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Government-Funded Development of Innovative Physical Technologies for Sustainable Agriculture and Food Production in Rural Germany through a University–Business Alliance Formation

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Abstract: ***Purpose:*** The alliance project "Physics for Food" aims to invent new physical technologies for sustainable agriculture and food production in Mecklenburg-Western Pomerania, an agrarian region in northern Germany. This article may serve as an example of good practice for regional collaboration and funding acquisition between academia and the industry, especially SMEs, that may be replicated in other rural contexts. ***Approach:*** The project consortium consists of a triple-helix setting of scientists from university and research institutes as well as technology suppliers, seed producers, and farmers. The German Federal Ministry of Education and Research (BMBF) funds the project in a special program called "WIR!" that addresses innovation and structural transformation of lagging regions in Germany. ***Findings:*** The program encourages development of regional innovation concepts and supports confederations that cross disciplinary, industrial, institutional, and administrative boundaries and thrive on civic involvement. Today already, there is huge potential and an increasing demand for the development and the supply of novel non-chemical alternatives in plant and storage protection in agriculture and food production. ***Originality:*** The project aims to lay the foundation for startup companies based in the region to act as innovative technology providers and to create jobs in the region while making the new technologies available nationally and internationally. The application of physical methods will decrease costs, conserve resources, and eventually contribute to protecting the environment.

Keywords: sustainable farming; food production; cold plasma; Germany; Mecklenburg-Western Pomerania

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1. Introduction

Traditional methods, such as the use of chemical plant protection products, will be examined critically and, where possible, replaced by physical methods that do not introduce synthetic substances into natural environments [1–3]. This process is referred to as path modernization. This government-funded research and development alliance provides a boost to innovations across the entire value chain (seeds, plant production and harvest treatment, processing and refinement, food). The economically disadvantaged target region in northeast Germany has already distinguished itself with the development of electron treatment of seeds as a successful alternative to seed dressing that is widely accepted by agriculturalists. The regional expertise incorporated in the activities of the alliance encourages systematic refinement of similar approaches. This allows the use of advanced

physical technologies to boost the resilience of plant production systems overall (general growth promotion, induced resistance to biotic and abiotic stresses) and reduces or even completely avoids the application of agrochemicals. The current structure of agriculture (the use of chemical plant protection products, the crop varieties cultivated, intensive fertilization) is cited as a possible cause of the major decline in biomass and diversity of regional insect populations. Physical treatment methods may provide a promising alternative to agrochemicals [1,2]. This process is referred to as path creation. At the same time, such innovative methods enhance the professional image of agriculturalists, and businesses are more competitive thanks to path modernization. This is associated particularly with the creation of jobs and services relating to the technologies. The cultural shift pushing for more sustainable agriculture and greater food safety while maintaining or improving quality and quantity is also directly addressed by these methods. In regard to climate change, cultivating crop plants that are capable of resisting water stress, heat stress, and pathogen attack is increasingly important. Consequently, adapting previous production methods is more important [4,5]. For example, methods in food technology can be optimized by physical processes (path diversification), and path creation can also generate new refinement processes, e.g., for solvent-free extraction.

Because other agrarian regions of Germany face similar challenges, and because ensuring food security while minimizing environmental impacts and resource consumption is a matter of great urgency internationally, the approaches and methods developed here can also satisfy global needs. The innovations in the region presented here that are developed by stakeholders from universities and industry can be transferred with this perspective to other structurally weak agricultural regions that are facing similar challenges. For regional businesses, successfully shaping the field of innovation means ensuring their competitiveness in the context of increasing globalization.

The project consortium consists of a triple-helix setting of scientists from university and research institutes as well as technology suppliers, seed producers, and farmers. The project is funded by a special program—"WIR!" of the German Federal Ministry of Education and Research (BMBF)—that addresses innovation and structural transformation of lagging regions in Germany. The program encourages the development of regional innovation concepts and supports confederations that cross disciplinary, industrial, institutional, and administrative boundaries and thrive on civic involvement. Figure 1 shows each of the phases of the collaborative project "Physics for Food".

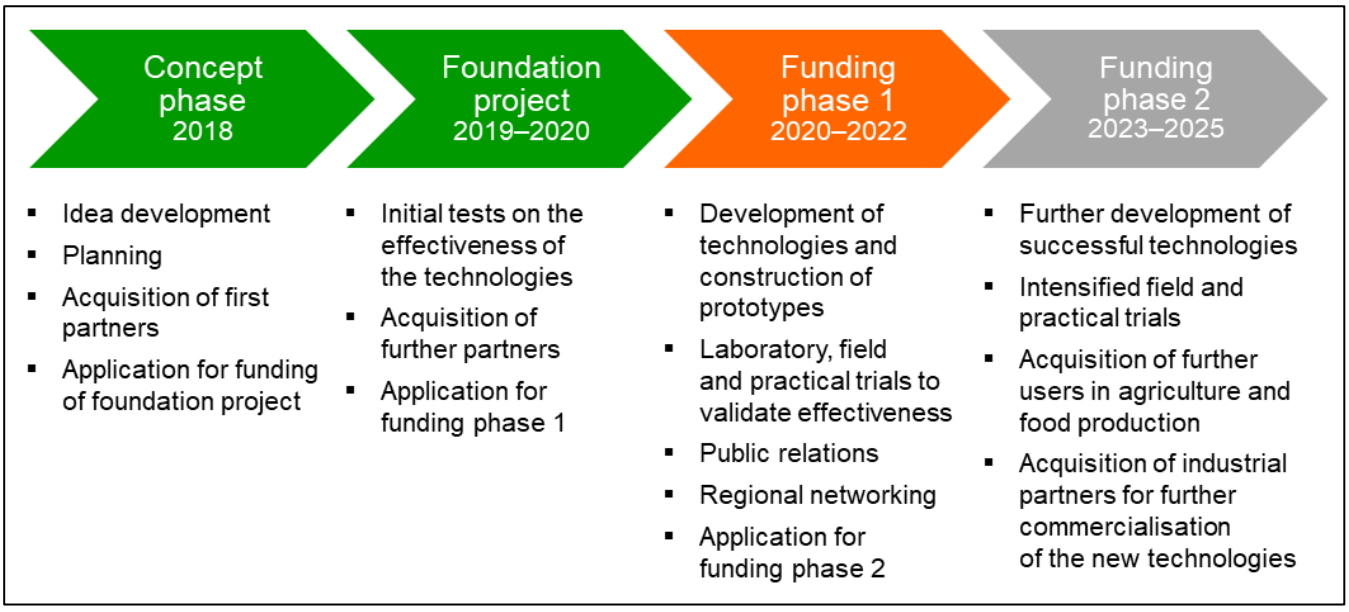

Figure 1. Phases of the collaborative project "Physics for Food".

The alliance started in 2018 with a concept phase in which the initial idea was developed and initial planning was carried out. This also meant bringing together the first partners to form the alliance and drafting grant applications to fund a foundation project. During the foundation projects, which ran from 2019 to 2020, the alliance conducted initial small-scale studies of the effectiveness of the technologies identified, while acquiring more partners, especially from industry and among end users. Subsequently, the alliance applied for phase 1 funding based on these preliminary results. "Physics for Food" is currently in funding phase 1, which started in 2020. In this phase, the alliance is now focusing on developing new technologies and constructing prototypes. Laboratory, field, and practical trials were initiated to validate the effectiveness of these new technologies. The alliance also began public relations efforts to expand its regional network. Funding phase 2 will facilitate the initiation of follow-up projects for further development of the technologies that were identified along with intensifying the field and practical trials. A very important part of funding phase 2 is to find industrial partners that can start commercializing the new technologies.

This article may represent an example of good practice for regional collaboration and funding acquisition between academia and the industry, especially SMEs, that may be replicated in other regional contexts.

2. Overview of Prerequisites and Intentions for the Development of Innovative Physical Technologies for Sustainable Agriculture and Food Production in Northeast Germany

2.1. The Target Region

The northeast coastal hinterland (see Figure 2) is one of the most economically weak regions within the German state of Mecklenburg-Western Pomerania, in particular, and the Federal Republic of Germany, in general. A small industrial base and demographic changes mean that the northeast coastal hinterland is facing exceptional challenges. Mechanical engineering and construction as well as the energy sector are gaining importance, but are poorly developed compared to the rest of Germany. Nevertheless, the area is known nationally and internationally as an agricultural region. Large-scale agriculture has long been firmly established. For grains and rapeseed, both high yields and top quality are achieved when compared internationally. The rapeseed area in Mecklenburg-Western Pomerania in 2019 was the largest in a comparison of German states [6]. Mecklenburg-Western Pomerania is fourth behind Bavaria, Lower Saxony, and Saxony-Anhalt for wheat cultivation [7]. In 2019, 54.1% of arable land was used for cultivating crops for production of grain, while 15.8% was used for oil seeds [8]. The area used to cultivate legumes in Mecklenburg-Western Pomerania increased from 5300 to 27,450 hectares between 2014 and 2020 [9]. The overwhelming majority of agricultural land in the northeast coastal hinterland is under conventional cultivation, that is, the use of mineral fertilizers and various chemical plant protection products. The trend toward organic production is rising and is supported financially by the state government. The food industry holds a prominent position in the manufacturing sector. Currently, the food industry, which is characterized by small and medium-sized enterprises and employs over 14,500 people, contributes about 33% of the added value of the manufacturing sector in Mecklenburg-Western Pomerania [10].

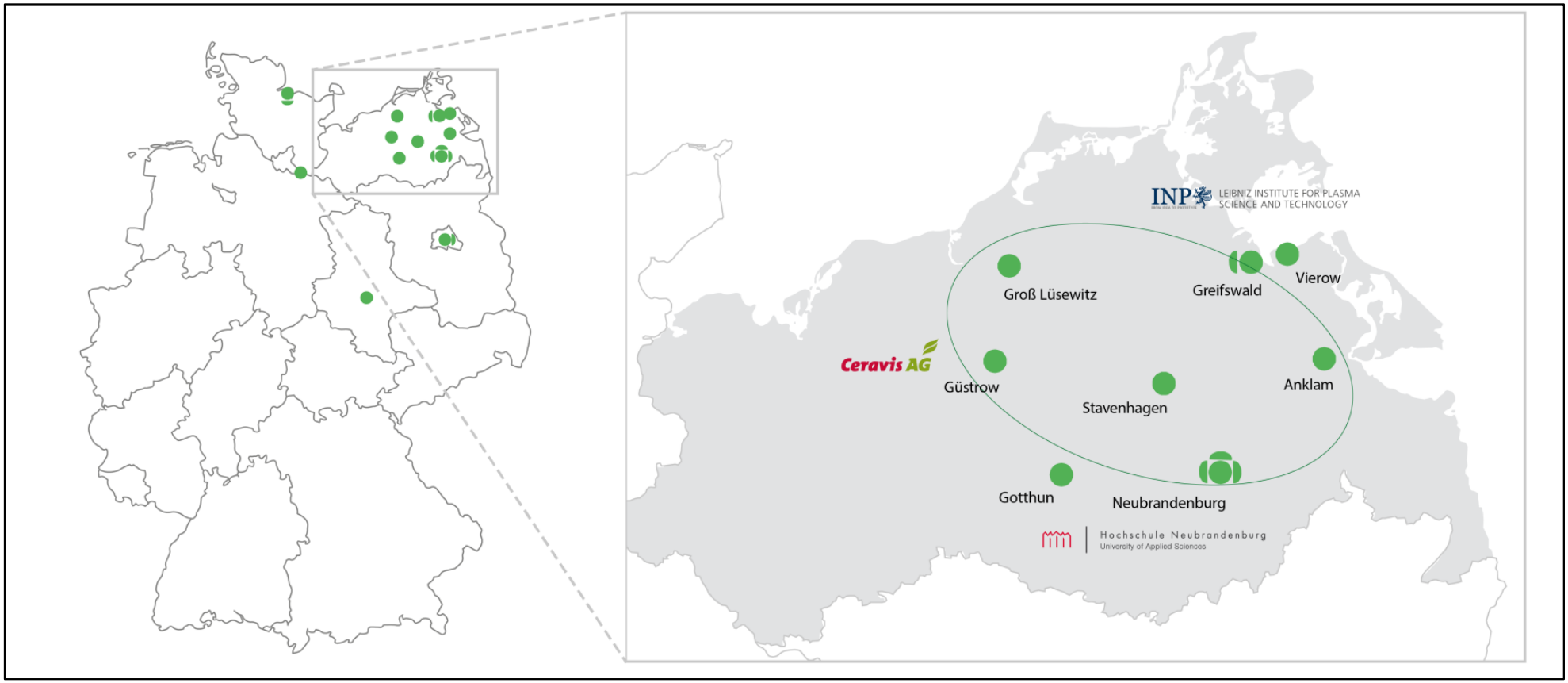

Figure 2. Geographic boundary of the northeast coastal hinterland with the locations of the alliance partners and coordinating institutions: Neubrandenburg University of Applied Sciences, Leibniz Institute for Plasma Science and Technology e.V. (INP), and Ceravis AG.

The importance of agriculture and food production is also reflected in the establishment of many research institutes that either focus exclusively on relevant issues, such as the Centre for Nutrition and Food Technology, Neubrandenburg, Germany (in German: Zentrum für Ernährung und Lebensmitteltechnologie, ZELT gGmbH), or have their focus shaped by the opportunities within agriculture, such as the Leibniz Institute for Plasma Science and Technology e.V. (INP) with its plasma agriculture research group. Most of the research institutes that are relevant outside the region and internationally are involved in the project alliance. The geographic boundary of the project region results, on one hand, from geographic, economic, and natural aspects and, on the other hand, has arisen from the few existing collaborations of the project leaders with regional stakeholders from agriculture and food production and applied research. Over the course of the project to date, the structural foundation of the stakeholders to be incorporated as indicated above has proven to be particularly well suited for this approach and this region. As a result of the unique constellation of stakeholders in the alliance and the selected strategic approach, the project has great appeal and has also generated keen interest far beyond the region itself. Particularly for regions that are facing similar challenges in agriculture and food production and confronted by similar framework conditions, our region is both a role model and trendsetter with this concept. Figure 2 shows the various locations of the alliance stakeholders (universities, research institutes, and regional industry).

2.2. Potentials of the Government-Funded Alliance

Based on the expertise and potential that exist in the northeast coastal hinterland, and considering the current ecological, economic, social, and political challenges, the following potentials for innovation emerge for the "Physics for Food" field of innovation of the alliance:

A. Reduction in the use of chemical agents in agricultural plant protection, particularly for harvested crops.
B. Improvement in the establishment of crops of cultivated plants and the growth of plant crops.
C. Strengthening of plant health to maintain and increase yields under changing environmental conditions.
D. Improvement in refinement processes for plant raw materials and optimisation of the composition of constituents of products using non-chemical processes.
E. Integrated technology transfer driven by the social values of regional and sustainable agriculture.

The scientific and technological work of the alliance is currently concentrated primarily on the following physical technologies that have been identified as being promising: UV-C light, pulsed electric fields, and atmospheric pressure plasma. This is summarized is Figure 3.

The selection is characterized in part by consideration of the different developmental stages of the technologies (technology readiness level, TRL) [11]. UV-C light has already found its way into use to some extent and questions relating to approval have been resolved comparatively quickly (TRL 7–9). Pulsed electric fields are in the prototype stage for individual applications with greater development necessary (TRL 5–7). Direct and indirect plasma applications for agriculture are mostly still in the phase of providing proof of concept (TRL 3–5). According to the experiences and demands of the businesses involved, these physical technologies are specifically adapted to specific process steps in cultivation, crop handling, and storage, as well as processing to expand, optimize, or replace existing technologies.

While the concept was being developed, the alliance partners selected the following cultivated plants as key crops for subsequent studies: rapeseed, barley, and lupins. The selection of these plant varieties is driven by their strong relevance for the region (rapeseed is a traditional agricultural crop strongly identified with the region) and importance for the global market (export and scale effects). The selected crops also cover the entire globally integrated value chain from cultivation to processing carried out by stakeholders in the

region. An important criterion for choosing the specific crops was also the plant systematics themselves, because these three crops are from completely different plant families. Barley represents the family of true grasses, to which wheat, rye, and oats also belong. Rapeseed is a representative of the oil plants, while lupin is a protein source. The seed or plant growth in particular could therefore be compared in the different classes regarding the development or adaptation of the physical treatment methods. Opening the technologies up to other cultivated plants, and thus consequently expanding the potential for application, is taken into account and deliberately prepared for from the outset.

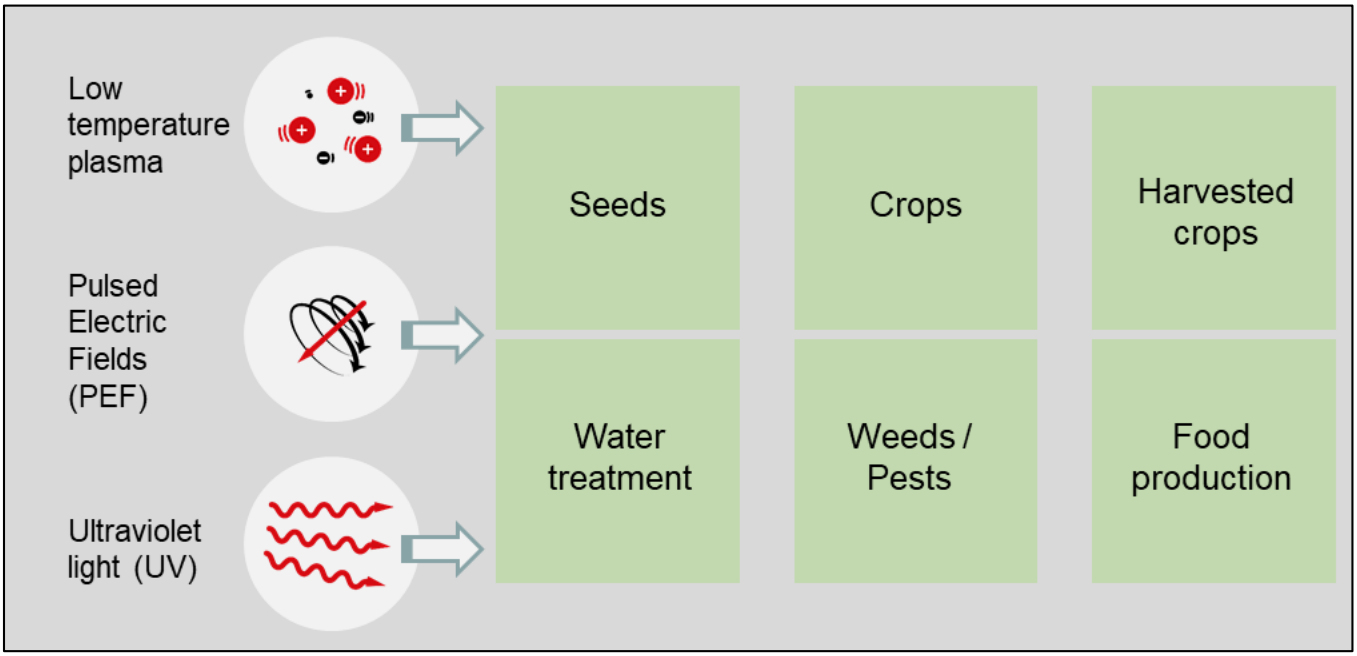

Figure 3. Innovative physical technologies for agriculture and food production investigated and developed in "Physics for Food".

The five innovation potentials are specifically suitable for this region and its stakeholders to generate sustainable innovations that are accepted socially, satisfy legal and regulatory requirements, and are economically competitive. A broad interdisciplinary range of research into new technologies is managed, as outlined in Figure 4. This affects regional business startups and transregional business models for regional production and servicing of international markets equally.

2.3. Objectives of the Government-Funded Alliance

Overall, it is intended firstly to strengthen agricultural production businesses sustained by a transformation of social values for healthy and sustainable food, and secondly to bring about a paradigm shift in plant production extending from cultivation to processing.

An initial short-term development objective was the networking of the regionally based economic partners with the scientific institutions involved and the construction of a reliable operational level in the first year of the implementation phase.

The medium-term objective up to the end of the second implementation phase after five years is to transfer the physical processes to additional precision field trials and large-scale fields of practice of the businesses in the region to demonstrate project outcomes using examples. It is expected that the relevant alliance partners will have upscaled systems for decontaminating stored goods in operation. Systems for improved digestion of processed crops have been implemented prior to the project start. Likewise, work on process water treatment was running on schedule and had been completed in December 2022. Aspects of securing a workforce and qualifying and creating new job profiles and educational materials were also included in the medium-term objectives.

Figure 4. Illustration of the broad range of research for new technologies in the collaborative project.

The dialogue about improved communication of initial results with sectors and institutions that are not directly involved in the alliance within the region will be stepped up. As a result, awareness and acceptance of the developed technologies will be increased, long-term establishment of an innovation structure created in the implementation phase will be assured, and lastly, sought-after structural change will be supported.

In May 2022 and May 2023, two international spring schools were conducted for the purpose of transferring research results, which will be firmly established in the teachings of Neubrandenburg University of Applied Sciences in the medium term. In the second implementation phase, citizen dialogues in collaboration with the University of Greifswald will start (focus of the studies is transformation processes in agriculture and food production). In summary, the medium- to long-term social development objectives are to initiate and intensify innovative processes in the region, retain and acquire skilled personnel, reduce out-migration, and develop new professional fields.

Preparations will be made in the current implementation phase and will be consolidated in a second funding phase to ensure self-sustaining continuance of the concept after funding ends. The long-term development objectives include reinforcing and further developing the addressed economic sectors, creating momentum for the development of local businesses, supporting their market development and investment decisions, facilitating new development and service provision approaches in businesses that deal with advanced physical processes, supporting business startups, and attracting external investors to invest in existing structures or establish new operations. These economic development objectives aim to exploit new areas of application for physical processes in agriculture and food production. The long-term benefit will be the systematic preparation of transfer opportunities for the physical processes used for other crops (wheat, soy, maize, rice, etc.) or cultivation processes, which have already been considered and should be supported by appropriately designed research. The aim is to transfer the results on a national and international scale and to introduce them into the global value chain by demonstrating the opportunities.

A technical development objective that is planned is the construction of systems with industry or investment partners. Modularization and standardization for price positioning and alignment with specific customer benefits (e.g., throughput, speeds and properties of the plants, bulk goods, and seeds treated) will be clarified with interested investors and manufacturers. As part of the further development, aspects such as safety, user-friendliness, and carbon neutrality will be considered.

2.4. Strategic Approaches of the R&D Alliance

To invigorate the field of innovation, three central areas of activity were identified in advance that our project addresses in a healthy balance:

1. "Collaboration between science, business and society" by carrying out joint research and development projects (lead projects) with regional partners.
2. "Boosting the innovative capability of businesses" by generating disruptive innovative process steps and developing effective product innovations.
3. "Securing skilled professionals" by enhancing the professional image of agriculturalists, expanding the expertise of skilled professionals, and increasing the attractiveness of the rural region.

The perspectives developed for the regional structural change in the northeast coastal hinterland in the context of the field of innovation take into account the above three areas of activity in the alliance project.

2.4.1. Area of Activity 1: Collaboration between Business, Science, and Society

The collaboration between business, science, and society (area of activity 1) is primarily facilitated by carrying out joint research and development projects (lead projects) with regional partners. An interdisciplinary and transdisciplinary network of stakeholders that had been established was considered from the start to be a prerequisite for realizing innovations in northeast Germany. Through the collaboration with regional transfer projects, such as *HiRegion*, the Neubrandenburg Chamber of Industry and Commerce for eastern Mecklenburg-Western Pomerania, and institutions to support the establishment of businesses, such as the research association Forschungsverbund M-V e.V., the structures for entrepreneurship that are already in place in the state are integrated into the project.

2.4.2. Area of Activity 2: Innovative Capability of Regional Businesses

The innovative capability of regional businesses (area of activity 2) is consolidated by generating disruptive–innovative process steps and developing effective product innovations.

2.4.3. Area of Activity 3: Qualification or Acquisition of Young Talent

Qualifying or acquiring young talent for business and science (area of activity 3) is pursued by expanding and enhancing the professional field of the agriculturalist, developing expertise of skilled professionals, and increasing the attractiveness of the rural region.

3. Members of the Alliance

Partners with the necessary expertise for implementing the innovative concept "Physics for Food" were identified and incorporated along the innovation and value chain. This generated a wide range of stakeholders. The strategy of concentrating on key expertise proved to be exceptionally well suited to establish a trust-based and effective collaboration. The partners completing the alliance were rapidly identified, approached, and integrated by making fine adjustments to the strategy. Five additional alliance partners have been included since the start of the first implementation phase. Those involved all make considerable contributions to the further development and implementation of the alliance's strategy, not least because they already have exceptional expertise in the implementation of physical technologies from basic research to application. What must be highlighted here is the unique character of the alliance with its complementary composition that also includes business, which ultimately influences and can ensure the success of new products, as well as the willingness of those businesses from agriculture, construction, and the food industry that are involved to innovate. The high degree of motivation and commitment and the capital that the businesses involved have already dedicated over the entire lifetime of the project must be emphasized. The members of the alliance and their roles in the collaborative project "Physics for Food" are listed in Table 1.

Table 1. Overview of the alliance partners (beneficiaries) of the overall project "Physics for Food" as of October 2021.

Alliance Partner	Location	Website	Lead Project	Role/Expertise
Agrarconcept Schneider	Gotthun, Germany	https://www.agrarconcept.de/	Physics for Crops	Field trials
AUTOSOFT automation and software Günther Tausch GmbH	Neubrandenburg, Germany	https://www.autosoft-nb.de/	Physics for Food and Feed	Mechanical engineering
Bio Eichenmühle GmbH and Co. KG	Stavenhagen/Basepohl, Germany	http://bio-eichenmuehle.de/	Physics for Food and Feed	Silo storage
Ceravis AG	Güstrow, Germany	https://ceravis.de/	Physics for Seeds; coordinator of the alliance	Electron treatment/field trials
Cosun Beet Company and Co. KG	Anklam, Germany	https://www.cosunbeetcompany.de/	Assistant project management for Physics for Environment	Agrotechnological production
Hafen Vierow GmbH	Vierow, Germany	https://hafen-vierow.de/	Physics for Food and Feed	Silo storage
Hanse Agro GmbH	Gettorf, Germany	https://www.hanse-agro.de/	Assistant project management for Physics for Crops	Agricultural consultancy
Harbauer Umwelttechnik GmbH	Berlin, Germany	https://www.harbauer-berlin.de/de/	Physics for Environment	System construction
Neubrandenburg University of Applied Sciences	Neubrandenburg, Germany	https://www.hs-nb.de	Coordinator of the alliance Physics for Food; lead project management for transfer, procedures, permissions (TPP)	Research expertise "Food"
Leibniz Institute of Plant Genetics and Crop Plant Research (IPK)	Groß Lüsewitz, Germany	https://www.ipk-gatersleben.de/	Assistant project management for Physics for Seeds	Laboratory and greenhouse trials
Leibniz Institute for Plasma Science and Technology e.V. (INP)	Greifswald, Germany	https://www.inp-greifswald.de	Coordinator of the alliance Physics for Food	Research expertise "Physics"
NPZ Innovation GmbH	Holtsee, Germany	https://www.npz-innovation.de/	Physics for Seeds	Field trials
PiCA Prüfinstitut Chemische Analytik GmbH	Berlin, Germany	https://www.pica-berlin.de/	Transfer, procedures, permissions (TPP)	Analysis
Power Recycling Energyservice GmbH	Neubrandenburg, Germany	http://www.pre-mv.de	Physics for Environment	System construction
Saatzucht Bauer GmbH and Co. KG	Bernburg (Saale), Germany		Physics for Seeds	Field trials
TIGRES GmbH	Marschacht, Germany	https://www.tigres-plasma.de/de/	Transfer, procedures, permissions (TPP)	System construction
University of Greifswald	Greifswald, Germany	https://botanik.uni-greifswald.de/pflanzenphysiologie/mitarbeitende/	Physics for Crops	Plant physiology
Zentrum für Ernährung und Lebensmitteltechnologie gGmbH (ZELT)	Neubrandenburg, Germany	https://www.zelt-nb.de/	Physics for Food and Feed; alliance coordination	Demonstrator implementation

In addition to the alliance partners, more than 60 other regional partners have been reached through the project that are not beneficiaries, are already involved, or have expressed interest in future involvement. Most of these partners are small and medium-sized enterprises. They contribute as associated partners to workshops and surveys and attend the alliance assembly in the overall project with no voting rights. For example, additional agriculturalists in the region contribute their experience and wealth of knowledge to secondary projects as potential users and partners, and regional trade promotion agencies provide additional input for site-based exploitation.

4. Structure of Alliance and Project Management

The organizational and management structure of the collaborative project "Physics for Food" is shown in Figure 5.

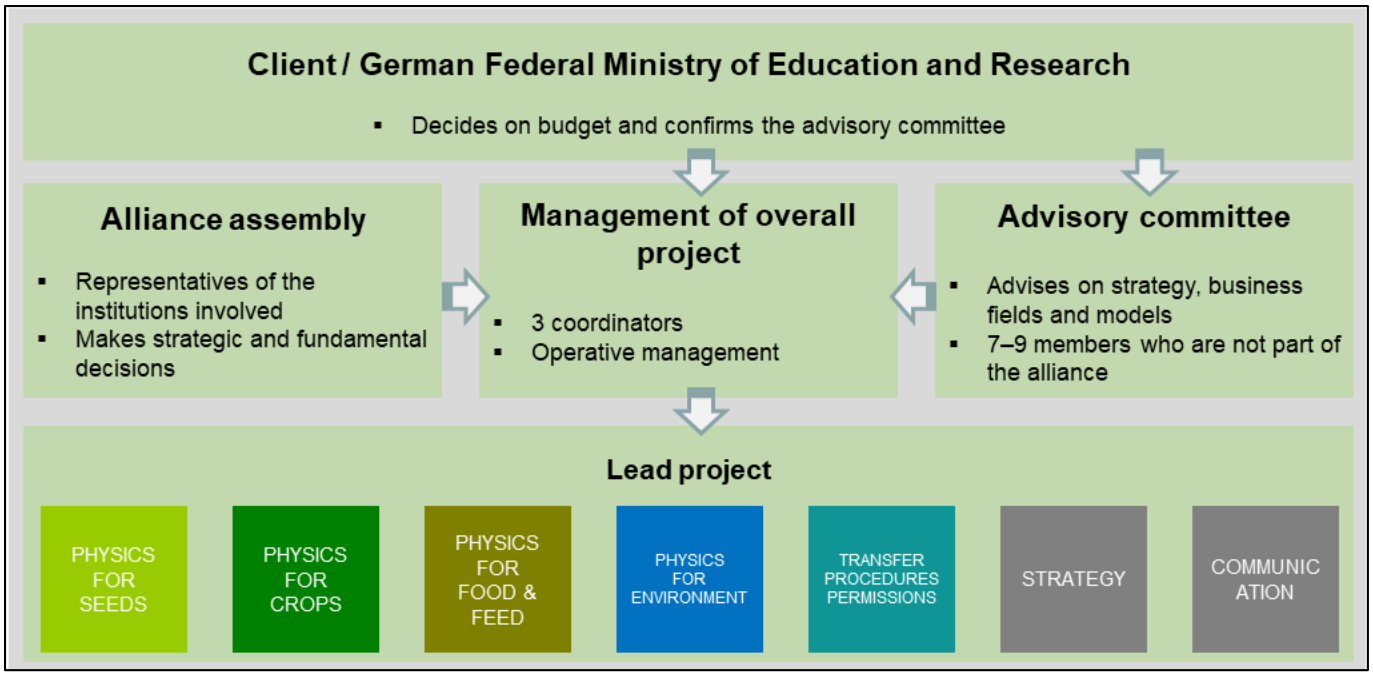

Figure 5. Overview of the organizational and management structure of the collaborative project "Physics for Food".

The alliance has a consensual project and management structure. Three coordinators with complementary expertise and an operative management head the alliance. Each lead project is coordinated by its own technical and strategic project manager. Monitoring of the project is ensured by clearly defined and regular reporting requirements that include all beneficiaries. Representatives of all beneficiaries make up the alliance assembly. This board makes strategic decisions and policy resolutions. The tasks, expertise, and responsibilities across the coordinators, operative management, project managers, and alliance partners are clearly defined and were again confirmed by the alliance assembly before devising this concept. Management of the alliance is the responsibility of the coordinators and the operative management. A total of three project coordinators were assigned. Two of the coordinators thus come from the relevant scientific fields of "Physics" and "Food" and the third from business (some select previous publications of these two coordinators from the fields of "Food" are [12–27], and "Physics" [1,2,28–34]). Together with operative management, the coordinators make decisions that ensure the project proceeds efficiently and successfully within the defined strategic alignment and the project and management structure. They represent the alliance externally. The coordinators can only make decisions unanimously. In cases of conflict, the decision is escalated to the alliance assembly.

Operative management controls the overall project and acts as a permanent contact partner for all involved in the project. Operative management reviews and documents the progress of the overall project. The reporting system established for this purpose, which incorporates all beneficiaries, has proven successful, as have monthly meetings of the project managers. Management is supported by two cross-section projects ("Strategy Development" and "Communication"). The tasks in the "Strategy Development" project are carried out complementary to one another at the three coordinating institutions. The cross-section project "Communication" fundamentally supports and frames public relations activities.

Individual subprojects (lead projects) are organized as industry-led collaborative projects. For each funded project, there is a project manager (collaborative project coordination, representative from business or science, the deputy representative from science or business) who is responsible for the strategic and overall technical coordination of the project and those institutions that are involved. Each institution is solely and fully responsible for their subproject. Thus, the scientific responsibility in the overall project lies with the managers of the lead projects. However, aside from their technical and subject matter expertise, management of the overall project "Physics for Food" does not have any management instruments, such as the option to impose sanctions, that extend beyond their own institutions. Thus, binding cooperation in the overall project "Physics for Food" is achieved exclusively through appeals. These depend on the goodwill of the individual partners and the cooperative agreements drawn up for the funded projects. In cases of conflict, solutions are suggested by the management of the overall project if necessary, confirmed by the alliance assembly and advisory committee, and implemented together with those responsible for the funded projects. This constellation creates a particularly responsible and integrative, but also steering, role for the three coordinators. This structure forms a foundation that has proven successful over the course of the project to date. The coordinators and boards continuously review the progress of the projects. If needed, the subject matter of ongoing projects can be adjusted or alternative or supplementary funded projects can be developed in accompanying strategy workshops and suggested to the boards for implementation. This steering of the project portfolio is also subject to a participative process with existing and future partners that will be identified using a permanent strategic consideration of future markets and customers. The continuous review and adaptation of the strategic concept of the overall project "Physics for Food", the higher-level innovation management, and the development of the concept for a sustainable structure are carried out with the support of an external management consultant.

Strategic fundamental decisions are made by the alliance assembly. This steering board is made up of one representative from each of the institutions involved (beneficiaries). It was planned to convene this board twice a year, but this could only be implemented for the first time in 2021, due to the coronavirus pandemic. The alliance assembly has established procedural rules whereby decisions are made with a two-thirds majority. This board made the key decisions about the strategic alignment of the concept for the second funding phase. It thus fundamentally determines the course of the overall project.

Selection of the Advisory Committee

An advisory committee supports the alliance in the implementation and further development of the strategy and provides advice regarding the business fields and models. The advisory committee is made up of persons with a broad range of experience from business, science, society, and politics. The members of the advisory committee are not partners/members of the alliance "Physics for Food". They are independent in their advisory role and free of personal business interests. The filling of the advisory committee with both regional and transregional representatives serves to prevent lock-in effects while also enabling better consideration of future national and international trends. As an external consultation and evaluation instrument, the advisory committee provides recommendations about the establishment, continuance, or termination of projects as part of the overall strategy. Meetings are held twice a year as planned. The collaboration with

the advisory committee has shaped up to be exceptionally constructive, thanks to the self-motivation of the members of the advisory committee and the heterogeneous range of experience. At the end of the first funding phase, and with the imminent start of the second funding phase that will focus on exploitation of the results, the composition of the advisory committee will be supplemented. It is planned to appoint persons to the advisory committee who come from the areas, "investor network", "regional development", "regional business development", and "nature conservation association".

5. Existing Subprojects of the Alliance Project "Physics for Food" (Phase 1)

To achieve the objectives of the alliance, individual and intertwined smaller projects form the body of the overall project "Physics for Food". The project portfolio for the first implementation phase is made up of eight funded projects (lead projects) that are currently ongoing or have already been completed:

1. Foundation project—"Scientifically strategic foundation project", which has already been completed.
2. Physics for Seeds—Chemical-free decontamination of seeds, increase in germination capacity and power.
3. Physics for Crops—Strengthening plants against the consequences of climate change, controlling weeds and pests, monitoring processes.
4. Physics for Food and Feed—Controlling pests and pathogens in harvested crops, extending shelf life in production, increasing quality and yield in protein production.
5. Physics for Environment—Reduction in harmful substances in process, waste, and service water in agriculture and food production.
6. TPP—Transfer, Procedures, and Permissions—Construction of the technical systems, preparation for approval procedures, transfer to science and society.

There are also two cross-section projects being conducted to support the research: "Communication" (cross-section project VI) and "Strategy Development" (cross-section project VII). An additional "investment project" boosts the scientific coordinating institutions in terms of their strategic instrumentation for the purpose of exploitation.

5.1. Lead Project 0: Foundation Project

The foundation project was managed by Neubrandenburg University of Applied Sciences. The partners were the University of Greifswald, Leibniz Institute for Plasma Science and Technology e.V. (INP), and the Zentrum für Ernährung und Lebensmitteltechnologie gGmbH (ZELT). It was carried out from September 2019 to December 2020. The scientific strategic foundation project aimed to generate and evaluate initial results to ensure a rapid start to the research and development work in all lead projects. In the first step, the most promising approaches were identified. For example, trials of seed treatment were conducted on the three key crops on a laboratory scale and the suitability of physical treatment methods was determined with appropriate sets of parameters for the duration and intensity of the treatment. Based on these results, the first field trials for winter and spring sowing were started. Further work included investigations of the dose–effect relationship of UV-C light treatment and application with plasma-treated water, including suitable methods of application for growing plants in different stages of development. These were also then specifically implemented in multifactorial field trials at various sites. The necessary laboratory setups for the physical treatment methods were then purchased, which enabled the five scientific lead projects to carry out further investigations.

5.2. Lead Project I: Physics for Seeds

The lead project "Physics for Seeds" has been completed (July 2020–October 2022). The partners for "Physics for Seeds" are under the management of the Leibniz Institute for Plasma Science and Technology e.V. (INP), Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Ceravis AG, NPZ Innovation GmbH, and Saatzucht Bauer GmbH and Ko. KG. In this lead project, atmospheric-pressure plasma has been applied to seeds

primarily of barley, rapeseed, and lupins to decontaminate the seed surface, to increase the germination capacity and power, and to reduce the hardness of the seed coat of the legumes. Atmospheric-pressure plasma has also been applied together with plant growth-promoting bacteria, and the effect of the atmospheric-pressure plasma treatment on the formation of symbioses in legumes has been investigated. In previous trials of decontamination, model spores were reduced on all key plants by 90–100%. Upcoming studies will provide evidence of the effectiveness for various seed-borne phytopathogens. Furthermore, there have been strong indications that plasma application enhances the juvenile development of the plants and improves the root growth for all key crops. Atmospheric-pressure plasma treatment, also in combination with plant growth-promoting bacteria, increased the yields for barley at some field sites. The testing of the physical seed treatment has been performed under real-world conditions in the field and will be continued in the second year of trials. Thus, the initial steps toward achieving the objective of the alliance of reducing the use of chemicals in agriculture using physical processes are realized. Figure 6 summarises the objectives and methods for the lead project "Physics for Seeds".

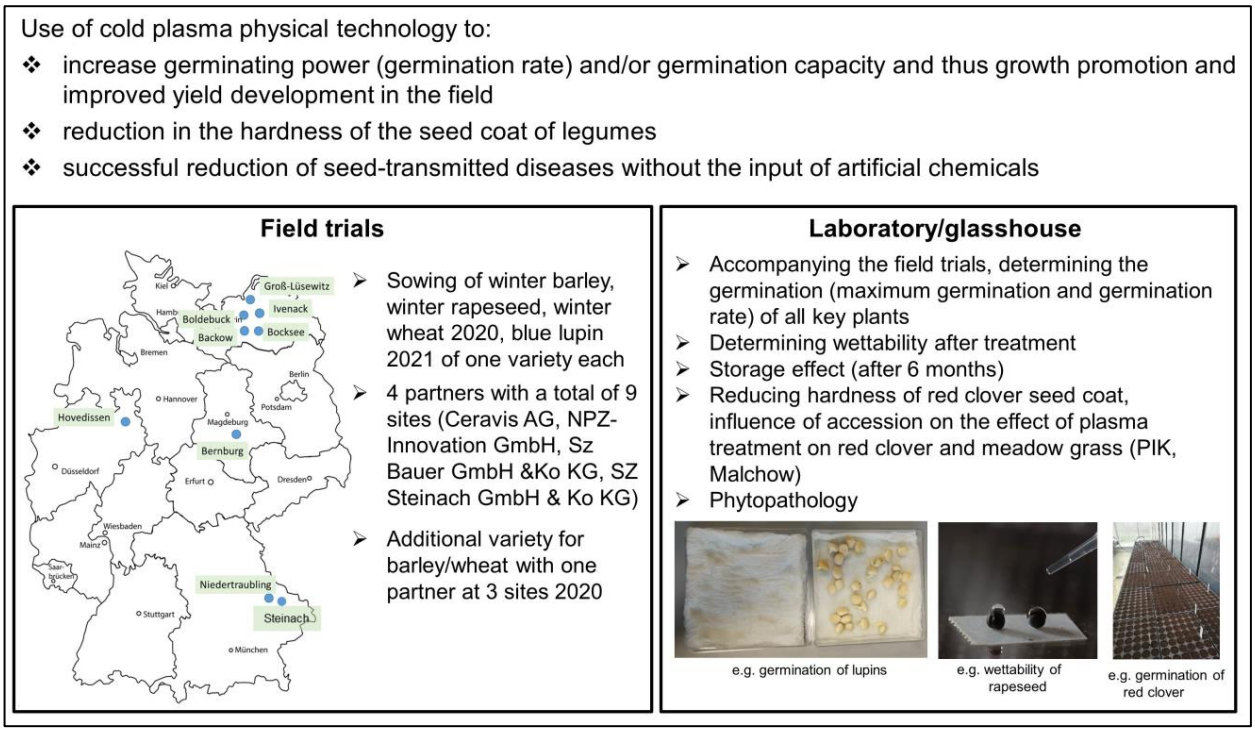

Figure 6. Objectives and methods for the lead project "Physics for Seeds".

5.3. Lead Project II: Physics for Crops

The lead project "Physics for Crops" was managed by Neubrandenburg University of Applied Sciences. The partners are the University of Greifswald, Leibniz Institute for Plasma Science and Technology e.V. (INP), Hanse Agro Beratung und Entwicklung GmbH, and Agrarconcept Schneider. It ran from July 2020 to September 2022. "Physics for Crops" aimed to use UV-C or plasma-treated water to enhance plant growth, to induce resistance to biotic and abiotic stressors, to control weeds and fungal pests, and to develop practical monitoring processes in plant production. The growth promotion investigated in three precision field trials in the first year of testing was successful in principle, with significant surpluses achieved in some cases with barley. In the laboratory and glasshouse, treatment with plasma-treated water increased tolerance to drought stress. The significant differences in the field trial that were specific in some cases to the plant type were validated in the second year of testing. There are indications of induction of systemic resistance to fungal pests in treatment with UV-C and plasma-treated water. It was demonstrated in the laboratory/glasshouse that the growth of

weeds is greatly inhibited by UV-C, but they are not killed. The refined monitoring procedures, particularly image capture and analysis, improved the analysis of the trials. Concepts for scaling up can now be prepared based on the results achieved to date. The exploration of the principles of action of the applied processes at a practically relevant scale require wide-scale introduction and transferability to other cultivated species and sites.

5.4. Lead Project III: Physics for Food and Feed

The lead project "Physics for Food and Feed" was carried out by the alliance partner, Zentrum für Ernährung und Lebensmitteltechnologie gGmbH (ZELT), functioning as the alliance coordination along with Automation and Software Günther Tausch GmbH (autosoft), Bio Eichenmühle GmbH and Co. KG, Hafen Vierow GmbH, and Neubrandenburg University of Applied Sciences. It ran from November 2020 to October 2022. "Physics for Food and Feed" ensures that the three key physical technologies can be deployed in the post-harvest area using the three key crops. It must be noted that UV-C treatment has been successfully used in industrial hygiene and extending shelf life in a brewery. The demonstrators for treatment of agricultural post-harvest crops with cold atmospheric-pressure plasma for microbe inactivation, both stationary (silo) and continuous (conveyor belt), are currently being optimized under production conditions. The studies of increasing yields for lupin protein extraction and removing alkaloids using pulsed electric fields to improve quality are being further developed and are ongoing. The objective has been the construction of needs-based and user-friendly demonstrators in collaboration with local small and medium-sized enterprises, which addresses the objective of the alliance of ensuring economic exploitation of all the development work. The objectives of "Physics for Food and Feed" are summarized in Figure 7.

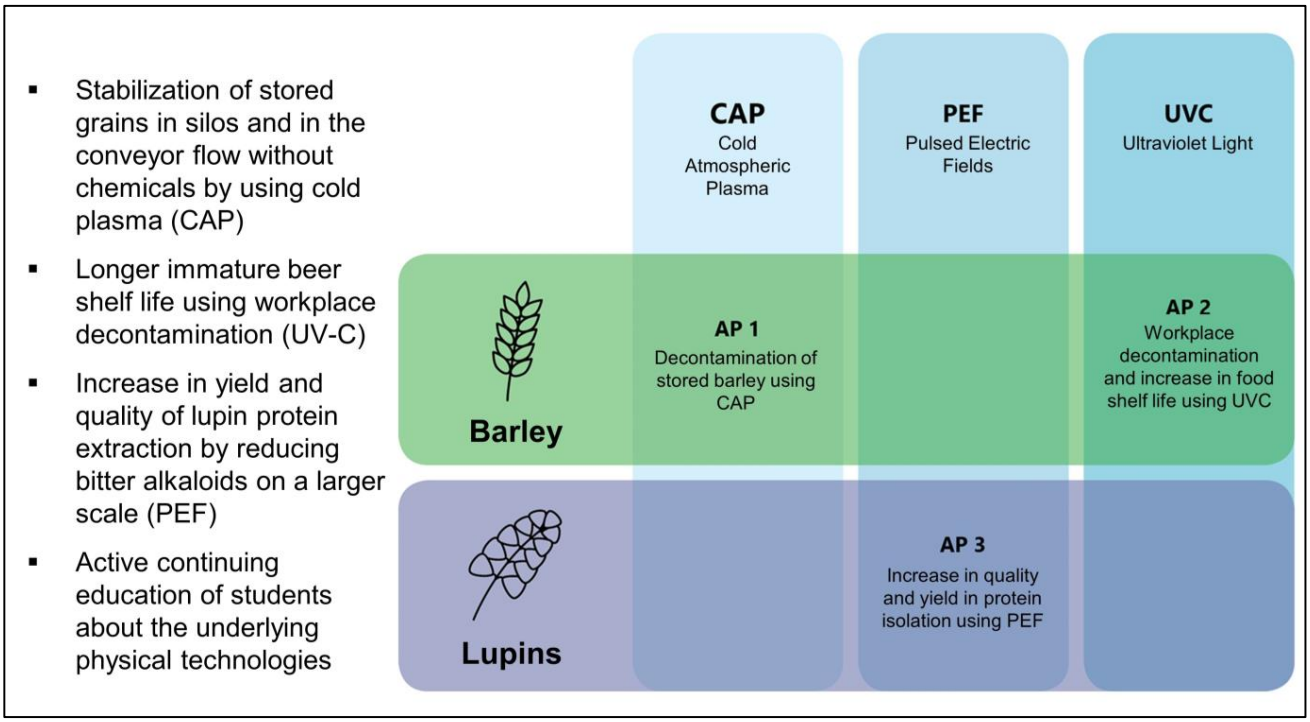

Figure 7. Objectives of the lead project "Physics for Food and Feed".

5.5. Lead Project IV: Physics for Environment

The lead project "Physics for Environment" aims to reduce harmful contaminants entering the environment through process, waste, and service water from agriculture and agrotechnical processing operations. In addition, adequate treatment of process, waste, and service water will enable recycling of such water back into production processes and thus to a reduction in the need for fresh water. The focus of the lead project is sustainable

physical methods for water treatment. Alongside the laboratory trials, a demonstrator is now installed that enables various physical processes (ultrafiltration, UV-C irradiation, ozonization, activated charcoal filters, ultrasonic treatment, pulsed electric fields, and plasma treatment) to be carried out, whether alone or in combination, under the relevant conditions. The Leibniz Institute for Plasma Science and Technology e.V. (INP) coordinates "Physics for Environment". Other partners are Cosun Beet Company GmbH and Co. KG (the Anklam sugar factory), Harbauer GmbH, and PRE Power Recycling Energyservice GmbH. The studies are proceeding according to schedule, so it can be assumed that all project objectives will be achieved in the current funding phase.

5.6. Lead Project V: TPP—Transfer, Procedures, and Permissions

The lead project "TPP—Transfer, Procedures, and Permissions" was conducted from January 2021 to December 2022. It included construction of suitable demonstrators for the physical treatment methods selected in the lead projects, clarification of questions relating to approval, and transfer of results to all business areas, e.g., as part of a living lab. This cross-section project has been managed by Neubrandenburg University of Applied Sciences together with the partners PiCA Prüfinstitut Chemische Analytik GmbH, TIGRES GmbH, and the Leibniz Institute for Plasma Science and Technology e.V. (INP). The first demonstrators were completed in the early stage and are currently in use, which has been a crucial step to ensuring economic exploitation. The underlying standard operating procedures (SOPs) have been prepared. A survey was conducted in the living lab, and the results of this survey have been integrated into the further development of the strategy. Clarification of the approval prerequisites for the treatment methods was recognized as a rate-determining step for the overall project and was promoted in 2022 as a focus in line with the criteria for fundability.

5.7. Cross-Section Project VI: Communication

The cross-section project "Communication" is managed by the Leibniz Institute for Plasma Science and Technology e.V. (INP). It ran from July 2020 to June 2022. As part of the "Communication" project, various interest groups were informed comprehensively and transparently from a central source about the overall project. The project increased awareness and acceptance of the technologies used, as well as the overall alliance project "Physics for Food". Based on a communication concept developed at the outset, communication instruments and concrete communication actions, as well as criteria for monitoring success, were defined. A website (www.physicsforfood.org), flyers, digital project presentations, a touch display with project information, and a trade-fair booth with the corporate design of the project were developed and used for specifically targeted communication. A "Communication" subproject supported and initiated the networking with other external groups of stakeholders, such as the positioning of articles as part of the BMBF initiative, "Year of Science Bioeconomy", or public appearances at events run by the marketing association of Mecklenburg-Western Pomeranian agriculture and food industry (Marketinggesellschaft der Agrar- und Ernährungswirtschaft Mecklenburg-Vorpommern, AMV). Due to the coronavirus pandemic, some of the communication activities based on citizen dialogues, such as public events (e.g., M-V Day, court festivals) and building personal contacts, could not take place as planned. The actions have in part been replaced with digital formats and online presentations. Meetings with interest groups, associations, and government were postponed to early 2022.

5.8. Cross-Section Project VII: Strategy Development

The cross-section project "Strategy Development" has been conducted parallel to the overall project with the aim of developing the alliance strategy. It ran from January 2021 to December 2022. The project partners were the three coordinating institutions, with the Leibniz Institute for Plasma Science and Technology e.V. (INP) in a leading role, as well as Neubrandenburg University of Applied Sciences and Ceravis AG. The project contributed fundamentally to the implementation of the alliance strategy. It created the foundation for ongoing refinement of the strategic alignment of the alliance, taking into account internal

and external influences, and identified and addressed possible barriers to and potential for innovation. Continual and explicit discussion with the higher-level strategy groups ensured that the overall project was continuously refined. The necessary instruments and processes for strategic controlling were developed and established in their entirety early on so that continual review and, if necessary, adaptation of the strategy is assured. The advisory committee and the alliance assembly were continuously, comprehensively, and promptly informed and included. In an initial strategy workshop phase between January 2021 and October 2021 using the established participative approach, the alliance strategy until 2025 and beyond was developed. Consideration of the value chains and commercialization steps increasingly came to the forefront in the process and were targeted in the second strategy workshop phase in 2022.

5.9. Investment Projects

The work conducted by the alliance will also be supported by investment projects funded by the German Federal Ministry of Education and Research (BMBF). The investments of 2021 and 2022 accelerated the upscaling of systems and their testing for relevant production volumes under conditions appropriate for their application using pre-commercial prototypes, expanded the use of mobile systems for treatment and diagnostic capacities by users on site, and created better diagnostic opportunities in accordance with DIN standards. This means that the alliance activities can be progressed to market launch more rapidly.

6. State of Implementation in Winter 2022 and Conclusions

The alliance "Physics for Food" creates an innovative, sustainable, and environmentally friendly structural change for agriculture and food production in the northeast coastal hinterland using advanced physical technologies. A strategy-driven, participative approach aims to realize alternatives to agricultural chemicals. Regional expertise and potential across science, business, and society are bundled and expanded to identify solutions for the challenges resulting from climate change (preservation of biodiversity and food security). Various lead projects consider the overall life cycle of the plants, from seed to processed food.

In the first funding phase, evidence was provided of the effect of treatment with plasma, pulsed electric fields, and UV-C light. This includes decontamination of seeds, enhancement of plant growth, and increase in stress resistance. Treatment systems and processes for extending the shelf life of foods, increasing hygiene in food production, and cleaning of process water were successfully introduced. Future potentials were also identified, such as technologies for "vertical farming", storage of bulk goods, rapid tests for plant health, and soil regeneration.

Over the course of the strategy implementation, a target–actual analysis was devised and the strategic development was adapted as necessary. It builds in part on trend analyses and benchmarks, consultation with relevant organizations, and citizen dialogues. New scientific knowledge and current studies on climate change and social and political framework conditions were also considered with a focus on local food production in an international context.

This approach reinforced the cohesion of the alliance, enhanced the exchange of information between the partners, and inspired innovations and new (business) ideas. The lead projects are running according to schedule and are achieving positive results to form the basis of developments in this funding phase and planning for the second funding phase. In the second phase, these developments will be sustainably established. This will be accomplished by path modernization that addresses the international markets, as well as by path creation using regional, circular models. This disruption of existing business models allows for local stakeholders and new regional participants in innovation, such as agriculturalists and young entrepreneurs.

Figure 8 shows the current status of the contributions to achieving the objectives of the collaborative project "Physics for Food", which are described in more detail in the following sections.

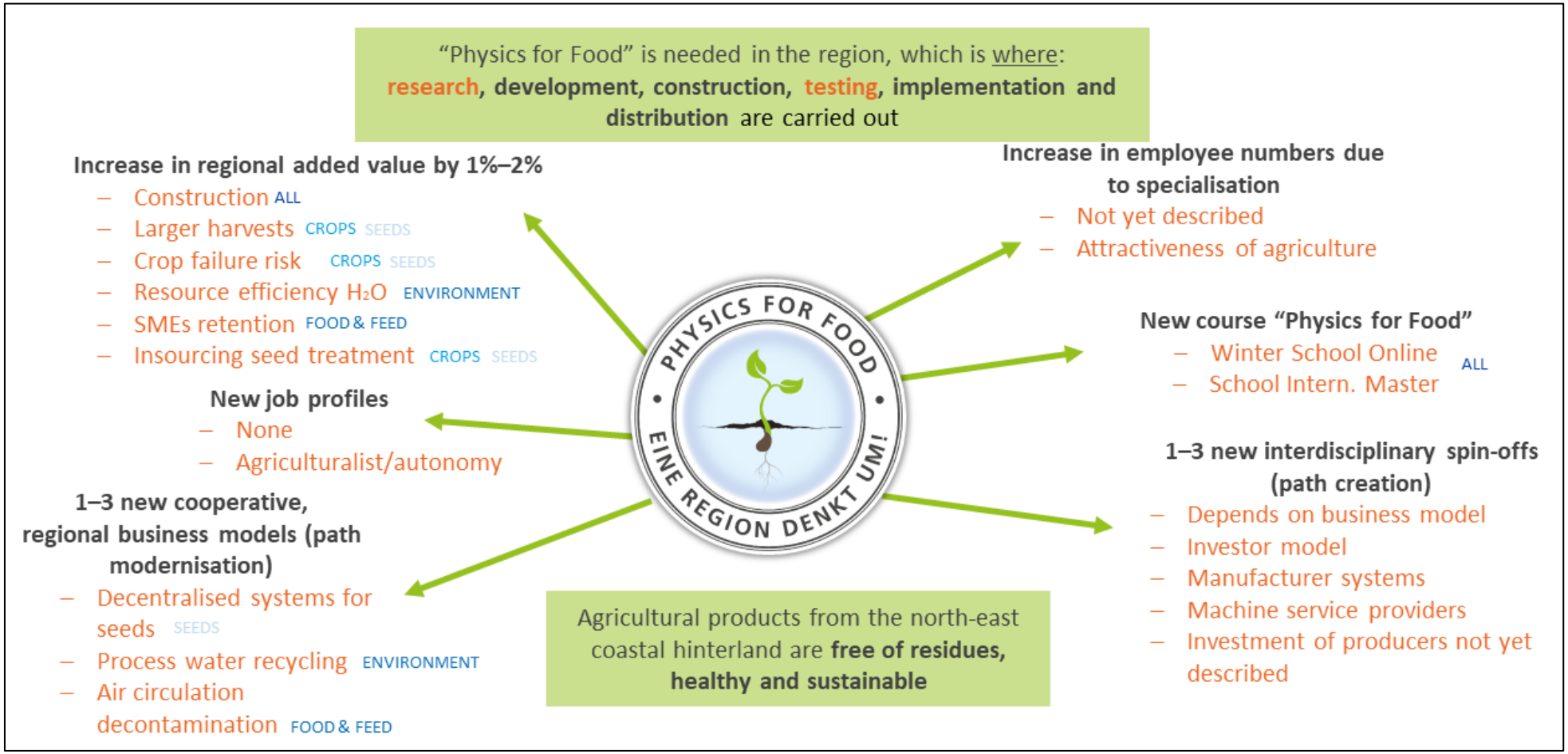

Figure 8. Current state of the contributions to achieving the objective of "Physics for Food" with reference to the different lead projects.

6.1. The Target Region

The geographic boundary of the northeast coastal hinterland is derived from regional challenges (persistent structural change processes in agriculture, low industrial base, severe demographic shifts) and the expertise that is present in the region. The latter includes the traditional anchoring of conventional large-scale agriculture in the region, an innovative food industry characterized by small and medium-sized enterprises, and research institutes that are renowned both nationally and internationally. For successful implementation of the project, there has been no need to date to redefine or adjust the region.

6.2. Partner Structure and Geographic Network

The outcome of the strategy process and the implementation phase as part of the BMBF-funded WIR! initiative is a constellation of stakeholders drawn from agriculture (agriculturalists, plant production, agricultural economy), construction, food industry, science (physics, agricultural science, plant research, food sciences, risk analysis), and trade and society (politics, associations, chambers of industry and commerce, finance) that are unique in the region to date (see Table 1). The trust-based and strengths-oriented collaboration has drawn together complementary core competencies. This partner structure, which can also be strategically expanded in future, can and will build regional and transregional value chains.

6.3. The Field of Innovation

The field of innovation of the alliance is developments and applications of disruptive technologies in agriculture and food production. The alliance thus creates a new interdisciplinary and transdisciplinary research field with the potential for path creation, path diversification, path modernization, and social innovation. The values of the regional population are incorporated and taken into account to support, for example, the development of regional business models. Using this participative approach to deal with a highly topical issue, the research and development alliance can shape structural change and thus the associated cultural change using the traditional strengths and competencies that exist in the region. This rapidly changing field of innovation, particularly when considered from an international perspective, addresses both regional and global challenges in agriculture and food production ranging from biodiversity loss to soil health and food security. A SWOT analysis of the current status of the contributions to achieving the objectives of the collaborative project "Physics for Food" was carried out and is shown in Figure 9.

6.4. Intermediate State for Achievement of Objectives

The first short-term development objective was linking the regionally based economic partners with the scientific institutions involved and building up a reliable operational level in the first year of the implementation phase. This development objective has already been achieved. A solid, functioning network is established. Currently, the various physical processes in the planned application areas have largely reached at least the laboratory and glasshouse scale, and in some cases, they have already undergone comparative and specific testing in precision field trials over a year at various sites in Germany. For the applications in agricultural plant production, this includes successful completion of open-field trials on a plot scale. The fundamental effectiveness and suitability of the selected physical methods for decontaminating harvested crops and improving digestion of processed crops were also demonstrated using physical, chemical, and sensory analyses (proof of principle). For the treatment of various process, waste, and service waters from agricultural production or processing using physical methods, the effects on the degree of contamination and content of harmful substances were analysed and quantified. A demonstrator in which the new physical processes will be integrated has already been constructed. All work with short-term development objectives has proceeded according to schedule and has been successfully implemented.

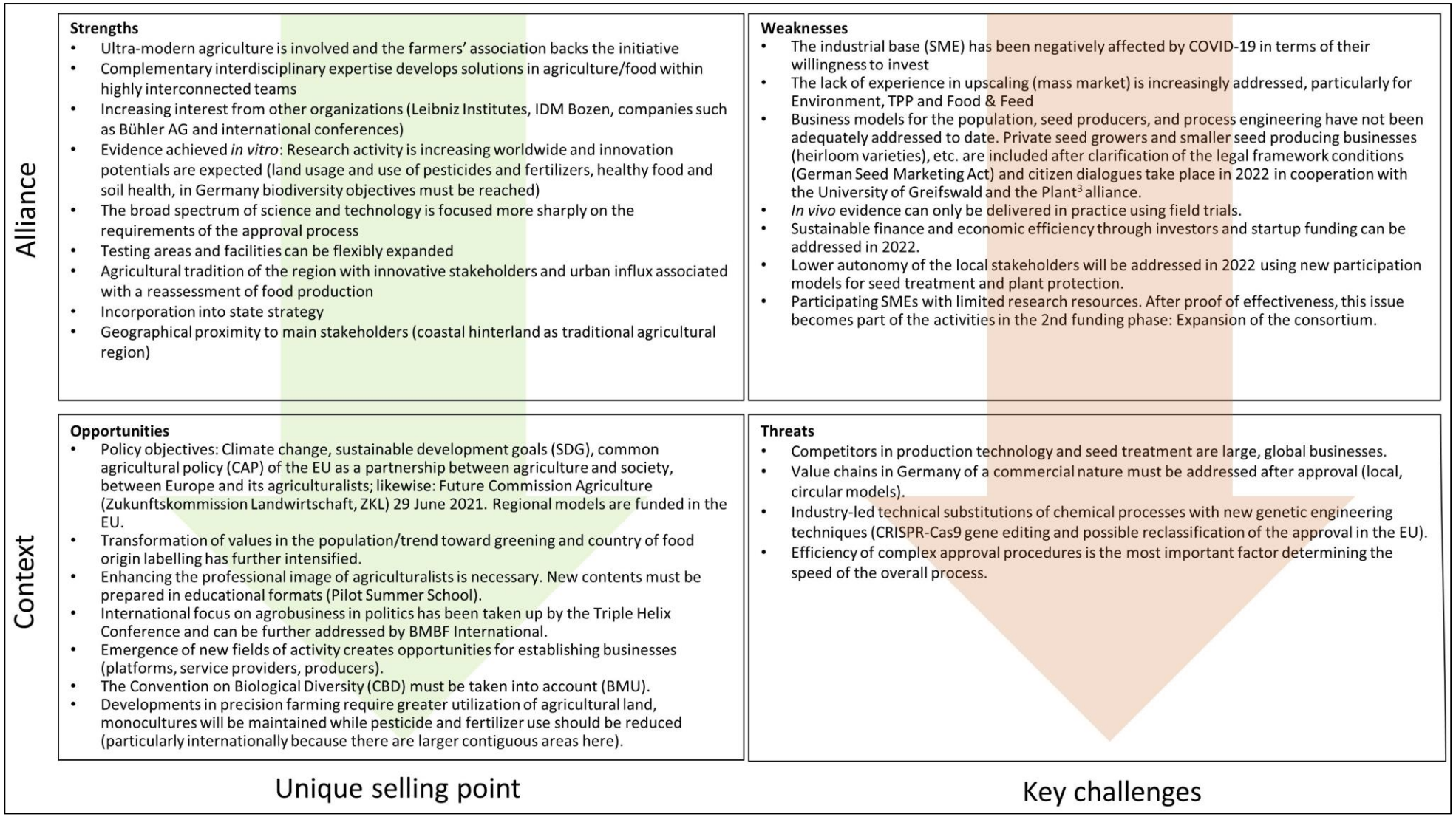

Figure 9. SWOT analysis of the field of innovation "Physics for Food".

The medium-term objective up to the end of the second implementation phase after five years is to transfer the physical processes to additional precision field trials and large-scale fields of practice of the businesses in the region to demonstrate project outcomes using examples. This includes upscaled systems for decontaminating stored goods at the relevant alliance partners. Systems for improved digestion of processed crops have already been implemented over the course of the project. Likewise, work on process water treatment was completed in late 2022. Aspects of securing a workforce and qualifying and creating new job profiles and educational materials are also included in the medium-term objectives.

The research and development alliance has not yet had to deal with fundamental barriers to progress while exploiting the potentials for innovation. Any competing developments are researched and analyzed on an ongoing basis. This work in strategy development has been integrated into the focus of the new concept for the second implementation phase.

6.5. Current State of Implementation of Strategic Approaches

The strategic concept described in Section 2.4 is continuously validated and developed. To this end, the scientific and technical results will be subjected to critical analysis, markets and customers will be integrated, and social and political requirements will be considered.

The lead project "Strategy Development" is conducted in parallel with the alliance as a whole and the lead projects specifically in the development and implementation of specific solutions. At the level of the overall project, the advisory committee and the alliance assembly continuously reviews and adapts the strategy based on the results achieved and takes into consideration possible changes in internal and external factors (see Section 4. "Organization and management structure"). Any necessary adaptations to the strategy were and are discussed in a dialogue with the funding bodies and the management of the overall project and decided by the alliance assembly. The integration of an external management consultant ensures neutral moderation of the strategy adaptation process and strategy implementation. These general approaches have proven successful and will be retained.

In concrete terms, a check of premises was carried out in early 2021 together with the alliance partners in accordance with the participative approach. The innovation potentials forming the higher level and binding objectives of the alliance were once again confirmed in this process in May 2021 by the advisory committee and the alliance assembly. Surveys and interviews were conducted with stakeholders in the field of innovation regarding their expectations and priorities for the field of innovation. They validated the focuses and direction of the alliance and, for example, revealed potentials that had not yet been considered. This approach enables the interests of business, science, and society to be related to one another and aligned. The results were combined in a new SWOT analysis, and the resulting key challenges and opportunities were discussed in the alliance in August 2021.

External factors are taken into account by continuously observing the markets and customer needs along with social, political, and regulatory developments, and are integrated into strategic considerations. For example, the coronavirus pandemic was reflected in an increased demand for locally produced food. Current market analyses and feedback from organic producers in Mecklenburg-Western Pomerania show that the coronavirus crisis has led to growth in sales for the German organic market. The organic food trade thus reported an increase in sales of more than 30% to 60% [35]. At the same time, regional areas are experiencing an influx due to the pandemic, e.g., as a result of greater acceptance of flexible work models, and this is accompanied by the consumer behavior of the usually urban newcomers. These trends may well be sustained and continue to shape the northeast coastal hinterland and will be considered strategically. Furthermore, German and European policy on more ambitious climate and biodiversity goals has become established since the start of the implementation phase and aims to develop concrete measures and objectives to which the potential innovations of the alliance can be adapted to a large degree. Other technological approaches continue to be monitored and strategies for action that are relevant for the alliance are being developed.

As a result of the strategy development process to date, the project advisory committee and the alliance assembly voted in September 2021 and October 2021 to continue the strategy-driven approach and to submit the expanded strategy concept with a clearer focus. The collective value proposition (innovation potentials) therefore remains a consensus within the alliance.

6.5.1. Area of Activity 1

The area of activity 1 (collaboration between business, science, and society) will continue to be facilitated primarily by carrying out joint research and development projects (lead projects) with regional industry. As early as the concept phase of the project, an interdisciplinary and transdisciplinary network of those involved in the alliance was established that has since been expanded by additional expertise. The results achieved to date are based on close collaboration between the scientific research institutes and partners from industry. The alliance is made up of one-third science participants and two-thirds business partners. It has proven to be stable, robust, and competent, enabling any constraints on development that have arisen to be resolved using solutions developed internally by the network. The cooperation with local small and medium-sized enterprises has already been greatly strengthened. Regional companies such as seed producers, those undertaking field trials, plant manufacturers, and transregional and international agricultural consultants all contribute concretely to the project. Development projects were designed based on concrete enquiries from and the needs of business partners. The demonstrators and processes developed over the course of the first implementation phase are utilized in the relevant lead projects. They form the basis of the planned business spin-offs or exploitation by established equipment manufacturers. Overall, future transferability to other areas of application is considered for the ongoing research and development projects. The preliminary work on clarifying the approval requirements for the physical treatment methods for the purpose of their future market launch reinforces the commitment of the business partners.

The innovative physical technologies were publicized using a range of articles in print media, radio, television, and on topical internet platforms throughout the region and beyond. The various communication measures help to develop and anchor the field of innovation in the region and beyond using messages specific for target groups that are understandable and enable examination and discussion outside scientific circles. With positive representation, acceptance for the processes among the different target groups rises, e.g., the public or potential users from agriculture and food production.

6.5.2. Area of Activity 2

The area of activity 2 (boosting the innovative capability of regional businesses) is realized by generating disruptive–innovative process steps and developing effective product innovations by the project alliance. For example, the mechanism of action of the physical seed treatment and the treatment of growing plants in precision trials at various sites throughout the region and across Germany was tested, completing the move from the laboratory into the field that is needed for successful integration into practice in this early phase and thus laying the foundation for acceptance by business. The investigations completed on the impact of the physical processes on a scale that is relevant for practice in plant production contribute to reliably quantifying the effects achievable under real-world conditions for presentation to other interested businesses and thus promoting sustainable wide-spread introduction of successful cases. Visible progress in the application of the physical methods, system dimensioning, and logging and analysis of the data from the treatment samples that are generated all testify to the existing innovative capability of those partners from science and business that are involved, and this capability is enhanced through the cooperation. This progress supports the visibility and acceptance of the methods within and outside the alliance and lays the groundwork for their successful implementation. Ultimately, the applied research completed to date has created a pool of data for the budding innovation to ensure that it is workable.

The developments initiated to date by the "Physics for Food" project in the region primarily include further research and development activities on possible additional applications with both existing and new partners, consequently driving the expansion of the cooperation between business and science.

6.5.3. Area of Activity 3

Area of activity 3 (qualification or acquisition of young talent for business and science) aims to expand and enhance the professional field of agriculturalists, which will, in future, increase the attractiveness of the regional area and grow the expertise of skilled professionals. The preparation for this long-term task has already been started by communicating with professional associations, such as the local chambers of commerce and industry and attending trade fairs such as MeLa. More specific education and training opportunities are currently being developed. The plans for a spring school for master's students in May 2022 and May 2023, which has been designed as a prototype and will later be integrated into the regular teachings of Neubrandenburg University of Applied Sciences, proved to be a successful tool for communicating the project contents to students and future leaders of food technology. In the spring school, 25 international master's students were taught the skills needed to deal with the challenges of sustainable agriculture by applying new technologies and stakeholder approaches to develop and implement holistic concepts. Concepts such as sustainability, resilience, soil health, plant physiology, new varieties, processes, physical processes versus chemical, and yield development under changed climatic conditions were conveyed. The aim was partly to teach participants how technological and social innovations can be introduced and managed. The spring school familiarized future skilled professionals with fundamental issues in the field of innovation. Furthermore, regional collaborative relationships with other scientific institutes, such as the University of Greifswald or major state-funded regional projects (such as the Plant^3 project), were expanded as part of the spring school.

Results from the lead project "Physics for Crops" for monitoring and phenotyping using image analysis are already being incorporated into teachings at Neubrandenburg University of Applied Sciences in the 2021/2022 and 2022/2023 winter semesters as part of a master's research seminar with German and Argentinian students. Plans for a new study module at the same site have been initiated. It will be based on the alliance themes, and the results and innovations generated will be transferred through the graduates to regional and transregional businesses. These highly topical and modern study materials will not only qualify skilled professionals in the region and for the region, but will also expand and enhance the professional image of agriculturalists.

6.6. Public Relations Activities

The public is being informed about the objectives and activities of the alliance through active media relations. A range of media articles were thus generated through press releases and targeted positioning. This involves both specialist media, such as *VR Agrar*, *Lebensmittelbrief*, or *f3 farm.food.future*, and public media, such as *NDR 1 Radio MV*, *Schweriner Volkszeitung*, and *Norddeutsche Neueste Nachrichten*. The alliance is also visible on online platforms, such as the initiative, *Wissenschaftsjahr Biodiversität* (Year of Science Biodiversity), that is supported by the German Federal Ministry of Education and Research. The media articles have, to date, reached more than 13 million readers, more than 5 million TV viewers, and about 740,000 radio listeners. At the start of the overall project, a program on ZDF *heute Journal* and online articles in leading media, such as *Welt* and *FOCUS*, reached a broader German public. The public relations work aims, on one hand, to generate acceptance of the developed technologies by the public, government, and advocacy groups, such as environmental associations. On the other hand, it will ensure that the technologies are familiar on a large scale to potential users in agriculture and the food industry. Comprehensive and transparent communication and information from the alliance is delivered from a central source using contents and channels that are specific for the target groups.

Strategically designed PR and marketing campaigns are supplemented by event formats that enable personal exchange of information and participation by external stakeholders.

Another essential channel for information about the objectives, technical processes, and partners involved in the project is the website physicsforfood.org, which registers about 2000 views per month. The website also presents innovations resulting from the project and serves as a communication channel for interested parties. Despite restrictions due to the coronavirus pandemic, directly exchanging information in line with the participative approach at face-to-face events with the specialist public and the broader public was possible. At last year's German agricultural trade fair MeLa (16–19 September 2021, Mühlengeez) alone, about 400 visitors to the "Physics for Food" booth learned about our technologies. Online events have also been used successfully to approach relevant transregional and international target groups. The online conference IWOPA–3rd International Workshop on Plasma Agriculture (1–3 March 2021) organized by INP enabled about 70 internationally renowned researchers to intensively exchange ideas about the latest research results from around the world. "Physics for Food" was also presented as part of two conferences organized as online events by the Triple Helix Association. Up to 500 people from science, industry, and governments discussed regional innovations (XVII Triple Helix Conference, Cape Town, 2019) and innovations for a sustainable future (XIX Triple Helix Conference, Sao Paulo, 2021). In Brazil, the abstract of a presentation by "Physics for Food" to the international expert audience was nominated as one of three contenders for the Best Practical Case Award. There were intersections with other WIR! projects as part of a presentation at the online regional forum "Wissenschaft im Dialog" (Science in Dialogue, 29 May 2021) of the WIR! initiative "Klimaschutzregion Ilmtal" (Ilmtal Climate Protection Region).

7. Prospects and Focusing on the Strategic Objective by Future Activities of the Alliance

7.1. Expected Impact on Region and Regional Developments

The northeast coastal hinterland is also shaped by the general shift toward greater demand for healthy food and more environmentally friendly agriculture and food production. Participation in the project by many regional and transregional businesses from all sectors of agriculture and food production as funding recipients, subcontractors, and associated partners emphasises the openness to innovation and the innovative spirit of the region. The geographic definition of the northeast coastal hinterland as the region of the alliance "Physics for Food" is established and will be retained in future. The economic and social challenges that will be faced by the region over the long term are expected to remain largely unchanged. The demographic shift is continuing on the whole (ageing population, death rate higher than the birth rate), with a recent increase in migration to the region recorded compared to losses from the region. While in 2019 there was a net gain due to migration in the Vorpommern-Greifswald district of 944, in the first year of the COVID-19 pandemic, 2020, it increased to 2070. In the same period in the Mecklenburg Lake District, this number increased from 748 in 2019 to 1789 persons in 2020 [36]. Migration in both districts in 2019 was, however, below the state average [37]. Whether urbanites' interest in life in the rural region is sustained beyond the coronavirus pandemic or even increases remains to be seen. More flexible modes of working on one hand and the emerging expansion of the internet network in the region on the other could also act as drawcards for innovative businesses and startups. This trend will not remedy the lack of skilled professionals in the region, but when considered from an optimistic viewpoint, the influx from urban areas could also attract skilled personnel to the region. It therefore appears all the more important to enhance transfer to society in the next funding phase. The trend to greater demand for local and sustainably produced food will also remain the focus of the alliance. It can be assumed that this trend will continue to rise along with the general shift toward greater awareness of environmental and climate issues.

A powerful innovation ecosystem for agriculture and food production is currently developing in the region. This is demonstrated by initiatives and projects over the last three years in which many alliance partners from "Physics for Food" have been involved in related topics. This includes (a) the *WIR!* alliance *ArtIFARM* located at Stralsund University of Applied Sciences that aims to support the use of artificial intelligence in agriculture; (b) the *HiRegion* project at Neubrandenburg University of Applied Sciences for knowledge transfer from the entire University to society; and (c) the RUBIN alliance "MaltFungiProtein" that developed a process to transform brewery waste materials to fungal proteins. Exploitation of biogenic residues primarily from food production is also the subject of the (d) "biogeniV" project in the WIR! alliance in which the INP is also involved as a coordinating institution. Another project located in the region is the (e) *WIR!* alliance Plant^3, which implements innovative strategies for high-quality refinement of plant-based raw materials from coastal waters and wetlands. The Bioeconomy Innovation Center in Anklam established in September 2020, which aims to bundle services and training in the food and pharmaceutical sector, must also be mentioned in this context. The Centre for Life Science and Plasma Technology in Greifswald that is soon to be completed will become another specialist research, service, and startup center in the region. The Fraunhofer Center for Biogenic Value Creation and Smart Farming is also planned in Rostock for data-based, intelligent technologies for highly customized and automated agriculture. The alliance "Physics for Food" will be able to make use of synergistic effects as part of this innovation ecosystem.

7.2. Future Contribution to Regional Structural Change

The collaboration with regional small and medium-sized enterprises to implement innovations in competitive processes, the design of new study materials at Neubrandenburg University of Applied Sciences, and the increased international interest in "Physics for Food" (requests for collaborations, presentations at international meetings) have already made considerable contributions to structural change in the northeast coastal hinterland. The field of innovation will continue to gain in importance in the region. This is justified both by a general political and social shift to more sustainable agriculture and food production and by the specific conditions of a region that is traditionally agricultural in character (economic and scientific competitive environment, innovative agriculturalists, fit with the Regional Innovation Strategy (RIS) for intelligent specialization 2021–2027 of the state of Mecklenburg-Western Pomerania).

Thanks to the many opportunities for diversification to other cultivated plant species, processing operations, and ultimately regions, the overall project will act as an effective incubator, particularly for startups. Future consolidation of the innovation process will become self-sustaining in that the results from businesses will be directly implemented, further developments from businesses and research institutions will be pursued in bilateral projects or, in individual areas, ongoing problems will be explored in publicly funded projects (collaborative research).

Particular focus will be placed on supporting young entrepreneurs. The spring school and the subsequent teaching sessions at Neubrandenburg University of Applied Sciences must first and foremost be mentioned here. Support provided specifically for startups, such as the newly created funding program from the German Federal Ministry of Food and Agriculture, which supports innovative agricultural-related startups in the early financing phase in cooperation with the Landwirtschaftliche Rentenbank, a development agency for agribusiness and rural areas, should also be mentioned here [38].

By means of the cooperation between research institutions and businesses, innovative solutions for economic problems will be developed. The increased demand from the alliance business partners for such collaborations is most readily demonstrated by the increased proportion of industry in the overall project. The share of capital in the project costs has increased from 18% to 27% as things presently stand. Additional parallel projects have already been or will be submitted in the coming months. In most cases, these projects are collaborative projects between business and science. Along with their

active involvement in the alliance, this demand demonstrates the affinity of the businesses with innovative solutions and their recognition that such solutions are the means to retain and expand their competitive employment potential. To boost the innovative capacity of regional businesses, cooperative financing models incorporating venture capital companies will also be tested to provide small and medium-sized enterprises, such as plant manufacturers, agricultural operations, and the food processing industry, with the opportunity to implement technological reforms in the sense of generating disruptive–innovative process steps and methods. In general, it is expected that by implementing project results and, for example, generating intellectual property rights, business strategies will be adapted and product and service portfolios will be modified and thus the competitiveness of regional businesses will be increased.

To date, the alliance has been visible on a technical level primarily at international conferences. The XVII International Triple Helix Conference 2019 in Cape Town, South Africa dealt with the influence of science and technologies on regional innovations and socioeconomic development. The XIX International Triple Helix Conference 2021 in São Paulo, Brazil was dedicated to innovations for a sustainable future. Parallel to this, concrete activities are planned for a scientific exchange and joint projects with the São Paulo State University (UNESP) that will be supported by CAPES (Brazil) and DAAD (Germany). A consortium of Chinese companies and institutes have also become aware of the project and expressed interest in the experiences of the alliance and a possible collaboration. The importance of "Physics for Food" was also a critical criterion for the Ministry of Economics of the state of Mecklenburg-Western Pomerania in initiating and funding a collaboration on individual relevant issues with Peter the Great Polytechnic University of Saint Petersburg. A corresponding memorandum has since been signed by both parties with the state ministry. The international interest in "Physics for Food" is also reflected in the steadily growing page views of the English-language summary on the website physicsforfood.org, which are about 10% higher than previous visitor numbers. As part of the broad communication of the project results about the mechanism of action of the technologies being researched, for example, through presentations at public affairs or articles in public media such as daily newspapers, radio, and TV, the alliance is contributing to increasing the receptiveness of citizens to innovations. Demonstrating physical alternatives to conventional agrochemicals supports openness toward more sustainable and environmentally friendly agriculture in the region. Thanks to the regional composition of the alliance partners from science and business, the innovative capacity within the region is also practically demonstrated and thus increases confidence and trust in the population regarding the opportunities for a sustainable structural change.

7.3. Influence of External Factors on Future Activities

The alliance follows current developments in the sector and technologies with great interest, not only because this identifies competitive situations, but also because new potential applications and combinations can be determined. From the viewpoint of the alliance, there are no national or international developments that challenge the alliance strategy. It must also be noted that the current political strategic direction and social trends corroborate the alliance strategy. The demand for alternative processes for agriculture is rising in the context of the European "Green Deal" and "Farm to Fork" strategies and the "Food 2030—Pathways for Action" initiative. The efforts and recommendations of, for example, the agricultural strategy for 2035 or the future commission for agriculture also aim to reduce usage of or to identify adequate substitutes for synthetic fertilizers and chemical plant protection products. Current sectoral and technological developments will be analyzed in the monthly project reports from the lead projects carried out by the alliance. Through additional research as part of the strategy development and with the incorporation of the business partners, this will generate a truly complete picture of current developments in our field of innovation from the viewpoint of the alliance. Therefore, the alliance continuously tracks current developments in the sector and technologies with

great interest, not only because this identifies competitive situations but also because it can determine new potential applications and combinations.

The alliance sees approaches for combining processes in the development of monitoring technologies. Work from ATB Potsdam, with which the INP has cooperated on related areas for over 10 years, on the subject of detecting plant diseases using sensor-carrying vehicles must be mentioned here. In this area, combining this work with our developments on UV-C treatment of weeds and application with plasma-treated water could be developed to combat plant disease. Similar issues such as those dealt with in our alliance but using other cultivated plant species are also being investigated at HAWK Göttingen, but the underlying studies have only just been completed. Drones and satellite-supported monitoring processes that are being developed by some groups are either not suitable for combination or only aim to reduce the application of chemical plant protection products ("Precision Farming", Rumex).

For the storage of harvested crops, initial laser-supported processes were developed on a laboratory scale to detect and tackle beetle infestations (Julius Kühn Institute, Fraunhofer IZM). Initial discussions with future providers of this technology have already been held by the alliance. A combination with technologies developed in the collaborative project "Physics for Food" appears entirely plausible and desirable. In the international scientific arena, there has recently been an observed increase in activity aimed at establishing research groups or enhancing existing groups to deal with the subject of "Physics in agriculture and food production".

Regarding the resistance of plant populations to drought stress, studies have been published that concentrate on varieties that are suitable for cultivating in drier regions thanks to their initial genetic makeup [39–42]. The alliance views these studies as competition only to a certain degree because "Physics for Food" focuses on technologies in its subprojects that preserve the full range of varieties and species rather than driving the loss of diversity of varieties and species. Using the technologies that are used in our project, it appears possible to not only preserve the diversity of varieties but even to increase it (improvement in the germination capacity).

It must also be noted that the current political strategic direction and social trends corroborate the alliance strategy. The demand for alternative processes for agriculture is rising in the context of the European "Green Deal" and "Farm to Fork" strategies and the "Food 2030—Pathways for Action" initiative. By 2030, the application of chemical pesticides must be lowered by 50% and the use of hazardous pesticides must be reduced by 50%. The efforts and recommendations of, for example, the agricultural strategy for 2035 or the future commission for agriculture, also aim to reduce the usage of or to identify adequate substitutes for synthetic fertilizers and chemical plant protection products [43]. These strategies are directly integrated into future funding programs that thus enable further research studies in the field of innovation and of the innovation potentials of the alliance.

The field of innovation being developed by "Physics for Food" contains enormous potential because the development work is not limited to just the plant species considered here, but can be expanded to a range of other plant species. This also includes related sectors and technologies and different market segments and business models. The following examples show that along with direct activities in the overall project "Physics for Food", work has already been started or the planning is well advanced extending beyond the alliance.

- The *LuzNutz* project, which is funded by German Federal Ministry of Food and Agriculture (BMEL) and has already started (1 February 2021–31 January 2024), aims to expand and improve the cultivation and exploitation of small-seeded legume lucerne in Germany.
- In the BMEL-funded digital experimental field *AgriSens DEMMIN 4.0* (1 March 2020–28 February 2023), eight partner institutes are working together on practically relevant processes for utilizing remote sensing data in plant production, including for crop

monitoring and demarcating low-yield areas, and designing new training modules for transfer to practice.

- The German Federal Environmental Foundation (DBU) is currently funding the *PALEA* project (1 May 2020–31 December 2021), which is investigating gentle extraction from algae using pulsed electric discharges and its application.
- In the related *WIR!* alliance *Plant*^{3} the *LeguLand* project, which investigates improved protein extraction from legumes, has been funded since 2022.
- The RUBIN project *MaltFungiProtein* (2022–2025), funded by the BMBF and to be implemented at Neubrandenburg University of Applied Sciences, is investigating how fungal proteins can be extracted fermentatively from bypass flows and used in foods.
- The German–Chinese collaborative project *PlasAMR* ("Development of plasma-based decontamination processes for the inactivation of multidrug-resistant microorganisms and transformation of antibiotics") as part of a BMBF tender has already been positively reviewed by experts and will soon receive approval.
- The EU *Horizon Europe* project *Aqua+* ("Plasma-based advanced oxidation processes for water") with a total of 17 European partners has already been submitted, but the results of the expert review have not yet been received.
- In the European context, inclusion of the INP in the COST network *PlAgri* ("Plasma application for sustainable agriculture and food production") must also be mentioned (2020–2024).
- There is currently a project that is in detailed planning for submission to the funding line: "Knowledge Transfer by Standardization" of the German Federal Ministry for Economic Affairs and Energy (BMWi). The aim is to define the constituents of plasma-treated water for a DIN SPEC and thus to specify a quality standard.
- At the institutional level, initial laboratory trials to increase diversity in cultivation ("heirloom varieties") are being conducted in cooperation with the Association for the Conservation and Recultivation of Crops (VERN e.V.) and the Eberswalde University for Sustainable Development.

Other project ideas or initiatives involve water treatment in aquaculture, decontamination of wastewater in hospitals, and meat processing operations, as well as livestock farming.

7.4. The Future of the Field of Innovation

To thematically anchor the field of innovation deeper in the region, the alliance has reviewed and refined its strategy for future activities for the purpose of commercial exploitation. The focus is on clarifying approval issues and possible effects of the technologies used on the environment, increasing acceptance of innovations in business and society, approaching and attracting users and investors, and transferring knowledge to society, particularly using education and study modules. Another aspect for further thematic anchoring of the field of innovation in the region is expanding the research and development work into new fields of application (e.g., regeneration of agricultural soils, digestion of biomass as organic fertilizer). The alliance is pursuing a higher-level exploitation strategy that is driven by the ability to implement scientific knowledge in the context of regulatory, economic, environmental, and social requirements.

The economic competitive situation in the region is still shaped by large-scale agriculture and the upstream and downstream sectors that depend on it. The processing industry in agriculture is still only weakly developed and the potential added value for agriculture has not been exhausted. Nevertheless, in 2018, agriculture in Mecklenburg-Western Pomerania achieved the highest proportion of 2.4% of the total gross value added in a comparison of all German states (Germany: 0.9%). Plant production of €2.237 billion made up 51.4% of the production value (Germany 44.8%) [6]. The number of trainees in agriculture has increased slightly in recent years in Mecklenburg-Western Pomerania [44]. Agriculture thus continues to play an important role in the northeast coastal hinterland, a region that is traditionally agrarian. The alliance "Physics for Food" therefore aims, for the future, to better tap the existing potential for added value. The existing committed

involvement of the innovative companies in agriculture and food production is critical for this. To thematically anchor the field of innovation deeper in the region, the alliance has agreed on measures that guide the actions of all partners. Sustainable commercial exploitation is at the heart of these measures. Starting from the results from the first funding phase that are the most promising in this respect, the alliance will concentrate in the second implementation phase on appropriately selected aspects.

Work in the lead projects will continue to be systematized. Research designs will be prepared particularly in the area of pre-harvests (treatment of seeds and plants). The particular matrix of test criteria and methodological details will help to narrow future selection of methodological designs that will be pursued for the purposes of application by satisfying essential test criteria to focus on the most promising aspects and to rule out methodological designs that are ineffective in the early stages.

The opportunities inherent in digitalization for efficient and effective collection and analysis of research results will also be more rigorously utilized. Initially, digital platforms will be examined that are particularly well suited for collecting and utilizing data from agriculture and food production. The INP will contribute its experience in the construction of research data management systems. It is planned in the next step to develop and utilize a joint platform using the specific approaches and objectives of "Physics for Food". This systematization serves to provide the data necessary for the approval procedures.

Clarification of approval questions was identified as a pacemaker for exploitation and will be appropriately prioritized in future. One of the planned lead projects in the second funding phase will be dedicated to the approval prerequisites (see Section 7.5.5: Future Lead Project 5: Transfer). Different pathways to approval for the key technologies will be pursued separately. While it is assumed that approval issues for applications with pulsed electric fields and UV-C will be quickly clarified, this process is likely to be more elaborate for direct plasma treatment and the application of plasma-treated water. Based on the current status, the latter process in particular must undergo testing in accordance with the EU Regulation 1107/2009 concerning plant protection products.

Possible effects of the new technologies on the environment are included as a new topic and will also be considered by a dedicated lead project. While harmful effects are not assumed, it is very important to generate appropriate evidence, not least for approval and acceptance of the processes.

In relation to commercial exploitation, there will also be a greater focus on approaching and attracting users and investors. It is planned that the cross-section projects in strategy development and communication that support the research will be dedicated even more closely to this task. The activities for transfer to society will also be further expanded. Attracting and qualifying skilled professionals using new modules in vocational education and degree courses is planned to achieve this. Another aspect for further thematic anchoring of the field of innovation in the region is expanding the research and development work into new fields of application. Issues related to regenerating agricultural soils, digestion of biomass to produce organic fertilizers, and revitalizing rehabilitated or infertile soils will therefore be included as new topics.

The alliance is pursuing a higher-level exploitation strategy that is driven by the ability to implement scientific knowledge in the context of regulatory, economic, environmental, and social requirements. For the viewpoint of businesses, project results will be exploited within the collaborative agreements for the lead projects. The research institutions are seeking commercial exploitation paths for business creation, out-licensing, and alienation of intellectual property and scientific exploitation paths for publications, conference papers, and initiating further research projects.

Based on these premises, the managers of each of the lead projects and their partners have defined their own exploitation strategies that fundamentally determine the direction of ongoing and future work. They continue to discuss different paths and pursue different objectives with short-, medium-, and long-term exploitation horizons. For example, for decontaminating bulk goods and exploiting plant proteins, existing technologies are pref-

erentially being adapted to new specific areas of application, which is why exploitation of the work is already possible in the short to medium term (2022–2023). The aim for processes used to treat and recirculate process water used for agricultural crops was to have developed systems as early as late 2022 that promise economic added value and can be transferred to industry for further development. Meanwhile, a long-term exploitation horizon is realistic for constructing an industrial pilot plant for seed decontamination (2025 onward) because, along with clarification of approval issues, concrete effective rates of elimination of a range of phytopathogens also must be confirmed.

A new lead project will also be established for more rapid commercialization: "Physics for Sustainable Vertical Farming". In this project, different partial results from the lead projects will be combined to address current issues for vertical farming (pathogen infestation, germination capacity, plant growth). The cooperation in this area will concentrate primarily on startups, which are a byword for rapid commercial exploitation (2022–2023).

To accelerate the market launch of technologies for the treatment of young plants to increase stress resistance and plant growth, a DIN project is currently being drawn up that aims to define the dose–effect relationships for the application of plasma-treated water in agriculture and food production. The time horizon for this project must be considered to be the medium term (2024).

Further partial aspects of the overall project and its subprojects, such as the incorporation of other agriculturally relevant plant species or expanded fields of application of physical methods, can be included in the medium term for public research funding and prepared for technology transfer in collaborative projects between business and science. The current programs from BMBF and BMEL along with *Horizon Europe* are appropriate here. Concrete efforts in this regard that are already being pursued by alliance partners are aquaculture, treatment of hospital wastewater (DBU application submitted), and wastewater processing (PlasAMR, Sino-German Cooperation BMBF-NSFC).

The application-oriented work will in future be accompanied by associated basic research that will, however, be outsourced from the alliance. Carrying out such work in parallel will generate synergistic effects for both paths: a gain in scientific knowledge and research funding for the processes being applied. An overview of the parallel projects that are currently running is shown in Section 4. These associated scientific projects will ensure that the knowledge generated in the region will also remain in the region in the long term to create a "knowledge center" for the application of physical methods in agriculture and food production.

7.5. Planned Subprojects

The analysis of the progress made to date in the overall project indicated the direction for future lead projects with a tight focus on nearness to application:

1. Physics for Seed Treatment—Economic seed treatment.
2. Physics for Cropping Systems—Stress resistance and integrated plant protection.
3. Physics for Storage and Food—Storage and food.
4. Physics and Ecology—Focus on environmental effects and wastewater treatment.
5. Transfer—Approval and transfer to society.
6. Physics for Sustainable Vertical Farming—Implementation of the physical process into novel glasshouse concepts.

The cross-section projects "Communication" and "Strategy Development" will continue to support the alliance. The overall funding that is required, €7.69 million, will be supplemented by capital of €2.85 million. This corresponds almost to a doubling of capital compared to the first funding phase of the alliance (see "Existing Subprojects" in Section 5). Most of the projects have already been planned in detail. The conception of future funding projects is based on analysis and evaluation of the previous and expected results and the external influencing factors that have already been described. The lead projects designed in this way will be autonomous projects that are based on the current body of knowledge and focused on commercial exploitation of the results.

7.5.1. Future Lead Project 1: Physics for Seed Treatment

The planned lead project "Physics for Seed Treatment" will focus on improving seed hygiene and seed vitality through the application of cold physical plasma. The objective remains optimization of establishing crops and yield stability. For seed decontamination, evidence of effectiveness will be provided for pathogens that are particularly relevant for selected cultivated species of winter barley, winter wheat, winter rapeseed, legumes (large-seeded = blue lupin, small-seeded = red clover), as well as meadow grass (green fodder). In regard to seed vitality and increasing yields, the germination, rate of germination and germination power, field emergence, root development, yield, and harvest quality will be considered in particular. Trials in combination with physical methods and plant growth-promoting bacteria will also be pursued.

7.5.2. Future Lead Project 2: Physics for Cropping Systems

The planned lead project "Physics for Cropping Systems" will focus on the physical processes of UV-C and plasma-treated water and their integration into plant production systems. The first year of trials, 2020–2021, for the current lead project "Physics for Crops" showed positive effects for growth promotion, yield stability, and induction of systemic resistance to pests. The induced resistance to abiotic stress (drought, flooding) and biotic stress (fungal pests) will be investigated in greater depth in future. Along with this work that influences the physiological status of the plants, fungal pests will also be directly tackled and weed growth will be regulated. Thus, "Physics for Cropping Systems" will address challenges posed by climate change (drought, establishing crops) and reducing the use of plant protection products (fungicides, herbicides). The focus in the planned project will be precision field trials along with laboratory and glasshouse trials. The non-destructive monitoring methods used to record plant parameters will also be expanded and further automated. Future knowledge transfer to different site and production conditions as well as to other crops will also help with systematic characterization of the physiological status of plants using marker substances of stress metabolism. The demonstrators for the application of UV-C and plasma-treated water will eventually be optimized so that these processes can be applied more efficiently and universally.

7.5.3. Future Lead Project 3: Physics for Storage and Food

The planned lead project "Physics for Storage and Food" will concentrate on developing innovative systems to reduce storage losses for bulk goods and cold decontamination of plant proteins. The physical technologies of cold atmospheric plasma, plasma-enriched water, and pulsed electric fields and high-pressure treatment will be applied. The objective of the project is to develop a pilot plant to establish storage stability of bulk goods by screening or treating existing pests (corn weevils, molds, and storage fungi). Based on promising results from the first funding phase, a new field with high market potential will thus be tapped. The option of reducing the use of chemically bound mold toxins (mycotoxins) will also be researched for this purpose. The physical technologies will also generate added value for partners, for example, by reliably decontaminating bulk goods, reducing the use of chemical active substances, minimizing storage losses, reducing costs with the help of increasing quality, and cost effectiveness, as well as by means of publications, patents, and licences.

7.5.4. Future Lead Project 4: Physics and Ecology

The planned lead project "Physics and Ecology" will deal with the reduction of harmful substance inputs and regeneration of agricultural land. Starting from work successfully completed in the first funding phase, additional fields of application will now be exploited. This includes the option of providing waste or grey water processed using plasma as plasma-treated water for field processing or preparing rainwater for irrigation. The approaches that have already been trialed for process water treatment for recirculation will be intensified. The provision of plasma-treated water as a substitute for mineral fertilizers, biomass

digestion for organic fertilizers, and the treatment of leachate from silage, which represents a considerable threat to soils and systems, will be included as a new topic. Overall, the environmental effects of the developed processes with UV-C and plasma-treated water will be examined in greater detail in future in order to rule out negative effects on biodiversity and to carry out impact assessments for subsequent approval procedures. There are indications that soil microbes are enhanced by the application of plasma-treated water. Options for regenerating damaged soils will also be demonstrated. The lead project "Physics and Ecology" will thus achieve a broad spectrum of application.

7.5.5. Future Lead Project 5: Transfer

The planned lead project "Transfer" will transfer results to society and prepare for the approval procedures for the developed technologies. The transfer activities will concentrate in part on designing relevant training and education materials for creating a highly qualified workforce and in part on knowledge transfer from the alliance to users by means of a technology consultancy in businesses. Approval preparations will be carried out at different rates depending on the technology and the application. To validate the results from the lead projects, crop analyses will be carried out by a certified body.

7.5.6. Future Lead Project 6: Physics for Sustainable Vertical Farming

The planned lead project "Physics for Sustainable Vertical Farming" will combine promising results from all prior work from the lead projects "Physics for Seeds", "Physics for Crops", and "Physics for Environment" for more rapid commercialization. It is planned to utilize the key technologies of direct and indirect plasma treatment and the application of plasma-treated water. The project will also incorporate current market trends in plant production both in urban centers (urban farming) and substrate-less cultivation (hydroponics and aeroponics). This will be reflected in a specific cooperation request to a business that aims for cultivation that is completely free of plant protection products. On the basis of the results achieved to date in the first funding and lead project phase, the project "Physics for Sustainable Vertical Farming" can cover the entire process chain from seed decontamination, increasing germination capacity and germination rate, fertilization, and process water treatment in closed circuits. Results from the various lead projects that will likely be more rapidly available for exploitation and approval than those from the open field will thus be integrated, partly because the necessary research and development work can be carried out independently of the vegetation periods.

7.5.7. Ongoing Cross-Section Project VI: Communication

The cross-section project "Communication" will in part focus increasingly on informing the broader public about project results to increase acceptance of innovations in particular. With the increasing level of maturity of the developed technologies, the targeted approach of users, partners for commercialization (licensing), and investors (startups) will be shaped.

7.5.8. Ongoing Cross-Section Project VII: Strategy Development

The cross-section project "Strategy Development" will continue the strategy-driven approach and will focus on market surveillance and partner acquisition in the exploitation phase (second funding phase). The necessary information will be collected and processed to drive the process of commercialization based on market knowledge, technological developments, social trends, and political framework conditions. The cross-section project will thus continue to support the sustainability of the overall project beyond 2025.

7.6. The Alliance in 2025

The value propositions of the alliance "Physics for Food" guide the actions of all alliance partners and will also endure beyond 2025. From the beginning, the alliance strategy has systematically pursued the transfer of project results to innovative processes and prod-

ucts in collaborations between science and business and in spin-offs. Stabilization of the cooperation between the partners has already expressed itself in the demand for additional innovative development projects. The alliance has felt obligated from the beginning to satisfy the value propositions (innovation potential). These innovation potentials will still aim to (a) reduce the use of chemical active substances in agriculture; (b) improve the establishment of crops and the growth of plants; (c) enhance plant health; (d) improve the refinement processes for plant raw materials; and (e) ensure holistic technology transfer based on social values. This obligation was confirmed again during the last alliance assembly in August 2021. It is considered by the members of the alliance to guide all actions. On this basis and that of the proven organizational and management structure of the alliance, it is possible that the planned work will be successfully completed and new, promising, more advanced approaches will also be realized once funding ends in 2025. Upon completion of the work in the second funding phase, the scenarios described below are expected.

7.6.1. Expected Scenario 1

Work that still requires further research and development steps will be carried out in publicly funded collaborative projects up to commercial exploitation. This can be implemented using specialist programs at the level of the German federal government or states or even at the level of the European Union. The issues that must be dealt with here concern innovative technologies with a market-launch time frame that is more medium term because of approval barriers as well as the complexity of the plant production systems and the number of factors that must be taken into account, such as sustainable yield stability through targeted and temporally optimal induction of resistance to biotic or abiotic stressors using physical treatments. In addition, a considerable developmental leap is expected for those UV-C wavelengths that have been identified as effective, meaning that the construction of equipment and thus practical transfer can be designed using more energy efficient LED technology. Likewise, the integration of growth-inhibiting weed control in cultivation processes must include the medium-term processing of technological aspects and approval issues as well as the application parameters for various weed elimination situations.

7.6.2. Expected Scenario 2

Work that is already approaching commercial exploitation will be continued at the end of the funding in bilateral collaborative partnerships between the necessary research expertise and the businesses involved without the use of public funding. This includes particularly the work on cleaning agricultural process wastewater and storing harvested crops where technologies with a comparably high technology readiness level (TRL) meet a high demand for innovations in the businesses that are and will be involved.

7.6.3. Expected Scenario 3

The stated objective is continuing the commercial exploitation of the project results by establishing spin-offs in the scientific institutions involved. For this purpose, Neubrandenburg University of Applied Sciences offered to conduct spring schools in May 2022 and May 2023, initially as a prototype, that aimed to inspire young entrepreneurs in regard to these issues and provide them with the tools needed to ensure successful spin-offs. These activities were supported by contacts with partners from the venture capital sector. In future spring school, it is therefore also planned to appoint appropriate persons from venture capital networks to the advisory committee. The alliance envisages activities related to spin-offs based on the current status primarily in the areas of “Urban Farming”, “Vertical Farming”, and “Plant Protein Extraction”.

7.6.4. Expected Scenario 4

The work by the scientific partners has already thrown up issues that are not essential for commercial application, but are of great interest for basic research. Working through the underlying issues will be continued for the purpose of scientifically validating the

applications in relevant programs from the German Research Foundation (DFG), the European Research Council (ERC), and other institutions. Based on the current status, this work will concentrate particularly on plant physiology because metabolic processes in the cell are influenced by physical stimulation, and clarification of the underlying mechanisms is of fundamental interest.

7.6.5. Preliminary Assessment of Expected Scenarios

Work that can be considered as complete at the end of the second funding phase serves primarily to enhance the field of innovation in the region in that, as an example of best practice, it demonstrates that the strategy of the overall concept has been successfully implemented and thus is suitable to also generate future innovative developments from the region. The alliance partners are already actively involved in managing these scenarios. Consolidating the cooperative relationships between the alliance partners will succeed by initiating and implementing the bilateral projects that have been demonstrated. Along with existing and increasingly strengthened personal contacts, there has been greater success in developing firm ties with the regional and transregional business and sector networks, also with the support of regional chambers of industry and commerce and business development agencies. The lead project managers will be incorporated in the research and discussions with interested parties and in competitor analyses so that the exploitation of scientific results, including market parameters, can be used, on one hand, as a personal career objective and on the other, learning effects will arise in the transfer of knowledge in use. For this purpose, the strategic knowledge and tools should be implemented transparently and know-how communicated to the lead project managers concerned and other interested alliance partners in the course of strategy coaching or retreats. This will particularly affect those projects that are likely to more rapidly reach application maturity. These measures also include matters of patent applications, EU regulations and certifications, and NDAs and confidentiality agreements during R&D. Results achieved so far are promising. Limitations of the project and the methods developed do exist, but, as with the original research result data, cannot be disclosed at this point, for these will be part of separate publications or patent applications at a later stage.

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