Bioökonomierat

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Bioeconomy for sustainable nutrition
New approaches to the protein supply of the future

Preliminary Remarks

A central task of the bioeconomy is to secure the food (food and nutrition security[1]) of a growing world population. This means providing adequately nutritious, healthy, tasty and sustainably produced foods. Protein supply plays a key role in this. While large parts of the world's population continue to lack an adequate supply of high-quality, high-protein foods, many people in the growing middle classes of the industrialized and emerging economies are already consuming too much protein – with negative consequences for the environment and health. Excessive consumption of animal food, in particular, has significant adverse effects on the environment and climate as well as consuming a high level of resources. The Food and Agriculture Organization of the United Nations (FAO) therefore characterizes sustainable diets as having little negative impact on the environment and providing a positive contribution to food security and a healthy life for present and future generations[2]. The Bioeconomy Council has already published background papers dealing in depth with the sustainability of animal food production for a rising global demand (especially the growing middle class in emerging economies)[3,4]. In developing countries, the frequently inadequate supply of protein is a relevant problem that urgently needs to be solved[5]. The present BÖRMEMO focuses primarily on the situation in Germany and other industrialized countries

The production and consumption of protein-containing foods have very different effects on the environment, climate and health.

The importance of proteins in the human diet

- Proteins are composed of chains of up to 20 different amino acids whose exact sequence (resulting from the DNA sequence) determines the structure and thus the function of the protein. It is estimated that more than 100,000 different proteins are present in the human body. In addition, almost every one of the 20 amino acids also has other very specific metabolic functions.
- Of the 20 amino acids required for protein synthesis, 11 can be synthesized in the body of healthy, adult humans themselves; all the others are essential and must therefore be added through the diet. The value of a protein for human and animal nutrition is determined by the content or pattern of these essential amino acids.
- In the first years of life especially, in addition to an adequate supply of energy, the quantity and quality of protein intake are of overriding importance for growth and development[5].

In its recommendations, the Bioeconomy Council repeatedly emphasized the need to promote resource-efficient food consumption with the help of research and behavioral approaches. In industrialized countries such as Germany, this mainly involves a reduction in the consumption of animal foods[6,7,8,9]. This BÖRMEMO also focuses on a variety of approaches to more sustainability in production. Innovations within the existing system can contribute to further optimization in the production and consumption of agricultural products[10,11].

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However, in the future, a more sustainable protein supply may also be served by novel and possibly more efficiently produced protein sources. The more efficient use of traditional protein sources, such as plants and fish, can also make a contribution.

Approaches to optimizing sustainability in livestock farming

In many countries, livestock farming is the largest source of income in agriculture and, thanks to its integration with intermediate inputs and value chains, is an important part of the bioeconomy. Measures to increase sustainability are necessary to counteract the effects of livestock farming on the environment and climate as well as their consumption of resources. Advances in digitization, automation and biotechnology can further increase the efficiency of agricultural production, reduce losses and mitigate negative impacts. The Bioeconomy Council has already commented on BÖRMEMOs and background papers on the role of livestock farming in the bioeconomy and on the production of animal-based foods[4,10,11]. The present BÖRMEMO therefore focuses not on traditional livestock farming but on new approaches for a more sustainable protein supply.

Novel approaches to the production of high-protein foods and feedstuffs

A large number of publicly funded and commercial initiatives address the issue of supplying the growing world population with a quantitatively and qualitatively adequate amount of protein. One focus is on a better supply in developing countries and a reduction and partial substitution of the consumption of animal products in industrialized countries. A growing awareness of the negative consequences of animal-based food production and the emergence of new biotechnological processes for protein production has also led to increased investor interest and, particularly in the USA, Israel, France and the Netherlands, to significant capital investment. The new approaches are aimed at a) the exploitation of new protein sources and b) the development of new products based on traditional protein sources.

Production of animal proteins: Sustainability, environmental and climate relevance

- Globally, 30% of the land area and 70% of the arable land is used for the cultivation of animal feeds and as grazing land[12].
- In Germany, agriculture accounted for the emission of 7.3% of the total greenhouse gas emissions in 2014[13]. Primarily methane (CH_4) and nitrous oxide (N_2O) are emitted, which enter the atmosphere mainly through digestion in ruminants and the application of organic fertilizer.
- On the other hand, ruminants contribute to the sustainable use of grassland and convert grass which is worthless for the human diet into high-quality protein. They are also an important source of income and part of the established agricultural culture.
- 29% of freshwater consumed in agriculture is used for livestock farming and the irrigation of forage crops. About one third of water consumption is attributed to beef production[14].
- The quality of fertile soils can be affected by less sustainable cultivation of animal feeds. The excessive discharge of nitrogen has a negative impact on groundwater. The emergence of antibiotic-resistant germs in livestock farming is also considered to be a risk to public health in the context of the discussion on “One Health”[15,16].
- A large proportion of the soybean meal needed to meet the protein needs of feeding is imported from South America and its production there is critically evaluated for environmental and social sustainability[17,18].

a) Exploitation of novel, alternative protein sources

Algae-based foods: Algae are subdivided into marine macroalgae (also seagrass or seaweed) and single-celled microalgae which usually also include cyanobacteria. In both groups there are a number of edible species with some beneficial properties for human nutrition. In addition to high-quality protein, they also contain other nutrients, such as unsaturated fatty acids and vitamins, whose concentration can be further increased by breeding. The protein content of many species is similar to or higher than that of legumes or animal products such as eggs[19,20,21]. Less space is required to cultivate algae than agricultural crops and there is the potential to save large quantities of greenhouse gas emissions, especially if the remaining components of the algae are also used after protein

Protein supply – between scarcity and surplus

- Forecasts assume that the demand of the world's population for protein-rich animal foods will increase by approximately 80-100% between 2000 and 2050[25]. The biggest increase is likely to be in emerging and developing countries. Experts estimate that global meat production will also double at the same time[12].
- Animal protein generally has a higher value for the human diet than vegetable protein. In particular, the world's most consumed cereals have a shortage of individual essential amino acids. However, a balanced combination of different high-protein plant sources can certainly replace animal protein adequately[27].
- The supply of high-quality protein for nutrition is very unevenly distributed in the world. While shortages continue to exist in many developing countries, notably Africa and Asia, a growing global middle class is consuming ever-increasing amounts, especially from animal sources. In industrialized countries, the average per capita consumption of protein is about 100 g/day, in developing countries often only about 70 g/day. In some countries of sub-Saharan Africa, it is even below 50 g/day[28]. The reason for malnutrition is often the undersupply of individual essential amino acids.
- Both extremes have negative consequences for health. Too little intake of protein leads to delayed growth and sometimes irreversible deficiency symptoms[5]. Excessive protein intake is associated with the occurrence of metabolic disorders[29]. In addition, high consumption of red and processed meat is associated with other diseases[30].

extraction (e.g. as biofuel). Various freshwater microalgae can also be produced on building façades and on other previously unused surfaces. The high nutrient requirement and the provision of energy for aeration, temperature control and mixing pose a challenge for sustainable large-scale production[22]. For this, however, it would be possible, for example, to use nutrient-rich wastewater and renewable energy sources[23]. In order to produce microalgae as sustainably as possible, preference should be given to sites where water, carbon dioxide (CO_2), nutrients (e.g. from purified wastewater) and electricity with a low carbon footprint are available[24]. For both freshwater and saltwater algae, closed-loop systems are a good solution for optimally controlling conditions and mitigating negative impacts on ecosystems. Combined production of algae for food and feedstuffs and for other uses, such as biofuel, could further increase the efficiency of production; however, there is still a great need for research here.

Insect-based foods: Insects represent an alternative animal-based source of protein. About 1,500 to 2,000 insect species are consumed in more than 100 countries around the world[25]. They could also contribute to more sustainable protein production in Europe but they are still poorly accepted as food and have also not yet been authorized for consumption in the EU (with a few exceptions in selected countries). Like other animal-based foods, insects have a high protein content with a high biological value. Often there is also a high content of unsaturated fatty acids, as well as dietary fiber in the form of chitin[31] and important minerals such as iron, calcium and zinc[32]. However, there is a need for research and studies regarding the safety of consuming larger amounts and over a longer period of time[33,34], especially if the insects are to be fed, for example, with food waste. There are certainly microbiological risks here, as insects can also be carriers of disease. There is also a need for research into identifying potential allergens and processing insects for the isolation of protein and/or other components. Among other things, in larger production facilities it may also be necessary to use antibiotics to prevent infections. This requires feasibility studies and pilot projects that test the potential and risks of large-scale insect production in practice[35]. According to current interpretations, insects are covered by the Novel Food Regulation of the EU. Thus, they and the products manufactured from them can only be marketed as novel foods after EFSA approval. Ethical aspects of farming insects should also be discussed at a sufficiently early stage.

Microbial protein: In addition to microalgae, microbial protein can also be obtained from yeasts, fungi and bacteria. The biological value of the proteins obtained varies depending on the organism but is generally relatively high[36]. With regard to the consumption of water, area and other resources, the production of microbial protein can be a very economical or efficient alternative. Production with photosynthetic microorganisms (microalgae and cyanobacteria) has the advantage of using solar radiation as an energy source, but the disadvantage of a high area requirement. In contrast, production with heterotrophic bacteria or unicellular fungi has a very low area requirement, but requires the input of energy or needs a suitable source of energy[36]. Renewable energy sources or the recycling of residual materials could be used for this. Similarly, appropriately filtered industrial waste gases could be used as a carbon source. If meat is not the desired product, but the requirement is for proteins as functional ingredients (for example as an emulsifier or for

foaming), they can likewise be produced microbiologically. In particular, genetically modified yeasts are used to specifically produce those proteins that are best suited to the particular application. This results in significantly fewer by-products, which means that higher efficiency can be achieved compared to animal production.

In vitro meat: The idea of growing only the desired parts of animals in a suitable medium was considered in a much-quoted statement by Winston Churchill as early as 1932[37]. However, it is only recently that technology has progressed so far that the production of meat in the form of muscle fibers is possible in vitro[38]. The aim is usually to generate protein-containing muscle meat from appropriate stem cells and thus to bypass production via an animal. It thus becomes unnecessary to slaughter animals. Theoretically, the efficiency of production is also increased because "inferior" parts of the animal are not included in the production process. In this way, the production of in vitro meat could make it possible to save a lot of space, water and resources. However, there are still numerous challenges and technological uncertainties for the sustainable in vitro production of meat or fish on a large scale[39]. This includes the relatively high energy demand and high costs for culture media and growth factors. The high technical and infrastructural costs for appropriately dimensioned sterile production plants necessitate high investments in construction and operation. Criticism of the idea of in vitro meat is directed primarily against this expense and the considerable use of resources. However, there are also cultural and social aspects that play an important role in the perception of in vitro meat.

Novel plant sources: For some years now, new plant species have also been found as food on the German market. Some of them have a relatively high protein content, such as quinoa and chia seeds, both of which are covered by the Novel Food Regulation. Duckweeds are another novel protein source of plant origin. They have a high protein content and also produce biomass quickly. As they grow in water, their production (like that of algae) does not compete with terrestrial plants for fertile soil[40]. Plant research is expected to identify other plants with beneficial properties that can supplement the supply of protein and replace animal products. State-of-the-art technology and modern breeding methods could also enable the efficient use of previously non-domesticated species.

Alternative feedstuffs: Optimizing the feeding of livestock is also a way of mitigating the protein problem[41]. Alternative sources of protein can be used not only for human nutrition, but also for feeding, thus replacing fishmeal and soybean meal. Protein-rich rapeseed meal is produced as a residual material during oil extraction and the production of biofuel, and is already widely used as animal feed. Grain residues (dry slurry) arising during the production of bioethanol can also be used as animal feed. Insects are also suitable as a sustainable and efficient substitute for fishmeal. Due to the higher value of their proteins, they can also be a good supplement to plant-based feeds[42]. However, further optimization in breeding, husbandry and processing is still necessary to enable large-scale production and make it sustainable[43]. There is a need for research on safety (toxicological and microbiological) and acceptance by feed users. Legislative adjustments are also urgently needed[44,45]. In December 2016, the EU Commission granted permission to add insect proteins to fish feed with effect from July 2017[46]. Algae are also an alternative protein source for feeding[21]. As with fish, feeding with marine microalgae can also lead to an increased content of omega-3 fatty acids in meat, eggs and milk[47]. However, due to undesirable side effects, the use of algae has so far been limited to 5% to 10% of the total feed[48]. Almost all marine microalgae used in food and feed are already cultivated varieties optimized by breeding (mostly by undirected mutagenesis). However, recent biotechnological methods could further improve the suitability of algae for use as feed.

Although many of these approaches may appear to be useful alternatives, they require comprehensive and careful analysis with regard to efficiency and sustainability, which does not come out better a priori than for conventional feed. For example, a comparative assessment concludes that a partial replacement of soybean meal in animal feed by insects or algae may rather increase the carbon footprint[49]. This is mainly due to the energy needed for air conditioning and the required post-harvest drying.

b) New products and approaches based on traditional/ existing protein sources

Product innovations from vegetable proteins: Vegetable foods as protein-rich alternatives to meat, milk and eggs have been around for a long time, for example in the form of tofu, soy milk or seitan (wheat protein). These and similar products are particularly popular with vegans and still have a very small market share. Domestic pulses such as peas, beans, field beans and lupins also provide high-quality protein and products based on them. Numerous R&D projects deal with substituting animal products or proteins for plant sources and have developed novel processes. It may be an approach to reconstruct the properties of conventional animal foodstuffs in terms of sensory properties (taste, odor, texture), but also in terms of appearance, in order to be a satisfactory substitute for consumers. Some of the most modern biotechnological processes are used, for example in the production of hematogenic proteins from root nodules of legumes[52] which give the products meat-like taste and color. Such products are aimed at the market of average meat-loving consumers who want more sustainable and animal-friendly products. In some cases, the products obtained undergo fermentation or other processing in order to improve their flavor properties. The market success of food products based on vegetable proteins will depend above all on their sensory qualities, the ability to prepare them and the willingness of consumers to get used to them.

Sustainable development of aquaculture: Fish provide high-quality protein, various micronutrients and, in the case of marine species, omega-3 fatty acids. In countries with relatively high rainfall, such as Germany, the availability of water in principle permits the expansion of freshwater aquaculture. Freshwater fish is a good alternative to meat and can be more sustainable than terrestrial animal husbandry[53] because, among other things, no fertile arable land is needed and production is also possible in urban areas. However, in industrial-scale aquaculture there are still frequently problems, such as the introduction of nutrient-rich effluents into the environment and the development of resistant pathogens due to excessive use of antibiotics. Sustainably managed, aquaculture can be used to replace some of the consumption of other animal products. A more recent approach is aquaponics, which combines the production of fish in aquaculture with the production of suitable vegetables in hydroponic systems. The nutrients released by the fish can be used by the plants as fertilizer. For marine aquaculture, nutrient cycles with algae, mussels and other seafood are possible. Cycle approaches such as this can increase the efficiency of production and minimize its negative impact on the environment. Questions of animal welfare will also play a role in these new approaches.

Utilization of residues: Proteins which, for example, arise in the production of oils from oilseeds such as sunflower or rapeseed or in the production of bioethanol[54] and which so far have been used mainly as feedstuffs, would certainly generate higher added value if used directly in foods. Among other things, this requires improvements in the quality of the raw material with regard to color and texture, and corresponding research efforts are needed. State-of-the-art technology and modern breeding methods can also enable the efficient use of previously unusable protein. Brewery waste and other organic waste can serve as nutrient-rich substrates for fungi, insects, algae or microorganisms[55]. As a result, the proteins contained in the residual materials are converted back into

New sources of protein: the legal framework for placing on the market

Novel protein sources or foods are usually covered by the Novel Food Regulation of the EU (Regulation 2015/2283) [50]. It requires a special authorization procedure for all foods that were not consumed to a significant degree in Europe before the Regulation entered into force in 1997. The arrangement covers novel foods themselves, products made from them, novel ingredients and novel processing techniques and technologies. After approval (in Germany by the Federal Office for Consumer Protection and Food Safety; BVL), corresponding products may only be marketed with appropriate labeling. Some species of algae are now listed in the catalog of the Regulation, insects on the other hand are not yet specifically mentioned but are also expected to be classified as novel food. For these new sources of protein, the Novel Food Regulation, with its high food safety standards, represents a major barrier to market entry. There is still a lack of clarity regarding definitions and regulation for husbandry or cultivation and for processing of these novel sources of protein and food. For example, some prescribed procedures, such as the bleeding of slaughter animals, cannot be applied to insects[51]. The production and use of animal feeds are also strictly regulated in Germany and the EU. So far, according to current animal feed legislation, insects, for example, may only be fed live to livestock, and conversely these insects must not be fed with organic waste as they themselves are considered as production animals.

usable protein for nutrition. Particularly in the processing of waste, however, there is still a need to clarify food safety issues and to adapt the legal regulations governing the placing of products on the market.

Opportunities and challenges for new protein sources and derived foods

Novel approaches and technologies in the bioeconomy should be classified by means of an appropriate evaluation framework in order to identify and, if necessary, quantify opportunities as well as possible adverse effects. This assessment framework covers the impacts on human health, the environment, soil and climate, the use of key resources, and economic, structural and social affordability.

Novel protein sources and the foods made from them are expected to increase the sustainability of the future protein supply. The aim need not be to completely replace the consumption of animal products. Any reduction in the consumption of conventional animal products and their partial substitution with more sustainable sources of protein can increase the sustainability of the food system[61,62]. Studies show that the majority of consumers would like to eat more sustainably but usually act against this intent when buying[63]. New foods made from more sustainable protein sources must therefore better meet the needs of consumers; they must taste good, be healthy, but at the same time be affordable, usable and available. In the case of unfamiliar products, it is often difficult to overcome socio-cultural barriers.

Research Recommendations

- The development of alternative sources of protein and novel approaches to using traditional sources of protein requires research that covers both basic science and application-related issues.
- It is necessary to explore the impact of scaling up the production of alternative sources of protein to the environment, climate and public health, including in terms of economic viability, resource consumption and the necessary infrastructure. “Proof of principle” projects seem to be the most suitable way of achieving this. Computer models and simulations, which may also need to be scientifically expanded and optimized, may also be useful here. In particular, it makes sense to develop and evaluate new production processes and facilities for protein production, taking into account site-specific conditions.
- There is a specific need for research on efficiency (energy, water, surface area, emissions) and food safety (including analyses of undesirable ingredients and microbiological contaminants). Similarly, a risk assessment must be carried out with regard to the transmission of diseases (it may be necessary to continue the use of antibiotics in large-scale production) and the influences on existing cascades of use for all areas of novel protein sources. Appropriate monitoring should be developed for all these parameters.
- Consumer interest and curiosity are important criteria for the acceptance of new products, especially in foodstuffs. Behavioral science approaches to promote consumer interest, awareness and experimentation, but also the dissemination of information must therefore be central research areas to enable or make it easier for consumers to translate a usually existing desire for more sustainable consumption into practical action.

Consumer behavior and acceptance of novel foods

The success of alternative foods in the market is ultimately determined by the way it is perceived and the decision to purchase. In addition to affordability, “healthy” and “sustainable” are now important attributes that can provide alternative sources of protein with market advantages. However, some of the new products also cause socio-cultural skepticism and reserve. For example, in Western cultures insects are associated with poor hygiene and their consumption is often associated with phobia[56]. Microorganisms, on the other hand, are often associated with diseases[57]. In vitro or cultured meat is often perceived as unnatural and benefits are seen more for society and not for themselves personally[58]. Such barriers can be counteracted in terms of consumer needs and wishes through credible quality control, appropriate communication, transparent labeling and other incentives to buy. Initial studies on alternative sources of protein certainly show their positive perception by consumers and the basic potential for market penetration[59, 60].

Policy Recommendations

The transition to more sustainable consumption plays a central role in future nutrition. The Bioeconomy Council has addressed this topic in previous papers and has recommended research into the effectiveness of such approaches (including nudging, taxation, education)[6]. However, reference is also made to the recommendations of other committees[8,9]. The present BÖRMEMO focuses on new approaches to more sustainable production.

- Regulatory framework:Where necessary, the regulatory framework should be adapted to enable or facilitate the use of new protein sources and products derived from them. The existing legal regulations primarily serve to ensure the safety of new foodstuffs and protect consumers from deception. Of course, the safety of novel products must be ensured, but some of the rules seem to unduly hinder market access and should therefore be adapted.
- Communication, labeling and consumer information: Transparency about the use of novel protein sources in products must be guaranteed. Milk, meat and egg substitutes must therefore be labeled as such.
- Develop a strategy for sustainable protein supply: The promotion of alternative sources of protein with beneficial properties in terms of resource use, environmental and climate impact should be included in a holistic strategy for sustainable protein supply.

About this BÖRMEMO

BÖRMEMOS summarize the Council's appraisal of key aspects of the bioeconomy in a condensed form. They do not claim to provide a comprehensive study of these facts. Rather, they present a focused and generally comprehensible view of each area and its relationship to the bioeconomy. BÖRMEMOS undergo a peer review process. While this process is taking place, they are identified as preliminary. After assessment, they are incorporated in the items of the Council as a whole. They are part of a series of analyses published by the Bioeconomy Council. This BÖRMEMO is based on the background paper "Bioeconomy for a sustainable protein supply - The importance of animal products and biobased innovations" which summarizes the current state of knowledge[4].

Endnotes

[1] Food and nutrition security, Definition: https://ec.europa.eu/europeaid/sectors/food-and-agriculture/food-and-nutrition-security_en

[2] Sustainable diets, Definition: http://www.fao.org/nutrition/education/food-dietary-guidelines/background/sustainable-dietary-guidelines/en/

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[54] http://www.ufop.de/rapsoel-and-ernaehrung/ernaehrungsinfos-fuer-verbraucher/eiweiss-der-ernaehrung/. Rapeseed cake also falls under the “Novel Food Law” and was approved in the EU in 2014.

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