four reasons: consumers' disgust and neophobia regarding IBMA, requirement of a market authorization as Novel Food in the EU, requirement of new production infrastructure for rearing insects, and lack of added functionality of insect proteins compared to plant proteins. As IBMA are considered as an inferior solution compared to PBMA, insect proteins no longer target the meat alternative market, but the protein supplement niche market and, to an even larger extent, the pet and livestock feed market.

Globally, the CM TIS is driven by dedicated CM start-up companies, financed by private investments. Only few such CM companies are active in Germany. Several German companies have positioned themselves as globally competitive, major providers of technological solutions to dedicated CM companies, providing e.g. cell culture media, scaffolds, fermenters, and system solutions for production facilities. The current focus is on knowledge development to move from the R&D to the scale-up phase, to establish production facilities and to start market formation. First pioneering CM products are commercially available in a few selected restaurants in Singapore and the USA. No application for market authorization as Novel Food has been filed in the EU yet.

Interaction between the three innovation systems was modest, due to the differences in maturity and technology-specific challenges that have to be addressed for each meat alternative specifically. Because the three innovation systems are still niches struggling to establish and grow, they cooperate and join forces in system building functions under the umbrella of alternative proteins. Activities of mutual benefit can be observed in creation of legitimacy, guidance of the search, resource mobilization as well as knowledge generation and exchange. Competition between the innovation systems for financial resources was observed, whereas market competition was not yet relevant, due to the lack of commercialized PBMA, IBMA and CM products.

The traditional meat industry had shown strong resistance to prior transitions, making use of its strong political lobby. However, resistance of incumbent actors from the livestock and meat regime to emerging niches of meat alternatives was less pronounced than anticipated. Resistance differs between different actor groups and actors: early-mover incumbents get involved in the production of meat alternatives, while still retaining their focus on traditional meat products. Actors such as artisanal butchers extend their craft to meat alternatives as a unique selling point for their business. Using the existing incumbents' production and logistics infrastructure is essential for a rapid upscaling of meat alternatives production and gaining larger market shares. Actors such as livestock farmers and slaughterhouses who do not see a viable future for themselves within a transformed system fight changes for as long as possible. Using insect proteins as feed ingredient is a strategy for feed and livestock producers to reduce the environmental footprint per unit meat produced and thus reacting to landscape pressure to make their business less unsustainable. However, this strategy aims at stabilizing or even expanding mass livestock production, and does not contribute to a transition to less meat consumption and more plant-based diets. This may be seen as a material resistance strategy which aims at an incremental improvement of the environmental footprint of livestock production with the potential to delay more radical changes.

Based on the results of the project, the following recommendations were derived:

- Transition research on meat alternatives and alternative proteins, respectively, should be continued to provide a sound knowledge base for improving the functioning of the innovation systems and designing appropriate policy mixes.
- A weakness of the meat alternative innovation systems has been a low level of activities of guidance of the search and of creation of legitimacy within and by policy. Policy should start a process with all relevant stakeholders to develop a comprehensive strategy for alternative proteins to provide direction for the development of the innovation systems. The outcome of this process should be specific and measureable short-, mid- and long-term goals with a clear timeline, coordinated and coherent measures to achieve them, and binding commitments.
- To foster the development of meat alternatives, it is recommended to better integrate the agricultural sector, to develop a coherent R&D strategy and action plan for publicly funded research which complements R&D efforts by the private sector, and to support market formation and the development and amendment of regulations and standards to generate a positive environment for meat alternatives, but steer their development towards strengthening their sustainability profile.

Because meat alternatives will not automatically lead to reduced livestock production, it is essential that the recommended policy process also addresses frame conditions for livestock and meat production and the shaping of exnovation for conventional livestock farming and meat consumption at the same time. Both strands – fostering meat alternatives and exnovation in the livestock and meat sector – have to be closely aligned and coordinated to be effective and to avoid conflicting or contradictory incentives.

2 Introduction and Objectives

The transformation process towards a bioeconomy cannot be limited to research-intensive sectors alone if the bioeconomy is to make significant contributions to overcoming challenges such as climate and environmental protection, sustainable resource use and food security. Transformation must also take place in traditional economic sectors, such as the livestock and meat sector as part of the food industry.

A growing world population and increasing prosperity are leading to rising demand for animal-derived food such as meat. However, expanding conventional agricultural livestock farming would increase its negative effects on the environment, climate, animal welfare and human health (Jetzke et al. 2019; Parlasca et al. 2022) and compromise the urgently needed sustainability transition of the agro-food sector. From the nutrition perspective, animal-derived food and meat are a major source of high-quality protein. Against this background, a protein transition (Aiking et al. 2018 // 2020) is called for which should provide the nutritionally required amounts of protein in food in a more efficient, sustainable way. Since meat consumption is deeply rooted in Western cultures, traditions, life styles and is associated with socio-economic status, a significant reduction of meat consumption in Western diets is required, but difficult to achieve. One approach to satisfy the demand for high quality protein for human nutrition, pursued within the bioeconomy, is the development of innovative food products, meat alternatives. They mimic meat products in appearance, taste, texture, and cooking practices, but do not rely on traditional livestock farming.

We investigate the innovation systems (IS) of three alternative meat product groups: plant-based meat alternatives (PBMA), insect-based meat alternatives (IBMA), and cultivated meat (CA) from the interdisciplinary perspective of innovation research and the multi-level perspective of transformation research. For this purpose, we carry out a comparative analysis with the aim to analyze and answer the following questions:

- How can the innovation systems for plant-based, insect-based meat alternatives, as well as cultivated meat be characterized, what are their strengths and weaknesses in comparative analysis?
- How do the innovation systems for plant-based, insect-based meat alternatives, as well as cultivated meat interact with one another?
- How does the incumbent dominant regime of the livestock and meat sector interact with the emerging niches of meat alternatives?
- Which conclusions, options for action and recommendations can be derived for the further development of the meat alternative innovation systems and for harnessing their potential contribution within a protein transition in the agro-food sector?
- What can be learnt from this analysis for innovation, exnovation and transformation processes in other traditional sectors?

3 Comparative analysis of the technological innovation systems for plant- and insect based meat alternatives and cultivated meat

3.1 Definitions of the studied meat alternatives

Plant-based meat alternatives (PBMA)[1] and insect-based meat alternatives (IBMA) are innovative food products which mimic meat products in appearance, taste, texture, and cooking practices. The basis for PBMA are plant proteins, isolated from agriculturally grown crop plants such as wheat, soybeans, peas, and beans etc. The basis for IBMA are protein fractions from the larvae of edible insects (e.g. mealworm, migratory locust, grain mould beetle, domestic cricket). The insect larvae are reared in industrial mass production and fed with food-grade side streams of agro-food production. Plant and insect protein fractions of different quality and purity (flour, protein concentrates, protein isolates) can then be processed by conventional food procession technologies to meat-like products such as burger patties, nuggets, cold cuts and sausages.

Presently, different terms or names are used for cultivated meat (CM), and no consensus has yet been reached which name should be used. Often used names are cell-based meat, cultured meat, in vitro meat, lab-grown meat, laboratory meat. In this report, we will use the term cultivated meat.

Cultivated meat is produced by cultivating animal cell lines in bioreactors under controlled conditions. The technological basis is cell culture and tissue engineering, developed as advanced therapies within the regenerative medicine concept, and now being transferred and adapted to the food sector. The first step is the establishment of reproducible, quality-controlled stem cell lines and preserving them in a master cell bank. In the second step, cell line samples are cultivated in bioreactors under controlled conditions to multiply to a large number of cells (proliferation phase), feeding them with a cell culture medium containing essential nutrients. In the third step, differentiation of the cells into different cell types which make up meat (e.g. muscle cells, fat cells) is induced by adding differentiation factors (e.g. hormones, growth factors) and scaffolds. The resulting cells are harvested and processed further to create the required nutritional profiles, taste and texture (Good Food Institute 2023).

These three meat alternative options have in common that they promise to be solutions within a protein transition (Aiking et al. 2018 // 2020). This means they promise to satisfy the demand of a growing world population for high-quality protein in the form of meat in a more sustainable way than by simply providing meat through expansion of conventional agricultural livestock farming. Table 1 summarizes similarities and differences of the approaches.

The technological innovation systems (TIS) in Germany for plant-based meat alternatives, insect-based meat alternatives and cultivated meat were characterized following the approach of Bergek et al. (2008). As can be deduced from Table 1, the three innovation systems are all in the formative phase, with the PBMA innovation system being the relatively most advanced.

[1] Not included in our analysis of PBMA are plant-based foods such as tofu, tempeh, seitan, quorn, soy flakes, falafel etc. Although they often fulfil the same function as meat within dishes, they do not intend to mimic meat in appearance, taste and texture. Also not included are plant-based meat alternatives based on algae proteins.

Table 1: Key features of different approaches to provide meat or meat alternatives

	Livestock farming	CM	IBMA	PBMA
Production system for raw material	Livestock farming	Few livestock animals, cell banks	Insect larvae mass production	Agriculture
Raw material	Animals	Cell lines	Insect larvae	Protein crops
Processing	Slaughtering	Cell culture, tissue engineering Innovative food processing (e.g. 3D printing)	Conventional protein isolation, conventional food processing (e.g. extrusion)	
Product	Meat	Cultivated meat	Meat alternative	
Technological maturity	Mature	R&D phase, in transition to scale-up	Insect mass production in scale-up phase, MA-productin established, still potentials for improvement	Established, still potentials for improvement
Commercialization	Huge mature market	Worldwide, very few pioneering products approved for placing on the market in Singapore and USA	Hardly any products on the German market	Growing German niche market

Source: Fraunhofer ISI, own compilation

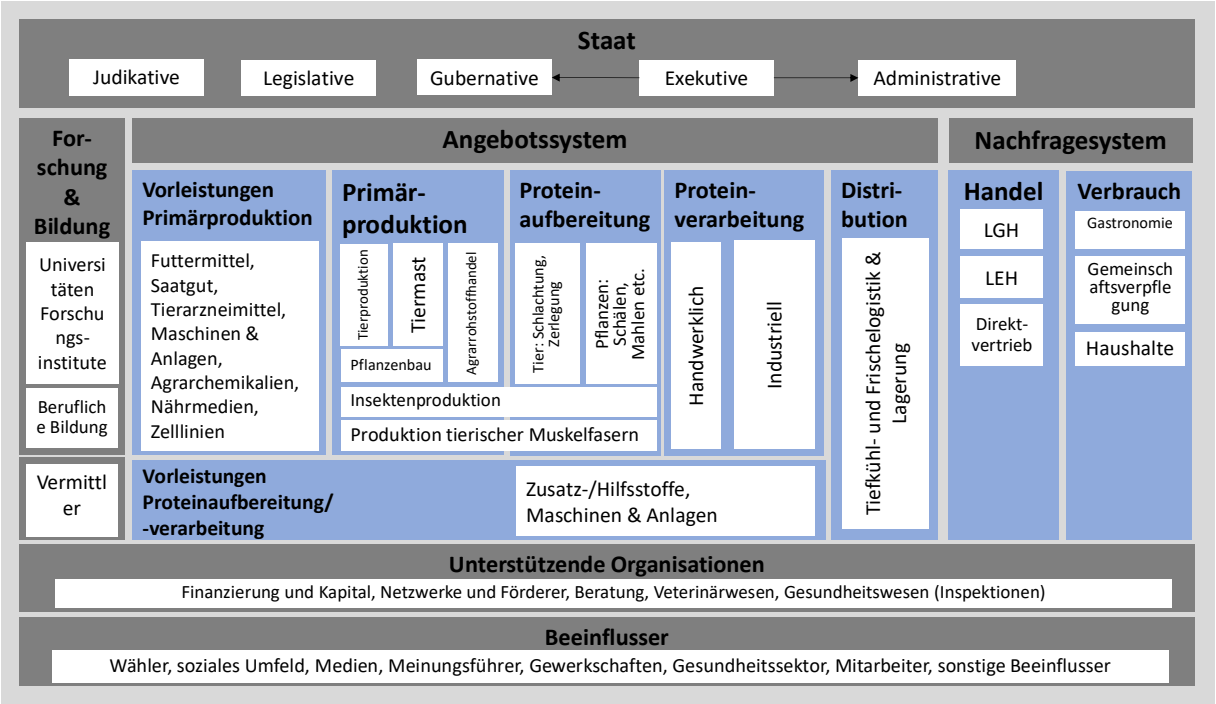
3.2 Actors

The actors of the three innovation systems were identified according to the categories depicted in Figure 1.

All in all, more than 400 actors could be identified for the three TIS in Germany, some of them active in more than one TIS. The majority of actors are companies, followed by academic, private not for profit and federal research institutes, but also (industry) associations, foundations, NGOs and government/regulatory bodies.

Most actors were identified in the PBMA TIS, followed by the IBMA and CM TIS. The actor profile differs between the three TIS. Companies form the largest share in all three TIS, but are most prevalent in the PBMA TIS. By contrast, the relative share of research institutions is larger in the IBMA and CM TIS. These different profiles are most likely due to the development stage and maturity of the respective meat alternatives.

Figure 1: Actors in meat alternative innovation systems



Source: adapted from Warnke et al. (2016)

Some years ago, the meat alternative field was mainly driven by innovative start-up companies and research institutions. This picture has changed now, especially in the PBMA TIS: in addition to dedicated PBMA companies, many established food firms diversify into this sector and integrate PBMA into their portfolio. Providers of machines, equipment, and complex food processing systems have recognized alternative proteins as a promising field and have established business units for alternative proteins, serving both dedicated PBMA companies in scaling up, as well as established food firms in adjusting their recipes and existing production lines to PBMA. Also major companies from the livestock and meat sector are active in this TIS. PBMA are available to consumers via retailers, supermarkets and catering, including fast food chains. Plant breeders and trade companies to provide agricultural supplies have recently entered the field. However, the integration of the agricultural sector and farmers could still be improved.

The starting situation in the IBMA TIS some years ago was comparable to the PBMA TIS. However, first insect-based meat alternatives, developed by start-ups, were commercially not successful. Meanwhile, many actors seem to have abandoned the IBMA business. If they still work on insect-based food products, they rather aim at the protein supplement market. They often process and sell insects or insect proteins imported from other countries (van Huis 2020). However, only few food products are readily available on the German market which contain insect-based ingredients. Insect proteins are now predominantly targeted to the pet food and livestock feed market, attracting the respective players in the aquaculture business as well as the poultry and pig feed and production business (van Huis et al. 2023). Various research institutions are also active in this field.

In global perspective, the CM TIS is driven by dedicated CM companies. Only few such companies are active in Germany. However, several German companies have positioned themselves as competitive, major providers of technological solutions to dedicated CM companies, e.g. cell culture media, fermenters, equipment, and system solutions for production facilities. Established German

livestock and meat companies also invest into the CM business. Only few academic institutions are active in the CM field. This may be due to the low level of public R&D funding (chapter 3.5).

3.3 Networks

Important network organizations for alternative proteins in Germany are BalPro e.V.[2], ProVeg Deutschland[3] and the Good Food Institute Europe/Germany[4]. They provide platforms for information, knowledge dissemination and initiating collaboration and cooperation between actors, as well as working towards creation of legitimacy for alternative proteins. They focus especially on PBMA and CM, and in recent years also fermentation and cellular agriculture. They cover all types of food and food ingredients in the alternative protein field, not only meat alternatives. Balpro also represents actors who derive alternative proteins from insects.

On EU level, the International Platform of Insects for Food and Feed (IPIFF)[5] represents the interests of the insect production sector in the EU to EU policy makers, European stakeholders and citizens. Founded in 2012, the association currently has 31 members and 17 associated, mainly European small and medium-sized enterprises.

In 2021, CM companies from Europe and Israel founded Cellular Agriculture Europe[6], a policy advocacy association. In October 2022, the U.S. based Alliance for Meat, Poultry, and Seafood Innovation (AMPS Innovation), APAC Society for Cellular Agriculture (APAC-SCA), and Cellular Agriculture Europe (CAE) formed the tripartite Global Alliance for Advancing Cultivated Foods. This alliance aims at identifying regional synergies, advocating for regulatory harmonization, and communicating cellular agriculture information[7].

Since the 2020s, several national and international conferences, fairs and events specifically devoted to alternative proteins and products derived from them have been established. Their main target groups are companies and investors, but academia, government or regulatory agency representatives as well as media also attend these conferences.

Moreover, established conferences and fairs for vegetarian and vegan nutrition, agriculture, food processing, and meat have integrated alternative proteins into their program. Examples are IFFA[8] - International trade fair for the meat industry, Internationale Grüne Woche[9] and the Allgemeine Nahrungs- und Genussmittel-Ausstellung Anuga[10].

3.4 Institutions

Up to now, uses of alternative proteins have reached the market which are well covered by existing regulation and may be placed on the market without prior approval. This is the case for PBMA and pet food with insect-derived ingredients. However, IBMA and CM are considered "novel" and are

[2] Verband für Alternative Proteinquellen e. V.; https://balpro.de

[3] https://proveg.com/de/

[4] https://gfieurope.org/de/

[5] https://ipiff.org/

[6] https://www.cellularagriculture.eu/

[7] https://www.cellularagriculture.eu/news/apac-europe-united-states-industry-associations-join-forces-in-a-global-alliance-for-advancing-cultivated-foods/

[8] https://iffa.messefrankfurt.com/

[9] https://www.gruenewoche.de/de/

[10] https://www.anuga.de/

therefore subject to the Novel Food Regulation (EU) No. 2015/2283. It is considered as very likely that in the near future ingredients produced by precision fermentation will become much more relevant for producing PBMA, IBMA and CM with superior quality parameters. Many of these ingredients will also require permission by the European Commission to be placed on the market according to the Novel Food Regulation.

By January 2023, six insect-based novel foods from four different insects have been granted market approval by the European Commission, and 16 applications have been filed[11]. No German actor has filed an application. Only very few products are commercially available in Germany.

For CM, no application for market approval has been filed yet in the EU[11]. Officers from the authority responsible for safety assessment, EFSA, have started an intensive exchange with international regulatory authorities as well as dialogues with companies[12] which intend to file an application. The aim is to specifically define the scope and requirements of the risk and safety assessment of CM and to develop guidance for applicants which information they have to provide in their dossier. Globally, CM is currently only approved for human consumption and commercially available in selected restaurants in Singapore and most recently also in the USA: in June 2023 the FDA gave the companies Upside Foods and Eat Just Inc. the permission to place their products on the market.

It is expected that the next generation of meat alternatives will be hybrid products which no longer fall neatly into the categories of e.g. plant-based, fermented or cultivated products. This will challenge existing regulations and standards. To avoid hindrances, this development has to be addressed in a proactive and timely manner.

3.5 Knowledge development and diffusion

Public funding of projects on meat alternatives was analyzed for the period from 2009-2023. In this period, a total of nearly 180 projects with an overall budget of 41.6 mio. € were conducted (Table 2). As information on project budgets was incomplete, this may be an underestimation. PBMA and IBMA received similar funding volumes in the order of magnitude of 20 mio. €. Public funding of CM remained in the low single-digit million € range.

If in addition, projects on insects as feed or for industrial use are included, a total of 226 projects with a budget of 55.6 mio. € were funded.

Analysis of the data by funding organization showed that by far the largest budget is provided by BMBF (39.1 mio. €), followed by BMEL (8.2 mio. €) and the sum of "other" funding organizations (7.1 mio. €), mainly Federal states. Project funding by BMWK seems to be low (1.2 mio. €), but is definitely underestimated, because for the vast majority of projects funded by BMWK, budget information was not given in the databases.

Looking at the funding profile of the funding organizations, BMBF allocates the largest share of its funding to insects (23.2 mio. €; equally distributed to food and feed/industrial application), followed by PBMA funding (13.1 mio. €).

Appr. 75 % of BMEL funding is allocated to insects (6.4 mio. €), nearly exclusively for food. 25 % (1.9 mio. €) are allocated to PBMA. Feed applications of insects are not in the BMEL focus.

[11] Fraunhofer ISI analysis of the 'Union list of novel foods in accordance with Regulation (EU) 2015/2283' in its latest version (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02017R2470-20230531&qid=1685905686233#tocId2); and EFSA websites https://food.ec.europa.eu/safety/novel-food/authorisations/summary-applications-and-notifications_en#not-2022; https://open.efsa.europa.eu/questions

[12] https://www.efsa.europa.eu/en/events/efsas-scientific-colloquium-27-cell-culture-derived-foods-and-food-ingredients#documents

Table 2: Number of publicly funded projects and project budgets for PBMA, insects and CM in Germany 2009-2023

Topic	Number of projects	Project budget (mio. €)	Number of projects without budget information
PBMA	101	17.7	30
IBMA	59	20.8	13
CM	16	3.1	3
Total MA	176	41.6	46
Insects for feed, industrial use	45	15.4	4
Total	226	55.6	50

Source: Fraunhofer ISI analysis of project databases. Inconsistencies in sums in this table are due to allocation of projects to several topics.

Taking the number of funded projects as indicator, BMWK funding shows a food funding focus, addressing mainly PBMA, followed by IBMA. The incomplete budget information does not allow a budgetwise characterization of the BMWK funding profile.

Other funding organizations also allocate the larger share of their funding to insects (4.8 mio. €), with a focus on feed/industrial use, followed by insects for food. The smaller share of their funding goes to PBMA (2.0 mio. €).

R&D activities on meat alternatives are also publicly supported on the EU level. In the EU project database CORDIS, a total of 72 project with an overall EU contribution of 248 mio. € were identified in the 7th framework program, Horizon2020 and Horizon Europe.

Food applications comprising PBMA, IBMA and CM had a budget of 183.2 mio. €. Insects for feed and industrial applications were allocated 71.6 mio. € (Table 3).

Both EU and Germany allocate appr. 95 % of their overall food MA budget to PBMA and IBMA, and only appr. 5 % to CM. However, they differ in the ratio of PBMA to IBMA funding: EU allocates approximately 2/3 of its budget to PBMA and 1/3 to IBMA, whereas Germany distributes its budget nearly equally to PBMA and IBMA.

If insects for feed/industry are also considered, approximately 72 % of the budget both in EU and Germany goes to different food applications, 28 % to feed applications.

It can be concluded that public funding of meat alternatives in Germany has been modest in the past 15 years. It was mainly focused on PBMA and IBMA, whereas CM was not a priority. Moreover, funding of projects is nearly the only instrument. We could not identify larger R&D programs and only very few coordination or network forming activities that were publicly funded.

Table 3: Comparison of funding profiles of EU and Germany, 2009-2023

Topic	Budget (mio. €)		%	
	EU	Germany	EU	Germany
PBMA	110.9	17.7	60.5	42.5
IBMA	62.8	20.8	34.3	50.0
CM	9.5	3.1	5.2	7.5
Total	183.2	41.6	100.0	100.0
Insects feed/ industrial use	71.6	15.4	28.1	27.0
Total	254.8	57	100.0	100.0

Source: Fraunhofer ISI analysis of project databases

For each of the meat alternatives, specific knowledge gaps and R&D challenges exist. It will depend on solving the following challenges whether market volumes and shares for PBMA will increase:

- Optimization of plant raw materials regarding protein yields and protein functionality, to be achieved by plant breeding, improvement of (domestic, regional) supply chain infrastructure, and optimization of plant material processing,
- Improved methods for texturing and structuring plant proteins, to achieve better texture and enable more complex products,
- Improved taste and nutritional quality, enabled, among others, through improved recipes and ingredients from precision fermentation and hybrid products with components from plants, fermentation and cultivated meat.

For IBMA, comparable challenges as for PBMA apply. In addition, the following R&D challenges are relevant (van Huis 2022):

- Establishing large scale production facilities,
- Improvement of insect strains for industrial production by breeding,
- Optimization of the insect production process with respect to economics, insect growth physiology, insect health,
- Insect feed substrates for different applications,
- Valorization of insect by-products (e.g. chitin, insect frass).

For CM, R&D priorities are the scale-up of CM production to industrial scale, significant cost reductions and improvements in the environmental footprint. Moreover, optimization of taste, texture and composition are required. This is also expected from hybrid products which contain components from plants, algae, fermentation and ingredients from precision fermentation.

3.6 Guidance of the search

Guidance of the search comprises activities and events that convince actors to enter the TIS or to further invest in it, due to a positive expectation about the development.

Reasons for actors to enter the meat alternative field lie on the one hand in changes in the landscape and comprise e.g. global demographic trends and economic development, leading to an increased demand for meat, need of sustainability transition of the agro-food sector, debates about the unsustainability of livestock production (e.g. land use and land use change, emission of green-

house gases and environmental pollution, resource consumption, contribution to antibiotic resistance, emergence of zoonosis, animal welfare, working conditions of employees), but also in changing consumer preferences.

The accelerated transformation towards sustainable food and farming systems, reduced land use for feed and reduced meat consumption are mentioned as goals in various policy strategies. Examples are the EU bioeconomy strategy, the EU Farm-to-Fork-Strategy, and the German National Bioeconomy Strategy. However, meat alternatives are only explicitly mentioned in the Farm-to-Fork Strategy. The German government states in its coalition agreement "We strengthen plant-based alternatives and advocate for the approval of innovations such as alternative protein sources and meat substitutes in the EU[13]" (SPD et al. 2021), but does not give additional indications how to support the field.

Concrete guidance of the search by and within German policy has been low in recent years. Neither a common understanding which role meat alternatives should play in various policy fields, nor a common vision how the sector should develop has been communicated.

On the other hand, companies from the agro-food sector have positive expectations at least about the development of PBMA. Reasons are business opportunities to diversify into a market segment with above average growth rates, and to make use of established know-how and competencies, equipment, and production lines. For incumbents of the livestock and meat sector, meat alternatives offer an opportunity to position the company as innovative and to reduce their environmental footprint. For B2B providers of technological solutions and complex food processing systems, not only meat alternatives, but the whole alternative protein field is attractive because they provide enabling technologies for all alternative protein sources and market segments (e.g. dairy, cultivated seafood, totally new product concepts).

3.7 Entrepreneurial experimentation, market formation and resource mobilization

PBMA

Compared to the other two TISs, the PBMA TIS counts by far the largest number of entrepreneurs, comprising academic spin-offs/start-ups, diversifying medium-sized firms, process equipment and consumables/ingredient companies, large agro-food companies, large and medium-sized food companies, all of which bring different knowledge and perspectives into the industry.

While start-ups experiment with innovative product types or processing technologies, incumbents also have to adapt to start-ups as their new customer group. These customers do not yet have standardized processes or a clear product concept. Both has to be developed in interaction with e.g. process equipment providers which must become more agile, and have to provide solutions based on their experience instead of relying on established routines.

Market estimations for meat alternatives or the alternative protein market differ to a large extent. The most reliable market figures are available for PBMA. In Europe, Germany is the largest market for PBMA. A large variety of PBMA is commercially available in German supermarkets. In 2022, 109.800 tons of PBMA were produced in Germany, with a production value of 537 mio. €, an increase by 82 % compared to 2019. Sales of PBMA were 643 mio. € in 2022, with above average growth rates (Good Food Institute Europe 2023). Target groups for PBMA are not only vegans and vegetarians, but to a large extent flexitarians.

[13] translation by Fraunhofer ISI

Despite a dynamic market development, PBMA are still a niche market, compared to meat. The PBMA production of 109.800 tons is only 1.6 % of meat production (7 mio. tons in 2022) (Good Food Institute Europe 2023). The calculated per capita consumption of PBMA is in the order of 1 kg/year, whereas the annual per capita meat consumption was 52 kg in 2022.

Consumers' attitudes and acceptance are generally lower for meat alternatives than for meat, but are highest for pulses and PBMA, followed by CM, and are lowest for IBMA (Onwezen et al. 2021). Consumers' purchase decisions for PBMA depend on price, followed by taste. Health aspects, environmental footprint, animal welfare and curiosity play a role, but hardly influence the purchase decision. Therefore, significant improvements in production costs, and in product taste and texture are required for further growth of the meat alternative market segment.

IBMA

Dedicated insect food companies in Germany are mainly small start-up companies. Examples are WicketCricket[14] or EntoSus GmbH[15]. A high dynamic can be observed regarding market entry and exit of these companies, making it difficult to keep track of the actual status. Most of them process insect proteins obtained from companies abroad or are active in retail or education/information, e.g. Catch-your-bug[16]. Entrepreneurial experimentation with IBMA around 2019/2020 was commercially not successful. For simple meat alternatives such as burger patties, insect proteins offer no additional functionality compared to PBMA. Consumers' lack of acceptance and their low willingness to try and eat is due to food neophobia and disgust. Insect-based foods in which insects are not visible to the consumer create less aversion. As a consequence, several start-ups had to give up their business, other companies still active in the food business have moved to insect proteins as food supplement or protein ingredient.

In 2019, 500 tons of insect-based food products were produced in Europe (IPIFF 2020), the total EU insect production is estimated at a few thousand tons (including insects for feed and industrial uses). It is estimated that ~50% of the insect industry is engaged in producing pet feed which contains insects (example Fauna Topics[17]). Pet feed is an attractive market, because no regulatory restrictions apply - in contrast to livestock feed - because pets do not enter the food chain. Several companies previously engaged in insect food have lost their interest in the food market (e.g. BUGS-international[18]; Fauna Topics, after integration of start-up company Six-Feet-To-Eat) or started operations in the feed market, with the option to diversify into the food segment in the future (e.g. Madebymade GmbH[19]). Moreover, pet feed, especially for cats and dogs which emphasize its hypoallergenicity, offers attractive profit margins.

In recent years, the major activity in the insect field of researchers and industry is directed towards processed insect proteins as feed in aquaculture, poultry and pig feed (IPIFF 2021; van Huis et al. 2023).

[14] https://wickedcricket.de/

[15] https://www.entosus.de/

[16] https://www.catch-your-bug.com/

[17] https://www.faunatopics.de/

[18] https://www.bugs-international.com/

[19] https://madebymade.eu/

CM

In global perspective, the CM TIS is driven by dedicated CM companies. Their number is estimated at least 150 (Good Food Institute Europe 2023). Only few such companies are active in Germany, e.g. Innocent Meat[20], Alife Foods[21], and Cultivate Food Labs[22]. However, several German companies have positioned themselves as globally competitive, major providers of technological solutions to dedicated CM companies, providing e.g. cell culture media, growth factors, scaffolds, fermenters, equipment, and system solutions for production facilities. Examples for German companies are GEA with its business unit New Food, Handtmann with its sector unit alternative proteins, Merck, Sartorius, Brain Biotech, and DenovoMatrix. Established German livestock and meat companies also invest into the CM business, e.g. Rügenwalder Mühle, the PHW Group and InFamilyFoods.

Globally, CM is currently only approved for human consumption in Singapore and most recently also in the USA (permission granted to Upside Foods and Eat Just Inc.). Small amounts of pioneering products are commercially available in selected restaurants in Singapore and two US cities.

Mobilization of resources

The alternative proteins market is driven by private sector investments. According to research of the Good Food Institute Europe (2023), the global alternative protein sector acquired a total of 14.2 bn US-$ from 2010 to 2022 for PBMA, CM and fermentation. Table 4 gives an impression of global investment activities into PBMA and CM in the past three years, summing up to appr. 8 bn US-$. The largest share has been invested in the USA. Table 6 shows investments in Europe in the past three years, summing up to nearly 1.2 bn €.

The total investment into EU insect business (including pet and livestock feed) is estimated to be in the order of magnitude of 1.5 bn € (as of December 2022, no time period given)[23]. Appr. 1 bn € are allocated to feed, 0.5 mio. € to food (Eurogroup for Animals 2023).

Information on public funding is given in chapter 3.5.

Table 4: Worldwide investments (mio. US-$) into PBMA and CM, 2020-2022

Meat alternative	2020	2021	2022
PBMA	2.213	2.028	1.188
CM	379	1.341	896
Total	2.592	3.369	2.084

Source: Good Food Institute Europe (2023)

[20] https://www.innocent-meat.com/

[21] https://alifefoods.de/

[22] https://cultivatedfoodlabs.com/

[23] https://ipiff.org/faqs_2020/

Table 5: Investments in Europe (mio. €) into PBMA and CM, 2020-2022

Meat alternative	2020	2021	2022
PBMA	364	247	284
CM	86	92	120
Total	450	339	404

Source: Good Food Institute Europe (2023)

3.8 Creation of legitimacy

The innovation system function of creation of legitimacy is understood as obtaining a status of perceived social compliance or desirability. It is a generalized perception or assumption that the innovations are desirable, proper, or appropriate within a socially constructed system of norms, value, beliefs, and definitions (Bergek et al. 2008). Three different ways to characterize legitimacy can be distinguished (Suddaby et al. 2017):

- Legitimacy as product property: achieved through fit between attributes of MA and actor groups' expectations or existing norms,
- Legitimacy as perception: socio-cognitive construction, perceptions, judgements and actions of individuals under the influence of collective-level institutionalized judgments,
- Legitimacy as a process: interactive process of social construction, created between those pro or against meat alternatives.

Legitimacy as product property and as perception are used to characterize the current status of creation of legitimacy for PBMA, IBMA and CM with respect to aspects which either support or challenge legitimacy. Moreover, the resulting firm and policy behavior regarding legitimacy as a process is given.

PBMA

For PBMA, the following arguments are made to support their legitimacy:

- By mimicking meat in appearance, taste, texture and cooking properties, PBMA serve the cultural and socio-economic values assigned to meat.
- PBMA are a solution to environmental challenges in the agro-food sector and a means to support sustainability transition by reducing the need for livestock farming.
- The overall environmental footprint of PBMA is the most favorable of all three meat alternatives. If protein plants are sourced domestically, they also provide opportunities to diversify crop rotation and offer perspectives for development of rural regions.
- PBMA raise no animal welfare concerns.
- PBMA make use of familiar raw materials and food production processes.
- PBMA promise to offer a superior solution to meat from livestock from an individual health perspective (clean eating, more plant-based, meat-reduced diet).
- Benefits of more plant-based diets can be achieved without a major shift in eating habits and diets. For flexitarians, PBMA increase the variety and convenience of plant-based meals, compared to plant-based diets with a focus on low-processed food.

- The agro-food industry can base PBMA production on established skills, processes, routines, infrastructures, logistics and business relationships and sees the field as attractive option to diversify their business and to satisfy consumer demand with innovative products.
- PBMA conform to a large extent with the existing food law and do not require market authorization.

The following arguments are made which pose a challenge for PBMA to gain legitimacy:

- PBMA are inferior mimics of meat regarding taste, texture, variety of products, nutritional value.
- PBMA cannot be considered healthy, due to their ingredients and being highly processed.
- PBMA are an inferior solution to plant-based diets with high proportions of fresh and not highly processed components.
- PBMA confirm and solidify the iconic status of meat and run counter to efforts to reduce the importance of meat in dishes and diets and towards more plant-based diets.
- PBMA are overpriced, and therefore are neither accessible nor affordable for all citizens.

These legitimacy challenges led to the following industry association and firm behavior:

- Intensive efforts to improve products with respect to meat-like taste and texture, recipes, and environmental footprint,
- Lobbying for a level playing field regarding taxation of meat and PBMA,
- Lobbying for PBMA labelling with terms usually used for meat dishes (DLMBK 2018; Deutsche Lebensmittelbuch-Kommission 2023),
- Lobbying for inclusion of PBMA in the National Nutrition Strategy (BMEL 2022) as option towards more plant-based diets and reduced meat consumption by stressing the bridging function.

IBMA

For IBMA, the following arguments are made to support their legitimacy:

- By mimicking meat in appearance, taste, texture and cooking properties, IBMA serve the cultural and socio-economic values assigned to meat.
- IBMA are framed as additional, still underutilized food source to fight global hunger and ensure sufficient food for a growing world population, as a solution to environmental challenges in the agro-food sector and as a means to support sustainability transition of the sector by reducing the need for livestock farming.
- IBMA provide environmental advantages compared to livestock farming and meat, use agro-food waste streams as insect feed and thus contribute to circularity, offer perspectives for development of rural regions if agricultural waste is valorized.
- IBMA raise no livestock welfare concerns.
- IBMA make use of familiar food production processes from the stage of raw material (insect larvae) processing onwards.
- IBMA offer a superior solution to meat from livestock from an individual health perspective (clean(er) eating, meat-reduced diet).
- Benefits of a meat-reduced diet can be achieved without a major shift in eating habits and diets. For flexitarians, IBMA increase the variety and convenience of meat-reduced meals, compared to plant-based diets with a focus on low-processed food.
- The food industry can base IBMA production on established skills, processes, routines, infrastructures and logistics and business relationships from the processing of raw materials (insect larvae) onwards.

- The established EU regulatory framework for Novel Food applies to IBMA. The mandatory risk and safety assessment ensures the safety of IBMA placed on the market. As of 2023, four insect species and six insect-based products have been granted market approval.

The following arguments are made which pose a challenge for IBMA to gain legitimacy:

- IBMA are inferior mimics of meat regarding meat-like taste and texture, variety of products, nutritional value.
- IBMA cannot be considered healthy, due to their ingredients and being highly processed.
- IBMA are an inferior solution to plant-based diets with high proportions of fresh and not highly processed components.
- IBMA confirm and solidify the iconic status of meat and run counter to efforts to reduce the importance of meat in dishes and diets and towards more plant-based diets.
- IBMA are an inferior option compared to PBMA in several aspects: the input-to-protein conversion rate is lower than for PBMA, insect proteins offer no superior functionality compared to plant proteins.
- Insect larvae as raw material are unfamiliar in Western countries, there is no tradition to eat insects, and entomophagy leads to disgust and aversion in large parts of the population.
- Industrial insect mass production raises ethical concerns regarding the welfare of farmed insects due to the rearing conditions and killing procedures. There are also concerns regarding safety, hygiene, use of antibiotics, accumulation of toxic substances etc. (Parodi et al. 2022)
- Insect mass production processes are not yet cost-competitive. Their cost-competitiveness depends to a large extent on the use of waste substrates to feed the insects, and valorization of by-products. However, there are currently legal restrictions to this due to food safety and hygiene reasons.
- High resource demand for investment into insect production facilities and obtaining approval as Novel Food. Return on investment uncertain due to lack of consumer acceptance of and demand for IBMA.

These legitimacy challenges led to the following industry association and firm behavior:

- Withdrawal from the IBMA market which targets flexitarians, switching to insect-based food protein ingredient and supplement market which addresses very specific small consumer groups,
- Withdrawal from insect food applications, switching to insect-based pet food and livestock feed market,
- Withdrawal from the IBMA field, switching to other meat alternatives or alternative protein options without insects,
- Lobbying for regulatory change regarding insect feed use and quality requirements for insect by-products.

These legitimacy challenges led to the following policy activities:

- Support of IBMA R&D, support of research of consumer acceptance,
- Advocate for the approval of innovations such as alternative protein sources and meat substitutes in the EU (SPD et al. 2021).

CM

For CM, the following arguments are made to support its legitimacy:

- CM is communicated as "real meat", CM serves the cultural and socio-economic values assigned to meat.
- CM is framed as an innovative solution to solve all concerns and challenges related to livestock farming. CM is framed as a solution to environmental challenges in the agro-food sector

and as a means to support the sustainability transition by reducing the need for livestock farming.
- CM assumes environmental advantages compared to livestock farming and meat, substantiated by life cycle assessments (Sinke et al. 2023).
- CM raises hardly any livestock welfare concerns.
- CM offers a superior solution to meat from livestock from an individual health perspective (cleaner eating, option to fortify CM with health-promoting ingredients) without any changes of eating habits or diets.
- Industry engagement in CM development is seen as innovative, offers the potential to become a major player in a disruptive development, bears the potential to strengthen the competitive position of leading meat companies, but with improved sustainability.
- The meat industry can base the processing of cultivated meat to other products on established skills, processes, routines, infrastructures and logistics and business relationships.
- First market approvals of pioneering CM products and their commercial availability in selected restaurants in Singapore and the USA.
- The established EU regulatory framework for Novel Food applies to CM. The mandatory risk and safety assessment will ensure the safety of CM, when authorized for placing on the market.

The following arguments are made which pose a challenge for CM to gain legitimacy:

- CM cannot be considered "real" meat due to its production process. It is artificial and unnatural, as shown by terms such as "lab meat".
- CM is a highly processed product, requiring unfamiliar production processes.
- The energy-intensive production process contradicts the sustainability advantages of CM products.
- CM is an inferior solution to plant-based diets with high proportions of fresh and not highly processed components.
- CM confirms and solidifies the iconic status of meat and runs counter to efforts to reduce the importance of meat in dishes and diets and towards more plant-based diets.
- CM runs counter to efforts to reduce meat consumption for health reasons, CM does not provide a bridging function to more plant-based diets.
- It is uncertain whether CM will be accepted by larger consumer groups, or whether there is a lack of willingness to eat CM due to the perceived "unnaturalness".
- Ethical concerns may relate to just availability and affordability. They may be hindered in case CM will be marketed as an exclusive luxury product.
- The food and meat industry lacks the skills to develop and operate CM production processes.
- Lack of positive perspectives and business models for livestock farmers and regions with a strong livestock production sector.
- Developing, scaling-up, obtaining market approval and marketing CM requires large resources. The return on investment is uncertain due technological challenges in product design and quality, the scale-up with first of its kind facilities, and uncertain consumer demand.
- The requirements and procedures for risk and safety assessment of CM in the EU Novel Food regulation are just in the process of being developed. CM-specific guidance for industry is not yet available. No applications have been filed yet in the EU.

These legitimacy challenges led to the following industry association and firm behavior:

- Foundation of CM-specific industry associations (Cellular Agriculture Europe, Global Alliance for Advancing Cultivated Foods) to lobby for political support of CM,
- Incumbents engage in CM by providing financial and material support of dedicated CM (start-up) companies to experiment, incumbents monitor their development,

- Providers of enabling technologies for CM diversify into the sector,
- Feasibility studies and living lab experiments to test the viability of farm-based CM production by the Foundation Respect Farms.

These legitimacy challenges led to the following policy behavior:

- Support of CM R&D on a low level, support of research of consumer acceptance,
- Advocate for the approval of innovations such as alternative protein sources and meat substitutes in the EU (SPD et al. 2021).

Conclusion

PBMA, IBMA and CM differ in the currently achieved strength of legitimacy. They show individual, but partly overlapping profiles of factors supporting or challenging their legitimacy. From this, different foci result for the processes to gain legitimacy.

Bergek (2008) distinguishes three types of legitimation processes: institutional alignment, conformance and creation.

Creation of legitimacy seems to be the least challenging for PBMA because there is a high level of conformance with the food law, and with competencies, practices and infrastructures in industry. From a consumer perspective, there is a high level of familiarity with food raw materials production processes, and PBMA are largely in line with cultural and societal values. Therefore, PBMA have currently achieved the highest strength of legitimation of the three meat alternatives.

The focus of the legitimation processes for IBMA and CM is institutional alignment in various areas: in applying current EU legislation in an effective way to these novel product groups or amending regulations; in offering positive business perspectives to industry in order to mobilize resources; and in better understanding consumer acceptance. In the case of IBMA, the lack of consumer acceptance (legitimacy as perception) could not be overcome in recent years, so that the industry focus has now shifted from IBMA to pet feed and livestock feed (where different challenges to achieve legitimacy have to be mastered (Parodi et al. 2022)). From the meat alternative point of view, IBMA currently have the lowest level of legitimacy. CM legitimacy seems to be positioned between PBMA and IBMA.

The development of a new institutional framework ("creation") is not (yet) relevant due to the infant stage of the meat alternatives. It might become necessary in the future if TIS mature and e.g. hybrid products gain importance.

4 Interactions between the innovation systems for plant- and insect based meat alternatives and cultivated meat

The three meat alternative TIS are not independent from each other. Rather, interactions between them can occur. Interactions between innovation systems may have significant impacts on TIS development: for example, they could accelerate processes of change, but could also have hampering and conflicting effects. Hence, for concluding actions for the stakeholders of these TIS, such dynamics or hurdles should be considered for the food system transformation.

Transition scholarship has studied the interaction of different technologies or innovation systems mainly with respect to competition between them, or with technologies of the energy sector as objects of their research (Suurs et al. 2009; Sandén et al. 2011; Magnusson et al. 2018). Evidence is accumulating that different types of interactions can be observed, and that the interaction may change over time (Sandén et al. 2011; Bergek et al. 2015).

We analyzed the interactions between the innovation systems for PBMA, IMBA and CM, using the six modes of interaction outlined by Sandén et al. (2011) (Table 6). We adapted their analytical framework, which starts from a value chain perspective, to an innovation systems framework. We then analyzed pairs of TIS with respect to their interactions. In this analysis, we identified for each of the innovation system functions (or aspect within a function) the mode of interaction between the two TIS. The results are given in Table 7 and Table 8. Only the results for interaction between the PBMA and CM TIS and the PBMA and IBMA TIS are shown. This is due to our finding that only few interactions between the CM and the IBMA TIS exist because of their early stage of development. These interactions are the same that are already captured in the analysis of their interaction with the PBMA TIS.

Table 6: Possible modes of interaction between two innovation systems

Mode of interaction	Innovation system 1	Innovation system 2	Characterization of interaction
Competition	-	-	Both IS inhibited because common resource is in short supply, or market limited
Symbiosis	+	+	Interaction of TIS is favorable for both TIS
Neutralism	0	0	No interaction, both TIS are not affected by interaction
Parasitism/ predation	-	+	One TIS benefits, the other TIS is inhibited/negatively affected
Commensalism	0	+	One TIS benefits, the other TIS is not affected
Amensalism	0	-	One TIS is negatively affected, the other TIS is not affected

Legend: +: interaction has beneficial effect on the TIS, 0: interaction has no effect on the TIS, -: interaction has negative effects on the TIS, inhibits the TIS
Source: adapted from Sandén et al. (2011)

Our interaction analysis is a snapshot of the interactions that take place at the present stage of development (2022), or are very likely to occur within the next three to five years. Taking a longer-

term perspective for the analysis would have been speculative, because there are significant uncertainties how each TIS will develop.

Looking at the overall picture of TIS interaction, symbiosis of all three TIS prevails under the overall umbrella of alternative proteins. Activities of mutual benefit to the three TIS can be observed especially in these TIS functions:

- Knowledge generation and exchange in alternative protein networks and platforms,
- Guidance of the search by offering the common vision of a potentially more sustainable alternative to meat from livestock, or animal products respectively, and by attracting more actors to the field because expectations about the future development of alternative proteins in general are even more attractive than for one TIS alone,
- Resource mobilization e.g. by lobbying for more public R&D funding of meat alternatives or investments into expansion of production infrastructures, and
- Creation of legitimacy by joining forces for gaining political support for meat alternatives.

In the interaction of the PBMA and the CM TIS, symbiosis also prevails. In addition to the above-mentioned issues, symbiosis is also due to the expectation that the next generation of products in both TIS could be hybrids of plant-based, cell-based and fermentation-based products. These hybrids are expected to be improved with respect to consumer satisfaction and price. These products will result from convergence with fermentation and precision fermentation as shared enabling technologies.

Competition between the PBMA and CM TIS exists in the product concept. Both promise to deliver a superior product for the same function (meat experience) to consumers, but differ in the way to achieve this (plant raw material and a familiar production process (PBMA) or livestock cells and a novel production process (CM)). At present, it is an open question whether the same or different consumer groups will be targeted by PBMA and CM in the future (implying either competition or neutralism). Competition also exists regarding scarce resources, especially acquisition of financial support (e.g. public R&D funding, venture capital, investments in expansion of production infrastructure).

At the present stage of development, some frame conditions and interaction between the PBMA and CM TIS can be classified as parasitism or commensalism, in which PBMA benefit while CM are inhibited or not directly affected: PBMA rely on established food production processes and infrastructure and do not need a market authorization, and therefore are already readily available on the market at affordable prices. By contrast, production infrastructures for large scale CM production still have to be built up, only exclusive limited product volumes are commercially available at selected restaurants in Singapore (and in the near future also in the US) and the development of guidance for CM product safety assessment as prerequisite for market authorization in the EU has only just started. This allows PBMA to establish quickly and gain market shares while for CM, these prerequisites for market access still have to be established.

Commensalism in the opposite direction, in which CM benefits from PBMA, is due to the fact that PBMA can be considered a pioneering product group. The lessons learnt from PBMA about markets, consumer groups and their preferences and from entrepreneurial experimentation can guide strategies and avoid pitfalls in CM development.

At present, it cannot be decided whether competition, neutralism or parasitism/predation will become the dominant interaction between PBMA and CM: it is possible, that PBMA will serve as bridging products to CM, so that they will be replaced by CM in the future. It is also possible that PBMA will serve as bridging products to a plant-based diet, making CM obsolete. And it is possible that hybrid products will thrive and replace PBMA and CM (parasitism/predation), or coexist with PBMA

and CM (commensalism), or will coexist with either PBMA or CM, and inhibit the other option (amensalism).

Table 7: Interaction of the PBMA and CM innovation systems

IS function		Overlaps, description of interaction	Type of interaction					
			Competition (-/-)	Symbiosis (+/+)	Neutralism (0/0)	Parasitism, predation	Commensalism (+/0)	Amensalism (-/0)
Knowledge development and diffusion	technology and knowledge base	To a large extent distinct and different knowledge and technology			x			
		Precision fermentation and fermentation as enabling technology for both IS		x				
		Food processing technology and knowhow relevant for both IS		x				
	R&D actors and R&D activities	To a large extent distinct and different R&D actors and activities			x			
	R&D needs/challenges	Improvement of product characteristics, development of hybrid		x				
	public R&D funding	public R&D funding (lobbying for alternative protein funding)		x				
		public R&D funding (acquisition of alternative protein funding)	x					
	Learning about markets	PBMA as pioneering products, CM as followers					x (CM +)	
	Learning about customers/consumers	PBMA as pioneer to address new consumer group flexitarian					x (CM +)	
	Networks and platforms for knowledge exchange and learning processes	Alternative proteins networks and platforms		x				
		CM-specific networks and platforms			x			
Guidance of the search	Common vision	More sustainable alternative to livestock meat		x				
	expectations about future development	alternative proteins as (more) attractive field for engagement of actors (than PBMA or CM alone)		x				
	Coordination of efforts	Promoting alternative proteins as attractive business opportunity		x				
		Lobbying for better policy coordination		x				
Entrepreneurial activity	Companies and activities	To a large extent distinct and different companies active			x			
		Food processing knowhow and equipment providers enablers for		x				
		Fermentation and hybrid products		x				
	Technological options, product concept, design, quality	Product concept	x					
		PBMA as bridging product to CM				x (CM +, PBMA -)		
		PBMA as bridging product to plant-based diet				x (PBMA+, CM -)		
	Learning from entrepreneurial experimentation	PBMA as pionieering products, CM as followers					x (CM +)	
Market formation	Target consumer group	same function (meat) in a mature market	?			?	?	?
		different target groups (flexitarians, meat consumers)	?		x			
	Price	PBMA much more affordable than CM				x		
	Availability, accessibility	PBMA much better accessible/available than CM				x		
	Standards (e.g. labelling)	Lobbying for MA supportive labelling					? (CM +)	
Resource mobilisation	Financial support	Investment, financial support	x			(x)		
		public R&D funding (lobbying for alternative protein funding)		x				
		public R&D funding (acquisition of alternative protein funding)		(x)				
	Required infrastructure	PBMA relies on existing infrastructure, CA requires new one				x		
		Expansion of fermentation infrastructure (lobbying for investment)		x				
		Expansion of fermentation infrastructure (use, supply)	x					
Creation of legitimacy	Demand by consumers	each TIS promises to provide the superior product/function	(x)					
	Political support	Joined forces for creation of legitimacy of meat alternatives		x				
	compliance with/adaptation of regulatory framework and standards	Referring to alternative proteins as common and larger goal		x				
		Market authorisation not required for PBMA, Novel Food authorisation required for CM				x (PBMA +)		

Source: Fraunhofer ISI

In the interaction of innovation systems of PBMA and IBMA, the predation mode prevails in which PBMA benefit, whereas IBMA are inhibited. This is due to the fact that entrepreneurial experimentation with IBMA was not successful, mainly for four reasons: lack of added functionality of insect proteins compared to plant proteins, consumers' disgust and neophobia regarding IBMA, requirement of new production infrastructure for rearing insects, and requirement of a market authorization as Novel Food in the EU. As a consequence of IBMA as inferior solution compared to PBMA, insect proteins no longer target the meat alternative market, but the protein supplement market (IB food). In this segment, insect protein food products benefit from experience gained with PBMA (commensalism).

Another consequence of IBMA as inferior solution compared to PBMA is that insect proteins now predominantly target the pet food and livestock feed market. If in the future costs of insect proteins as livestock feed were reduced and their positive effects on livestock production, health and welfare increased, insect proteins on the one hand could make livestock production less unsustainable, but at the same time could stabilize livestock production and meat consumption. This may negatively affect both PBMA and CM (parasitism/predation).

Table 8: Interaction of the PBMA and IBMA innovation systems

IS function		Overlaps, description of interaction	Type of interaction					
			Competition (-/-)	Symbiosis (+/+)	Neutralism (0/0)	Parasitism, predation (+/-)	Commensalism (+/0)	Amensalism (-/0)
Knowledge generation and diffusion	technology and knowledge base	To a large extent distinct and different knowledge and technology			x			
		Food processing technology and knowhow relevant for both IS		x		x (PBMA +)		
	R&D actors and R&D activities	To a large extent distinct and different R&D actors and activities			x			
	R&D needs/challenges	Improvement of MA characteristics		(x)		x (PBMA +)		
		Improvement of IB non-meat food products					x (IB food +)	
		Improvement of IB feed products				? x (IB feed +)	x (IB feed +)	
	public R&D funding	public R&D funding (lobbying for alternative protein funding)		x				
		public R&D funding (acquisition of alternative protein funding)	x					
	Learning about markets	PBMA as pioneering products, IBMA as inferior solution				x (PBMA +)		
		PBMA as pioneering products, IB non-meat food products					x (IB food +)	
	Learning about customers/consumers	PBMA as pioneer to address new consumer group flexitarian				x (PBMA +)		
		IB food to address consumers of protein supplements					x (IB food +)	
	Networks and platforms for knowledge exchange and learning processes	Alternative proteins networks and platforms					x (IB food +)	
		IB protein/IB feed-specific networks and platforms					x (IB food/feed +)	
Guidance of the search	Common vision	IBMA and PBMA more sustainable alternative to livestock meat		x				
		IB feed as more sustainable option for livestock production				x (IB feed +)		
	Expectations about future development	alternative proteins as (more) attractive field for engagement of actors (than PBMA or IBMA alone)		x				
	Coordination of efforts	Promoting alternative proteins as attractive business opportunity		x				
		Lobbying for better policy coordination		x				
Entrepreneurial activity	Companies and activities	To a large extent distinct and different companies active			x			
		Food processing knowhow and equipment providers enablers for		x				
		Feed producers and livestock producers			? IB feed +, PBMA -			
	Technological options, product concept, design, quality	IBMA Product concept	(x)			x (PBMA +)		
		IB feed product concept				? IB feed +	x (IB feed +)	
	Learning from entrepreneurial experimentation	PBMA as pioneering products, IBMA as followers				x (PBMA +)		
		IB food and IB feed products					x (IB food/feed +)	
Market formation	Target consumer group	same function (meat) in a mature market				x (PBMA +)	?	?
		different target groups (PBMA: flexitarians, IB food: protein supplement consumers)			x			
	Price	PBMA more affordable than IBMA				x (PBMA +)		
	Availability, accessibility	PBMA better accessible/available than IBMA				x (PBMA +)		
	Standards (e.g. labelling)	Requirement for labelling IB protein ingredients				x (PBMA +)		
Resource mobilisation	Financial support	Investment, financial support	x					
		public R&D funding (lobbying for alternative protein funding)		x				
		public R&D funding (acquisition of alternative protein funding)	x					
	Required infrastructure	PBMA relies on existing infrastructure, IBMA requires partly new one				x (PBMA +)		
		Expansion of required infrastructure (lobbying for investment)	x					
		Expansion of required infrastructure (use, supply)					x (IB food/feed+)	
Creation of legitimacy	Demand by consumers	each TIS promises to provide the superior product/function				x (PBMA +)		
	Political support	Joined forces for creation of legitimacy of meat alternatives		x			?	?
	compliance with/adaptation of regulatory framework and standards	Referring to alternative proteins as common and larger goal		x				
		Market authorisation not required for PBMA, Novel Food authorisation required for IBMA				x (PBMA +)		

Source: Fraunhofer ISI

From this analysis, the following conclusions can be drawn: Which interaction modes can be identified depends on the resolution of the observation - a more differentiated pattern can be observed if interactions of innovation system functions are analyzed in detail, compared to interactions of whole innovation systems. We could identify all six interaction modes in our analysis. Symbiosis and parasitism/predation were the most prevalent ones, followed by competition.

All in all, interaction of the TIS was modest, due to the differences in maturity and technology-specific challenges that have to be addressed. Nevertheless, all three TIS are still niches struggling to establish and grow. It is therefore not astonishing that symbiosis, i.e. joining forces, can be observed in system building functions under the umbrella of alternative proteins, especially in creation of legitimacy, guidance of the search, resource mobilization as well as knowledge generation and exchange. Competition was mainly for financial resources, because market competition is not yet relevant, with nearly only PBMA commercially available.

Our analysis is only a snapshot of TIS interaction during a short time period. It can be assumed that the interaction modes will change with time, as the innovation systems mature and grow, as feedback loops between them show effect, or in response to changing exogenous factors/forces.

Should innovation policy aim to further develop all three TIS to support their co-existence, a strong support on the functions with synergies as well as in particular a differentiated support to market

formation would be crucial. Moreover, policy considerations should take (desired, unintended) interactions and feedback loops between the TIS into account.

5 Characterization of the livestock and meat sector

While the prior sections have focused on the development of innovations, successful sustainability transformations usually also require exnovation processes. The term exnovation is often used in sustainability literature as a counterpart to the term innovation (Antes et al. 2012; Arnold et al. 2015; Clausen et al. 2016; Hermwille 2017; Paech 2006). It is understood as the purposive and explicit phasing out or modification of unsustainable systems,[24] including "existing (infra)structures, technologies, products and practices" (Heyen et al. 2017, p. 326) as well as associated or stabilizing policies and other governance mechanisms. In some cases, entire industry sectors can be phased out, such as the use of brown coal for energy generation in Germany. In the case of the meat and livestock industry, the transformation is likely to involve only a partial exnovation, leading to a significant reduction in sector emissions and industrial livestock farming, but not to a complete elimination of the industry as a whole. Considerations of exnovation processes alongside innovation are essential, because while politics and classical transformation research often deal with the emergence of innovations (Antes et al. 2012; Heyen 2016), a more systemic view must not neglect what happens to the incumbent (non-sustainable) systems that existed before.

Due to various parameters (techno-economic factors, economic interests, political framework conditions), such incumbent regimes are usually subject to particular stability (Zundel et al. 2005). For example, the active or passive resistance of central actors who see their raison d'être threatened by the emergence of innovations often inhibits change and transition (Kahlenborn et al. 2013). Such resistance can arise towards innovations such as new products, practices or regulations (Turnheim et al. 2013) and occurs particularly when the new, more sustainable system does not include an obvious role for incumbents (Grießhammer et al. 2015). Geels (2014) differentiates four different types of power and resistance:

- **Instrumental**: using resources (such as financial & human resources, power, skills) "in immediate interactions with other actors" to further one's own goals and interests (Geels 2014, p. 28);
- **Discursive**: shaping the narrative of which issues are being discussed and how (i.e. agenda-setting); this can include spreading doubt with regard to the necessity, feasibility or usefulness of a transition or innovation, or exaggerating its costs (Heyen 2016);
- **Material**: using technical know-how and financial resources to incrementally improve the status of the existing socio-technical regime, while seeking to avoid more radical changes;
- **Institutional**: making use of incumbents' embedded position in "political cultures, ideology and governance structures [through which] the government privileges powerful regime actors with more capabilities, financial resources and established market positions" (Geels 2014, p. 34).

On the one hand, these dynamics are problematic because they can prevent or significantly complicate transformation. On the other hand, if possible negative socio-economic consequences and their moderation are not considered early on, a sustainability transformation can in turn lead to unsustainable consequences (Heyen 2016).

Work package 5 of the TRADINNOVATION project therefore focused on characterizing the traditional meat and livestock industry in Germany, including the identification of factors that stabilize the system in forms of path dependencies and an analysis of its past strategies of resistance. The

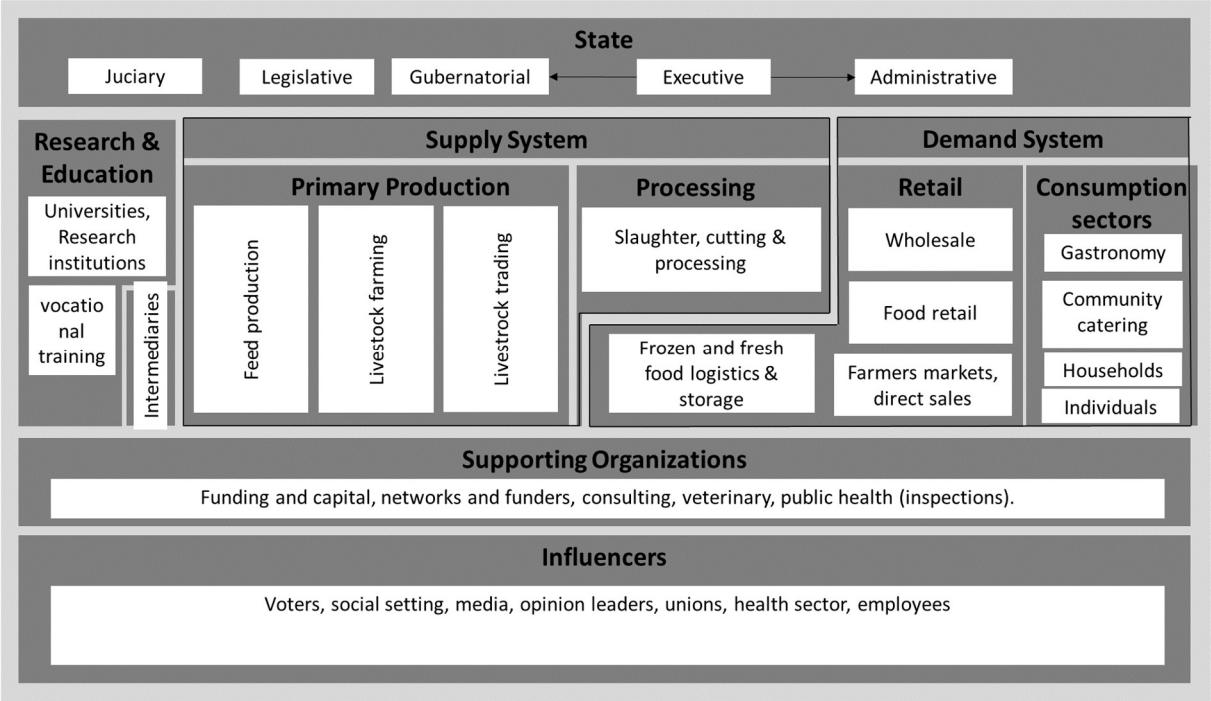
[24] Like Heyen (2016), our focus is on politically(and more specifically sustainability-)-motivated exnovation, i.e. exnovation that is politically forced or at least politically intended. We do not cover exnovation that takes place more "naturally" due simply to technological changes and/or a change in consumer demand or other market changes.

following results were obtained using desk-research and discourse analysis. Various data sources, such as statistical data, media reports and scientific publications, were used for this purpose. This chapter includes excerpts from two manuscripts, one of which has been submitted to the journal GAIA. The second manuscript is currently in preparation for journal submission (more information in chapter 8).

In the first step, the sector was characterized by its stakeholders, relevant path dependencies and important, past innovations. Subsequently, the resistance was examined on the basis of five different transitions. The current drivers from the social and economic environment were presented in the last section of the chapter.

Figure 2 shows all stakeholders in the sector along the value chain to the end customer.

Figure 2: Stakeholder groups in the livestock and meat sector



Source: adapted from Dütschke et al. (2019)

Current framework conditions of the sector are a strong densification in the last decades. The number of livestock farms has decreased sharply during this time, while the number of animals kept has stagnated or even increased over the same period (Destatis 2017). Meat-processing artisanal farms are becoming fewer and fewer, while large mass slaughterhouses are dividing up the market and changing business models by cooperating with discounters. At the same time, they receive concessions on fees for meat inspection. They can also benefit from export subsidies and government funding for additional processing capacity, as well as tax relief. Due to their economic importance for the regions or federal states in which they are located, meat companies are also able to exert political influence (Münchhausen et al. 2019). This creates a political or economic path dependency. Another path dependency arises in this sector primarily through pricing. Due to the market power of large corporations, they can drive competitors out of the market with low-price offers and exert political influence, especially on regional decisions (Münchhausen et al. 2019). The most important technological path dependency concerns the breeding animals themselves, which have been bred over decades in such a way that they can be kept as efficiently as possible economically and slaughtered with high yields (Clausen et al. 2017). Path dependencies in infrastructure are present due to

the regional centering of meat companies, as well as the large number of industrial fattening operations with corresponding barns/cages and industrial-scale slaughterhouses.

Innovation activities within the sector are lower than in other industries (Stockmeyer 2001). In the last twenty years, this can be illustrated primarily by the two major novel food trends, genetically modified food and functional food, neither of which, however, has generated any product or process innovation in the sector. Despite public pressure to adapt operational processes to animal welfare, no innovations have been established here either.

The sector is characterized by resistance strategies that severely delay innovation efforts. Discursive or material resistance strategies are often chosen. These strategies were explained using five different examples. These include the phase-out of anesthesia-free piglet castration (started in 2008, animal protection law in 2021), cage size for laying hens (started in 1999, regulation from 2025/2028), recording of the area-wide, preventive use of antibiotics (started in 2011, new reporting obligation in 2023), determination of maximum residue levels of hormones in meat (law since 2009; however, media coverage repeatedly relativizing the use of hormonal pharmaceuticals and strong resistance to the publication of contrary (scientific) results), cross-border animal transport (amendment of the Animal Welfare Transport Ordinance in 2021, but development of a separate strategy (Animal Welfare Standard Transport (TSW-T) by the sector).

The sector is economically driven by a strong export orientation. Another characteristic of the sector is the strong formation of monopolies, which have resulted from numerous corporate mergers in the context of pricing policy (Spiller et al. 2008) The sector is predominantly production-oriented and is characterized by low market and consumer proximity (Spiller et al. 2008). Neither societal and political empowerment nor readiness for transformative approaches exist in Germany, so association and lobbying work can be defined as key driver of the sector. The "Commission on the Future of Agriculture" (Zukunftskommission Landwirtschaft) has set new impulses at the political level with its report (ZKL 2021). It remains questionable to what extent the proposals will be applied in the coming years.

The social driver in the context of meat consumption is the ever-increasing availability and consumption of products of the meat industry. Meat is not a luxury good, but a daily commodity. The current low prices, triggered by the high competition or price pressure as a driver, contribute to this to a very large extent (Buschmann et al. 2013). Numerous civil society protest actions and meat scandals in recent decades have not had an impact on consumer behavior either - but after a brief outrage, consumption is not fundamentally questioned as a result (Eyerund 2015). Transformative approaches within society have so far had no demonstrable effects on meat consumption in Germany (Eyerund 2015). Thus, although many people are aware of the conditions of animal husbandry, personal norms or habits prevent a change in behavior (Quack 2016; Voget-Kleschin et al. 2014).

To sum up, the results of this work package show that the sector is 1. dominated by strong monopoly companies that replace small butchers, 2. represented by strong lobbying, 3. successfully resists innovation, choosing mainly discursive resistance strategies. The sector is also characterized by 4. strong export orientation and 5. high price pressure. 6. There are hardly any social drivers that exert an effective influence on the discourse, although the low animal welfare standards are very well known.

6 Interactions between the livestock and meat sector and the meat alternatives innovation systems

Based on the more backwards-looking characterization of the meat and livestock industry (chapter 5), we now focus more on future developments, assessing the reactions and resistance strategies employed by the incumbent industry with a view to the meat alternatives innovation systems discussed in chapters 3 and 4. The discourse analyses in chapter 5 focusing on prior changes in animal husbandry and meat production (e.g. anesthesia-free piglet castration, ban on battery cages for laying hens) showed quite clearly the open resistance of the incumbent meat industry to change. Most often this resistance was discursive, employing strategies that included sowing doubts about the necessity or effectiveness of a change, exaggerating its costs – either directly or in terms of international economic competition – and conveying that incremental solutions are being worked on and there is no need for further regulatory actions. In some cases, lobbying associations also threatened legal recourses, which they acted on in some instances, thus delaying or preventing unwanted legislation. In this section, we therefore began by examining the reactions of the traditional incumbent meat industry towards innovative meat alternatives[25].

Beginning in the mid-2000s, plant-based meat alternatives began to have some success in agenda-setting at a broader socio-political level in Germany, for example when the German government acknowledged the role of agriculture and more specifically livestock farming in generating significant CO_2-emissions (Deutscher Bundestag 2007). As public attention to the issue rose, so did resistance to change from the traditional meat sector. In 2009, the German farmers' association (DBV), one of the most powerful lobbying associations in German agricultural debates, declared its vested interest in stringent climate protection policies as a directly impacted stakeholder. In the same publication, however, it argued that foregoing certain food products (i.e. meat) "is not very effective in terms of climate protection" and that consumers should instead choose regional and seasonal products.[26] Cattle farming is framed by the DBV as making a valuable contribution to landscape management and nature conservation, while converting otherwise unusable grass into protein (DBV 2009). In a 2013 press release, the DBV declared meat to be a part of a "wholesome and healthy diet" that should be consumable without a guilty conscience (DBV 2013). This framing is further upheld by TV commercials for meat products from the early 2000s, in which they are presented as necessary for strength, health and fitness and associated with traditional masculinity (Trummer 2014).

Research on and discussion of climate change have strongly increased in the 21st century, including a specific focus on the role of meat consumption (Engelhardt et al. 2020; Haack et al. 2020; Schrode et al. 2019; Wunder 2019), as well as state-funded R&D projects for the advancement of plant- and insect-based meat alternatives (chapter 3.5). Additionally, the German government appointed a large multi-stakeholder commission (Zukunftskommission Landwirtschaft) in 2019 to develop recommendations for a sustainability transformation of the agricultural system. The unilateral report was seen as surprisingly progressive and included recommendations for a primarily "plant-oriented" diet and a reduction in the consumption of animal products (ZKL 2021, p. 61). At the same time, the European Commission published its Farm to Fork Strategy in the context of the Green Deal, which likewise aims to develop a sustainable food system (European Commission 2020).

[25] This chapter includes excerpts from two manuscripts, one of which has been submitted to the journal GAIA. The second manuscript is currently in preparation for journal submission (more information in chapter 8.

[26] own translation

Against this background, the struggle for discourse leadership has intensified in recent years. The arguments from the niche for a vegetarian or vegan diet have become increasingly diversified over time, including combatting climate change (Heinrich-Böll-Stiftung et al. 2021) and other ecological issues, such as land use, eutrophication and water consumption (Haack et al. 2020), health benefits (Jetzke et al. 2019), animal welfare, and the security of the world's food supply for a growing population (forsa 2021). Taken together, these factors resulted in the development of the EAT-*Lancet* Commission Planetary Health Diet (Willett et al. 2019). Overall, this has led to an increased amount of resonance in the general population: Surveys show that by 2021, 10% of Germans followed a vegetarian and 2% a vegan diet (forsa 2021). In 2019, customers already had 60 different brands from 52 companies to choose from for meat alternative products (Jetzke et al. 2019, p. 27). Some of the major players producing meat alternatives are early mover incumbents originally from the traditional meat sector, such as Rügenwalder Mühle, whose turnover with plant-based meat alternatives exceeded classical meat products in 2020, and the PHW-Gruppe, a partner of Beyond Meat (Heinrich-Böll-Stiftung et al. 2021). Discounters like Lidl and Aldi as well as food-giants such as Tyson (Raised & Rooted) and Nestlé (Garden Gourmet) have launched their own vegetarian/vegan brands (Heinrich-Böll-Stiftung et al. 2021; Scherbaum 2020). This is an early indicator that some parts of the regime are positioning themselves for an upcoming transformation of the sector.

Other incumbents instead respond to these developments with an increase in resistance. The narratives from the traditional meat industry have evolved over time. At first, it downplayed the problem by denying the contribution of livestock farming to climate change, while in parallel promoting meat through cultural messaging. With the increasing relevance of vegetarianism and other meat alternatives, the narratives became more offensive, more openly attacking meat alternatives. Confronted with a reduction in demand for its own products, the German Butchers' Association (DFV) responded in 2019: "Meat substitutes were again unable to benefit from weakening demand for meat and meat products in 2018. Purchased volumes were close to last year's levels, falling nearly 9 percent short of 2016 purchase volumes." It further argues that no development, such as "time-limited consumption trends like the hype around meat substitute products [... will] cause lasting damage to the [meat] sales market"[27] (DFV 2019, p. 87). The same document, however, also acknowledges that meat consumption is expected to decrease in the coming years due to an increasing consumer awareness regarding health, animal welfare and environmental concerns.

With steadily rising pressure on its incumbent status, the traditional meat industry launched multiple regulatory attempts to forbid marketing of meat substitutes with meat-related food terminology, both in Germany and at EU level, which have so far failed to achieve this desired result (DBV 2020; DFV 2016; FAZ 2020; Thümler 2016). In 2017, the EU Court of Justice ruled that "purely plant-based products cannot, in principle, be marketed with designations such as 'milk', 'cream', 'butter', 'cheese' or 'yoghurt', which are reserved by EU law for animal products" (EU Court of Justice 2017, p. 1). However, the situation is more ambiguous for meat alternatives: The German food code was changed in 2018 to prohibit the use of designations of special grown meat cuts (e.g. 'filet' or 'steak') as well as specific sliced meats like 'schnitzel' or 'beef tenderloin' for meatless products. However, these terms may be used if meatless products are sufficiently similar to the animal product in their sensory characteristics and are explicitly labelled as vegetarian or vegan, e.g. 'vegan seitan goulash (Deutsche Lebensmittelbuch-Kommission 2018). This ruling was met with criticism by consumer and vegetarian/vegan associations, who argued that it is so complicated and unclear that it surpasses consumers' understanding. A revision process was started in 2020, which finally reached consensus on a draft version in early 2023 and is now subject to public consultation (Deutsche Lebensmittelbuch-Kommission 2023).

[27] own translation

Outside the court room, the German Farmers' Association (DBV) publicly supported the EU-wide image and marketing campaign "Ceci n'est pas un steak" to lobby against the use of traditional meat-related designations for vegetarian or vegan alternatives (DBV 2020).

How much the public discourse has changed in just one or two decades is illustrated by two particular examples: a national ex-soccer-star published an opinion piece in the conservative German magazine *Focus* in 2021 titled "Real men eat plants" (Hildebrand 2021), while a politician of the conservative CDU party argued in 2019 that "cheap meat is immoral" and that the preservation of God's creation concerns us all (Gerig 2019).

As can be surmised from the summary above, the resistance of the traditional meat and livestock farming sector to meat alternatives is not as unified and as clear-cut as it was with regard to earlier changes in animal husbandry. Like in other traditional sectors, some incumbents in the meat sector have realized by now that climate and other ecological changes will force their industry to make adjustments in the future and have begun to invest at least some amount into building up alternative structures. This is especially the case for the pioneer Rügenwalder Mühle, but also for the four largest meat industry companies (Tönnies, Vion Food Germany, Westfleisch and PHW-Group) and actors in the meat processing sector, who are most likely to be able to incorporate plant-based meat alternatives into their operations. Livestock farmers and slaughterhouses, on the other hand, are more likely to show significant resistance to change, as their businesses cannot simply be converted to work with plant-based alternatives. These are the actors who are most likely to be "losers" in the transformation process, as there are to date few future-proof ideas for business models available to them. Alternatives that are being discussed (e.g. activities by the foundation "Respect Farms") are too often still vague or not considered to be economically viable.

So far, descriptions of incumbent reactions and resistance have mostly been qualitative. We therefore developed a quantitative survey approach for measuring incumbents' degree and types of resistance in exnovation processes. These were then correlated to incumbents' affectedness, i.e. degree of personal relevance and emotional attitude associated with each innovation.[28] The survey was conducted between February and April 2022 using a scenario technique approach that presented respondents with five different scenarios, made up of three innovation scenarios (insect-based meat alternatives, plant-based meat alternatives and cultivated meat) and two baseline scenarios (organic livestock farming and conventional livestock farming) in randomized order. Three response categories were formed for the assessment of the scenarios: Assessment of the relevance of the scenario (relevance), emotional attitude, and resistance and type of resistance. The general critical attitude (resistance) was surveyed with the item "I am critical of this scenario" (see Table 9). The types of resistance (instrumental, discursive, material, legal) were formed as response categories in accordance with the descriptions by Geels (2014) and Heyen (2016). The two items on emotional attitude were taken from a questionnaire on openness to change (Barghorn 2011). The items of the relevance scale were newly formed.

[28] Details of the methodology and discussion of the results have been documented in the manuscript "How does resistance arise in exnovation? Measuring personal relevance, emotional attitude and resistance using the example of the German meat industry", submitted for publication (see also chapter 8.3).

Table 9: Overview of the scale and items used in the survey to measure incumbents' resistance to meat alternatives

Relevance	Emotional attitude	Resistance and type of resistance
This scenario is relevant to my workplace or organization	I am enthusiastic about this scenario	I am critical of this scenario (*general critical attitude)*
I think this scenario has great potential for consumers and there is demand for it	This scenario worries me	The conventional agricultural and meat industry is independent of this scenario based on its own resources and market. It can pursue its strategies independently (*instrumental)*
I think that this scenario has great potential for the development of agriculture and the meat industry in Germany		This scenario does not play a role in the current discussion within agriculture and the meat industry or on their markets, because there are more important issues (*discursive)*
I think that this scenario is necessary from a political point of view		This scenario does not play a role in the current discussion within agriculture and the meat industry or on their markets, because other technical or material options are being pursued to prepare the sector for the future (*material)*
I think that it is highly likely that this scenario could occur		Current laws and standards do not permit the implementation of such a scenario (*legal/institutional)*

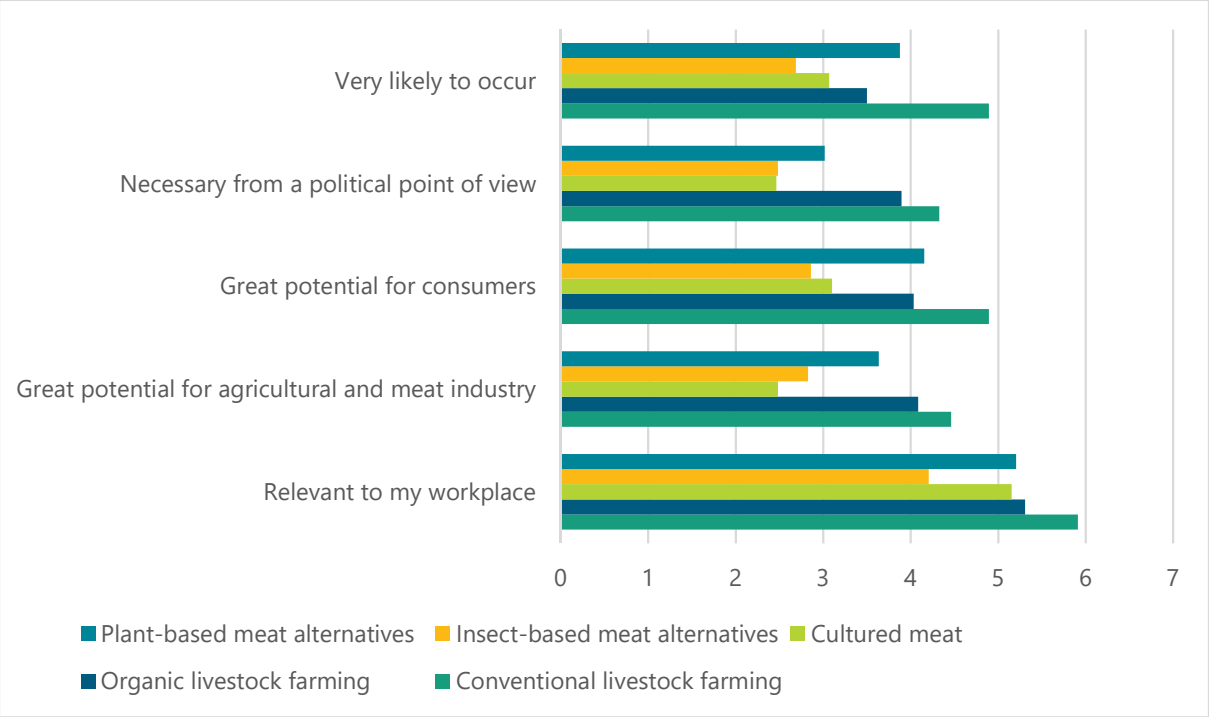
Source: Fraunhofer ISI

To recruit participants, a total of 94 representatives from 13 industry associations, 8 chambers of agriculture, 25 subdivisions of the network "Fokus Tierwohl" ("Focus Animal Welfare"), and 23 companies from the meat production, food retail, and system catering sectors in Germany were contacted by e-mail. Representatives of associations, chambers of agriculture and the Fokus Tierwohl network were asked to invite their members to participate in the survey by e-mail; company representatives were asked directly to participate. A total of 8 associations, two chambers of agriculture, the Fokus Tierwohl network and one company each from the meat production and food retail sectors agreed to participate. 58 people completed the questionnaire in full (N = 58).

The results confirmed that there are different types of resistance in the context of exnovation in the traditional meat sector. Instrumental resistance scored the highest, while legal resistance strategies scored the lowest, averaged across all scenarios. With regard to the individual scenarios, insect-based meat alternatives generated the highest degree of resistance, followed by cultivated meat. The resistance to plant-based meat alternatives as well as conventional livestock farming was the lowest. In terms of predictors for resistance, our results showed that the assessment of relevance (Figure 3) has a significant influence on resistance in the insect-based and cultivated meat scenarios. Emotional attitudes, on the other hand, had no measurable predictive influence on resistance in our study. Possible explanations for this somewhat surprising finding include methodological issues or the fact that we did not examine consumer acceptance of certain types of food, but instead presented members of the meat supply chain with differing future scenarios of the market for proteins. This more business-oriented approach may explain why emotional attitudes played less of a role in our study.

Figure 3: Estimated relevance of each scenario

Note: n = 58, mean values



Source: Fraunhofer ISI

Given the strong resistance of the traditional meat industry to prior transitions, as well as its strong political lobby, our hypothesis at the beginning of the project was that interactions between emerging meat alternative niches and incumbent actors from the livestock and meat regime would be dominated by resistance strategies. Our analysis showed, however, that while resistance exists – especially to the more novel innovations of insect-based meat alternatives and cultivated meat – it is less pronounced than we had anticipated. Moreover, the livestock and meat sector does not act as a uniform player in relation to meat alternatives. Rather, differentiations must be made between different actor groups and actors: there are early-mover incumbents, who have to some degree begun to get involved in the production of meat alternatives, while still retaining their focus on traditional meat products. There are also actors who see a transformation to meat alternatives as an opportunity, such as artisanal butchers, who seek to extend their craft to meat alternatives and view this as a unique selling point for their business (Deutscher Fleischer-Verband e.V. 2022). But there are also, as expected, those actors who do not see a viable future for themselves within a transformed system and therefore fight any and all changes for as long as possible.

Interactions of the livestock and meat sector with the PBMA innovation system

As outlined above, a significant share of incumbent livestock and meat sector players see (plant-based) meat alternatives as one means to respond - at least in part - to the multitude of landscape pressures they face.

By engaging at least in PBMA, they can position themselves as actively striving for reducing their environmental footprint. The threshold to engage in PBMA is rather low, as the largest required change is the exchange of the raw material meat by plant protein and the respective suppliers. Moreover, adaptation of recipes is required, but established production process lines and equipment as well as process knowhow can be used for manufacturing PBMA. The PBMA products can then be distributed via established logistics and existing B2B relationships with retail. From the MA

TIS perspective, making use of this existing incumbents' system is an essential requirement for a rapid upscaling of meat alternatives production and gaining larger market shares. This is a symbiotic interaction, a win-win situation for both the PBMA niche as well as the part of the regime which is involved in meat processing and can be considered as "harvesting the low-hanging fruits" in the meat alternative field. Presently, it is not known to which extent the expected increasing commercial success of PBMA will pose a challenge to the dominant business model of the livestock and meat sector as a whole, or whether expected decreases in domestic meat and meat product consumption (due to increased PBMA consumption) would be compensated by increased meat exports. Should the dominant business model be challenged, potential losers would be livestock production and slaughtering incumbents for whom hardly any positive perspective has been developed for this scenario up to now.

The analysis of the PBMA innovation system showed that incumbents' production infrastructure is a necessary, but not sufficient prerequisite to increasing market volumes and shares of PBMAs in the nearer future. Rather, in addition, substantial innovation is required in raw material optimization, production processes and products regarding taste, texture, nutritional quality, and price. Activities are ongoing to address these challenges by making use of fermentation and precision fermentation, and by creating hybrid products of PBMA and CM (chapters 3, 4).

Interactions of the livestock and meat sector with the CM innovation system

Several incumbent actors of the livestock and meat sector actively engage in CM and are thus already involved in the cellular agriculture community and related developments. Incumbents who choose to focus on conventional PBMA might lose their interest in MA, should their conventional PBMA be outcompeted in the market by improved hybrid MA products in the future.

However, it is uncertain whether cellular agriculture will succeed in delivering superior meat alternatives or cultivated meat at large scale. It is also possible that other types of innovative food products from alternative proteins (e.g. dairy, fish) will become the focus of cellular agriculture. The latter may not necessarily be in the strategic interest and business model of livestock and meat industry players. Against this background, it remains to be seen to which extent more incumbents of the livestock and meat sector will engage actively in this nascent development and shape and develop it further.

Should CM become commercially successful and deliver significant amounts of cultivated meat in the future, this bears the distant potential to become a disruptive innovation for the dominant business model of the livestock and meat sector. The prevailing mainstream vision for the cultivated meat industry are large, industrial-scale, centralized production facilities. This vision does not provide positive perspectives for livestock farmers and slaughterhouses who would be clear losers. Against this background, the foundation Respect Farms[29], operating in the Netherlands, Germany, Switzerland and Belgium, aims to establish a farm-based, decentralized CM production facility and test the feasibility and viability of this non-mainstream concept in a living lab experiment. If successful, the foundation sees the option of a farm-based CM production facility as an additional, not alternative option to the model of central large-scale production facilities. Among the (few) supporters of Respect Farms, the German PBMA-pioneering company Rügenwalder Mühle is the only company from the livestock and meat sector. The Dutch CM companies MosaMeat and Meatable also support the foundation.

[29] https://www.respectfarms.com/

Interaction of the livestock and meat sector with the IBMA innovation system

Only little information could be gathered in this project with respect to the interaction of the livestock and meat sector with the innovation system that focusses on insect-based meat alternatives.

On the one hand, only few actors actually develop and promote insect-based meat alternatives, e.g. in the form of burgers. Rather, in the human nutrition field, the current focus is on insect protein as an ingredient in various staple foods (e.g. bread, pasta, crackers) or as personalized nutrition for consumer groups such as athletes, favoring high-protein food in the form of candy bars, shakes, and snacks. These product groups are, however, outside the core business of companies from the livestock and meat sector.

Around 2019/2020, entrepreneurial experimentation brought insect-based burger patties to end-consumers. They were offered by the restaurant chain Hans im Glück as "Übermorgen-Burger" and on sale by various supermarkets, such as Tegut. Due to a lack of consumer demand, difficulties to supply permanently sufficient amounts of insect protein, and a lack of advantages of insect proteins compared to plant proteins, these experiments have ended (Schattauer 2023). Bugs International GmbH, one of the few German companies which produced food insects, has lost interest in the food market, due to lack of demand[30]. Currently, there are no indications that this situation would change soon, although six Novel Food products with insect proteins as food or food ingredient have been granted market authorization by the European Commission.

To our knowledge, the German PHW group in 2018 made an undisclosed strategic investment in Bugfoundation[31], the start-up company which provided the insect burger to Hans im Glück. In 9/2021, Bugfoundation was acquired by the meat company Kupfer Innovative Food GmbH & Co. KG, Heilsbronn. No more detailed information is available. Processing equipment and solutions providers to the food industry in general and also the meat industry, such as the GEA group, offer their knowhow and services to customers in the alternative protein business, among them also insect producers/processors.

Although the use of farmed insects as animal feed was not the focus of this project, this option is much more attractive for players in the livestock and meat sector than using insect proteins for food and especially meat alternatives. This is reflected by private investments of more than 1 bn € into insects as feed, compared to appr. 0.5 bn € into insects for food. Processed animal protein from farmed insects bears the potential to replace to a certain extent protein-rich feed ingredients that negatively impact climate, land use and biodiversity, such as soybean and fishmeal. If the insects are grown on organic residual streams (e.g. agrofood byproducts, food losses, waste), replacing fishmeal or soybean could contribute to more sustainable and circular livestock production, and may have additional beneficial effects on livestock health (Parodi et al. 2022; van Huis et al. 2023). In the EU, processed animal proteins derived from insects may be added to aquaculture feed since 2017, and to poultry and pig feed since 2021. Using insect proteins as feed ingredient is a strategy for feed and livestock producers to reduce the environmental footprint per unit meat produced and thus reacting to landscape pressure to make their business less unsustainable. However, this strategy aims at stabilizing or even expanding the existing livestock and meat sector and the practices of mass livestock production, and does not contribute to a transition to less meat consumption and more plant-based diets. From this perspective, it may also be classified as a material resistance strategy which aims at an incremental improvement of the environmental footprint of livestock production with the potential to delay more radical changes.

[30] https://www.bugs-international.com/index.html

[31] https://www.just-food.com/news/germanys-phw-gruppe-makes-investment-in-insect-burger-start-up-bugfoundation/; September 27, 2018

7 Conclusions, options for action and recommendations

Recommendation for sustainability transition research

This study focused on innovation systems for selected meat alternatives in Germany. Despite this comparably narrow focus of the project, the topic proved to be a very fruitful, yet under-researched study object for transition research. One the one hand, more research is needed due to the high need and urgency for sustainability transitions in the agro-food sector. On the other hand, the topic is cutting across many policy fields, ranging from agro-food, nutrition, environment to innovation and economic affairs. A deeper understanding of the innovation systems, their dynamics and interactions would provide a sound knowledge base for improving the functioning of the innovation systems and designing appropriate policy mixes. We therefore recommend to pursue studies on this topic further. Additional opportunities also arise for other animal-derived product groups than meat. We therefore suggest to also broaden the scope beyond meat alternatives to alternative proteins, to widen the geographical scope and analyze the dynamic development over time. In addition to the innovation systems approach chosen in this project, other well-established frameworks, closely related to socio-technical transitions, could be applied fruitfully in future studies, such as Multi Level Perspective, Strategic Niche Management, Transitions Management and Governance, Systems Theory, Social Network Analysis, or Social Practices Approach.

Recommendation for a comprehensive strategy for alternative proteins

In the past, innovation system building for meat alternatives was to a large extent driven by actors in the private sector. They were successful in moving the field quickly from a precompetitive to a competitive status and commercialize first products. This bears, however, the risk that building the innovation systems is biased towards company interests and commercialization whereas policy goals beyond the interests and resources of companies may not be exploited sufficiently. Examples for such goals are high nutritional quality and a minimized environmental footprint of meat alternatives, integration of meat alternatives into food environments which foster sustainable eating habits, and reducing the extent of livestock farming. Up to now, the level of activities of guidance of the search and of creation of legitimacy within and by policy has, however, been low. We see this as a weakness of the meat alternative innovation systems. Therefore, policy should improve these functions to provide direction for the development of the innovation systems. In the following paragraphs, we provide options how this could be achieved.

In the short term, there is a need to agree on the role of meat alternatives within nutrition policy. The German Federal Government's Food and Nutrition Strategy is in the process of being finalized by the end of 2023. The concept paper (BMEL 2022) highlights the goal of a reduced meat consumption and favors a plant-based diet, but seems to disfavor meat alternatives. But meat alternatives offer the potential of a low threshold entry and thus first step into reduced meat consumption, without requiring fundamental (and unrealistic) changes in dietary habits and cultural values underlying meat consumption. Under appropriate frame conditions, they bear the potential to provide a bridge towards reduced meat consumption and plant-based diets. We therefore recommend to take meat alternatives into consideration as an additional option within activities and appropriate food environments to incentivize and nudge citizens towards meat-reduced and more plant-based diets.

The development of meat alternatives and their innovation systems is not only related to nutrition policy and the national nutrition strategy. Together with alternative proteins, they also bear the potential within a protein transition to provide solutions to challenges in agricultural, environmental, climate protection, bioeconomy and innovation policy. However, these potentials can only be

recognized and exploited if alternative proteins or meat alternatives are not treated as a minor issue in each of these policy fields and related strategies. Rather, their cross-cutting character requires an own holistic policy approach which covers all relevant policy fields and aspects.

We therefore recommend to start a process to develop a comprehensive strategy for alternative proteins. This process should be supported at the highest political level, and could perhaps result in a mission within the sustainability transition of the agro-food sector. In this process, specific and measureable short-, mid- and long-term goals with a clear timeline and coordinated and coherent measures to achieve them should be elaborated. The process should lead to binding commitments in the end, and include all relevant stakeholders.

On the one hand, this process should develop goals and support measures how to foster the development of meat alternatives or alternative proteins respectively towards reduced meat consumption, plant-based diets and a lower environmental footprint. It should also take into account intended and unintended, synergistic and inhibitory interactions, spillovers, and feedback loops between the meat alternative innovation systems. On the other hand, frame conditions for livestock and meat production and the shaping of exnovation for conventional livestock farming and meat consumption have to be addressed at the same time. Both strands have to be closely aligned and coordinated to be effective and to avoid conflicting or contradictory incentives (e.g. as in the case of insects as livestock feed).

In the following section, recommendations are given how to overcome current weaknesses in the innovation system for meat alternatives with the goal to foster their development. Recommendations regarding exnovation are given afterwards.

Recommendations to foster the development of meat alternatives and alternative proteins

Integration of the agricultural sector

For the three innovation systems we have studied, we recommend to develop positive visions and additional business opportunities for farmers and to strengthen the integration of agricultural actors into (regional) supply chains. The prevailing mainstream vision both for the insect as well as cultivated meat industry are large, industrial-scale, centralized production facilities, neglecting positive perspectives for farmers. Efforts need to be made to meet their concerns and fears about loss of production and even more new regulations in a sustainability transition.

For plant-based meat alternatives, opportunities lie in regional sourcing of pure plant varieties, such as legumes. Their use (instead of processing imported protein crops) would support the development of PBMA with improved taste, nutritional quality and environmental footprint. This could be integrated into ongoing activities of the legume network LeguNet[32], funded in the context of the BMEL protein crop strategy. These activities aim at integrating legumes into crop rotations, increasing domestic production, supporting farmers in growing legumes and in the establishment of producer groups and value chains. However, a bottleneck is the agricultural infrastructure which is tailored to handling high volumes of major crops. For also handling niche and specialty crops such as lentils, chickpeas or food soybeans, additional silos for smaller harvest volumes at collection sites and agricultural trade companies and more processing facilities close to producers would be required.

Farm-based production modules for rearing insects as feed from agricultural waste streams have been developed. However, their economic viability and integration into value and supply chains still

[32] https://www.legunet.de/

remains to be achieved. Moreover, it depends on the overall balancing of conflicting policy goals (reducing the environmental footprint of livestock farming by circularity and valorizing agricultural waste streams by insects vs. reducing livestock farming and meat production) to which extent, for which purposes and in which regions insect production makes sense. Regarding cultivated meat, positive perspectives for livestock farmers and slaughterhouses need to be developed for a just transition within an exnovation strategy for the livestock and meat sector. One option is the approach of the foundation Respect Farms[33] which tests the feasibility and viability of a farm-based, decentralized CM production facility.

Publicly funded R&D

Our analysis of the innovation systems functions knowledge generation and diffusion showed that public funding of meat alternatives has up to now been modest in Germany. It is based on funding of individual projects, which are neither coordinated in larger programs nor follow a coherent strategy how to develop the sector. Defining such an R&D strategy and action plan would therefore be an important part of the policy process recommended above. Addressing R&D priorities specific for cultivated meat and plant- or insect-based meat alternatives should be embedded into the following, more general and cross-cutting considerations:

Publicly funded research on meat alternatives, or alternative proteins in general, should be complementary to R&D efforts undertaken by the private sector. It should therefore contribute to achieve longer-term goals. Therefore, the knowledge base should be strengthened and the technology base be broadened by application-oriented basic research. It could e.g. address the relationship between starting material properties and final product quality, and innovative or new combinations of technological options to improve starting materials, processes and product quality, including the convergence with (precision) fermentation. Options to support scale-up to pilot, demonstration and industrial scale should also be considered.

As a prerequisite to achieve health and environmental goals, publicly funded research should support the development of science- and evidence-based concepts for quality-, nutrition- and environmental standards or regulations that alternative protein products and processes should fulfill and comply with. It should also complement the knowledge base on which authorities responsible for market approval rely in their assessments by research from industry/applicant-independent actors. It is expected that the next generation of meat and alternative protein products will be hybrids which no longer fall neatly into the categories of e.g. plant-based, fermented or cultivated products, or meat, dairy etc. As this development will challenge existing regulations and standards, research should proactively address this aspect and foster early and open exchange between R&D, industry, and regulatory authorities.

Publicly funded research should also develop concepts for integrating alternative proteins into food environments, test them in living labs and assess their outcomes and impacts on the intended transition to reduced meat consumption and more sustainable diets.

Market formation, regulations and standards

Although first products of meat alternatives have reached the food market, they still are a small niche. The intended impacts of meat alternatives can only be achieved if this niche grows significantly. This requires the establishment and/or scale-up of production facilities and the development of new product generations which meet consumers' expectations regarding price and taste, followed by healthiness, sustainability and animal welfare. It should be decided in the policy process

[33] https://www.respectfarms.com/

recommended above to which extent this is to be accomplished by entrepreneurs investing into the required production infrastructure and providing improved products, and to which extent it should also be supported by policy. In addition to R&D support outlined above, we recommend to consider establishing a level playing field between meat and meat alternatives with respect to value added tax, procurement of meat alternatives e.g. in communal catering and shaping appropriate food environments, and financial instruments to support infrastructure investments.

Market development also depends on the extent to which current regulations stimulate or hinder the implementation of meat alternatives. Up to now, plant-based meat alternatives and insect protein-based pet food conform to a large extent with current regulations, do not need a market approval and therefore these market niches were the first to develop. Insect-based processed feed proteins for aquaculture, poultry and pigs are expected to follow since EU legislation authorized their use in 2017 and 2021, respectively. For cultivated meat, market authorization according to the Novel Food regulation is required. The European authority responsible for safety assessment, EFSA, has started an intensive exchange with international regulatory authorities as well as dialogues with companies which intend to file an application. However, guidance for industrial applicants still has to be developed. To do this, there is a high need for independently generated scientific evidence for the safety assessment. These data could complement the information which is provided by industrial applicants in their dossiers, and provide the basis for a scientifically sound assessment procedure.

In addition, several standards should be adapted to generate a positive environment for meat alternatives to develop and give directions towards strengthening their sustainability profile: Among these standards are labelling requirements, currently under development by the Deutsche Lebensmittelbuch-Kommission, as well as defining nutritional standards for meat alternative products and recommendations for their integration into well-balanced, sustainable diets, and environmental standards to be met by meat alternatives and their production processes. Additional challenges for existing regulation and standards may arise from emerging hybrid products.

We therefore recommend to address these issues in a timely manner on platforms for a permanent exchange between R&D, companies, regulatory authorities, and organizations involved in standard development.

Recommendations regarding exnovation in the livestock and meat sector

Unlike other exnovation processes like in the German coal industry, the goal is not to phase-out livestock farming and meat consumption completely. Rather, it will have to be reduced to a certain level. Defining this level and how to reach it requires a societal process of negotiation and consensus-building. Relevant questions that need to be answered in this process include:

- What is the goal of this partial exnovation and which indicators will be used to measure its success?
    - Possible indicators include: the reduction of climate and environmental footprints to a specific level; the reduction of per capita meat consumption or total production; achievement of a certain level of animal rights.
- If livestock farming continues, but with clear limits: what process is used to decide which farmers are allowed to continue and at what scale, with which animals? This requires negotiations about different understandings of just transitions.

Transformation and re-orientation of livestock farming and meat processing to more sustainable practices require large investments from farmers and the industry. This in turn requires long-term planning capabilities that are assured through mid- and long-term reliability in policy orientation, i.e. long-term political commitment to a specific transformation mission. It is therefore crucial to

design a mid- and long-term package of policy instruments that incentivize and support progress towards the established goals. Options that could be taken into consideration comprise:

- Review and adjustment of current regulations, norms and standards to reduce/eliminate incentives for unsustainable practices (instead incentivizing transition to sustainability); regulatory bans where necessary,
- Economic steering instruments on supply and demand side, e.g. internalization of environmental costs of livestock farming; elimination of the reduction of value-added tax from 19% to 7% for meat and meat products,
- compensatory payments for incumbent businesses that are conditionally linked to reinvestments into sustainable business models,
- (Infra)structural support packages for regions that are heavily affected, including support to build up future-oriented, sustainable industries,
- early retirement options for those near retirement age without significant financial disadvantages,
- Trainings and continued education to support reorientation.

For this transformation to be successful, both on the supply and the demand side, the agreed-upon goals must be based on a discourse involving society as a whole, which has yet to be conducted. A more open, more active and more public exchange about exnovation in the meat sector is needed. Relevant stakeholders for this process are not just those employed or invested in the traditional meat industry, but also all citizens who consume meat with any regularity. Because of the embeddedness of meat in culture, society at large has to be incorporated into the exnovation process in order for it to succeed.

8 Additional information

8.1 Use of project resources

Project resources were mainly personnel costs, required to carry out information searches, expert interviews, survey, analysis of information and data, pursue a dissertation project and writing of publication manuscripts. Due to pandemic travel restrictions, physical participation in events, conferences and interviews were replaced by online video conferences, thus reducing travel and workshop costs substantially, compared to the originally planned resources. The project work carried out was necessary and appropriate to achieve the project results.

8.2 Planned and potential exploitation of the project results

The project results provide the knowledge base at ISI to pursue the topic of meat alternatives and alternative proteins further. The gained insights into the innovation system of meat alternatives and alternative proteins will be further elaborated in case studies in ongoing projects, especially

- contributions to impact assessment of a protein transition within a case study in the project "Systemisches Monitoring und Modellierung der Bioökonomie (SYMOBIO)"[34], funded by BMBF within the concept of "Bioeconomy as Societal Change". The case study takes insights of the TRADINNOATION project as starting point, but extends them to a forward looking perspective regarding potential impact.
- to investigate meat-reduced or plant-based diets in the context of lifestyle changes towards sufficiency and ways how to foster them in the EU-funded project "Fundamental decarbonization through sufficiency by lifestyle changes (FULFILL)"[35]

Moreover, efforts are ongoing to acquire new thematically related projects on the subject of meat alternatives and alternative proteins, exploiting the gained better understanding of actor roles and activities in transition processes, of the increased expertise regarding the role of exnovation in transition processes, and of interaction of innovation systems or niches. Furthermore, the increased conceptual expertise on transitions processes can also be applied to other sectors that ISI works on, such as the fast fashion and electronics industries. The foundational background on exnovation processes gained during the TRADINNOVATION project has also been put to use in other projects, such as the project “Monitoring Social-Ecological Transformation”, funded by the Hans-Böckler-Stiftung.

Some of the work conducted in this project will contribute to a cumulative dissertation at the Georg-August University of Göttingen.

The project results may be of interest to ministries (especially BMBF, BMEL, BMWK and BMUV), policy makers and funding agencies as information basis for strategic decisions regarding bioeconomy, sustainability transitions in the agro-food sector, and nutritional policies. Potential uses may lie the setting-up of R&D funding programs on alternative proteins, or the finalization of the National Nutrition Strategy (BMEL 2022), to be published by the end of 2023.

Actors in the meat alternative innovation systems whom we contacted in the context of this project showed a high interest in the project results in order to compare our innovation system perspective with their own assessment of the field of meat alternatives and alternative proteins. They may use project results for own activities to contribute to an improvement of the innovation system.

[34] https://symobio.de/

[35] http://www.fulfill-sufficiency.eu/

Scholars from the sustainability transitions community can build on our results when studying meat alternatives or alternative proteins within agro-food transitions. This research object lends itself to be studied by different frameworks established in sustainability transition research, such as Multi Level Perspective, Strategic Niche Management, Transitions Management and Governance, Systems Theory, Social Network Analysis, Social Practices Approach.

8.3 Progress by third parties in the field of the project

Relevant results from other researchers, made available during the project period, were integrated in our project work. After completion of this project, in May 2023, the Good Food Institute has published a report on the status of plant-based meat alternatives and cultivated meat in Germany (Good Food Institute Europe 2023). This report is largely in line with the results and conclusions of this project.

Moreover, the meat alternative and alternative protein field increasingly attracts attention by scholars from the sustainability transitions community. Examples of publications after the completion of this project are Amato et al. (2023); Fesenfeld et al. (2023); Dueñas-Ocampo et al. (2023); Bulah et al. (2023b); Bulah et al. (2023a). These publications support our assessment that the meat alternative and alternative protein field is a scientifically rewarding research object for analyzing it in more detail.

8.4 Planned publications

Submitted (WP2, context of ongoing PhD work):

Schwarz, A.; Fischer, P.; Weinrich, R. "Was that it? Exploring the transitional purpose of companies on the German market for plant-based meat alternatives", submitted to Sustainable Futures.

Abstract: The paper explores the transitional purpose of leading companies in the field of plant-based meat alternatives to contribute to the discussion about a market-driven transition. Our main findings are that (i) businesses chiefly aim to change meat consumption without challenging meat's iconic status, (ii) the economic regime tends to lock them into meat-centered product designs, and that (iii) company activity nonetheless could prove a springboard for smart politics to facilitate a true protein transition.

Submitted (WP 6):

Bodenheimer, M.; Niessen, P.; Hüsing, B. „How does resistance arise in exnovation? Measuring personal relevance, emotional attitude and resistance using the example of the German meat industry" submitted to GAIA, currently under review.

Abstract: Incumbent actors often develop strategies of resistance in exnovation processes. These resistance strategies exist at multiple levels, with the individual level often being a causal one. The reasons for individual resistance are manifold and also vary greatly with respect to the context under consideration. One particular challenge to understanding resistance in the context of exnovation is that so far no methodology is available for measuring resistance quantitatively. This paper therefore presents a quantitative survey approach for measuring the degree and types of resistance relevant to exnovation from incumbent actors and correlates these to incumbents' affectedness (degree of personal relevance and emotional attitude associated with each innovation). Knowing the impact of affectedness on incumbents' degree and type of resistance can help guide practitioners in designing appropriate exnovation strategies that more effectively address incumbents' concerns. The methodology is illustrated using a survey among incumbents from the traditional German meat industry.

In preparation:

Bodenheimer, M.; Dütschke, E.; “Lost in transition? Disentangling agency, activities and actor roles”, including an exemplary case study on actor roles and activities in the sustainability transition of the traditional meat sector in Germany

9 Cited literature

Aiking, H.; Boer, J. de (2018 // 2020): The next protein transition. In: Trends in Food Science & Technology, 105, pp. 515–522. https://doi.org/10.1016/j.tifs.2018.07.008.

Amato, M.; Riverso, R.; Palmieri, R.; Verneau, F.; La Barbera, F. (2023): Stakeholder Beliefs about Alternative Proteins: A Systematic Review. In: Nutrients, 15 (4). https://doi.org/10.3390/nu15040837.

Antes, R.; Eisenack, K.; Fichter, K. (2012): Wirtschaftswissenschaftliche Ansätze zur Gestaltung von Wandlungsprozessen. In: Ökologisches Wirtschaften - Fachzeitschrift, 27 (3), p. 35. https://doi.org/10.14512/oew.v26i3.1221.

Arnold, A.; David, M.; Hanke, G.; Sonnberger, M. (2015): Innovation-Exnovation. Über Prozesse des Abschaffens und Erneuerns in der Nachhaltigkeitstransformation. Metropolis-Verlag.

Barghorn, K. (2011): Einstellungen und Verhalten von Mitarbeitern in betrieblichen Veränderungsprozessen, Universität Osnabrück (Ed.), Osnabrück. Available at https://osnadocs.ub.uni-osnabrueck.de/bitstream/urn:nbn:de:gbv:700-201103088005/2/thesis_barghorn.pdf.

Bergek, A.; Hekkert, M.; Jacobsson, S.; Markard, J.; Sandén, B.; Truffer, B. (2015): Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. In: Environmental Innovation and Societal Transitions, 16, pp. 51–64. https://doi.org/10.1016/j.eist.2015.07.003.

Bergek, A.; Jacobsson, S.; Carlsson, B.; Lindmark, S.; Rickne, A. (2008): Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. In: Research Policy, 37 (3), pp. 407–429. https://doi.org/10.1016/j.respol.2007.12.003.

BMEL (2022): Eckpunktepapier: Weg zur Ernährungsstrategie der Bundesregierung. Bonn, Berlin: Bundesministerium für Ernährung und Landwirtschaft.

Bulah, B. M.; Negro, S. O.; Beumer, K.; Hekkert, M. P. (2023a): Institutional work as a key ingredient of food innovation success: The case of plant-based proteins. In: Environmental Innovation and Societal Transitions, 47, p. 100697. https://doi.org/10.1016/j.eist.2023.100697.

Bulah, B. M.; Tziva, M.; Bidmon, C.; Hekkert, M. P. (2023b): Incumbent entry modes and entry timing in sustainable niches: The plant-based protein transition in the United States, Netherlands, and United Kingdom. In: Environmental Innovation and Societal Transitions, 48, p. 100735. https://doi.org/10.1016/j.eist.2023.100735.

Buschmann, S.; Meyer, E. (2013): Ökonomische Instrumente für eine Senkung des Fleischkonsums in Deutschland. Green Budget Germany. Forum ökologisch-soziale Marktwirtschaft e.V. (FÖS).

Clausen, J.; Fichter, K. (2016): Pfadabhängigkeiten und evolutorische Ökonomik. In: Inputpapier im Rahmen des Projekts Evolution2Green.

Clausen, J.; Mathes, M. (2017): Fleischkonsum: Transformationsfeldanalyse im Rahmen des Projekts Evolution2Green – Transformationspfade zu einer Green Economy. In: Working Paper.

DBV (Ed.) (2009): Land- und Forstwirtschaft tragen zum Klimaschutz wesentlich bei - DBV: Regionale und saisonale Lebensmittel sind erste Wahl fuers Klima.

DBV (Ed.) (2013): Fleisch gehört zu einer vollwertigen Ernährung. "Fleischatlas" des BUND einseitig und dramatisierend. Available at https://www.firmenpresse.de/pressinfo794725/fleisch-gehoert-zu-einer-vollwertigen-ernaehrung.html.

DBV (Ed.) (2020): Veggie-Imitate: Fleisch bleibt Fleisch. Available at https://www.bauernverband.de/fileadmin/user_upload/dbv/pressemitteilungen/2020/KW_30_bis_KW_52/KW_41/2020_-_161_PM_Veggie.pdf.

Destatis (2017): Viehbestand in Betrieben mit konventionellem und ökologischem Landbau. Available at https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Tiere-Tierische-Erzeugung/Tabellen/oekologischer-landbau-viehbestand.html, accessed 21.04.2021.

Deutsche Lebensmittelbuch-Kommission (2018): Leitsätze für vegane und vegetarische Lebensmittel mit Ähnlichkeit zu Lebensmitteln tierischen Ursprungs. Deutsche Lebensmittelbuch-Kommission. Available at https://www.bmel.de/SharedDocs/Downloads/DE/_Ernaehrung/Lebensmittel-Kennzeichnung/LeitsaetzevegetrarischeveganeLebensmittel.pdf?__blob=publicationFile&v=5.

Deutsche Lebensmittelbuch-Kommission (2023): Sachstandsbericht: Temporärer Fachausschuss für "vegane und vegetarische Lebensmittel". Available at https://www.bmel.de/DE/themen/ernaehrung/lebensmittel-kennzeichnung/deutsche-lebensmittelbuch-kommission/fachausschuss-veg-lebensmittel-sachstandsbericht.html, accessed 01.06.2023.

Deutscher Bundestag (2007): Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten Bärbel Hön, Hans-Josef Fell, Cornelia Behm, Ulrike Höfken und der Fraktion BÜNDNIS 90/DIE GRÜNEN. Landwirtschaft und Klimaschutz. Drucksache 16/5346.

Deutscher Fleischer-Verband e.V. (2022): Sonderschau des Fleischerhandwerks 2022. Available at https://www.fleischerhandwerk.de/veranstaltungen/iffa/sonderschauen.html.

DFV (2016): Vegane und vegetarische Produkte: Fleischerhandwerk findet Mitstreiter. Available at https://www.fleischerhandwerk.de/presse/pressemitteilungen/vegane-und-vegetarische-produkte-fleischerhandwerk-findet-mitstreiter.html.

DFV (2019): Jahrbuch 2019. DFV.

DLMBK (2018): Leitsätze für vegane und vegetarische Lebensmittel mit Ähnlichkeit zu Lebensmitteln tierischen Urspru. Neufassung vom 04. Dezember 2018 (BAnz AT 20.12.2018 B1, GMBl 2018 S. 1174). Available at https://www.deutsche-lebensmittelbuch-kommission.de/fileadmin/Dokumente/neufassung_leitsaetze_fuer_vegane_und_vegetarische_lebensmittel.pdf, accessed 02.06.2023.

Dueñas-Ocampo, S.; Eichhorst, W.; Newton, P. (2023): Plant-based and cultivated meat in the United States: A review and research agenda through the lens of socio-technical transitions. In: Journal of Cleaner Production, 405, p. 136999. https://doi.org/10.1016/j.jclepro.2023.136999.

Dütschke, E.; Bögel, P.; Choi, S.-M.; Globisch, J.; Burghard, U. (2019): Soziale Akzeptanz als erweitertes Verständnis des Akzeptanzbegriffs – eine Bestimmung der Akteure für den Prozess der Energiewende. In: Fraune, C.; Knodt, M.; Gölz, S.; Langer, K. (Eds.): Akzeptanz und politische Partizipation in der Energietransformation. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 211–230. https://doi.org/10.1007/978-3-658-24760-7_10.

Engelhardt, H.; Brüdern, M.; Deppe, L. (2020): Nischeninnovationen in Europa zur Transformation des Ernährungssystems - NEuropa. Steckbriefsammlung. Dessau-Roßlau.

EU Court of Justice (Ed.) (2017): Press Release No 63/17. Luxembourg. Available at https://curia.europa.eu/jcms/upload/docs/application/pdf/2017-06/cp170063en.pdf.

Eurogroup for Animals (2023): The future of insect farming: where's the catch? Brussels. Available at https://www.eurogroupforanimals.org/files/eurogroupforanimals/2023-03/The_future_of_insect_farming__where%E2%80%99s_the_catch__final_ver.pdf, accessed 11.06.2023.

European Commission (2020): Farm to Fork Strategy. For a fair, healthy and environmentally-friendly food system, accessed 17.07.2020.

Eyerund, T. (2015): Fleischkonsum in Deutschland und Europa. Ausgwählte Zahlen und Fakten. Köln: Institut der deutschen Wirtschaft Köln. Available at https://www.iwkoeln.de/fileadmin/publikationen/2015/259833/Fleischkonsum_Datenanalyse_IW.pdf.

FAZ. (10/23/2020): Burger bleibt Burger - auch mit Gemüse. In: FAZ.

Fesenfeld, L. P.; Maier, M.; Brazzola, N.; Stolz, N.; Sun, Y.; Kachi, A. (2023): How information, social norms, and experience with novel meat substitutes can create positive political feedback and demand-side policy change. In: Food Policy, 117. https://doi.org/10.1016/j.foodpol.2023.102445.

forsa (2021): Ernährungsreport 2021. Ergebnisse einer repräsentativen Bevölkerungsbefragung. Berlin.

Geels, F. W. (2014): Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. In: Theory, Culture & Society, 31 (5), pp. 21–40. https://doi.org/10.1177/0263276414531627.

Gerig, A. (7/29/2019): "Billiges Fleisch ist unmoralisch". Die Mehrwertsteuer für Fleisch zu erhöhen trifft vor allem die sozial Schwächeren. Besser wäre es, der Handel würde seine Lockvogelmentalität aufgeben. In: Focus, 36, 74.

Good Food Institute (2023): The science of cultivated meat. Available at https://gfi.org/science/the-science-of-cultivated-meat/, accessed 01.06.2023.

Good Food Institute Europe (2023): Alternative Proteine in Deutschland. Report zu aktuellen Entwicklungen rund um nachhaltige Proteinquellen auf Basis von Pflanzen, Zellkultivierung und Fermentation. Forest, Belgium: The Good Food Institute Europe.

Grießhammer, R.; Brohmann, B. (2015): Wie Transformationen und gesellschaftliche Innovationen gelingen können. Hg. v. Umweltbundesamt,

Haack, M.; Engelhardt, H.; Gascoigne, C.; Schrode, A.; Fienitz, M.; Meyer-Ohlendorf, L. (2020): Nischen des Ernährungssystems: Bewertung des Nachhaltigkeits- und Transformationspotenzials innovativer Nischen des Ernährungssystems in Deutschland. Dessau-Roßlau.

Heinrich-Böll-Stiftung; BUND; Le Monde Diplomatique (2021): Fleischatlas 2021. Daten und Fakten über Tiere als Nahrungsmittel. Berlin.

Hermwille, L. (2017): Auf dem Weg zu einer gerechten globalen Energietransformation? Die Gestaltungsmacht der SDGs und des Paris Agreement. Available at

https://epub.wupperinst.org/frontdoor/deliver/index/docId/6669/file/6669_Energietransformation.pdf.

Heyen, D. A. (2016): Exnovation: Herausforderungen und politische Gestaltungsansätze für den Ausstieg aus nicht-nachhaltigen Strukturen. In: Öko-Institut Working Paper, 3, pp. 1–32.

Heyen, D. A.; Hermwille, L.; Wehnert, T. (2017): Out of the Comfort Zone!: Governing the Exnovation of Unsustainable Technologies and Practices. In: GAIA - Ecological Perspectives for Science and Society, 26 (4), pp. 326–331. https://doi.org/10.14512/gaia.26.4.9.

Hildebrand, T. (7/10/2021): Echte Männer essen Pflanzen. Egal, wie emanzipiert wir uns finden: Veganismus, Yoga und achtsames Leben gelten vielen immer noch als hippiesk und feminin. Dabei sind Menschen, die auf Körper und Geist achten, vor allem eines: klug. Ein Gastbeitrag von Timo Hildebrand. In: Focus, 28, 120.

IPIFF (2020): Edible insects on the European market. Available at https://ipiff.org/wp-content/uploads/2020/06/10-06-2020-IPIFF-edible-insects-market-factsheet.pdf, accessed 19.05.2023.

IPIFF (2021): An overview of the European market of insects as feed. Brussels. Available at https://ipiff.org/wp-content/uploads/2021/04/Apr-27-2021-IPIFF_The-European-market-of-insects-as-feed.pdf, accessed 19.05.2023.

Jetzke, T.; Richter, S.; Keppner, B.; Domröse, L.; Wunder, S.; Ferrari, A. (2019): Die Zukunft im Blick: Fleisch der Zukunft – Trendbericht zur Abschätzung der Umweltwirkungen von pflanzlichen Fleischersatzprodukten, essbaren Insekten und In-vitro-Fleisch. Dessau-Roßlau: Umweltbundesamt.

Kahlenborn, W.; Mewes, H.; Knopf, J.; Hauffe, P.; Kampffmeyer, N.; Fichter, K.; Clausen, J.; Weiß, R.; Beucker, S.; Bergset, L. (2013): Treiber und Hemmnisse für die Trans-formation der deutschen Wirtschaft zu einer „Green Economy ". In: Endbericht im Auftrag des Bundesministeriums für Bildung & Forschung.

Magnusson, T.; Berggren, C. (2018): Competing innovation systems and the need for redeployment in sustainability transitions. In: Technological Forecasting and Social Change, 126, pp. 217–230. https://doi.org/10.1016/j.techfore.2017.08.014.

Münchhausen, S. von; Fink-Keßler, A. (2019): Exkurs: Rechtliche und strukturelle Rahmenbedingungen der Fleischerzeugung. In: Rückert-John, J.; Kröger, M. (Eds.): Fleisch. Vom Wohlstandssymbol zur Gefahr für die Zukunft. ISBN: 978-3-8452-8459-0, pp. 67–80.

Onwezen, M. C.; Bouwman, E. P.; Reinders, M. J.; Dagevos, H. (2021): A systematic review on consumer acceptance of alternative proteins: Pulses, algae, insects, plant-based meat alternatives, and cultured meat. In: Appetite, 159, p. 105058. https://doi.org/10.1016/j.appet.2020.105058.

Paech, N. (2006): Wirtschaften ohne Wachstumszwang. In: Ökologisches Wirtschaften - Fachzeitschrift, 21 (3). https://doi.org/10.14512/oew.v21i3.460.

Parlasca, M. C.; Qaim, M. (2022): Meat Consumption and Sustainability. In: Annual Review of Resource Economics, 14 (1). https://doi.org/10.1146/annurev-resource-111820-032340.

Parodi, A.; Ipema, A. F.; van Zanten, H. H. E.; Bolhuis, J. E.; van Loon, J. J. A.; Boer, I. J. M. de (2022): Principles for the responsible use of farmed insects as livestock feed. In: Nature Food, 3 (12), pp. 972–974. https://doi.org/10.1038/s43016-022-00641-5.

Quack, D. (2016): Trafo 3.0 Ausgangsanalyse in den Anwendungsfeldern. Öko-Institut e.V.

Sandén, B. A.; Hillman, K. M. (2011): A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. In: Research Policy, 40 (3), pp. 403–414. https://doi.org/10.1016/j.respol.2010.12.005.

Schattauer, G. (2023): Würmer im Burger – als ich in den Bratklops beiße, wird mir ganz anders. Insekten als Nahrungsmittel. Available at https://www.focus.de/panorama/insekten-als-nahrungsmittel-wuermer-im-fleisch-als-ich-in-den-burger-biss-wurde-mir-ganz-anders_id_195217495.html, accessed 25.06.2023.

Scherbaum, C. (2020): Zukunftsmarkt Fleischersatz: Das sind die bekanntesten Anbieter in Deutschland. Available at https://www.rnd.de/wirtschaft/fleischersatz-das-sind-die-bekanntesten-anbieter-in-deutschland-SOFILS3SWBAWNIEXKOKUENZNKI.html, accessed 30.08.2021.

Schrode, A.; Müller, L. M.; Wilke, A.; Fesenfeld, L. P.; Ernst, J. (2019): Transformation des Ernährungssystems: Grundlagen und Perspektiven.

Sinke, P.; Swartz, E.; Sanctorum, H.; van der Giesen, C.; Odegard, I. (2023): Ex-ante life cycle assessment of commercial-scale cultivated meat production in 2030. In: The International Journal of Life Cycle Assessment, 28 (3), pp. 234–254. https://doi.org/10.1007/s11367-022-02128-8.

Sozialdemokratische Partei Deutschlands; BÜNDNIS 90/DIE GRÜNEN; Freie Demokratische Partei (Eds.) (2021): Mehr Fortschritt wagen. Bündnis für Freiheit, Gerechtigkeit und Nachhaltigkeit. Koalitionsvertrag 2021-2025 zwischen der Sozialdemokratischen Partei Deutschlands (SPD), Bündnis90/Die Grünen und den Freien Demokraten (FDP). Berlin.

Spiller, A.; Schulze, B. (2008): Zukunftsperspektiven der Fleischwirtschaft. Verbraucher, Märkte, Geschäftsbeziehungen. Göttingen: Universitätsverlag. ISBN: 978-940344-13-7.

Stockmeyer, B. (2001): Ansatzpunkte und Methoden zur Effizienzsteigerung im Innovationsmanagement der Ernährungsindustrie. München: Technische Universität München.

Suddaby, R.; Bitektine, A.; Haack, P. (2017): Legitimacy. In: Academy of Management Annals, 11 (1), pp. 451–478. https://doi.org/10.5465/annals.2015.0101.

Suurs, R. A.; Hekkert, M. P. (2009): Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands. In: Energy, 34 (5), pp. 669–679. https://doi.org/10.1016/j.energy.2008.09.002.

Thümler, B. (2016): Antrag. Fleisch bleibt Fleisch und Wurst bleibt Wurst - Bessere Kennzeichnung von Fleischimitaten. Drucksache 17/6404.

Trummer, M. (2014): Die kulturelle Bedeutung des Felsichkonsums in Mitteleuropa - warum ist es so schwer, etwas zu ändern? In: Voget-Kleschin, L.; Bossert, L.; Ott, K. (Eds.): Nachhaltige Lebensstile. Welchen Beitrag kann ein bewusster Fleischkonsum zu mehr Naturschutz, Klimaschutz und Gesundheit leisten? Marburg: Metropolis-Verlag. ISBN: 978-3-7316-1089-2, pp. 316–328.

Turnheim, B.; Geels, F. W. (2013): The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967). In: Research Policy, 42 (10), pp. 1749–1767. https://doi.org/10.1016/j.respol.2013.04.009.

van Huis, A. (2020): Insects as food and feed, a new emerging agricultural sector: a review. In: Journal of Insects as Food and Feed, 6 (1), pp. 27–44. https://doi.org/10.3920/JIFF2019.0017.

van Huis, A. (2022): Edible insects: Challenges and prospects. In: Entomological Research, 52 (4), pp. 161–177. https://doi.org/10.1111/1748-5967.12582.

van Huis, A.; Gasco, L. (2023): Insects as feed for livestock production. In: Science, 379 (6628), pp. 138–139. https://doi.org/10.1126/science.adc9165.

Voget-Kleschin, L.; Bossert, L.; Ott, K. (Eds.) (2014): Nachhaltige Lebensstile. Welchen Beitrag kann ein bewusster Fleischkonsum zu mehr Naturschutz, Klimaschutz und Gesundheit leisten? Marburg: Metropolis-Verlag. ISBN: 978-3-7316-1089-2.

Warnke, P.; Koschatzky, K.; Dönitz, E.; Zenker, A.; Stahlecker, T.; Som, O.; Cuhls, K.; Güth, S. (2016): Opening up the innovation system framework towards new actors and institutions. Karlsruhe: Fraunhofer ISI. Available at https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cci/innovation-systems-policy-analysis/2016/discussionpaper_49_2016.pdf.

Willett, W.; Rockström, J.; Loken, B.; Springmann, M.; Lang, T.; Vermeulen, S.; Garnett, T.; Tilman, D.; DeClerck, F.; Wood, A.; Jonell, M.; Clark, M.; Gordon, L. J.; Fanzo, J.; Hawkes, C.; Zurayk, R.; Rivera, J. A.; Vries, W. de; Majele Sibanda, L.; Afshin, A.; Chaudhary, A.; Herrero, M.; Agustina, R.; Branca, F.; Lartey, A.; Fan, S.; Crona, B.; Fox, E.; Bignet, V.; Troell, M.; Lindahl, T.; Singh, S.; Cornell, S. E.; Srinath Reddy, K.; Narain, S.; Nishtar, S.; Murray, C. J. L. (2019): Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. In: The Lancet, 393 (10170), pp. 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Wunder, S. (2019): Nachhaltige Ernährungssysteme in Zeiten von Urbanisierung und globaler Ressourcenknappheit: Herausforderungen und Handlungsmöglichkeiten. UBA-Texte 85/2019. Dessau-Roßlau. Available at https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-08-15_texte_85-2019_run-ap_1-3.pdf, accessed 20.08.2019.

Zukunftskommission Landwirtschaft (2021): Zukunft Landwirtschaft. Eine gesamtgesellschaftliche Aufgabe. Empfehlungen der Zukunftskommission Landwirtschaft. Berlin: Geschäftsstelle der ZKL. Available at https://www.bmel.de/SharedDocs/Downloads/DE/Broschueren/abschlussbericht-zukunftskommission-landwirtschaft.pdf.

Zundel, S.; Erdmann, G.; Kemp, R.; Nill, J.; Sartorius, C. (2005): Conceptual Framework. In: Sartorius, C. (Ed.): Time strategies, innovation and environmental policy. Cheltenham Glos. u.a.: Elgar. ISBN: 1-8454-2090-X, S. 10-54.