Focus on the future:

Meat of the future

Trend report for assessing the environmental impacts of plant-based meat substitutes, edible insects and in vitro meat

For our environment

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BauGB	German Building Code
BImSchG	Federal Immission Control Act
BMBF	Federal Ministry of Education and Research
BMEL	Federal Ministry of Food and Agriculture
BVL	Federal Office of Consumer Protection and Food Safety
CAGR	Compound Annual Growth Rate
CH_4	Methane
CO_2e	Carbon dioxide equivalents, CO_2 equivalents
i.e.	id est
DDGS	Dried stillage
DIL	German Institute for Food Technology
DLG	German Agricultural Society
DLMBK	German Food Book Commission
EAAP	European Association for Animal Production
EFSA	European Food Safety Authority
etc.	et cetera
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FU	Functional unit
FCS	Foetal calf serum
FLI	Friedrich Loeffler Institute
g	grams
ha	hectares
IPIFF	International Platform of Insects for Food and Feed
iPS cells	induced pluripotent stem cells
JKI	Julius Kühn Institute
kg	kilograms
AI	Artificial Intelligence
m^2	square metres
m.	million
MJ	megajoules
b.	billion
N_2O	Nitrous oxide
NH_3	Ammonia
AI	Artificial Intelligence
Nox	Nitrogen oxides
PDCAAS	Protein Digestibility Corrected Amino Acid Score
PR	public relations
SO_2	Sulphur dioxide
GHG	Greenhouse gases
TRUE	TRansition paths to sUstainable legume based systems in Europe
TVP	Texturised Vegetable Protein
UN	United Nations
EIA	Environmental Impact Assessment
VeBu	German Vegetarian Association
VSMK	Conference of Ministers of Consumer Protection
WWF	World Wide Fund For Nature

1 Changing nutrition patterns

When the US company Beyond Meat went public in the United States at the beginning of May 2019, hardly anyone expected the hype that would surround the supplier of plant-based meat substitutes. The stock market price briefly grew by several hundred per cent (by July 2019), at least temporarily exceeding the IPOs of Amazon, Facebook or Google (Deutsch 2019). In Germany too, food discounter Lidl offered the “Beyond Meat Burger” as part of a temporary promotion, but demand exceeded supply, and many prospective customers went home empty-handed (FOCUS Online 2019). A similarly high level of media buzz was triggered in 2013 when Marc Post presented the first edible in vitro meat[1] burger produced as part of a research project. Moreover, since insects, in principle, have been permitted as food under the framework of the European Novel Food Regulation, edible insects are increasingly being considered an alternative protein source of the future.

These are just a few examples of the ongoing discourse about meat consumption, its consequences and possible alternatives that is currently taking place. For environmental reasons, global meat consumption is increasingly being criticised and called for a debate on alternative protein sources (see e.g. Bioökonomierat 2017). At least since publication of the report “Livestock’s Long Shadow: Environmental Issues and Options” by the UN Food and Agriculture Organization in 2006 (Steinfeld 2006), there has been consensus among scientists that the keeping and use of animals in agriculture in its current form are not sustainable, but can be transformed to become more sustainable. To achieve this outcome, both the production and consumption of animal products must be reduced and animal husbandry systems be made more sustainable (see also Bindra and Scanlon 2010; Food and Agriculture Organization of the United Nations (FAO) 2014; Westhoek et al. 2015).

Increased demand for meat alternatives, especially from vegetarians and vegans, but also from so-called flexitarians, has influenced the market. Since 2008, meat alternatives have seen a steady annual increase in sales of around 30 %. (Schmitt 2017). Especially flexitarians, whose diet is largely vegetarian but who occasionally eat meat, are considered particularly economically relevant because they are the largest of the mentioned target groups. In addition to start-ups that develop exclusively plant-based alternatives, meat producers are increasingly discovering the market for meat alternatives for themselves: for example, the PHW Group, to which the “Wiesenhof” brand belongs, as the largest German poultry breeder and processor is involved in Beyond Meat and SuperMeat, a company that produces in vitro poultry meat. North America’s largest meat producer, Tyson, is investing millions of US dollars in Beyond Meat and the agricultural group Cargill is investing in the in vitro meat company Memphis Meats. Nestlé has launched a vegan range of products with the brand “Garden Gourmet”, which in turn supplies McDonald‘s with vegan burgers. The Rügenwalder Mühle company is planning to increase its share of meat-free products to 40 % by 2020 (Baier and Krafft 2019). The economic potential of the growing demand for healthy, environmentally friendly alternatives to meat products is thus estimated to be very significant (Gerhardt et al. 2019).

However, it is not only individual product examples as well as the media coverage, which follows its own rules, and economic considerations that point to a change in nutrition patterns. In addition to the regular publications of the Heinrich Böll Foundation under the title “Fleischatlas” (Heinrich-Böll-Stiftung et al. 2014a; Heinrich-Böll-Stiftung et al. 2014b; Heinrich-Böll-Stiftung et al. 2018), representative surveys in Germany, such as the “Environmental Awareness Study”, show that there is public interest in alternative meat products, which may be accompanied by changes in dietary behaviour (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB) and Umweltbundesamt (UBA) 2017; Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU) and Umweltbundesamt (UBA) 2019).

From an environmental point of view, the above-mentioned discourse focuses in particular on greenhouse gas emissions stemming from animal husbandry, the large amount of land needed

1 Also discussed as “clean meat”, “laboratory meat”, “cultured meat”, etc. (see Chapter 4.3).

to produce animal feed and the inefficiency of using water, energy and soil for the production of animal proteins compared to the use of alternative protein sources. Another aspect under discussion is Germany's international responsibility for environmental damage outside Europe – such as rainforest destruction or soil degradation – which can be directly linked to imports of animal feed and meat (see Chapter 6.1)

From a health perspective, the excessive consumption of animal products in Germany, especially meat, is often considered one of the causes for a large number of diet-related diseases (currently approx. 60 kg, see Chapter 3.3.1). The German Nutrition Society considers a maximum of 30 kg of meat per year to be just about justifiable from a health point of view. The current EAT-Lancet report, in which 37 experts offer recommendations for a "Planetary Health Diet" that enables a healthy diet within planetary boundaries worldwide, assumes a maximum of 15 kg of meat only (Willett et al. 2019).

Other prominent aspects of the social discourse are about demands for improved animal welfare in the keeping, transport and slaughter of farm animals, the high use of antibiotics in animal husbandry and the potential contamination of meat with multi-resistant and other germs, e.g. listeria.

It becomes apparent that there is a need to reduce the consumption of animal-based foodstuffs in general, and meat consumption in particular. This can be achieved by either doing without any products of this kind or by demanding alternatives. In Germany and the EU there is an oversupply of plant and animal proteins, unlike in the global South. Thus, if meat products are replaced by alternatives, there is no threat of a lack of protein supply. However, meat consumption is deeply embedded in longstanding eating habits. Because the consumption of meat has long been and continues to be a symbol of wealth and status, reducing consumption and establishing alternatives is a major long-term challenge.

2 Objectives and approach

The primary objective of this trend report is to provide the German Environment Agency (Umweltbundesamt – UBA) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit – BMU) with an overview and thus a broad basis of information on the latest developments, with which future policy approaches and measures can be developed as proactively as possible. In addition to a detailed description of the trends surrounding meat alternatives, a further objective is to analyse environmental impacts, identify opportunities and risks, and formulate initial policy options.

The study, however, is not exclusively aimed at the UBA and BMU, but rather, the findings presented in this report are intended to contribute to the formation of public opinion. Through analysis of trends that are socially, economically and politically highly relevant, the UBA and BMU are therefore also able to make a contribution that can be taken up and continued in various (specialist) public discourses. The subject of this trend analysis is protein-rich alternatives to meat, which will be discussed in more detail in Chapter 3.

The primary motivation for the environmental policy debate on alternative protein sources results from the following widely held assumption: meat alternatives place less of a burden on the environment compared to meat and meat products and could thus help to move the food system in a more sustainable direction, especially in the context of avoiding greenhouse emissions. This assumption needs to be critically reviewed, however, especially as the topic of meat of the future will bring different interrelated developments and products into focus.

In comparison to conventional animal production, which is considered unsustainable in its current form, it is being investigated whether alternative meat products can be produced more sustainably, i.e. in particular whether they can be produced using less land and water, less energy and with fewer emissions.

For the UBA and BMU this trend report is intended to provide an overview of possible direct and indirect environmental effects of various meat alternatives, to formulate initial environmental policy measures, to uncover and correlate different positions and views on future developments in the field and to identify gaps in research.

Addressing the policy areas agriculture, food and environment

The topic “meat of the future” concerns three major policy areas. In particular: agriculture, food as well as health and environmental protection. Questions of animal ethics and animal protection are included but can only be touched upon. It can be expected that different interests will clash. In this respect, the study is also intended to contribute to the interministerial coordination of measures, recommendations and follow-up activities.

This already complex issue cannot be placed in every conceivable context. For this reason, the present trend analysis is limited in its breadth and depth. This concerns the findings presented on stakeholders, market developments and, in particular, the environmental effects assessed. Here, the focus is largely on Germany, although the products under consideration are often either manufactured abroad and imported into Germany or have so far been exclusively distributed to Germany. However, no analysis of worldwide trend developments and global environmental impacts is provided. Rather, international interrelations and effects are used at appropriate points to support the argumentation.

No predictions are being made

Within the context of this trend report no predictions are being made. Firstly, this is due to methodological limitations: trend reports tend to carve out possibilities for development and courses of action based on existing expertise rather than to simply extrapolate trends from the past into the future. Neither are scenarios developed that show different possible futures. Furthermore, factual aspects also make it difficult to formulate any kind of forecasts: while plant-based meat substitutes are considered to be established on the German market, it has so far only rarely been possible to completely imitate comparable meat products. Edible insects, in contrast, do not yet constitute a mass market in Germany, and products made from in vitro meat have not yet

Figure 01

Questions of trend description and environmental assessment

Questions	Chapter	
▸ What is the conceptual understanding underlying future meat? ▸ Which meat alternatives are covered by the analysis and which are not? ▸ Which factors influence the future development of meat alternatives? ▸ Why is the topic of meat of the future particularly relevant for UBA and BMU?	3	Conceptual understanding and determining factors
▸ What developments have the three meat alternatives gone through so far and what is the status quo? ▸ Which production processes exist? ▸ What different economic, scientific and social perspectives shape the debate on the three alternatives?	4	Trend description
▸ Which driving forces and barriers will shape the future development of the three alternatives? ▸ What uncertainties characterise the future trend development? ▸ What does the overall picture of future meat look like?	5	Driving forces, barriers and uncertainties
▸ What are the environmental effects of conventional animal production? ▸ Which health effects can be described? ▸ What environmental effects can be determined for the three alternatives? ▸ Which health effects of the three alternatives can be described?	6	Environmental assessment
▸ How can politics shape the changes? ▸ Which fields of action and options for action exist?	7	Political entry points and research questions

Source: Own illustration

reached market maturity. A forecast against the background of very different and complex starting positions will therefore always be characterised by uncertainties.

Nevertheless, an assessment of future development potentials for all three meat alternatives must at least be included for the development of recommendations for action. The resulting interactions and the formulation of governance approaches with which the change in the food system can be influenced, also belong to the assessment of future potentials.

Trend analysis to identify different governance approaches

The study therefore uses a modified form of the trend analysis method established at the UBA ("Employing trend analysis in environmental research and policy – a methods report"; published in 2020; FKZ 3714 17 102 0), the aim of which is not to predict the future but to describe and evaluate trends and identify different governance approaches. In a first step – the trend description – stakeholders, driving forces and causes of the trend as well as past developments, the current trend status and, if possible, quantitative assumptions of its future development are presented in a substantiated manner. The elements of the trend that are environmentally relevant, i.e. that can have a direct or indirect impact on the state of the environment, are highlighted. In the second step – analysis of negative and positive effects on the environment – the possible direct and, as far as ascertainable, indirect effects of the trend are identified, evaluated and supplemented by resulting environmental policy options for action. The aspects focused on in the individual chapters are listed below:

- **Chapter 3** formulates the determining factors and conceptual understanding assumed for future developments in the topic area of "meat of the future". The context is particularly marked by advancing climate change, demographic, economic and political developments, but also by technological innovations.
- A more detailed characterisation of the selected alternatives is the subject of **Chapter 4**. The respective background, the specific manufacturing processes and their technological maturity are presented, as well as information on relevant stakeholder groups.
- Future possible developments of the trend are presented in **Chapter 5** on the basis of the identifiable driving forces and barriers as well as the uncertainties to be taken into account in order to create an analytical basis for the assessment of environmental impacts.
- **Chapter 6** assesses the negative and positive effects on the environment of the three meat alternatives against the reference framework of currently established animal production. The chapter concludes with an overall assessment of the opportunities and challenges of the topic "meat of the future".
- **Chapter 7** formulates corresponding policy options for action for the UBA and BMU and identifies possible gaps in research.
- **Chapter 8** concludes with a summary of the central results of the trend analysis and environmental assessment as well as the recommendations for actions and ventures a brief outlook.

The trend analysis draws on currently available literature, market data, survey results (including those from the environmental awareness study conducted in 2018 and the accessible results data, see Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU) and Umweltbundesamt (UBA) 2019) as well as findings from interviews with experts, visits to events and the results of two workshops. The sources used are listed in the Annex.

3 Meat of the future: conceptual understanding and determining factors

3.1 What is "meat of the future"?

In order to bring about a change in meat consumption, many conceivable alternatives and substitutes are already available, which can be subsumed under the heading "meat of the future". Put simply, "meat of the future" is a group of food products with which the demand for animal proteins can be met without having to resort to conventional meat products. Against the backdrop of an increasingly critical debate on established forms of meat production, two questions are raised: (1) Which alternatives to conventional but also organic meat production are conceivable? (2) Which protein sources other than animal protein are available? Central to the decision which alternatives are being considered in this report is the question whether the respective meat alternative is meant to imitate the sensory spectrum of meat so that consumers can experience a comparable taste experience.

The selection and narrowing down of the three alternatives analysed in this trend report is based on the following criteria.

The selection process was not carried out by examining concrete product characteristics, but is the result of an intensive discussion process, which took place in the run-up to the analysis. Particularly as the product variety of plant-based meat substitutes could lead to a different classification of single products, a simplified version of the initial classification is provided in the above table. In addition, for the sake of simplification, not all evaluation steps are listed in detail.

Table 01

Criteria evaluation of meat alternatives

Imitation of ...	In vitro meat	Edible insects*	Plant-based meat substitutes	Other, partly unprocessed alternatives (e.g. tofu, jackfruit, etc.)
Smell	Yes	Yes; in processed form	Yes; in processed form	Partly; in processed form
Taste	Yes	Yes; in processed form	Yes; in processed form	Partly; in processed form
Texture	Yes	Yes; in processed form	Yes; in processed form	Partly; in processed form
Appearance	Yes	Yes; in processed form	Yes; in processed form	Partly; in processed form
Consistency	Yes	In part	In part	In part

*Edible insects can be consumed unprocessed as well as in processed form in meat-imitating end products.

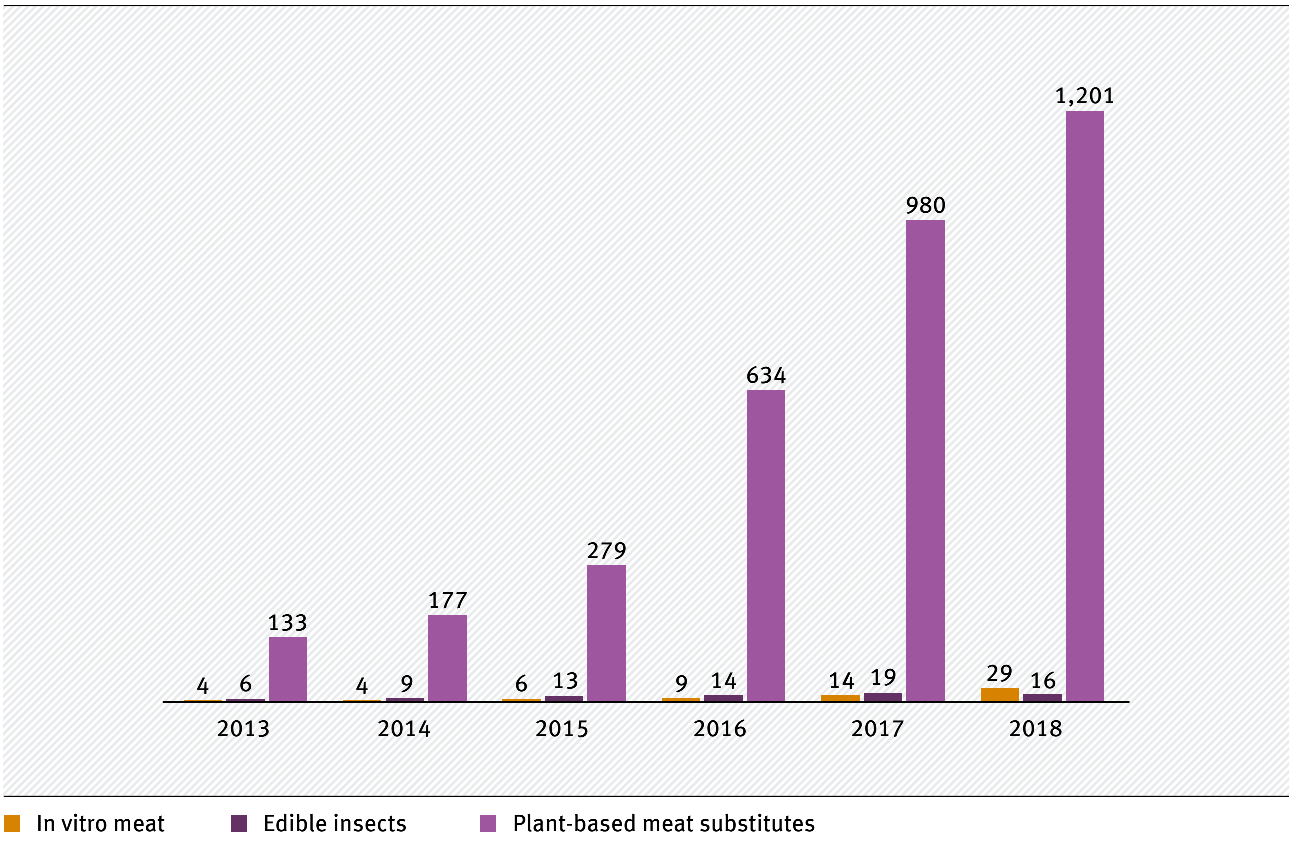
Excluded from the analysis are algae-based products, unprocessed protein-containing seeds such as pulses, nuts and tree fruits such as jackfruit, as well as soya- or cereal-based products such as tofu, as the aim here is not to achieve or only partly achieve an imitation of the full sensory spectrum of meat through processing. As a result, the scope of the analysis is limited to plant-based meat substitutes, edible insects and in vitro meat:

- Plant-based meat substitutes have been established for some time and are increasingly becoming imitations of meat products due to improved production processes (Buck 2014; Frankfurter Allgemeine Zeitung (FAZ) 2016). They are available in many different forms and consist of a wide variety of ingredients. Vegetable burgers, seitan and soya cutlets as well as soya-, cereal- and pea-based sausages, imitation poultry, imitation minced meat etc. are conceivable (see Chapter 4.1).
- Edible insects as an alternative to the consumption of animal proteins are conceivable in various ways. In processed form, they find their way into end products such as bars and the like, but can also be eaten fried etc. (Rempe 2014; Thompson 2016). In other cultures, edible insects have long been part of the established diet (see Chapter 4.2).
- In vitro meat is discussed as an alternative to established animal production (Maastricht University 2013; Schadwinkel 2013; Post 2014; Hocquette 2016; Kurrer and Lawrie 2018; Schuler 2018). It is a synthetically produced meat product bred from animal stem cells. It is also referred to as cultured meat, laboratory meat, "clean meat" and others (see Chapter 4.3).

Due to the diversity of available products, some of which are still in development, it is not possible to provide a detailed presentation of all variants within

Figure 02

Search results for the three meat alternatives on Google



(in 1,000)

Source: Own research

the scope of this trend analysis. Rather, the study discusses particularly relevant products or product groups in more detail. In view of the great variety of products, the environmental impacts are assessed on a basis of comparison with a reference framework for conventional animal production (see Chapter 6).

3.2 "Meat of the future": a topic of particular relevance

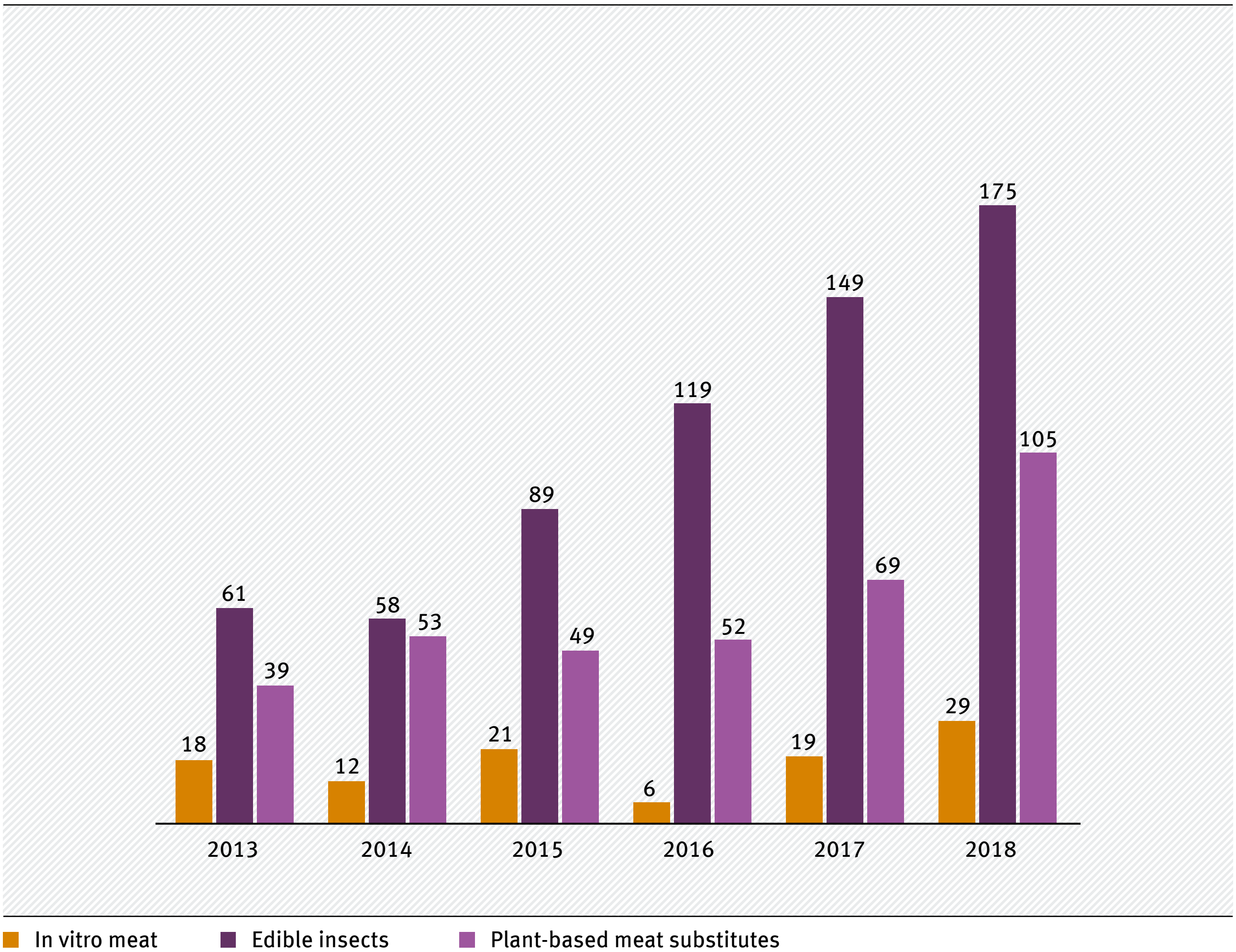
"Meat of the future" is of particular relevance as a topic for the transformation of the current food system towards sustainability. This can be seen in the increased public attention, growing economic activities, but also in the more intensive socio-political discourse.

Growing public interest in meat alternatives
One indicator of the increased relevance is the number of search queries on Google between 2013 and 2018 (see Figure 2). The selected time frame has to do with the public presentation of the first meat ever produced in a laboratory in 2013. The event turned the topic of in vitro meat from a hitherto specialist topic into public discourse. The search terms are listed in the Annex (see Chapter A.1.1).

The number of search results increased continuously over the last six years for all three product categories. For plant-based meat substitutes, approx. 280,000 search results could be obtained already in 2015; in 2018, the search produced 1.2 million results.

Figure 03

Number of annual international publications on the three meat alternatives in the Scopus database



Quelle: Eigene Erhebung

In contrast, the results for in vitro meat and edible insects are also characterised by growth, but to a much lesser extent. For edible insects, the total results even decreased slightly from 2017 to 2018.

Meat imitations are also a scientifically relevant issue

In order to gain an overview of the international scientific publication landscape on the topic of "meat of the future", the authors analysed international scientific publications – including specialist articles, conference contributions and review articles – which were published in the Scopus literature database between 2013 and 2018. The number of peer-reviewed articles is a common indicator for mapping scientific activities at universities and research institutions. The thematic focus was on (i) in vitro meat, (ii) edible insects and (iii) plant-based meat substitutes. The search terms used for the search can be found in the Annex (see Chapter A.1.2).

Figure 3 shows the development of annually published scientific articles for the above-mentioned three alternatives. The number of annually published scientific articles at international level has risen significantly since 2013 and has more than tripled by 2018. Although the publication rates in all scientific disciplines have increased in recent years due to a growing number of specialist journals, this multiplication of scientific articles indicates a very dynamic development in the field of meat alternatives. Especially on the topic of edible insects, the scientific community publishes above average.

The economic potentials of meat alternatives are increasing

The growing number of new companies being set up and the associated investment activities are further indicators that there is great potential for the production and sale of edible insects and, increasingly, for in vitro meat. The already established market for plant-based meat substitutes is growing continuously (see Figure 4). The rising number of product launches or the increasing number of manufacturers and brands characterise a dynamic segment. Although this segment is still a niche category compared to the growing global meat industry, market shares might shift in favour of alternative meat products in the future.

Meat alternatives become the subject of social and political discourses

In recent years, the public debate on meat alternatives has taken place at various levels. Most visible are high-profile publications such as the annual "Meat Atlas" of the Heinrich Böll Foundation[2], which has been published since 2013, the study "Meat Eats Land" of the World Wide Fund For Nature (WWF) (Witzke et al. 2011) or the work of the Albert Schweitzer Foundation for our Environment.[3] These publications all analyse the interrelationships between high meat consumption and negative consequences on the environment and significantly contribute to the formation of social discourse positions. For example, the development of artificial meat alternatives is discussed primarily with regard to the resource-saving use of means of production (Heinrich-Böll-Stiftung et al. 2018; p. 46–47). However, agricultural production methods and the manufacturing of meat products are important components of domestic value added. It is thus important that any transformation of the food system, which is driven by environmental concerns and agricultural policy, must ensure that different stakeholders are adequately taken into account.

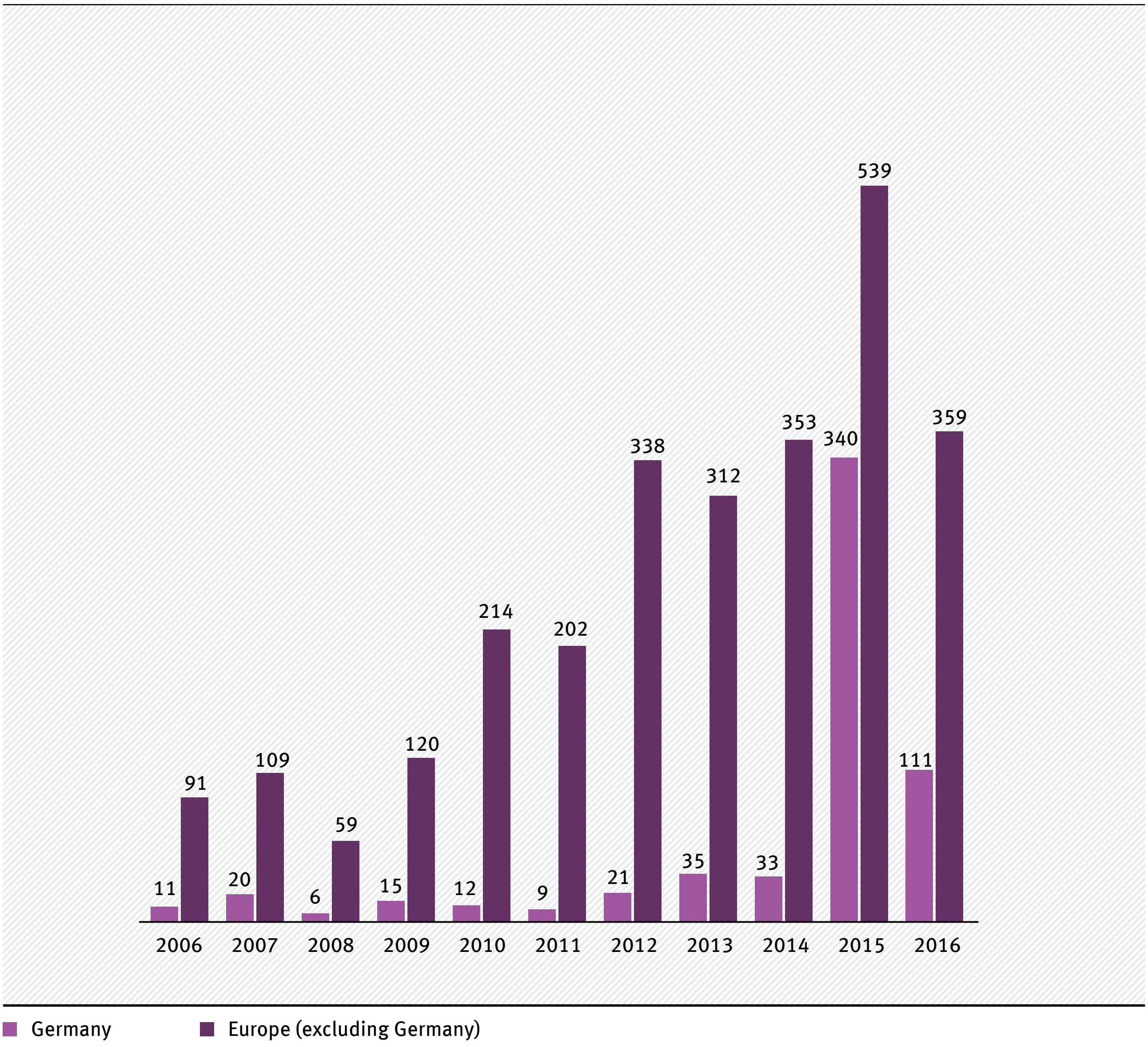
Meat alternatives – an environmentally relevant future-oriented topic?

There are numerous indicators suggesting that "meat of the future" is a complex, dynamic issue while its future development remains subject to uncertainties. This trend report provides an overview of this environmentally relevant topic. The analysis of current trends, the presentation of possible future developments, the assessment of conceivable environmental impacts and the formulation of initial options for action have been drawn up as part of the strategic foresight work regularly carried out by the UBA. The objective of this study is to increase the awareness of the UBA/BMU and other people and organisations already working, researching or interested in this field with respect to the ecological

2 Various publications available at: https://www.boell.de/de/fleischatlas
3 Various publications available at: https://albert-schweitzer-stiftung.de/aktuelles/veroeffentlichungen

Figure 04

Product launches in the meat alternatives category in Europe and Germany



Source: Statista GmbH (2018d)

relevance of the topic as early as possible, supporting them in taking advantage of the opportunities that arise and minimising or avoiding potential negative environmental and health effects from the outset.

3.3 Influencing factors and framework conditions

A change in the food system towards sustainability is influenced by demographic, economic, social and ecological factors. These factors determine not only the future development of meat consumption, but also the establishment of possible alternatives (Figure 5).

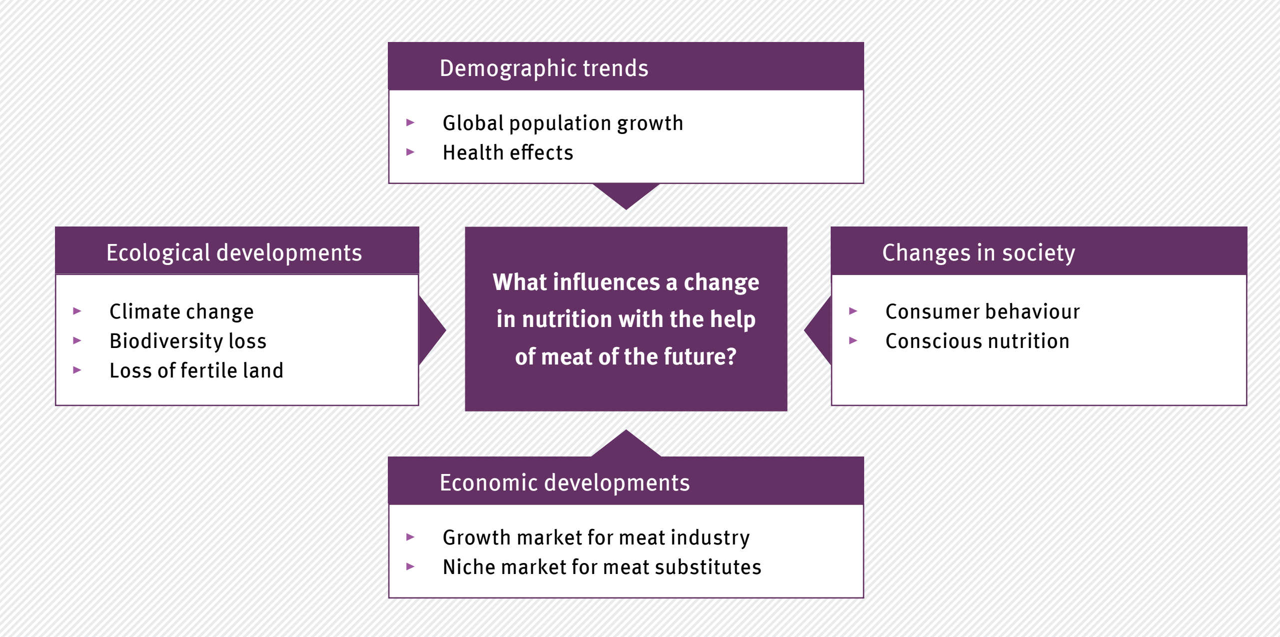
There are various interactions between these factors, so that individual factors can sometimes reinforce or weaken others. Feedback effects also arise when individual trends change their direction of development. A discussion of ecological developments is provided in Chapter 6.

3.3.1 Population change and ageing

According to current projections, the global population will continue to grow in the coming decades. In 2030, 8.6 billion people are expected to inhabit the earth. In 2050, the figure is projected to be 9.8 billion; this is an increase of 1 billion people

Figure 05

Factors influencing future changes in the food system



Source: Own illustration

in twelve years. (United Nations, Department of Economic and Social Affairs, Population Division 2017; p. 1 ff.). Consensus prevails that, as the population grows, the overall demand for calories, protein and especially animal protein is going to increase (Bodirsky et al. 2015; Food and Agriculture Organization of the United Nations (FAO) 2017; Henchion et al. 2017). In Germany, a population decline can be expected in the long term, to 79.2 million people by 2030 and to 67.6 million people by 2060 (Statistisches Bundesamt (Destatis) 2017). If the population is decreasing, it can be assumed that the total protein demand will decrease as well.

With an increasing life expectancy, the number of older people is increasing likewise. Societies in which larger parts of the population are over 65 face the challenge, among other things, of compensating for burdens on health and social systems. Nutrition-related health impacts are only one of many challenges. The consumption of meat plays a major role here. In recent years, an increasing number of studies have established a connection between excessive meat consumption and obesity, cardiovascular diseases, hypertension or type 2 diabetes (Sinha et al. 2009; Huang et al. 2012; Crowe et al. 2013) or generally attribute the occurrence of so-called lifestyle diseases to unhealthy nutrition (Sinha et al. 2009; Smet and Vossen 2016; O'Connor et al. 2017; Slot et al. 2017; Godfray et al. 2018). However, this does not only affect people over 65, but also children and young people.

A reduction in meat consumption could have positive health effects for large sections of the population and alleviate the burden on the health system caused by demographic change.

3.3.2 Consumer behaviour and conscious nutrition

Consumption and nutritional behaviour are not static; rather, they are subject to a variety of influencing factors and are constantly changing. The question in how far current patterns point towards change is therefore also relevant for the description of future consumption of meat and meat alternatives.

Consumers in Germany appear to be very reluctant to change their individual behaviour regarding meat consumption. For the majority of the German population, meat is still an important part of their diet. In 2013, 85 % of Germans stated that they eat meat every day (Heinrich-Böll-Stiftung et al. 2014a). Over the preceding five years – 2008 to 2012 – this share remained more or less the same (Gose et al. 2018; p. 16).

It is thus not surprising that current representative surveys reveal rather reserved attitudes towards meat alternatives (see Figure 6).

Nevertheless, German society is also showing initial signs of a change in values towards a more conscious diet. This includes not only a more in-depth examination of nutrition, for example through comprehensive information research when making consumption decisions, but also a critical examination of established diets and, as a consequence, a move away from these conventions. This can be illustrated by the example of vegetarian or vegan nutrition. A diet that reduces animal products or dispenses with them altogether is preferred by proponents, primarily for health, ecological and ethical reasons (see Figure 7).

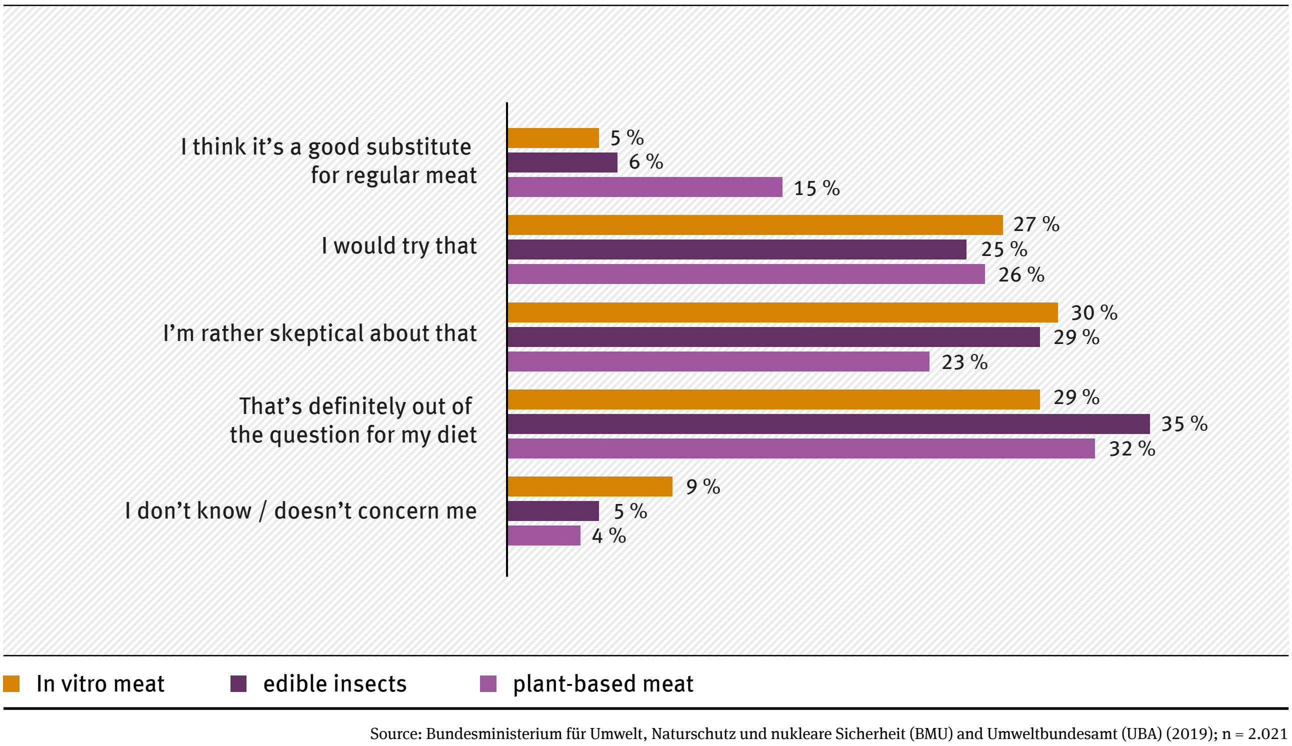
Although market developments (see Chapters 3.3.3 and 4.1.1) for vegetarian and vegan products point to different growth rates in different market segments, there is still insufficient empirical data on the size of the vegan and vegetarian population (Statista GmbH 2017d; ProVeg Deutschland e. V. 2018).

The range is from 6 to 12 % of the German population who eat vegetarian or vegan food. The lower limit corresponds to about 4.1 million people (Statista GmbH 2017e). Statements deviating from this, which assume a considerably higher number, are presented by the Vegetarian Association, which argues that there are about 10 million people (approx. 12 %) in Germany eating vegetarian or vegan food (ProVeg Deutschland e. V. 2018).

As a result, we see contradictory trends. On the one hand, there are observable changes in the behaviour of a minority (vegans and vegetarians). On the other hand, there is little evidence that these changes in behaviour reach a larger part of society. On the contrary, although sales of meat alternatives are increasing, meat consumption in Germany has remained more or less the same since the early 1990s. For the future, this means that changes in consumer behaviour and a more conscious diet might indeed trigger a change in meat consumption. However, this effect is likely to remain small without implementing

Figure 06

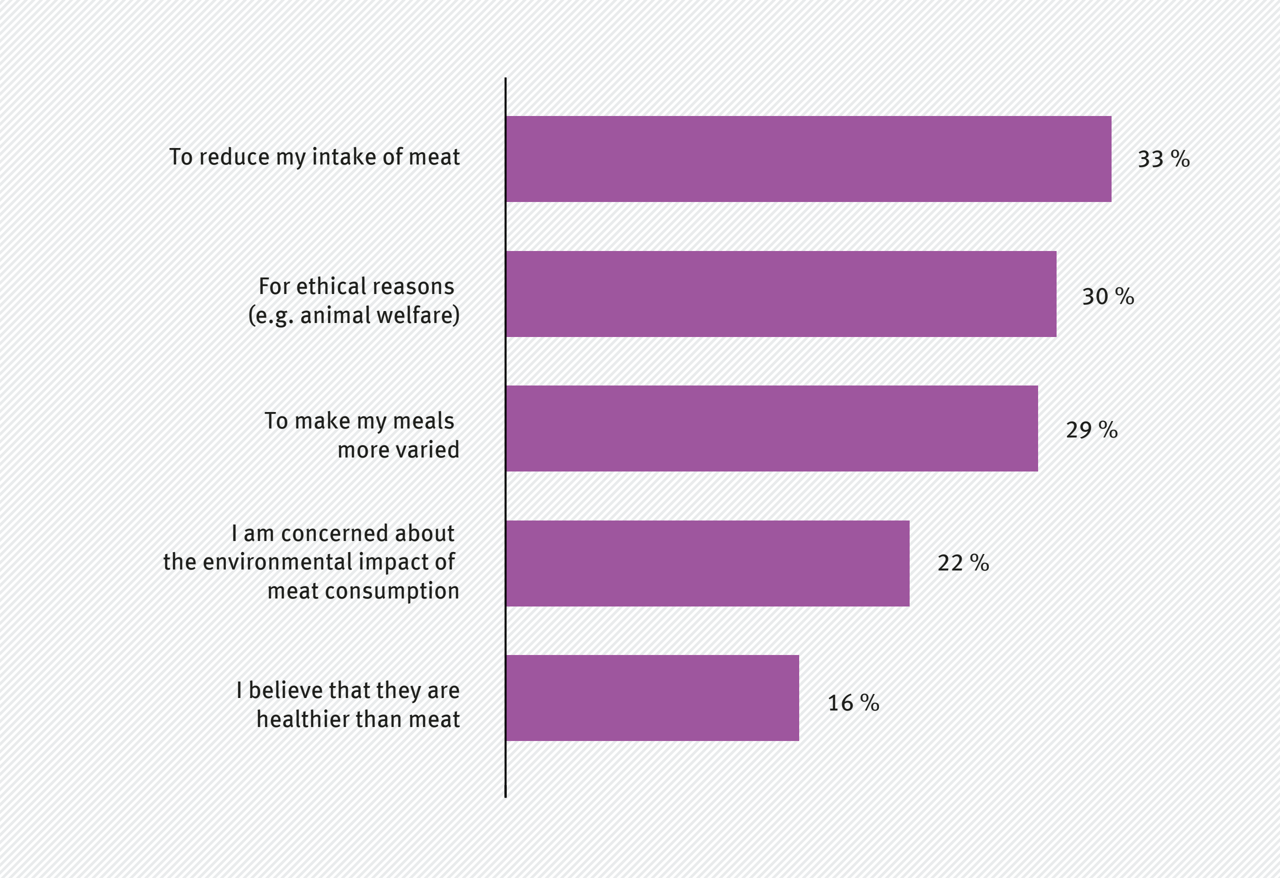
Attitude towards meat alternatives



Source: Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU) and Umweltbundesamt (UBA) (2019); n = 2.021

Figure 07

Reasons for the consumption of meat substitutes



Source: Nier (2016); n = 351

other measures such as regulatory levers in the form of adjusting VAT rates or labelling requirements etc.

3.3.3 Growth market for meat industry, niche markets for meat substitutes

Important factors influencing meat consumption are disposable income (especially for countries of the global South), age, gender, food prices and the food industry (Bodirsky et al. 2015; p. 1). The purchasing power of larger population groups is particularly growing in Asian, but also in African countries (Heinrich-Böll-Stiftung et al. 2014b; p. 10–11) while the prices for meat have also risen in recent years and are likely to continue to rise (OECD and Food and Agriculture Organization of the United Nations (FAO) 2018; p. 150 ff.). Against the background of an increasing world population (see Chapter 3.3.1), the global meat market is showing strong growth rates both in terms of quantities produced and sales generated.

Meat is a global growth market
The market value of the global meat industry in 2016 was around 714 billion US dollars. According to estimates, the value will double by 2022 (Statista GmbH 2018b; p. 7). It is also predicted that the world population's demand for animal protein will increase by around 80 to 100 % by 2050 – mainly in the so-called emerging and developing countries – and that global meat production will double in parallel if agricultural food production continues to develop as it has done to date (Boland et al. 2013).

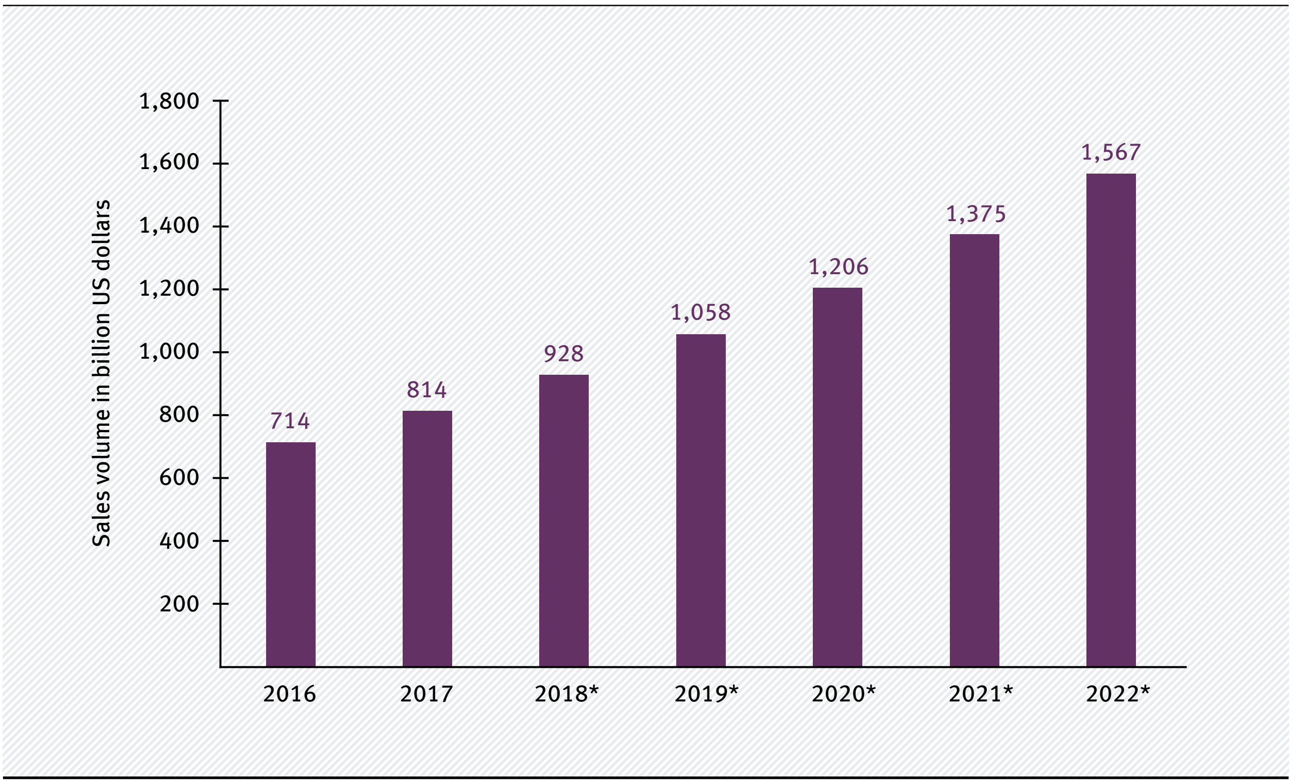
In 2017 alone, global meat production increased by 1.2 % compared to the previous year, with the main increases in the USA, Argentina and China (OECD and Food and Agriculture Organization of the United Nations (FAO) 2018; p. 19). A similar annual growth rate is predicted for the next ten years (OECD and Food and Agriculture Organization of the United Nations (FAO) 2018; p. 22). Translated into the global production volume for meat, this means growth of around 13 million metric tonnes from 2016 (317 million metric tonnes) to 2018 (330 million). By 2027, this quantity is expected to grow to 367 million metric tonnes, with average per capita consumption worldwide rising from 34.7 kg (2018) to 35.4 kg in 2027 (OECD and Food and Agriculture Organization of the United Nations (FAO) 2018; p. 238).

Meat substitutes are a global niche market

Compared to the above figures for the global meat market, the market for meat substitutes is currently a niche. According to estimates, turnover in 2017 was between 4 and 4.6 billion US dollars (Statista GmbH 2018c; p. 6). This represents between 0.5 and 0.6 % of the world meat market. However, depending on the market analysis, stronger growth rates are assumed for sales of meat substitutes until 2025. These growth rates are between 5 and 8 % per year. There are also estimates which assume a more significant market growth and already predict a worldwide market volume of about 10.9 billion US dollars for 2022: sales development from about 4 billion to 7.5 billion US dollars (Allied Market Research 2018); from USD 4.6 billion to USD 6.4 billion (Research and Markets 2018); up to USD 10.9 billion in 2022 (Research and Markets 2017).

Figure 08

Development of the worldwide market volume for meat products

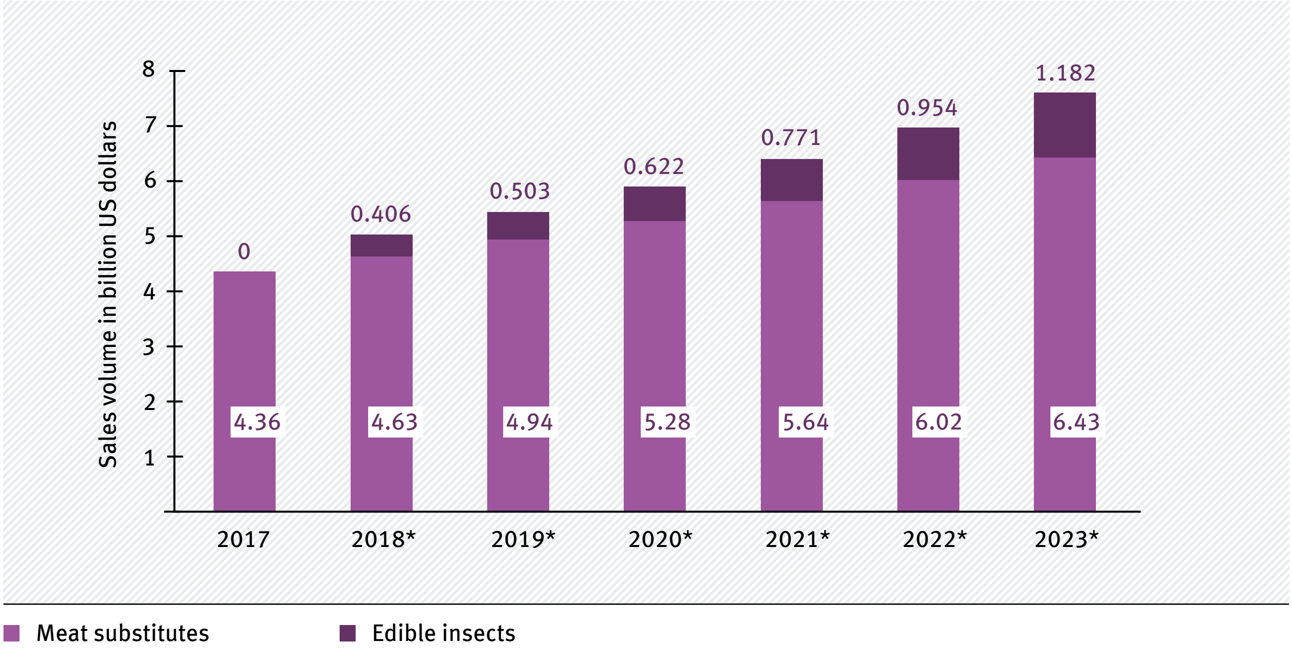


* Projection from 2018 onwards

Source: Statista GmbH (2018b)

Figure 09

Global market development for edible insects and meat substitutes



* Projection from 2018 onwards

Sources: Statista GmbH (2018a) and Statista GmbH (2018c)

4 Trend description: current developments in meat substitutes

For the purpose of this trend description, "meat of the future" consists of three categories:

- Plant-based meat substitutes as already available alternatives to animal proteins.
- Edible insects as a component of various products.
- In vitro meat, most of which is still under research.

The different levels of maturity of the three categories require separate descriptions to highlight their respective specific characteristics. These include the current state of development and a brief historical outline, the respective production processes and their technological maturity levels as well as the relevant stakeholders – producers, customers, research – whose different interests, needs and abilities may shape future developments of meat alternatives.

4.1 Plant-based meat substitutes: established alternatives with development potentials

4.1.1 Background and status quo

Compared to modern phenomena such as in vitro meat, plant-based meat substitutes have existed in various forms for centuries (Shurtleff und Aoyagi 2014; p. 5–6). Due to changing eating habits that do without animal products, a huge number of products have now become established that can be regarded as plant-based meat substitutes and are made from vegetable raw materials.

In the following, only those alternatives are described which attempt to imitate meat and thereby represent the entire sensory spectrum addressed in the preparation and consumption of meat. In other words, products that look, smell and taste like meat and also feel like meat and have a comparable or higher protein content are considered in the following analysis.[4]

The focus is therefore on products based on industrially processed plant proteins. These include seitan (wheat protein), Quorn (fermented fungal mycelium) and soya meat (textured soya protein) as well as products based on other protein-rich plants or seeds, such as lupins or peas. The analytical framework also includes products from individual companies such as the "Impossible Foods Burger", which consist of wheat protein, coconut oil and a haemoprotein liquid, among others.

Meat alternatives were referred to in China as far back as in 1301. It was not until the middle of the 19th century that meat alternatives were also mentioned in the western world; in 1896 the first commercial product, Nuttose, was available in the USA. In 1899, the term "vegetable Substitute for Meat" was also patented there. Since the 1960s and 70s an increase in the number of vegetarians in the USA and Europe can be observed. At the same time demand for and supply of plant-based meat alternatives was rising (Shurtleff und Aoyagi 2014; p. 5–6). According to estimates, the global market volume for plant-based meat substitutes in 2018 was approximately USD 4.36 billion (see Chapter 3.3.3).

4 This means that although soya-based products such as soya meat are mentioned below, tofu is not. Tofu is generally not sold as imitation meat without additional processing steps; Schmidinger 2012; p. 137.

Niche market with growth potentials
Europe is currently the largest market for meat substitutes (Statista GmbH 2018c; p. 9). Since 2010, this has been particularly evident in the growing number of product launches, which reached an interim peak in 2015 with around 900 new products in the meat alternatives category. Only about half as many new products were launched in Europe in 2016. Of these 470 launched products, 111 were marketed in Germany (Statista GmbH 2018d; p. 2).

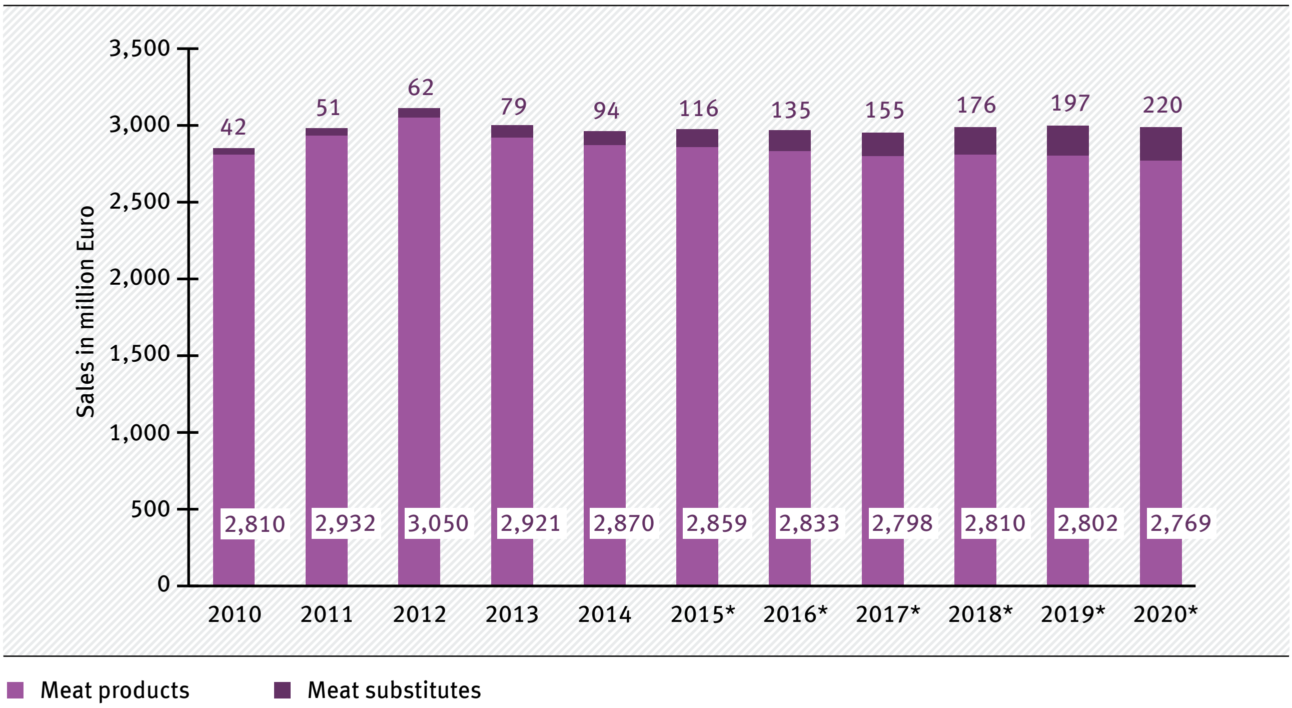
Although turnover from meat substitutes in German retail is increasing (Lebensmittelzeitung 2019), it only accounts for a small share of the meat industry's market volume: in 2017, it was estimated at 6 %. This means turnover from meat substitutes of 155 million euros (Statista GmbH 2017a; Statista GmbH 2017c). Since 2010, a significant increase can be observed here with an annual growth rate of about 18 %. Since sales of meat products have shown a slight downward trend (-0.74 % average annual decline in sales), the share of meat substitutes in the market volume of the meat industry will continue to increase in the future. Market shares of 8 % are estimated for 2020, which would still mean total annual sales of around 220 million euros (Statista GmbH 2017a).

The market in Germany for vegetarian and vegan products has shown a differentiated picture in recent years. After steady sales growth there was a downward trend from 2016 to 2017 (Tewes 2017) which is similarly reflected in the number of product launches (Statista GmbH 2018d). Both trends could be signs of market consolidation (Grossarth 2018).

The stakeholder landscape in Germany is heterogeneous. In addition to specialised manufacturers and private labels, young start-ups and innovative retailers, producers of conventional meat products are also entering the competition and expanding their product ranges to include plant-based meat alternatives (Frankfurter Allgemeine Zeitung (FAZ) 2016; Kitzmann 2018; Liebrich 2018). In total there are about 60 brands of vegan and vegetarian products, including plant-based substitutes, distributed by 52 companies (Schneider 2016). The company Rügenwalder has the largest market share – about one third (Tewes 2018).

Figure 10

Development of sales of meat and meat substitutes in Germany



* Projection from 2015 onwards

Sources: Statista GmbH (2017a) and Statista GmbH (2017c)

Simplified production processes, economies of scale and increased demand drive further development
One of the main reasons for the growing market potential of plant-based meat products is the simplified production processes that have made it possible to lift up production to an industrial scale, as well as to increase product differentiation. The growing world population and the associated question of sufficient food supply as well as the pluralisation of eating habits can also be seen as driving forces for an increasing supply of plant-based meat alternatives. The pluralisation of eating habits is also influenced by aspects such as the increased awareness of the consequences of one's own diet and the growing acceptance of alternative products (Reeken et al. 2016).

The above has led to where we are today: there is a wide variety of products, demand and supply are estimated to continue to grow and large meat producers are also offering plant-based meat products (Frankfurter Allgemeine Zeitung (FAZ) 2016; Liebrich 2018). However, this assessment is not universally shared. Grossarth (2018) points out that products are also disappearing from the market again due to declining sales. In the future, it can be expected that the imitation of meat by plant-based meat substitutes in terms of taste, consistency and nutrient content will be sought both through improved manufacturing processes and the use of a wide range of additives and genetically modified plants.

4.1.2 Production processes and technological maturity

Since plant-based substitute products have been part of the diet in various cultures for a long time, some of the manufacturing processes have been known for centuries. Today, however, industrial processing is possible, so that production volumes are increasing and new products are being created.

Most of the products mentioned below are manufactured in a comparable manner. The decisive factor is the use of vegetable proteins, which are mixed with water and spices and processed into a dough under the application of heat in an extruder. Depending on the desired end product, the fibrous dough mass is pressed through nozzles into appropriate moulds (Buck 2014; p. 41–42). In some cases, raw materials are fermented by adding fungal mycelia or yeasts (Weigel und Gensberger-Reigl 2017; p. 9 ff.). Due to the great variety of products in Germany, a wide range of additives is used. It would go beyond the scope of this analysis to elaborate in detail on all the substances and processes used. For this reason, the main processes and raw materials used will be discussed below.

Spotlight: Market for meat products in Germany

The market for meat products in Germany has some diverging characteristics compared to the global meat market. For example, the annual production volume has risen again in recent years after a slump in 2001 in the wake of the BSE crisis and was at a high level of approx. 9 million tonnes in 2017 (Agethen 2018; p. 2–3). Domestic annual consumption has remained more or less constant at 7.3 million tonnes, while exports have risen by 1.3 million tonnes over a ten-year period to 2.8 million tonnes in 2017 (Agethen 2018; p. 3).

Per capita meat consumption in Germany in 2017 was around 60 kg (Bundesanstalt für Landwirtschaft und Ernährung (BLE) 2018a; p. 185; Newmiwaka und Mackensen 2019). This figure has been roughly constant for about 15 years and is only about 3 kg below the 1991 value. (Statista GmbH 2017b). It is almost twice as high as the global average.

The development of sales on the German meat market has remained more or less unchanged compared with the growing world market. The average annual turnover from meat products in the retail trade in Germany is about 2.9 billion euros (Bundesverband der deutschen Fleischwarenindustrie e.V. (BVDF) 2019).

The market in Germany is characterised by several large manufacturers. The Tönnies Group alone as the largest player generated an annual turnover of 6.35 billion euros in 2016. This is followed by Vion Food Germany (2.97 billion euros) and Westfleisch (2.47 billion euros) as well as the PHW Group with 2.46 billion euros (Sieler o.J.).

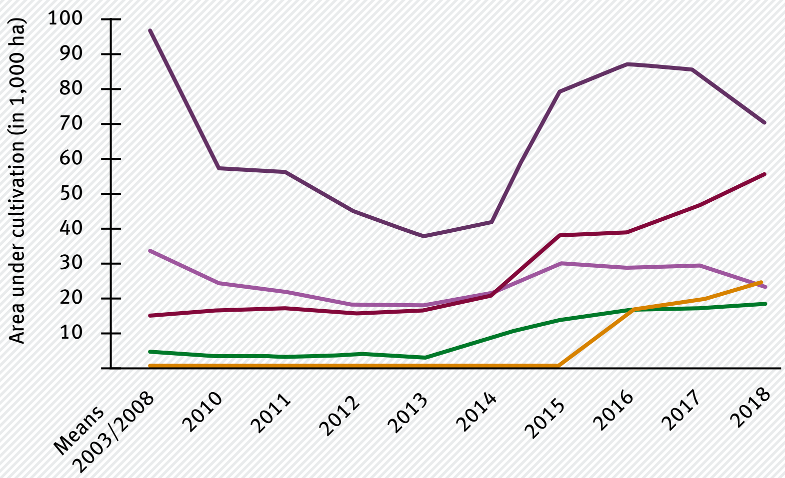
Raw materials from agricultural production
Plant-based meat substitutes are mainly obtained from plant proteins, protein concentrates or protein isolates (Pabel und Schiller 2017; p. 5). These may be proteins from legumes, including soya beans, peas or sweet lupins, from wheat or from mycoprotein.[5] Fungi grown in bioreactors are used for the production of mycoproteins (Thrane 2007; Groß 2016). In contrast, agricultural land is needed for the cultivation of wheat and legumes. Of the areas used for agriculture in Germany – around 16.7 million ha in 2017, which corresponds to about 51.1 % of the total area of Germany – about one fifth (3 million ha) was used for the cultivation of wheat. Peas were grown on 85,500 ha, sweet lupins on 29,000 ha and soya (statistically recorded only from 2016) on about 19,100 ha (Statistisches Bundesamt (Destatis) 2018; p. 8). Current developments are shown in the following Figure 11.

Domestic legumes in particular are gaining new importance as an alternative source of protein for the production of plant-based meat products compared to the import of soya (Bioökonomierat 2017; p. 5–6). A change can currently be observed with the result that the raw materials mentioned above are once again increasingly being cultivated in Germany and are also available in other parts of Europe, thus reducing imports from overseas (Pabel and Schiller 2017; p. 4).

Due to the widespread use of soya-based meat substitutes, the extraction of proteins, concentrates or isolates as the first step of further processing is described using the example of the soya bean. As lupins and peas are becoming increasingly relevant, the following explanations are partly transferable.

Figure 11

Cultivation of legumes for grain production in Germany



Field beans | Peas (excluding fresh peas) | Sweet lupins[1] | Soya[2] | Other[3]

[1] Until 2009: lupins; [2] Statistically recorded from 2016; [3] Excluding soya beans
Note: including seed production

Quelle: Bundesministerium für Ernährung und Landwirtschaft [BMEL] (2016)

5 Although fungi are not plants, they are listed and analysed here.

Spotlight: Lupin-based products and nutrient cycles

The domestic lupin is not only used as animal feed and as a raw material for the development of plant-based substitute products, but it also has – like all legumes – nitrogen-binding properties. This has a positive influence on nutrient cycles. These bind atmospheric nitrogen and make it available for other plants. Lupins also promote soil fertility and require very little fertilisation (Bundesanstalt für Landwirtschaft und Ernährung (BLE) 2014).

Thanks to special breeding, it has become possible to produce a wide range of products based on lupin seeds, such as sausages, fillet steaks or even yoghurt and ice cream. More research is needed to ensure higher yield reliability and quality and thus expand regional cultivation. (Böhm et al. 2018).

Industrial method of production of preliminary and final products
Soya beans – or other sources of protein such as peas or lupins – are mechanically crushed and degreased to achieve different protein concentrations by adding solvents. The solvents evaporate when heated or dried, and depending on the process parameters, precursors with different properties are available (Heiss 2013).

Usually, further processing steps are necessary to produce the final products. The production of a meat-like texture – i.e. a fibre-like structure of initially ball-shaped proteins – is usually achieved by using extrusion processes. Two processes can be distinguished:

- During dry extrusion the feedstock (protein, protein concentrate or protein isolate) is processed at a low water content with the addition of thermal and mechanical energy and appropriate additives (Heiss 2013; Pabel und Schiller 2017; p. 5). Depending on the design of the extruder, e.g. shape and number of screws inside or geometry of the nozzles, different product characteristics such as consistency or shape can be achieved. As a rule, dry-extruded intermediate products (Texturised Vegetable Protein, TVP) must be rehydrated later to achieve a sponge-like consistency of the end product (Gleisenberg 2016; p. 36ff.).
- Wet extrusion (High Moisture Extrusion, or cooking extrusion), which is a relatively new process, is characterised in that processing is carried out with a comparatively high water content (Wild et al. 2014; p. 46) which essentially corresponds to the desired water content of the end product. Using the additional process parameters of pressure and temperature, the required ingredients are mixed and kneaded. When the sponge-like end product leaves the extruder, the resulting mass is cooled (Osen o. A.; p. 2) – a further distinguishing feature from dry extrusion (Pabel and Schiller 2017; p. 6).

Innovations in both processes mean that combinations of the two extrusion processes as well as a combination of different ingredients are possible, e.g. pea proteins with soya or lupin proteins (Pabel and Schiller 2017; p. 6). This increases the possibilities of better imitation of different meat products.

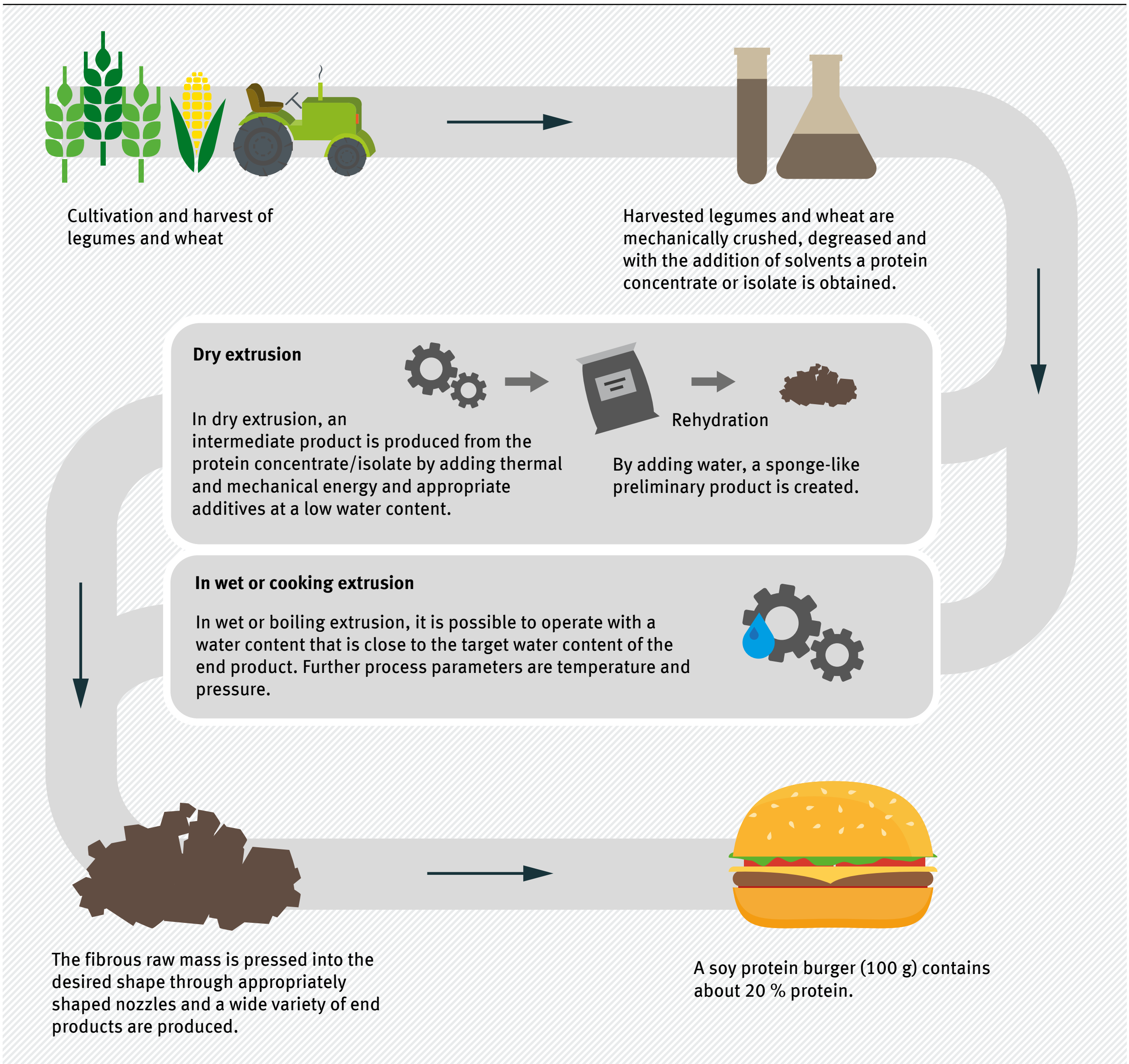
Through processing and further treatment of the preliminary products resulting from extrusion, taste, olfactory and optical characteristics are added. Depending on the extrusion process used, appropriate ingredients can also be added during extrusion. These include spices, salts, yeasts or flavourings for the desired taste and smell, as well as foodstuffs such as beetroot, blackcurrant juice or mineral iron oxide for colouring. Usually, colour-retaining substances such as ascorbic acid are also added. (Wild et al. 2014; p. 47; Pabel and Schiller 2017; p. 5).

Large product variety possible
With the help of the methods outlined above, a large number of different products can be manufactured, the listing of which would go beyond the scope of this analysis. Therefore, individual product group examples are presented below, based on the three most important raw materials primarily used:

- Legumes such as lupins, peas or soya beans are used to manufacture a wide variety of products. Soya meat (TVP) is only one example. It is produced according to the dry extrusion process described above and is used as a chopped pre-product for burgers, shredded meat and the like. Peas as a raw material lead to different taste and colour characteristics of the end product (Buck 2014). Product innovations are mainly achieved by combining different vegetable protein sources and improving production processes by varying the process parameters.
- Wheat proteins are traditionally used to make seitan, but have also recently become a core ingredient of the “Impossible Foods Burger”. The production of seitan is comparatively simple and can also be done at home on a small scale. It is made by washing out wheat flour until gluten is left over. By adding spices and liquid, the gluten is then made into a dough, which is boiled in water, vegetable broth or marinade (Ernst o.J.). The burger patty from the company Impossible Foods is more complex to produce. In addition to water, textured wheat protein, coconut oil and

Figure 12

Typical production process of plant-based meat alternatives



Source: Own illustration according to Böhm et al. (2017)

potato protein, various additives such as yeast, salts, soya protein isolate, vitamins, etc. are used (Impossible Foods 2018).

- The product "Quorn" is made from mycoprotein (or rather from a mould fungus to be precise; Venator 2019). In England the product was launched in 1985, while in Germany it took until 2012 before Quorn was available (Marlow Foods Limited 2018a). Today there are twelve product variants. Quorn is also produced with the addition of nutrient solutions, thermal energy and chicken egg white as a binding agent and is processed into various products depending on the machine used (Leitzmann 2013; p. 299). The manufacturer's vegetarian mince is produced, for example, using flavouring substances, chicken egg white and firming agents such as calcium chloride, calcium acetate, gluten-free roasted barley malt extract or natural caramel sugar (Marlow Foods Limited 2018b). However, the specific ingredients and manufacturing processes depend on the end product and vary accordingly.

Spotlight: Are vegetable meat substitutes vegan?

Plant-based meat substitutes are not vegan per se. Chicken egg white is often used to stabilise the raw mass or the substitutes contain dairy products. This opens up an innovation path – dispensing with animal ingredients and developing alternative stabilisers that do not contain chicken protein can make plant-based meat substitutes suitable for vegans. Whether companies follow this path, however, depends on economic aspects. While vegans make up only a small proportion of consumers, the much larger and economically more relevant target group is those who are less interested in individual animal components of their food.

4.1.3 Stakeholders

The development of plant-based meat substitutes is being driven forward in various ways by different stakeholders. The current research focus is on finding alternatives to soya as a raw material for plant-based meat substitutes and improving the extraction possibilities of individual plant components. Economic players operate in a market environment that is generally highly dynamic and growing. Consumers can choose between meat and a variety of plant-based products. In addition to the product price, the acceptance of alternative products and the perceived benefits, e.g. positive health effects, also influence the decision-making.

Science and research

The research landscape is highly differentiated and can only be presented here very superficially. In contrast to the other two developments, the research field cannot be clearly delineated and therefore statements on publication activities, research projects and levels of funding can by no means be considered complete. However, three lines of development in particular can be highlighted with regard to research in Germany:

The **use of new raw materials** such as peas, lupins, etc. to obtain plant proteins and the use of fungi as a starting point for substitute products are the subject of research projects. Examples of such projects are the following:

- "Product development of meat-like products from co-cultivated fungal proteins": The project, which received 147,000 euros of funding from the State of Hesse, aims to develop vegetarian and vegan meat alternatives from fungal mycelia (Stephan 2017).

- The project "Peas, Lupins & Co in Field Trials" of the Johann Heinrich von Thuenen Institute in cooperation with the Friedrich Loeffler Institute (FLI), the University of Rostock and the Julius Kühn Institute (JKI)is primarily investigating the use of lupins as animal feed, but also the ecological potential of lupin cultivation (Böhm et al. 2018).

- At European level, the TRUE project (TRansition paths to sUstainable legume based systems in Europe) has also investigated the potential of legumes for a sustainable transformation of the food system (Hohenheim Research Center for Global Food Security and Ecosystems 2018). The new EU project "Smart Protein" is scheduled to start in January 2020. The aim is to develop new, protein-rich alternatives to animal products. These innovative products are to be produced from plants, fungi and by-products and are expected to come onto the market in 2025 (vegconomist 2019).).

The **improvement of production processes** is primarily a question of food technology research, such as that conducted at the German Institute of Food Technologies (DIL) (Biedermann et al. 2018). In various projects, product and process innovations are being developed that not only enable plant-based alternatives to be produced, but also make established production processes for meat products more efficient.

The **improved use of existing raw materials** can help to increase the sensory proximity to real meat and make substitute products even more distinctive. The key research question is the search for individual components of vegetable raw materials, their extraction and combination possibilities and their potential for optimisation (Bundesvereinigung der Deutschen Ernährungsindustrie e. V. (BVE) und Deutsches Institut für Lebensmitteltechnik e. V. (DIL) 2017).

The application of technical innovations can therefore lead to a revolution in the production of plant-based meat substitutes.

Spotlight: Artificial intelligence as a driving force of innovation

The use of artificial intelligence (AI) methods can help to understand the factors influencing the perception of taste and to combine ingredients in a targeted manner during product development in order to create a taste experience that cannot be confused with that of meat consumption. Similarly, machine learning methods can help to understand the ingredients of plant-based raw materials, their interaction or possible combinations, and thereby contribute to the development of new products. But also beyond the research of plant-based raw materials for the development of new substitute products, AI methods can be applied in food production. In future, intelligent algorithms could be used to optimise the energy requirements via the production process or control the process parameters (Allen 2018; Varshney 2018).

Economic stakeholders
Established companies in the meat industry as well as venture capitalists invest in innovative companies and products. Not only has the world's largest meat producer Tyson Foods (Mumme 2018) invested several million US dollars in the American start-up Beyond Meat, which was founded in 2009 and manufactures products based on pea proteins. The German company PHW/Wiesenhof has also acquired an interest in Beyond Meat (Liebrich 2018). While the German wholesaler Metro would like to supply the wholesale trade, Wiesenhof sells the products to the catering and restaurant business (Mucke n.d.). In mid-2019, Beyond Meat products were available at the discount supermarket Lidl for a short time. The campaign met with very high demand, which could not be met due to production bottlenecks (see Chapter 1).

Another relatively new player in this field is the US company Impossible Foods, founded in 2011 and dedicated to the production of meat from vegetable feedstock. In addition to the use of wheat protein, coconut oil and potato protein in the production of alternative products, the use of a haemoprotein liquid is of particular importance (Impossible Foods

2018). Haemoprotein is present in animal muscle, but can also be obtained from soya root using a special fermentation process and contributes to the taste imitation of meat. By the end of 2018, the company Impossible Foods is planning to produce one tonne of the artificial meat per day. So far, the burger produced from the artificial meat has been offered by the White Castle fast food chain in the USA, among others. (Mumme 2018; Peters 2018). The products of Impossible Foods are not yet available on the German market (as of July 2019).

On the basis of the above distinction into three product categories – proteins from legumes, wheat proteins and mycoproteins – some examples of products on the German market and their manufacturers as well as market development perspectives are mentioned below.

- Proteins from legumes can be found in many products. Like Meat, for example, a company belonging to the Heristo Group, offers not only soya-based products but also two products made from pea protein: curry fillet pieces and ham bratwurst (Like Meat 2019). Pea proteins can be characterised as a growing market segment (vegconomist 2018a). The company Beyond Meat also uses pea proteins as well as rapeseed and coconut oil among other additives for their products. Furthermore, fillet pieces from lupin seeds are now offered in German food shops. This market segment is also expected to grow in the coming years (vegconomist 2018b).

- The Impossible Foods Burger, which is not yet available in Germany, has already been mentioned above as an example of products made from wheat proteins. Another wheat-based product that can be mentioned is seitan, which, both in its unprocessed and processed form, is widely available in food shops. A well-known manufacturer for this is Topas GmbH, which offers about 50 different products in Germany with its Wheaty brand (Popowska 2016).

- The company Quorn (see above) currently offers twelve mycoprotein products in food retail in Germany. The company is thus also experiencing strong sales growth in Germany, with double-digit growth rates that are even higher than the overall market (Tewes n.d.).

In all three product categories, the location of production and the source of raw materials are likely to be decisive for an assessment of environmental impacts. It is often the case with foreign suppliers that the products are exported to Germany and are not produced from raw materials that are typically grown in Germany.

Spotlight: The Impossible Foods Burger

The Impossible Foods Burger consists of vegetable ingredients and therefore has less environmental impact than a conventional burger made of beef. The background to this is that greenhouse gas emissions, water consumption and land requirements arising from animal husbandry and animal feed cultivation can be reduced (Khan et al. 2019). However, the ingredients for the burger do not come from organic farming and are partly genetically modified. The degree of processing of the individual ingredients in the Impossible Foods Burger is also high. In the future, the aim will be to further research the allergenic potential of leghaemoglobin and to exclude health risks of the genetically modified protein structure.

Consumers

From the consumer’s point of view, the above-mentioned product variety is an important factor, because consumer decisions always mean making a choice from an existing range of products to the exclusion of alternative products. As mentioned above, despite a growing market for alternative products, current meat consumption in Germany does not indicate that the majority of consumers are changing their behaviour. Rather, there is reason to believe that meat substitutes are occasionally consumed, but do not replace the consumption of meat.

This is mainly due to the fact that plant-based meat substitutes have so far only insufficiently imitated meat, which has a significant influence on the acceptance of the products and ultimately on purchasing decisions (Schrode 2016). Since taste in particular – besides price – is an important decision criterion for the repeated purchase of substitute products (Buxel and Auler 2017; p. 4ff.), changes in consumer behaviour can only be expected if the taste of meat, together with texture, smell, etc., can be convincingly imitated (Sexton 2019) and the price is lower compared to meat products.

To be able to completely imitate the smell, texture, taste, nutrient content and appearance of meat products is seen as a challenge for the further development of plant-based meat substitutes. This can most likely be achieved with products whose meat counterparts have already been further processed, such as minced meat and products formed from it.

The high degree of processing of plant-based meat substitutes requires the use of many ingredients and additives (Frankfurter Allgemeine Zeitung (FAZ) 2016). For consumers this means dealing with extensive information on the ingredients of the products on offer and often not easily understandable nutritional claims. Accordingly, manufacturers and consumer advocacy groups as well as politicians are faced with the challenge of formulating or complying with labelling requirements and obligations. However, due to the diversity of products and the associated variety of ingredients, it is difficult to make general statements on the nutritional value of products.

Another important deciding factor is the price. The industrial production of meat has led to comparatively low prices for meat products in Germany, although there has been a trend towards rising prices over the last six years (Bundesanstalt für Landwirtschaft und Ernährung (BLE) 2018a; p. 222). If customers are to buy meat substitutes, product prices must settle at a competitive level. So far, meat substitutes have not been separately listed in the relevant statistical surveys and therefore comparative statements on price developments are not possible.

The acceptance of meat substitutes is also influenced by the aspect of food safety, as most products are highly processed products. Due to manufacturing processes, they may also contain undesirable components or allergens.

For example, petroleum hydrocarbons have been detected, which have adverse health effects (Brauns 2016; Hinsch und Tölle 2019). Similarly challenging is the handling of allergy potentials, especially of lupins, wheat and soya (Bundesinstitut für Risikobewertung (BfR) 2011; Gleisenberg 2016; Pabel und Schiller 2017). On the one hand, the raw materials are the main components of plant-based meat substitutes, but on the other hand they can also be contained in small quantities in other end products due to the high degree of processing. Cross-contamination cannot be ruled out.

Therefore, from the consumer's point of view, lists of ingredients seem to be more important than labels such as vegan and vegetarian (Reeken et al. 2016). Product designations should be clear (Buxel und Auler 2017) and must not obscure the ingredients of the product (Volkhardt et al. 2017) so that consumers can make well-informed decisions.

Spotlight: Increasing product diversity for a heterogeneous customer base

Not only will the variety of available products continue to increase, but the needs and requirements of consumers will continue to evolve. Meat substitutes are by no means only relevant for vegetarians and vegans. Rather, the extremely heterogeneous clientele of people who have hitherto consumed meat, especially the so-called "flexitarians", is increasingly being addressed. This customer group has extremely heterogeneous characteristics, e.g. in terms of purchasing power, purchasing preferences, tastes, etc., which the producers can address with a corresponding variety of offers. In the future, products could even be designed according to the individual needs of customers and, for example, address certain health aspects (Hughes 2018).

4.2 Insects: a new alternative protein source on the market

4.2.1 Background and status quo

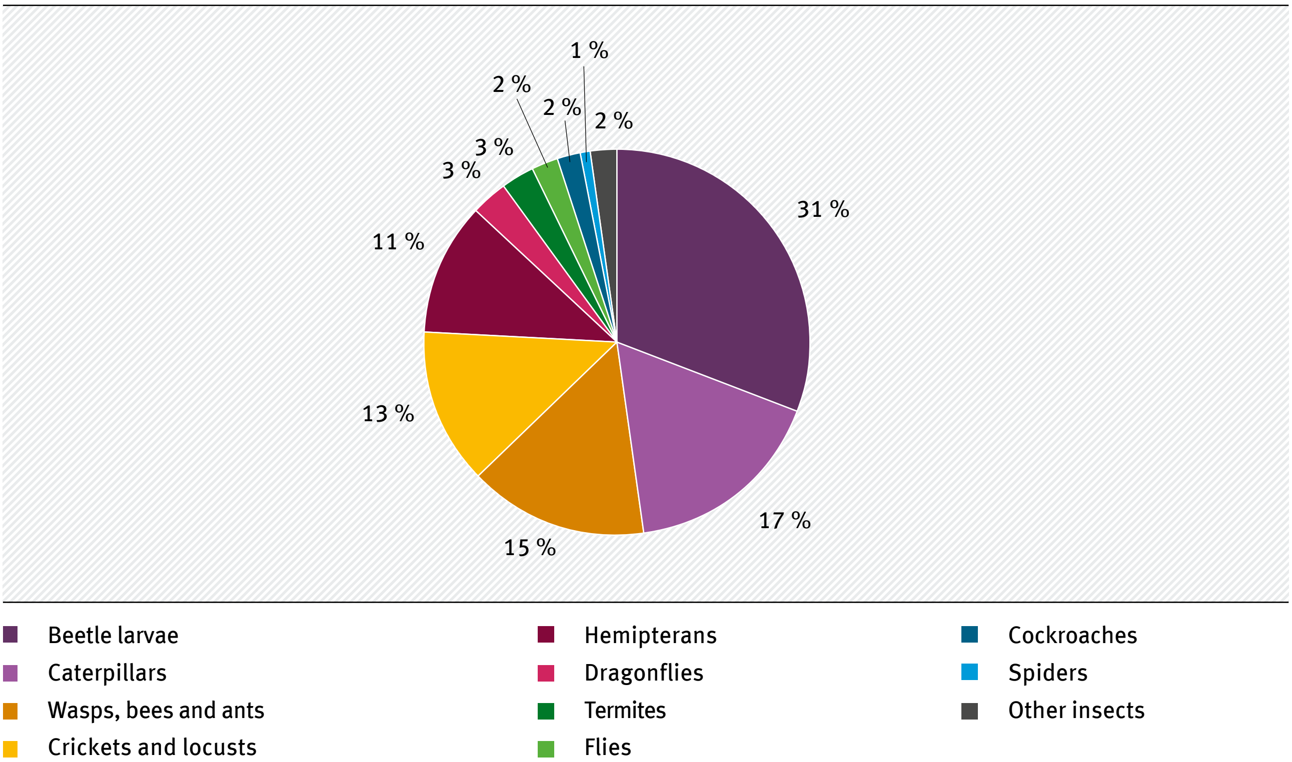
Although insects are mainly consumed in the tropics and less or not at all in the temperate climate zones (van Huis und Tomberlin 2017c) they have now arrived on the food market in Germany. There are 2,111 edible insect species worldwide (Jongema 2017). The share of different species is shown in Figure 13.

As ectothermic animals[6], insects are not considered to be meat according to the guidelines for meat and meat products (Bundesministerium für Ernährung und Landwirtschaft (BMEL) 2019). Only "parts of warm-blooded animals slaughtered or killed for human consumption" may be described as meat.

In terms of dry matter[7], insects have an average protein content of between 25 and 75 % and a fat content, including fat-soluble molecules, of between 10 and 70 % (Finke und Oonincx 2017). In addition to proteins, insects contain other nutrients that are important for humans, such as copper, iron, magnesium, manganese, phosphorus, selenium and zinc, the vitamins riboflavin, pantothenic acid and biotin, as well as fibres (Payne et al. 2016b). Due to the large range of edible insects, however, a general statement on "nutrient content of insects" is speculative. In addition, factors such as feed and holding conditions (temperature, humidity and light) have a great influence on the nutrient content of insects (Finke und Oonincx 2017). In a systematic comparison of the nutrient composition of insects and meat, however, it could be shown that the insect species investigated – locust, honey bee, silkworm, mopane caterpillar, mealworm and weevil larvae – are in no way inferior to conventional meat – beef, chicken and pork – from a nutritional point of view, but are in some cases even more nutritious (Payne et al. 2016b).

Figure 13

Share of the total number of edible insect species



(N = 2,111)

Source: Jongema (2017)

6 While ectothermic animals, such as insects and fish, do not have a constant body temperature, the body temperature of warm-blooded animals (e.g. mammals and birds) remains at a constant level.

7 The dry matter is that part of a substance which remains after removing the mass of water contained in it.

4.2.2 Production processes and technological maturity

Wild harvesting and breeding on small farms
In regions where insects are traditionally consumed – these include mainly Africa, Asia and Latin America – they are mainly collected in their natural habitats. In only a few cases can one speak of "semi-domestication", in which the habitats of the insects are modified to facilitate access to them (van Itterbeeck und van Huis 2012). Various methods are used to catch the insects. They are collected from plants by hand, shaken with sticks from trees and bushes and/or caught with cloths and nets. At night, light traps – usually illuminated cloths – are common to attract insects and collect them from the trap. The selection of the insects takes place on site, with e.g. inedible species being sorted out (Grabowski 2017). A sustainable "harvesting strategy" is often not the focus of attention, so yields are increasingly threatened by overexploitation, habitat changes or pollution (Ramos-Elorduy 2006).

In addition to collecting insects, there are also methods for breeding them. In Thailand, for example, 7,500 tonnes of locusts are produced annually on 20,000 small farms for sale on local markets or for self-sufficiency (Hanboonsong et al. 2013). The production of crickets often takes place "in the backyard" (van Huis et al. 2013; p. 102). This applies to Thailand, but also to Vietnam and Laos. Concrete rings less than one metre high or plastic containers sprinkled with rice husks are often used as rearing units. Cardboard egg cartons are often used to offer the locusts a larger area in the breeding units. Chicken feed or other animal feed, vegetable waste, rice and grass are used to feed the locusts.

Insects collected in the wild or bred on small farms usually end up on local markets and are not exported overseas.

Industrial production systems
Insects, which are offered on the German market as food, e.g. as a component of protein bars, are usually bred in industrial production systems, for example in Canada or Thailand. At an expert meeting to assess the potential of insects as food at the FAO headquarters in Rome in 2012, it was determined that if the production volume is at least one tonne of fresh insects per day,

then one can speak of industrial production (van Huis et al. 2013; p. 104). Such industrial production facilities are already in use, but mainly for the production of insects as animal feed. AgriProtein, for example, operates a standard plant designed for a theoretical production volume of 250 tonnes of insects per day (AgriProtein 2018). The company states that it intends to start up to 25 of these factories per year. Production facilities in which insects are produced as food on a large scale are less common, but the production technologies and parameters are transferable, regardless of the final product.

The parameters for the industrial production of insects, such as the level of light, temperature and humidity, vary greatly from species to species and are strictly guarded by the suppliers as a trade secret. The characteristics that make insect species particularly suitable for mass production include (van Huis et al. 2013; p. 104):

- Rapid population growth
- A short development cycle
- A high survival rate of the hatched insects and the high rate of oviposition
- A high weight gain per day
- A high conversion rate from feed to body weight
- The ability to live in a very confined space
- Low susceptibility to disease

The darkling beetle (Tenebrio molitor) – better known for its larval stage as mealworm – would be particularly suitable as food. However, the industrial production of edible crickets is also promising, because it can be built on a broad pool of experience from "smaller breeding farms".

Depending on the insect species and life stage, insects can have very different requirements regarding environmental parameters, substrates on and in which they live, and feed sources. In general, however, a constant temperature and humidity, a controlled light level, as well as the supply of oxygen and the removal of carbon dioxide and other metabolic gases are essential for the health of the insects and the productivity of the production unit. In addition, external contamination of the production unit must be avoided as far as possible. If, for example, an insecticide applied to an agricultural area were to enter the production unit through the ventilation system, the consequences would be fatal. To counteract this, (air) filter systems are a good solution.

As a feed source, insects require a diet adapted to the species and life stage. The feeding of organic waste is generally possible, but often only suitable to a limited extent because the insects may not be optimally supplied with nutrients on this basis. This can have negative effects on the growth, health and protein content of the insects. The general rule in the EU is that insects for food production must not be fed with catering waste, food waste containing meat or fish, or faeces (Meijer und van der Fels-Klerx 2017).

The waste streams, which are produced in considerable quantities in the industrial production of insects, must be adequately treated and/or disposed of, because they could endanger the environment and people (Kok 2017). These include (i) metabolic gases such as carbon dioxide, (ii) volatile nitrogen compounds such as ammonia, (iii) sulphur compounds and (iv) organic substances such as pheromones. In addition, dusts containing the smallest parts of insects may occur. Waste is also produced when cleaning the production plant and the equipment used, especially to remove excrement.

Processing

The basic steps for the processing of insects are described in Rumpold et al. (2017; p. 320). The source refers to insects bred on an industrial scale. The “ready for slaughter” insects are killed either by heat or cold and can be processed into three product groups and consumed as such: (i) as whole insects (ii) in ground or paste form and (iii) as an extract of protein, fat or chitin for enrichment of food.

Preservation and drying

Since edible insects, like any other food, can pose certain health risks through viruses, bacteria, fungi and parasites, they must be decontaminated. Possible methods of decontamination are mentioned by Rumpold et al. (2017) and include thermal processes, such as blanching, pasteurisation and sterilisation,

Spotlight: European Novel Food Regulation

In the current discourse on insects as food, the Novel Food Regulation (EU) 2015/2283, which came into force on 1 January 2018, is the main focus of attention. On the basis of this regulation, specific insect species can from now on be approved and marketed as food after their safety has been assessed; previously this was only possible in Belgium (Europäische Union 2015). The application for authorisation shall include the following information in accordance with Article 10: (i) the description of the production process, (ii) the exact composition of the novel food, (iii) scientific data demonstrating that the novel food does not present a safety risk to human health, and (iv) a proposal for the conditions of the intended use and for specific labelling requirements. Alternatively, a “notification procedure for traditional foods from a third country” may be used for authorisation. This requires evidence that the food has been consumed in the third country for at least 25 years and that no safety concerns have been raised.

In the spring of 2019, applications for various species of crickets, migratory locusts, mealworms and so-called buffalo worms had already been submitted. A transitional arrangement applies to insect-containing products that were placed on the market in Germany before the Novel Food Regulation came into force. These may continue to be marketed if the necessary application for approval has been submitted by the beginning of 2019.

The Novel Food Regulation not only regulates the approval of edible insects, but also applies to other “new” foods. Before in vitro meat can be offered on the German market, it would also have to be approved on the basis of the Novel Food Regulation.

or non-thermal processes, such as irradiation with UV, electron or gamma rays. Insects can then be preserved by treatment with electric pulses (Pulsed Electric Fields), plasma or high pressure. They can also be preserved by way of cooling or freezing as well as by reducing the water concentration in the insect, for example through processes such as drying, freeze-drying, salting and pickling, by smoking, reducing the pH value or by storing in a low-oxygen atmosphere.

In Germany so far only dried insects (or products from dried insects) have been available, and no fresh or frozen insects. During the thermal drying of insects, the moisture to be removed is evaporated or vaporised. The investigation of the economic efficiency of insect drying has so far not been the focus of research and the processing industry. It can be assumed that the drying processes for insects can be optimised in terms of energy consumption and drying times as well as the resulting product quality (Rumpold et al. 2017).

Three main sub-processes can be distinguished in the drying process (Schönherr 2018): (i) the heat transfer from the environment to the moist material, (ii) the phase transition of the solvent into a gaseous state and (iii) the removal of the solvent vapour. Different technologies are available for drying insects, which can be distinguished according to the type of heat input: (i) convective drying by a hot gas stream, (ii) contact drying by hot surfaces and (iii) jet drying, where energy is supplied by electromagnetic waves. Depending on the initial state of the moist product or the desired end state, specific drying processes or a combination of these can be used. The steam is removed by diffusion into the ambient air (or inert gas) or by steam flow as in vacuum drying.

Within the context of the EU project PROteINSECT, a concept was developed to dry one tonne of insects to a moisture content of 5 % in three hours with the help of a drum dryer (Rumpold et al. 2017).

Production of flour or pastes
To process insects into a flour or paste, they are mechanically crushed and/or ground. Different methods are available for this, depending on the starting material and the desired end state. For the production of cricket meal from dried crickets, the company Pleasant Hill Grain (Nebraska, USA) recommends the use of a vibrating disk mill, alternatively a meat grinder or a coffee mill for industrial production (Rumpold et al. 2017). A multi-stage grinding process is suitable for sieving out the heavily sclerotised insect parts – feet, wings etc. – after a first coarse grinding process. Insects with a high fat content require special treatment because a high fat content makes processing more difficult, e.g. handling the grinding equipment. It is advisable either to degrease the raw material before grinding or to process the insects in cooled or frozen condition (Rumpold et al. 2017).

Extraction of proteins and fats
The extraction of proteins from insects is a suitable way to obtain highly concentrated proteins. These can be added to processed foods with low protein content. This would be one way to circumvent the disgust at insects in Western countries.

Very little scientific data on protein extraction from insects has been published to date (Rumpold et al. 2017). Proteins can be classified according to their solubility, for example into water-, alcohol- and alkali-soluble proteins. For successful extraction, comprehensive knowledge of the properties of the extracted proteins is necessary, including the amino acid profile, thermal stability, solubility, etc. Industrial protein extraction from plants is usually carried out by means of isoelectric precipitation. In this process, a specific pH-value is set at which the desired protein precipitates from the solution (isoelectric point). Other methods include enzymatic processes for the extraction of proteins, fluidised bed chromatography and ultrafiltration. Currently, the extraction of proteins from insects is not economically viable (van Huis et al. 2013; p. 108).

The extraction of fats in the production of insect products, such as insect meal, reduces their "stickiness" and prevents undesirable oxidation processes (van Huis et al. 2013; p. 109). Traditionally, the fat obtained is used for frying meat and other

Spotlight: Waste as insect feed ("Waste to Feed")

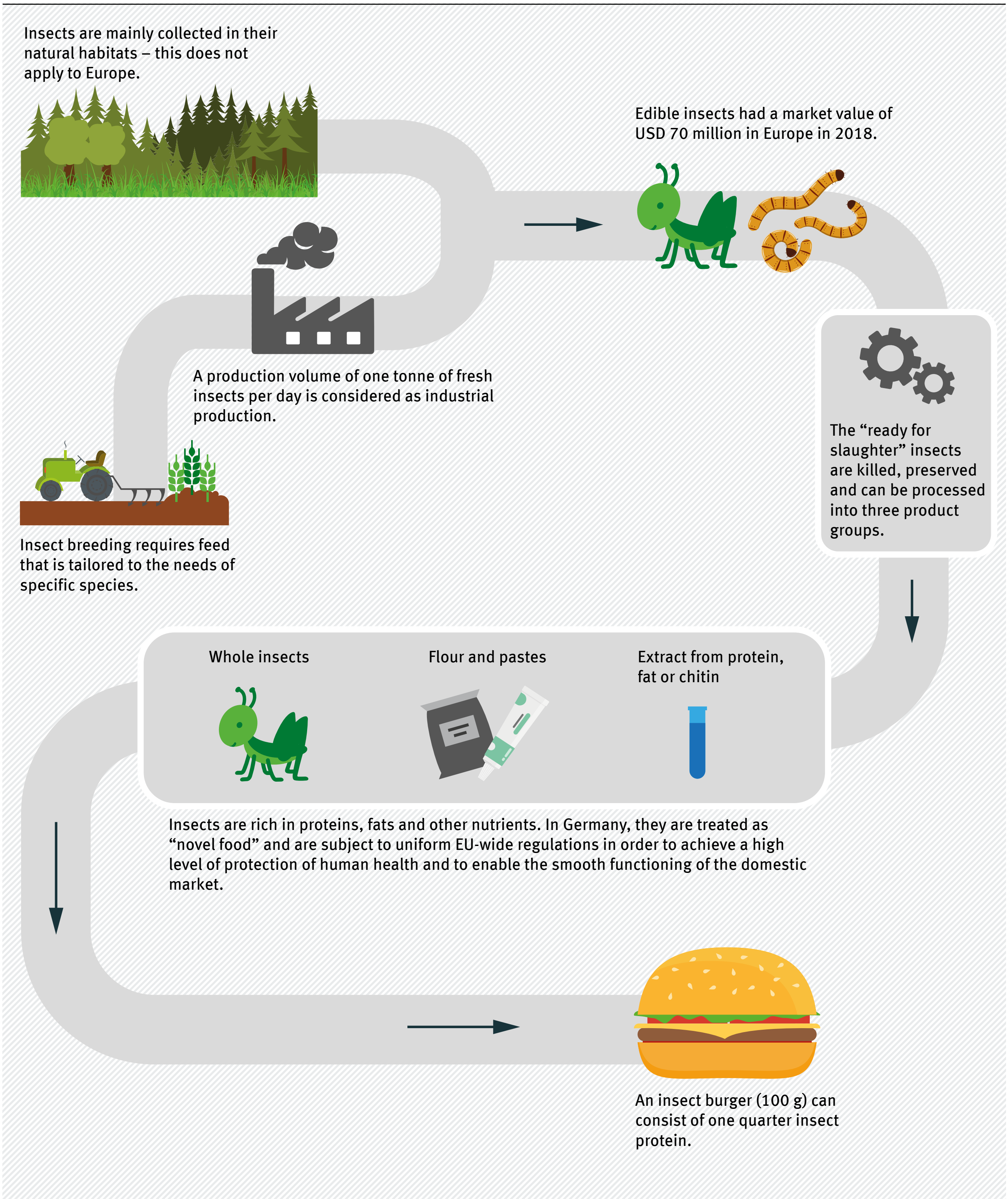
The discussion on feeding insects with organic waste and by-products and their subsequent use as feed for animals and fish arose particularly against the backdrop that globally around one third of all food is thrown away, i.e. around 1.3 billion tonnes per year (van Huis 2013). In addition to the reduction of such waste, the use of organic waste and by-products as feed for insect breeding can help to reduce the previously high cost of commercial feed in insect production systems (Halloran et al. 2017).

There are some insect species that are particularly well suited to transforming organic waste into compost, e.g. the larvae of the soldier fly (Hermetia illucens) and the common housefly (Musca domestica), and some mealworm species (van Huis 2013; van Huis und Oonincx 2017). However, depending on the animal species, different by-products or organic waste are suitable for breeding (van Huis und Oonincx 2017). For example, mealworms develop particularly well on dried organic waste materials from fruit and vegetables and dried by-products of beer brewing, whereas house crickets grow less well on these materials (van Huis und Oonincx 2017). Overall, organic waste seems to be the most suitable for rearing insects, but specific sources for each species have yet to be identified (Alexander et al. 2017). ¬However, the use of these organic residues for feeding insects as feed or food – as a result of the BSE crisis – is severely restricted by law throughout the EU (see Chapter 7).

Overall, there is a great need for research in this field. On the one hand, with regard to the use of organic waste and by-products for insect breeding and the subsequent use of insects as feed for animals and fish (Alexander et al. 2017), and on the other hand with regard to the economic and ecological consequences of this alternative source of feed for insects (Halloran et al. 2017).

Figure 14

Production process of edible insects



Source: Own illustration according to Böhm et al. (2017)

foods. However, it can also be added to processed foods. Scientific data on fat extraction from insects is, as in the case of protein extraction, rarely published. For the extraction of fats from insects, conventional methods can be adapted, e.g. mechanical methods or methods that extract the fat using extraction solvents such as hexane (Rumpold et al. 2017).

4.2.3 Stakeholders

Science and research

The scientific community, which focuses its research activities in Germany on insects as food, is small, but well networked and very closely linked to the community dedicated to insects as feed. Since 2015, it has been exchanging information annually at the international conference INSECTA[8] and discussing current research work on topics such as food safety, production systems and breeding conditions, applications with regard to food and feed as well as other applications.

At the international level, the second conference "Insects to Feed the World[9]" was held in China in 2018, where researchers, government representatives and representatives from the private food and feed sectors as well as from developing and industrialised countries exchanged views on all aspects of insects as food and feed. The aim was to enter into a global multi-stakeholder dialogue to further explore the potential of edible insects as food and feed. Two other important exchange platforms in the context of insects as food are the "Insectinov" meeting in France[10] and the Insect Study Commission of the European Association for Animal Production (EAAP)[11] (van Huis 2017).

The "INSECTA" and "Insects to Feed the World" conferences as well as other events have shown that in recent years, research-based knowledge and the number of innovations and applications in industry have increased. A similar picture emerges when looking at the number of internationally published scientific articles on edible insects. Payne et al. (2016a) have divided current research on insects as food in Europe into three categories. Current studies focus mainly on:

- (Industrial) insect production
- The nutrition and health of consumers
- Psychological, social and political issues.

Many research questions have not yet been conclusively answered, partly because the edible insect sector has only become increasingly commercialised in recent years and there has been a lack of funds to finance research projects. Van Huis (2017) sees a current need for research, especially in the following areas:

- Nature conservation management when removing insects from their natural habitats
- Breeding and breeding methods
- Disease management in (industrial) production systems
- Animal welfare (insect welfare) in the context of pain and emotion
- Food safety of insects (insect products)
- Health benefits of an insectivorous diet
- Consumer attitudes and gastronomy
- Profitable (circular) economy

A prerequisite for answering current research questions is the cooperation between all interested parties involved, especially from the public sector, science and the private sector.

Economic stakeholders

In recent years, a number of market studies on edible insects have been published, indicating the growth potential of this economic sector. Van Huis and Tomberlin (2017a; p. 440) compared various market studies on edible insects, which estimate the future

8 Further information is available at: www.insecta-conference.com
9 Further information is available at: http://ifw2018.csp.escience.cn/dct/page/1
10 Further information is available at: http://adebiotech.org/ins2/en.ins2.php
11 Further information is available at: http://www.eaap.org/insectsc

global market value at between USD 0.52 billion (period under consideration: 2016–2023) and USD 1.5 billion (period under consideration: 2016–2021). Statista GmbH, a German online portal for statistics, also addressed this topic in a comprehensive dossier (Statista GmbH 2018a). The global market value of edible insects is forecast to increase from $0.406 billion in 2018 to $1.182 billion in 2023. In Europe, the market value is expected to triple over the same period, from $82.1 million in 2018 to $261.5 million in 2023, representing a Compound Annual Growth Rate (CAGR) of around 26 %. At a global level, the market for insects as food and feed was divided across three groups of interested parties in 2016. The food industry had a market share of 59 %, insect breeders had a market share of 22 % and animal feed producers had a market share of 19 %.

The number of active companies breeding insects for food or distributing edible insects and insect-based foods has been estimated at over 150 worldwide (Taponen 2018). For Germany, only one breeder could be identified who claims to produce insects not only as animal feed but also as food, Bugs-International GmbH (Bugs International n.d.). A more differentiated picture emerges when considering the stakeholders in the food industry. More and more start-ups are offering insects as food or insect-containing products in Germany, including Bearprotein GmbH, Bugfoundation GmbH, Imago Insect Products GmbH, Plumento Foods GmbH, Snack-Insects including Bug Break, Swarm Nutrition GmbH and Wicked Cricket GbR. The product groups range from protein bars and shakes, snacks and confectionery to insect pasta or an insect burger, but whole, dried insects are also offered for consumption. The products are sold online and, more recently, also in (organic) supermarkets. The raw materials for the products of German suppliers, e.g. insect meal, have so far been purchased almost exclusively from insect breeders in Europe or outside Europe. An overview of internationally operating insect breeders is provided by van Huis (2016; p. 14).

The International Platform of Insects for Food and Feed[12] (IPIFF) is a non-profit organisation, representing the interests of the insect-producing sector in the EU

12 Further information is available at: www.ipiff.org

vis-à-vis EU policy makers, European stakeholders and citizens. Founded in 2012, the organisation currently has 46 members, mainly small and medium-sized European enterprises.

Consumers

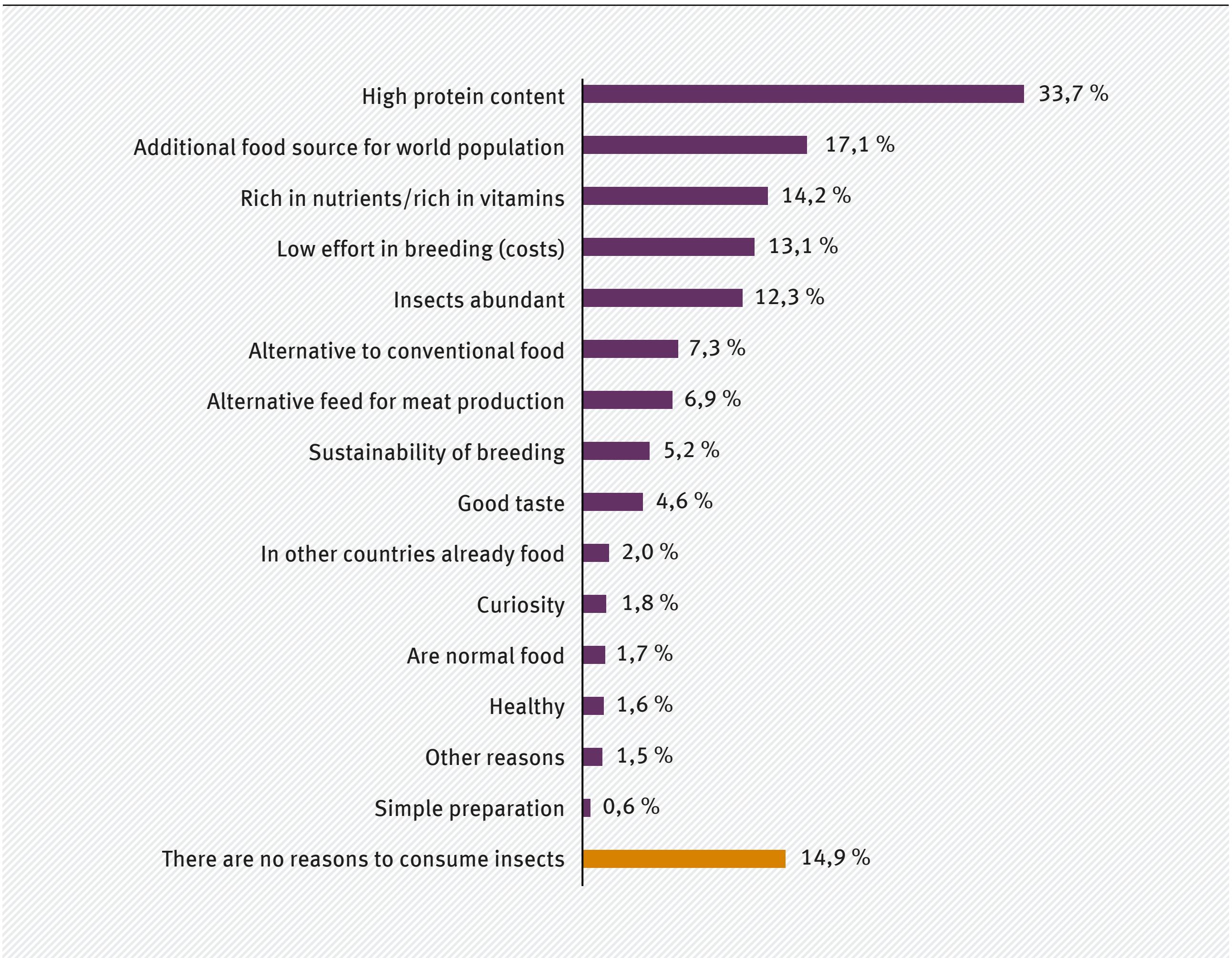
In the tropical regions of the world, such as Asia, Africa and Latin America, insects are often a traditional part of the diet and are currently consumed by more than 2.5 billion people. But insects are also eaten in temperate zones, e.g. in China, Japan and Mexico (van Huis et al. 2013; p. 36). In Germany, as in the rest of Europe, a different picture is emerging, where the consumption of insects is seen as rather disgusting.

Current opinions of German consumers towards insects as food were investigated by Epp (2016). It was shown that insects were known to be a foodstuff by 72.3 % of respondents. 29.7 % of respondents (n = 861) would be willing to try insects, 10.5 % could imagine eating them regularly. Insects had already been tried by 13.9 % of all respondents (n = 1,000). According to respondents, the main reasons for consumption were the high protein content and the richness in nutrients and vitamins, as well as the fact that insects could be used as an additional food source for the world population (Figure 15). In addition, the work involved in breeding insects is seen as low and insects are considered to be abundant.

The main reason against eating insects is disgust (Figure 16). Nearly 80 % of respondents stated that they were more or less strongly disgusted by insects (n = 1,000). Other aspects, which were given as the

Figure 15

Main reasons for eating insects: results of a representative survey

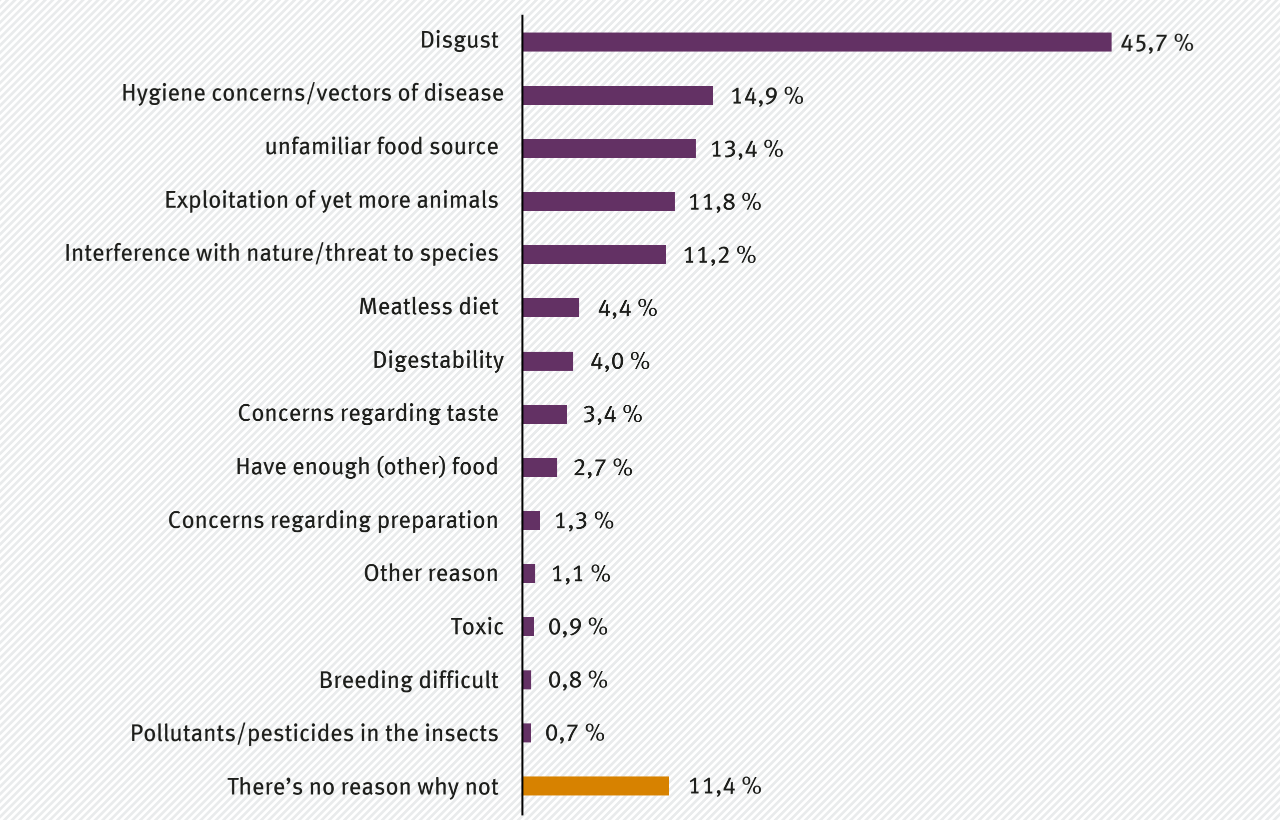


(in % of all respondents, n = 1,000)

Source: Epp (2016)

Figure 16

Main reasons for not eating insects: results of a representative survey



(in % of all respondents, n = 1,000)

Source: Epp (2016)

main reason by more than 10 % of respondents for not wanting to eat insects, include concerns about food safety, the unfamiliarity of insects as food, concerns about the exploitation of new animals, species protection and interference with nature.

A comparative study on the current acceptance of insects as food in Europe paints a similar picture (Hartmann und Siegrist 2017). Disgust is seen as the biggest hurdle for the introduction of insects to the Western food market. Furthermore, insects in Europe are more likely to be associated with food contamination, health risks and primitive nutrition. The willingness to consume insects as a substitute for meat is very low. Apart from the fact that gender does not play a major role – men seem to be more open to insect consumption – no other socio-demographic factors influencing the acceptance of insects as food could be identified.

To increase the willingness of European consumers to eat insects, different strategies are proposed (Hartmann et al. 2015; Hartmann und Siegrist 2017; Albores et al. 2018; Piofczyk 2018):

- Compiling and supplying information regarding insects as food, e.g. about preparation, safety, nutritional values etc.
- Implementing positive "taste experiences" in restaurants or at events where interested consumers can taste insects.
- Use of processed insect products, for example as insect meat balls in which the insect is no longer perceived as such.

- Combination with known carrier products, such as salad or pasta, or with known sauces and flavours.
- Use of insects, which in this country tend to have a positive connotation and are less likely to cause disgust.
- Increasing the social acceptance of eating insects.

4.3 In vitro meat: a long way from the laboratory to the market

4.3.1 Background and status quo

In media coverage of future nutritional trends, "in vitro meat"[13] (in vitro, Latin for "in glass") is playing an increasingly important role,[14] not least because future suppliers, such as the start-ups Memphis Meats from the USA (Memphis Meats 2019) and Mosa Meat (Netherlands) (Mosa Meat 2019) on their websites promise meat consumption with less negative environmental impact while at the same time improving animal welfare. The production of in vitro meat can be clearly distinguished from the production and processing of farm animals from conventional or organic farming. The meat is grown "in vitro" using tissue engineering techniques based on cell cultures outside the animal organism. The stem cells required for this can be taken from farm animals. In order to produce meat from cells a few micrometres in size, these are typically applied to a carrier scaffold, supplied with a culture medium in a bioreactor and, if necessary stimulated so that they multiply (proliferation) and form the desired tissue, e.g. meat from muscle fibres. Tissue engineering has so far been used primarily in medical applications, for example for cultivating skin tissue for patients with extensive burns or tissue for toxicity tests.
In contrast, the in vitro production of meat by cultivating cells is still in its infancy (Post 2012; Bhat et al. 2015; Kadim et al. 2015).

The pioneer of in vitro meat is considered to be John Burdon Sanderson Haldane, a British-Indian scientist who, in his 1927 book "Possible Worlds and Other Essays", described a future scenario in which the steak would be produced by tissue engineering, and who, even then, recognised the importance of and focused on the culture medium (Haldane 1927; p. 98). While the production of meat without the intensive use of animals was still a utopia almost a hundred years ago, in vitro meat is now one of the latest trends in food technology. The considerable investments in young start-ups, for example by Tyson Foods, one of the world's largest meat producers (Cosgrove 2018) are an indicator that in vitro meat could become established as a formative (socio-)technical innovation with far-reaching consequences for the environment, animals and society.

4.3.2 Production processes and technological maturity

For the production of in vitro meat, muscle cells are cultivated using tissue engineering (Figure 17). The basis for this meat is muscle tissue taken from a living donor animal. The stem cells are then separated from other cells, cultivated in a bioreactor and supplied with nutrients etc. through a culture medium. The bioreactor is a container in which the cells are cultivated under optimal environmental conditions. These include, for example, temperature and oxygen content. The culture medium consists of nutrients, vitamins and amino acids as well as growth factors and hormones, which play an important role in the well-being of the cells and their further development phases. Foetal calf serum (FCS) is currently an important "standard ingredient" of the typical culture medium for cell cultivation. FCS is

13 In the German-speaking world, the term "kultiviertes Fleisch" is also common; in English, the terms "cultured meat" and "clean meat".
14 Leading German daily and weekly newspapers, such as the online editions of Die Zeit, Süddeutsche Zeitung, taz or FAZ, have published various articles on the subject in recent years, e.g. (Schumann 2018) or (Frankfurter Allgemeine Zeitung (FAZ) 2016; Gurk 2018).

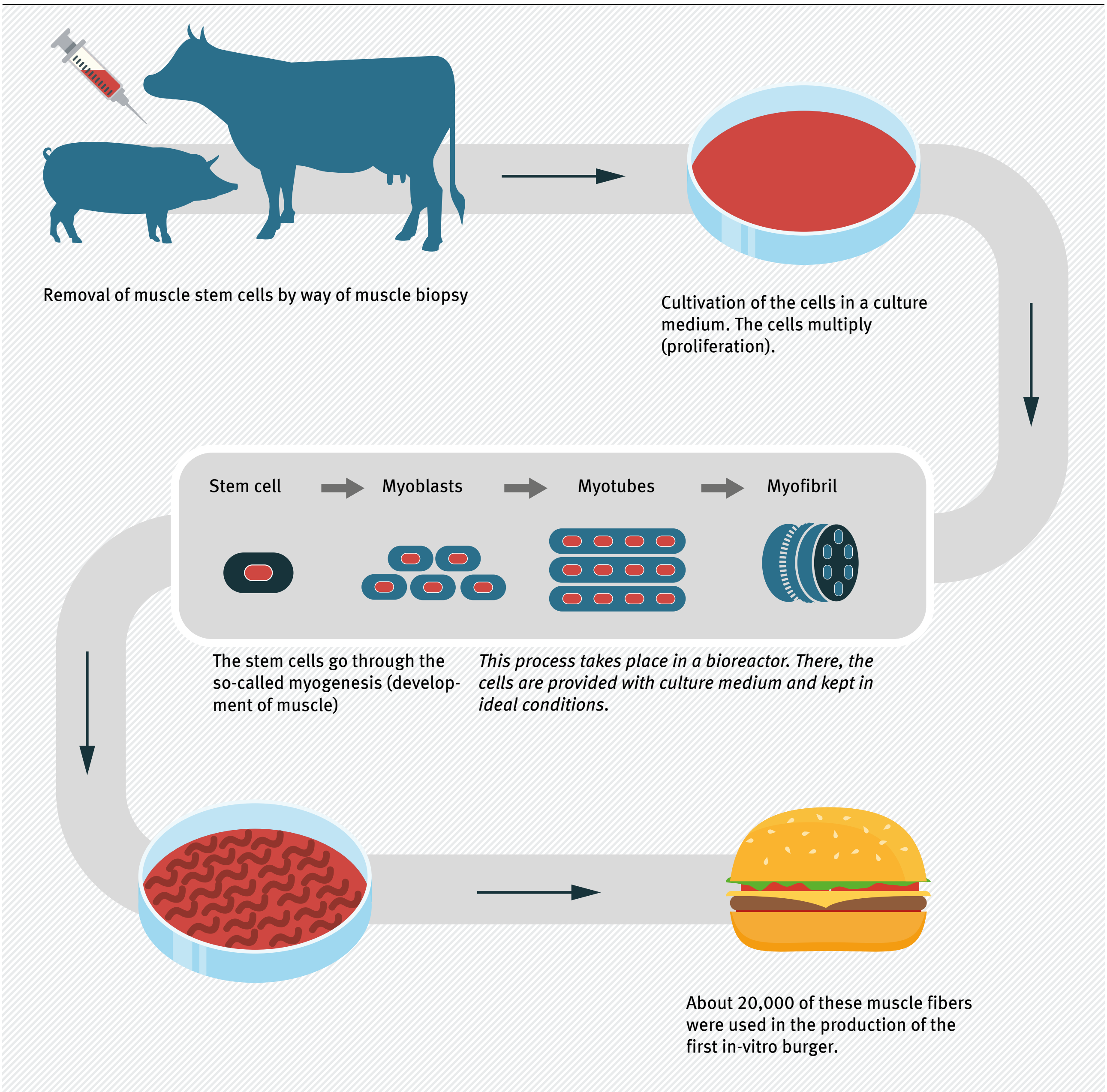
obtained from the blood of cow foetuses and contains various proteins and growth factors.

In the bioreactor, the stem cells pass through two phases: (i) the proliferation phase and (ii) the differentiation phase. In the first phase, the stem cells grow and multiply. In the second phase, the stem cells differentiate into myoblasts – spindle-shaped precursor cells of muscle fibres. The differentiation is triggered by chemical and physical stimuli. The myoblasts then form multinucleated myotubes, which in turn develop into muscle fibrils (muscle fibres). These are stimulated to grow on a carrier scaffold. The individually produced layers of muscle fibrils are then "harvested". From these thin layers of tissue, for example, a minced meat product can be made. In order to create a "natural" meat taste, fat cells should also be added to the muscle tissue. These can also be produced in an in vitro culture.

At present, small-scale production of in vitro meat is already possible, but there are still no processes

Figure 17

In vitro meat production process



Source: Böhm et al. (2017)

for industrial production. In order to produce in vitro meat on a large scale, there are still various technical price-determining challenges to be tackled and solved. Among the major challenges are: (i) the identification of suitable cell lines, (ii) the development of a low-cost culture medium without animal components specifically for the production of in vitro meat, (iii) the construction of bioreactors for large-scale production and (iv) the optimisation and development of carrier scaffolds for producing in vitro meat (Post 2012; Post 2014; Bhat et al. 2015; Hocquette 2016).

The **identification of suitable cells** for in vitro meat production is a crucial factor in industrialising production. Currently, different approaches are being investigated regarding the suitability of cell types for producing in vitro meat. The three promising stem cell types so far are: (i) embryonic stem cells, (ii) satellite cells and (iii) iPS cells (induced pluripotent stem cells). All cell types are stem cells. For the production of in vitro meat, mainly satellite cells are used. These can be developed into muscle cells with a high ability to divide.

To date, there are two possible sources of cells for producing in vitro meat: primary cells, which are taken directly from the (muscle) tissue of a farm animal – possibly also from a small herd of animals – and cultivated (primary culture), and immortalised cell lines, which, unlike primary cells, can theoretically be multiplied indefinitely (Ramboer et al. 2014). Immortalisation can be achieved by the selection of spontaneous mutations or by the specific modification of cells with the help of proteins, genes, viruses, etc.

A further challenge is the development of a **culture medium** suitable for the industrial production of in vitro meat. Usually a culture medium contains inorganic and organic components including carbohydrates, amino acids and vitamins, which are necessary to maintain cell viability in the cultured cell population (Arora 2013). Up to now, the price of the culture medium has been the main factor determining the production costs of in vitro meat. In addition, the foetal calf serum usually contained in the culture medium is a critical ingredient. Depending on the state of health and the husbandry conditions of the mother cows, the FCS may contain transmissible pathogens (Girón-Calle et al. 2008, Brunner et al. 2010). There are also serious animal-ethical aspects. FCS is taken from the hearts of living calf foetuses using a cannula, which is most likely to cause severe pain. Innovators therefore want to produce in vitro meat without using animal components in the culture medium. Currently, FCS can be replaced by alternative additives, e.g. Ultroser-G (Pall Corporation 2019); ready-to-use, serum-free culture media for cell culture such as AIM-V are also available (Thermo Fisher Scientific 2019). However, these alternatives are not yet optimally suited for the production of in vitro meat.

Another critical factor is the common practice of adding antibiotics to cell cultures to prevent infection of the cell culture (Stephens et al. 2018). However, if the culture is kept under sterile conditions, the addition of antibiotics is not necessary.

Spotlight: Marketability through cooperation

Before in vitro meat can be sold at marketable prices, various technical hurdles must be overcome. The relevant start-ups are faced with major challenges in this respect, as key technologies in the fields of (i) cell lines, (ii) culture medium, (iii) bioreactors and (iv) carrier scaffolds need to be further developed in order to enable industrial-scale production. The cooperation between companies and research institutions has great potential to successfully master the complex research and development tasks. In Germany, the biotechnology sector would be a suitable partner. The biotechnology sector is very diversified in Germany and it would make sense to jointly tackle the challenges of in vitro meat production, for example in the biotechnology areas of health and medicine as well as agricultural and industrial production. In 2017, there were more than 646 biotechnology companies in Germany with 21,860 employees, generating revenues of 4.105 billion euros. The enthusiasm for innovation that these companies have is reflected in their annual investments in research and development. In 2017, these investments amounted to 1.117 billion euros (Biocom 2018).

In addition, currently available **bioreactors** for tissue engineering applications are not designed for mass production of in vitro meat (Stephens et al. 2018). So far, bioreactors for tissue engineering applications are mainly used in scientific and clinical environments. They control environmental parameters such as temperature, CO_2 content, humidity and, if necessary, the constant supply of culture medium to the cell culture. Currently, bioreactors are not much automated and concepts, for example for the recycling of culture medium, have not yet been implemented.

In the production of in vitro meat, the cells are applied to a **carrier scaffold** that provides them with a supporting structure as they differentiate and develop into the desired cell types (muscle, fat, etc.). Collagen scaffolds are generally used for the production of muscle cells (Snyman et al. 2013). Collagens are structural proteins that are obtained from the bones of cattle and pigs, for example. However, there is intensive research to find alternatives to animal products. For example, decellularised plant cell scaffolds could be used in the future. For this purpose, the plant cells are removed from the leaf so that muscle cells can migrate into the empty spaces.

In principle, carrier scaffolds can be made of edible, tasteless materials – these would be present in the final product to a certain extent – or of biodegradable materials which the cells incorporate into their own extracellular matrix during growth; this matrix is a network of proteins and support structures.

In both cases, the carrier scaffold must be sufficiently porous to supply the cells with oxygen and nutrients and to allow the removal of cell excrements. The production of three-dimensional carrier scaffolds that can do this is still a challenge today. Muscle tissue can currently only be produced in a thickness of a few micrometres. If many of these "tissue snippets" are brought together, an in vitro meat mince can be produced, but a steak cannot. This would require the development of more complex carrier scaffolds (Stephens et al. 2018). Bioprinting is a promising 3D printing process for producing such highly

porous carrier scaffolds in which an artificial blood vessel system is integrated to supply cells in three-dimensional space.

4.3.3 Stakeholders

Science and research

At the beginning of the 1950s, Willem van Eelen, a Dutchman, began to promote the idea of producing meat on the basis of cell cultures. At that time, stem cell research and tissue engineering methods were still in their early stages. It took almost fifty years before Willem van Eelen and colleagues filed the first patent for the production of in vitro meat (Bhat und Fayaz 2011; p. 127). In the early 2000s, the technical possibilities were so advanced that various scientific working groups published the first publications on successfully produced, edible in vitro fish and meat, such as Benjaminson et al. (2002) or Edelman et al. (2005). The presentation of the first edible in vitro meat burger by Marc Post in 2013 – this was produced as part of a university research project – is considered the beginning of a movement to found various start-ups around the topic of in vitro meat. In the academic context, however, there was no comparable movement. Rather, it appears that research activities related to development are now taking place primarily in the newly founded start-ups, rather than in the university context.

A key player in promoting research projects and linking up science and industry is New Harvest[15], a non-profit organisation that has been active in the field of cellular agriculture, including in vitro meat production, since 2004. Since 2016, New Harvest has hosted an annual conference where industry and science meet to exchange ideas.

Another stakeholder with a similar profile is the Good Food Institute[16], which focuses on both in vitro meat and plant-based meat alternatives. The organisation's Good Food Conference is another important international conference, which, in addition to plant-based meat alternatives, is also dedicated to in vitro meat, with the aim of promoting its commercialisation. It is an important platform for industry-related research and development.

Economic stakeholders

In 2013, the first edible burger produced by Marc Post at Maastricht University was prepared and tasted in London in front of a public audience (Maastricht University 2013; Schadwinkel 2013). The ensuing discussion during the event and the reporting after the event helped the topic of in vitro meat to receive a great deal of media attention. Three years later the start-up Memphis Meats followed with an in vitro meatball (Memphis Meats 2016) and in 2017 in vitro chicken schnitzel and duck breast were tasted in a highly publicised way (Memphis Meats 2017).

While the first burger in 2013 incurred development costs of 250,000 euros (Szentpétery-Kessler 2018), Memphis Meats was able to reduce the production costs for the pound of in vitro burger patty to 18,000 US dollars in 2016 and $4,000 in 2018 (Forbes 2018; Szentpétery-Kessler 2018). The founder of Memphis Meats, Uma Valerti, expects to be able to significantly reduce production costs by 2021 and offer a first product on the market (Szentpétery-Kessler 2018). A similar assessment is made by Marc Post, who founded the start-up company Mosa Meat, which also aims to be able to offer in vitro meat products by 2021. Mosa Meat estimates that it will take another three to four years before the price drops to a level that is acceptable to a larger clientele (Fernández 2017). Memphis Meats founder Valerti reckons that the exclusive haute cuisine could be one of the first buyers of in vitro meat. (Szentpétery-Kessler 2018).

In vitro meat is currently not available on the market. Nevertheless, the market research company Markets and Markets estimates the market value for cultured meat in 2021 at USD 15.5 million and forecasts an increase to USD 20 million by 2027 (Markets and Markets 2019). This market study identifies increasing demand for alternative meat proteins, growing concerns about the food safety of conventional meat and technological advances in cellular agriculture as market drivers.

Currently, mainly companies from the USA, the Netherlands, Israel and Japan are involved in the production of in vitro meat. It can be observed that the start-up landscape is becoming increasingly diversified and, in addition to in vitro meat, in vitro fish has now also become the focus of the companies.

Spotlight: Dynamic development of investments in start-ups

The start-up scene in the in vitro meat sector is developing very dynamically. By the end of 2018, 27 start-ups had been founded worldwide that intend to produce in vitro meat and/or in vitro fish in the future. Of these, eleven companies were founded in 2018 (Cameron und O'Neill 2019). Of the 27 companies, 15 indicated that they were able to raise funds in external financing rounds. The externally financed start-ups come from the USA (8), Israel (3), the Netherlands (2), and one each from Spain and Japan. A total of 73.3 million US dollars was invested in in vitro meat companies between 2015 and 2018; 50 million US dollars of this in 2018 alone (Cameron und O'Neill 2019). Annual investments have been increasing strongly since 2015. From 2017 to 2018, investments in start-ups have risen by 169 %.

15 Further information is available at: https://www.new-harvest.org
16 Further information is available at: https://www.gfi.org

Consumers
In vitro meat is not yet available in shops, but has already been consumed at various "tastings", which have been staged by the producers for reasons of publicity. In current studies on the acceptance of in vitro meat, consumers are therefore being asked about a product which they are not usually familiar with and whose production process is largely unknown to them. Most of the studies report a wide range of feedback, ranging from positive to negative attitudes towards in vitro meat (Bryant and Barnett 2018; Stephens et al. 2018).

In Germany, in vitro meat is still unknown to a majority of society. This is shown by the representative survey carried out as part of the Environmental Awareness Study 2018 (Umweltbewusstseinsstudie 2018) by the Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU) und Umweltbundesamt (UBA) (2019). According to the results, 38 % of those questioned had heard or read about in vitro meat, 60 % had not and 2 % were uncertain (n = 2,021) (see Figure 18).

Of those surveyed, about one third considered in vitro meat a good substitute for conventional meat, and 27 % would try it. 59 % had a rather negative attitude to in vitro meat: 29 % would not consider in vitro meat as part of their diet, 30 % are rather sceptical.

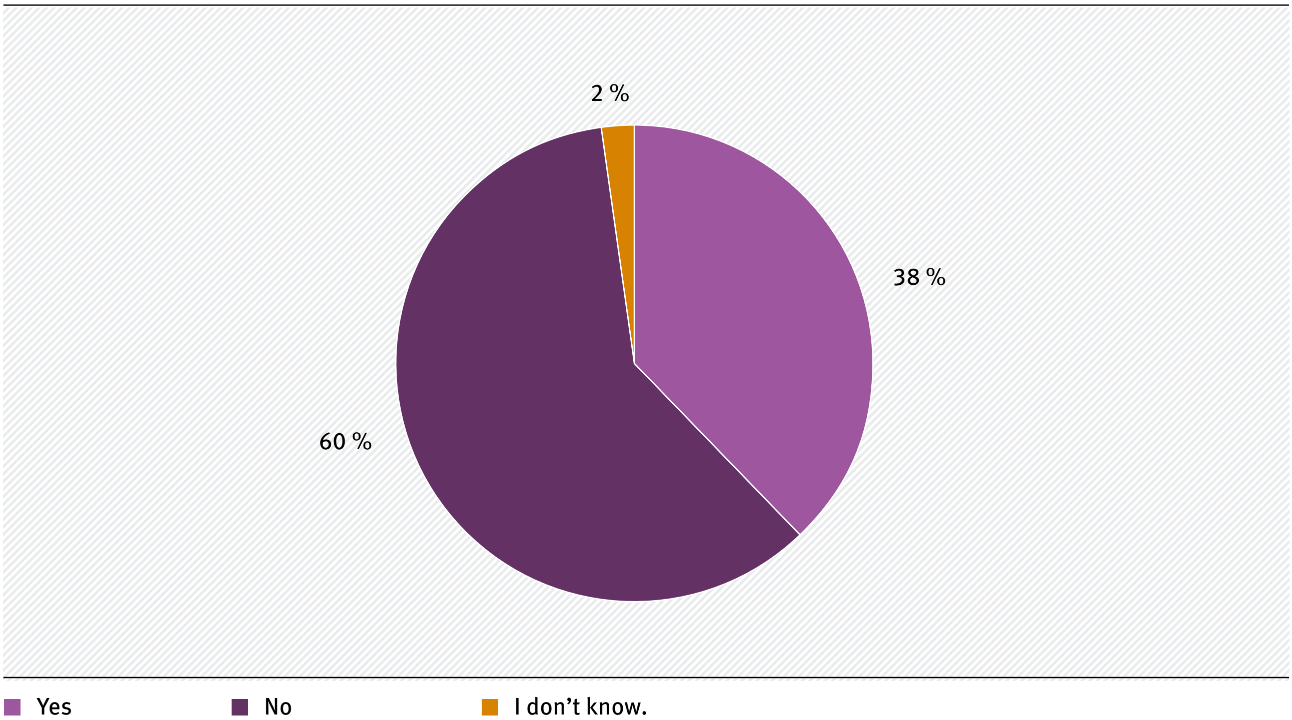
In their review based on scientific articles Bryant and Barnett (2018) summarised factors that may determine the acceptability of the introduction and/or consumption of in vitro meat:

- According to this, personal attitudes and societal concerns are two main factors leading to general objections to in vitro meat. In vitro meat is primarily seen as "unnatural". In this ideological context, "natural" is interpreted to mean good and healthy, whereas "unnatural" means bad and risky. There are other concerns about food safety and health.

- One objection to in vitro meat, for example, is the assumption that the nutritional value of in vitro meat is lower than that of conventional meat. In addition, many consumers also assume that the taste, texture and appearance of in vitro meat is

Figure 18

Survey of the state of knowledge with regard to in vitro meat in Germany



(n = 2,021)

Source: Basic data of environmental awareness study inferior to that of conventional meat. Social and societal concerns include that the introduction of in vitro meat may have a negative impact on traditional farmers for competitive reasons. There are also doubts and uncertainties as to whether large-scale production of in vitro meat is technically feasible and whether its regulation is implemented in a consumer-friendly manner, especially in the fields of food safety, transparent labelling and marketing. Inadequate labelling could, for example, lead to accidental consumption of in vitro meat.

- Improved animal welfare and more environmentally friendly meat production are among the most frequently mentioned benefits of in vitro meat. As a rule, consumers believe that the introduction of in vitro meat would improve current animal welfare standards and would not reduce the number of "happy" (farm) animals. In addition, it is generally assumed that in vitro meat is more sustainable than conventional meat, especially in terms of greenhouse gas emissions, although some consumers do assume that in vitro meat production is energy-intensive. Some studies also show that consumers expect benefits for public health, particularly through the possibility of producing meat with a low-fat content or preventing zoonoses.

- Several studies have also reported that respondents believe that introducing in vitro meat to the market would allow "the poor" worldwide to afford meat.

5 Trend development: meat of the future

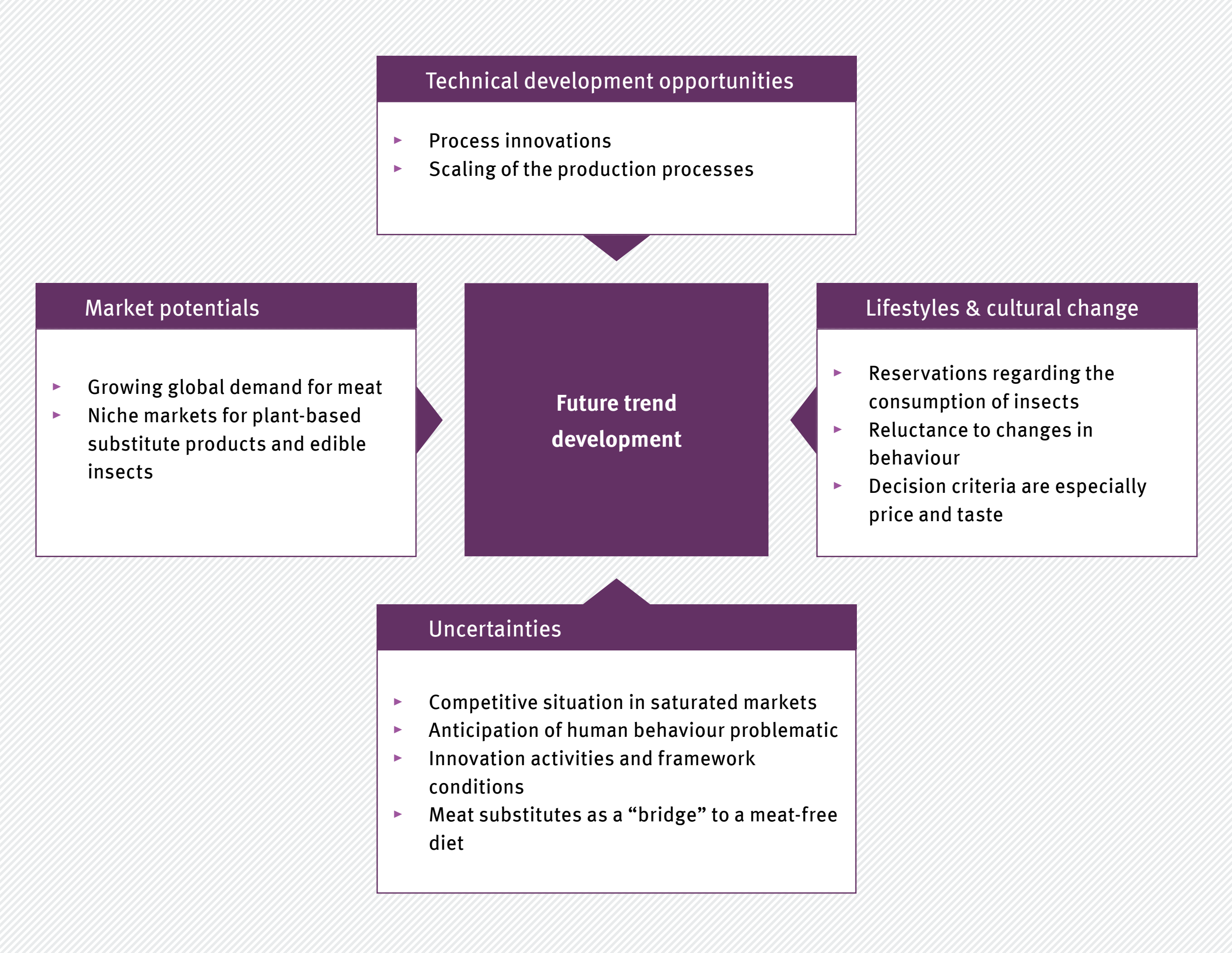
In the discussion of influencing and determining factors (see Chapter 3.3), it has become clear that developments that are highly interrelated have to be looked at together. This leads to a number of driving and limiting forces, which in turn influence the future development of meat alternatives. Picturing meat of the future as a whole is thus characterised by a high degree of complexity.

The spotlights shown so far also indicate possible turning or breaking points in a future trend development. A description of future trend development as a starting point for assessing possible environmental impacts will always be characterised by a certain fuzziness, and an overall picture of meat of the future is characterised by numerous uncertainties.

Although future developments can be sketched out only with a high degree of simplicity as regards their conceivable complexity, they provide a sufficiently precise basis for a further analysis of negative and positive environmental effects.

Figure 19

Driving forces, barriers and uncertainties of future trend development



Source: Own illustration

5.1 Driving forces and barriers

All three meat alternatives are influenced by driving and inhibiting factors with regard to their respective development direction and dynamics. In some cases, it has already been hinted at where the driving forces and barriers are. While certain factors affect all three alternatives, others affect individual alternatives only.

In all three meat alternatives there are innovation potentials through technical advancements

- Through process innovations, it is becoming increasingly possible to imitate meat by using plant-based meat substitutes, while offering a comparable taste experience. These innovations are achieved through improvements in the manufacturing process, but also through new combinations of the ingredients used, for example by employing AI processes to determine them. In the future, process innovations will drive the development of plant-based meat substitutes in particular.

- For all three alternatives, there is the hurdle of scaling up production, i.e. being able to manufacture larger quantities of intermediate and end products. Scalability depends on the availability of the necessary raw materials, e.g. plant extracts, insects and stem cells, and on resources such as energy, water, farmland, animal feed, etc. Especially for in vitro meat, the question of whether a suitable culture medium will be available remains unsolved. Scalability is also dependent on economic and ecological factors. From an economic point of view, production scaling must result in producers being able to achieve competitive prices. Especially for in vitro meat, no cost-effective alternative for the foetal calf serum is yet in sight. Ecologically sustainable scaling of production depends, among other things, on the sources from which energy and raw material requirements can be met. In the case of plant-based alternatives, for example, the question arises as to which vegetable protein sources are mainly used and where or under what conditions these raw materials are cultivated.

Compared to the global meat market, meat alternatives currently have only limited market potentials

- Depending on how the main driving forces, population growth and increased purchasing power, develop, the assumption of rising global demand for meat in the coming decades is plausible. The corresponding expansion of meat production is therefore conceivable. It remains to be seen, however, whether meat substitutes can leave their current niches and enter the mass market. In addition, if domestic demand falls, domestic meat producers might be able to tap economic potential by increasing exports. There is therefore hardly any incentive to reduce production capacities.

- The suppliers of plant-based meat substitutes, in particular, have managed to successfully occupy a niche market. The acquisition of additional market share, for example through the substitution of meat with substitute products, is most likely to be expected due to the wide range of plant-based meat substitute products. The fact that this market segment is highly dynamic and attractive may well have a positive effect here. Not only new suppliers are entering the market, but also existing producers – including meat producers – are strengthening their marketing and sales activities in order to gain market share.

Established lifestyles and consumption patterns are facing a cultural change

- There are reservations and concerns, even disgust, in Germany, particularly about the consumption of insects, but also of in vitro meat. While reservations and concerns about the consumption of plant-based meat substitutes can be considered as largely overcome, representative studies show that this is far from being the case for insects and in vitro meat. The substitution of meat by edible insects is not conceivable without addressing these concerns. As in vitro meat is not yet on the market, any statements regarding acceptance are at best hypothetical. Nevertheless, there are reservations here too, for example regarding possible genetic modification or health risks.

- Consumer acceptance of alternatives to conventional meat products plays an important role in the spread of these alternatives. Surveys show that the consumption of meat substitutes is viewed positively compared to traditional meat products, particularly with respect to health, environment, climate and animal welfare aspects (Buxel und Auler 2017). Various incentives are deemed necessary for accomplishing a real change in behaviour, such as information on products and pricing, but also regulatory measures (Heinrich-Böll-Stiftung et al. 2018).

- Reluctance to change individual consumer behaviour is in turn inhibiting the spread of meat alternatives. Although interest is expressed in alternative products and there is also a willingness to try them, it cannot be clearly shown either retrospectively or by projecting into the future that visible changes in behaviour have or will take place. This may be related to the fact that plant-based products in particular are often heavily processed and are not inevitably perceived as natural products.

Overall, the impression is that the inhibiting factors predominate, i.e. that numerous barriers still have to be overcome before meat products are replaced to a large extent by alternatives. However, there is also potential that can be exploited. In addition to innovations in the area of production processes, it is above all individual consumption and nutritional behaviour that can significantly shape the future development of the three meat alternatives.

5.2 Uncertainties

The interdependencies of the various driving and inhibiting factors lead to a lack of clarity, which makes it difficult to draw a definitive picture of the future direction of development. These include the following:

- Competitive situation: the market for meat and substitute products is limited and the suppliers compete with each other. This is already implicitly evident from the range of different market forecasts cited in the trend description. However, this range also makes it fundamentally difficult to formulate a uniform assumption of future market development that takes this competitive situation into account. In addition, consolidation tendencies can occur if suppliers in niches are bought up by market leaders, or if suppliers cease their business activities due to lack of demand or other reasons.

- Changes in human behaviour are generally very difficult to anticipate. Although studies show that consumer interest in plant-based meat substitutes or a meat-free diet is increasing, data on market development and the almost stagnating consumption of meat show that behavioural changes are taking place on a small scale at best. A lasting change in individual consumer behaviour can only be assumed if there is both the willingness and the opportunity to change behaviour. However, the option of consuming meat alternatives in particular depends on the available supply. This includes not only the availability of corresponding products in food shops, but also corresponding offers for consumption outside the home, e.g. in restaurants, canteens, etc.

- The further development of edible insects, but also of in vitro meat, into marketable, sought-after products depends, on the one hand, on the innovative capacity of individual stakeholders, and on the other hand on research policy framework conditions that can support innovation.

- So far, the study has discussed developments that are intended to provide alternatives to meat products, many of which are deeply rooted in a society's food culture. However, it is also imaginable that the alternative products are only consumed transitionally, i.e. that meat products are first replaced by imitations before consumers give up such imitations and, ultimately, meat products altogether.

- It is also conceivable that there will be completely new products made from plant proteins that do not even attempt to imitate meat, and that corresponding product categories do not yet exist today, but have to be developed first. In such a case, it is also very difficult to provide a reliable description of the future development of plant-based meat substitutes in particular.

5.3 Overall picture of meat of the future: starting point for the analysis of environmental effects

The three discussed alternatives show different degrees of maturity with regard to the efficiency of their production processes, their marketability and their acceptance by consumers. In addition, all alternatives are potentially in competition with each other, so that it cannot be assumed that parallel, possibly time-delayed linear developments will take place. Complex interactions and uncertainties characterise the future directions of development and make it difficult to make out negative and positive effects on the environment.

The analysis of the negative and positive effects on the environment is therefore carried out exemplarily for a clearly defined object of investigation. Based on the expected economic and social potentials, the future developments up to the year 2030 can only be described approximately on the basis of the previous statements:

- While the average per capita consumption of meat in Germany is still stagnating at a high level of around 60 kg per year (Bundesanstalt für Land-

wirtschaft und Ernährung (BLE) 2018a), global demand and production are increasing. Due to worldwide population growth and changing consumption habits in countries of the global South, a strong overall increase in demand for food is expected up to the year 2050 (Chrappa and Sabo 1996; Food and Agriculture Organization of the United Nations (FAO) 2017). It is also expected that the proportion of animal products in the total food consumption will increase (Bodirsky et al. 2015). **It can thus be assumed for the future that if no appropriate (counter) measures will be taken, meat consumption will remain at high levels. The German meat industry has the potential to expand its export business in addition to its almost constant domestic sales.**

- While plant-based meat substitutes are already established, they still have a strong growth and innovation potential. A complete imitation of the sensory spectrum of meat has not yet been achieved to the full satisfaction of consumers and therefore it cannot be assumed that consumers will increasingly replace meat with plant-based meat substitutes. The general population will most likely only be prepared to substitute meat if they are offered a substitute product with a superior taste, high quality and lower price. For the future, it can therefore be assumed that plant-based meat substitutes will remain the most important alternative to meat. In terms of market share, however, plant-based meat substitutes will continue to be more of a niche product. This is especially true if market potentials remain unused, product innovations are lacking and consumers change their consumption and nutritional behaviour only slightly.

- Insects prove to be an interesting alternative, but their substitution potential is limited mainly by social reservations. In comparison to meat and plant-based meat substitutes, it is hardly con-

ceivable that products containing edible insects could be distributed on a larger scale. Therefore, in the future, edible insects are likely to occupy a very small niche that is not in serious competition with the other alternatives.

- In vitro meat certainly has the greatest potential as a substitute for meat, as it comes closest to the original in terms of characteristics. However, it is very hard to realistically predict when the first products will be ready for market and how prices will develop. Future development will depend to a large extent on whether the current dynamic of research and development activities can be increased. In the foreseeable future, this could lead to breakthroughs in large-scale production facilities, the use of inexpensive and ethically produced raw materials and the marketability of in vitro meat products.

It becomes clear that a desired vision of the future, in which a reduction in meat consumption for ecological reasons will be successful, is linked to numerous prerequisites. The study concludes that there are very few signs of a change in which the decline in meat consumption is accompanied by substitution with alternative products. The object of the analysis of environmental impacts is thus not only to illustrate the overall consequences for the environment when remaining on the current path (see Chapter 6.1), but also to highlight the negative and positive effects that can currently be represented by available alternatives (see Chapter 6.5).

6 Impact on the environment, health and animal welfare

The following chapter discusses the environmental impacts that could result from the production of in vitro meat, insect-based meat alternatives and plant-based meat substitutes. It highlights the most significant impacts with a particular focus on climate, nutrient inputs, water, land use and biodiversity, based on the concept of Planetary Boundaries (Rockström et al. 2009).[17] For in vitro meat, energy consumption is also considered in a separate section, as it has been the subject of particularly intense debate in research.

Conventional animal production[18] is used as the benchmark for assessing the environmental impact of in vitro meat, insects and plant-based meat substitutes.[19] In addition, the chapter also discusses ethical aspects and health effects.

In order to be able to compare the three individual alternatives as consistently as possible with regard to their environmental impact, the production of 100 g of edible meat or meat substitute is used as the unit for visualisation purposes and for the conclusion in the present study.[20] Available data thus allows a uniform and consistent comparison of all the types of meat considered. In this report, the functional unit (FU) used in the literature is therefore converted from 1 kg of edible mass to 100 g of edible mass in terms of environmental impact.

Moreover, the product of the "burger patty" enables a concrete, consumer-oriented illustration. The data for the graphic illustration of the environmental impact of the burger patty is based on a study by Smetana et al. (2015a), which examined environmental impacts within the system boundaries from "cradle to plate", i.e. from livestock farming to consumption. Smetana et al. (2015a) consistently compare all meat alternatives presented in this analysis with poultry and therefore the study can be aptly used as a basis for the environmental impact considerations. With regard to greenhouse gas emissions of insects, it should be noted that these are only based on initial

observation data. In order to be able to compare the figures with data on conventional meat from other authors, the share of emissions for the preparation of the products is eliminated from the data from Smetana et al. (2015a) (cradle-to-plate approach) for the following explanations. This renders possible a comparison with large parts of the research literature, which predominantly uses a cradle-to-gate approach, i.e. from livestock farming to the factory gate, e.g. Mattick et al. (2015b). The different assumptions are clarified in each case. Only that way, a comprehensive picture of the relevant developments can be obtained.

6.1 Conventional animal production

The following section on conventional animal production is intended to give a rough outline of important environmental and health impacts of conventional animal production in order to allow a

17 The "planetary boundaries" describe the ecological limits of our earth, which must be maintained in order to guarantee the stability of our ecosystem and our livelihoods.
18 The focus is on meat production and not on milk production.
19 Pulses and other unprocessed meat alternatives were not considered for the report (see Chapter 3.1)
20 Alternatively, there are approaches that use the supply of a certain amount of protein to the consumer as the basis of the life cycle assessment, which would not, however, allow the concrete comparison with a burger patty that is aimed for here.

better comparison of the effects of meat substitutes. This section is not intended to address the issue of conventional meat production in its entirety.

6.1.1 Currently observable environmental impacts

Livestock farming[21] accounts for over 15 % of man-made greenhouse gas (GHG) emissions worldwide and thus contributes to climate change (Steinfeld 2006). These emissions are primarily composed of: (i) carbon dioxide (CO_2) from slash-and-burn clearing[22] of forests for animal feed and pasture, (ii) nitrous oxide (N_2O) from the use of fertilisers for animal feed production, and (iii) methane (Steinfeld 2006). Methane emissions play a particularly important role in meat production.[23] They are produced during the digestive process of ruminants and are released during the storage and application of manure (manure management). The figure below shows the greenhouse gas emissions from global agricultural production in 2010.

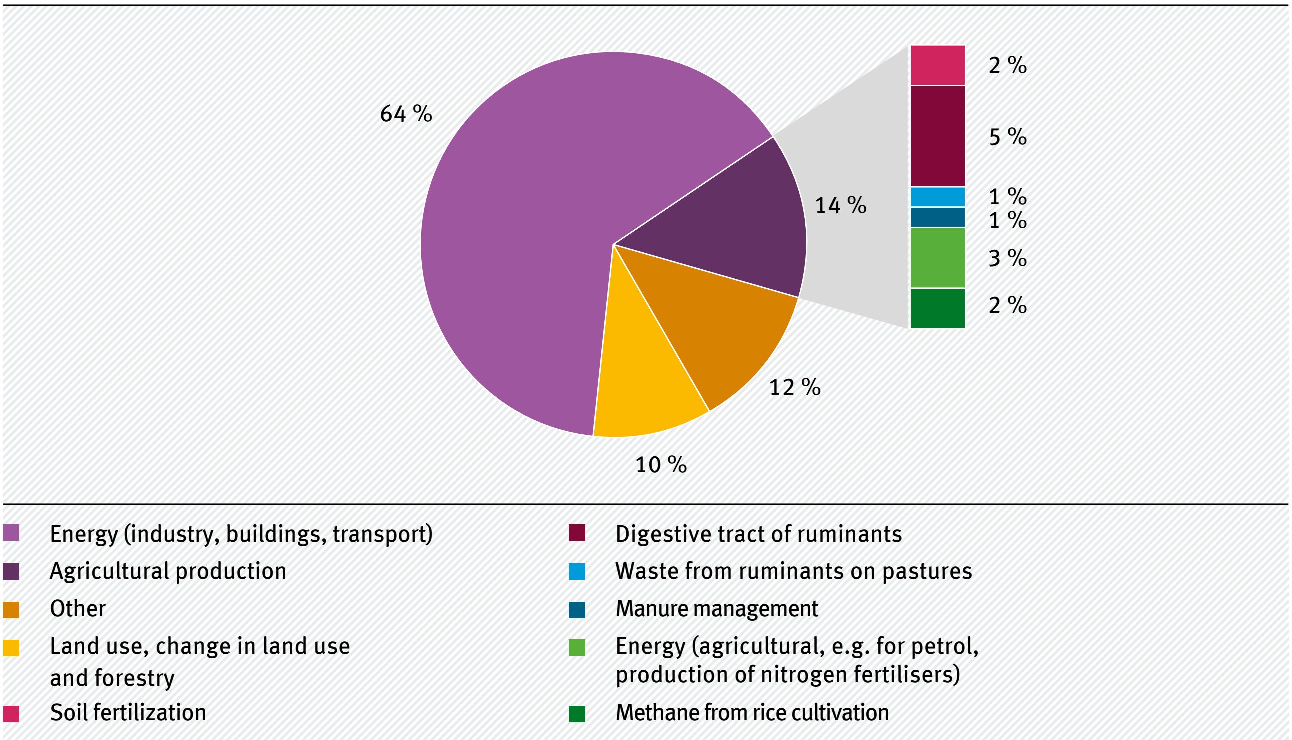
The climate impact of methane is 25 times greater and the climate impact of nitrous oxide is almost 300 times greater than that of carbon dioxide. In order to present the climate impact uniformly, these are converted into CO_2 equivalents.

In 2017, agriculture in Germany was responsible for the emission of approximately 66 million tonnes of CO_2 equivalents, corresponding to approximately 7.3 % of Germany's total greenhouse gas emissions. More than 1.2 million tonnes of methane were emitted. In addition, nitrous oxide emissions and nitrogen oxides, a precursor substance for nitrous oxide, of just under 16,000 tonnes (Umweltbundesamt (UBA) 2018) were produced, also from manure management.

In principle, the production of different types of meat causes different amounts of GHG emissions[24]. The production of 100 g of beef produces considerably more CO_2 equivalents (CO_{2e}) than

Figure 20

Greenhouse gas emissions from agricultural production compared to other sectors

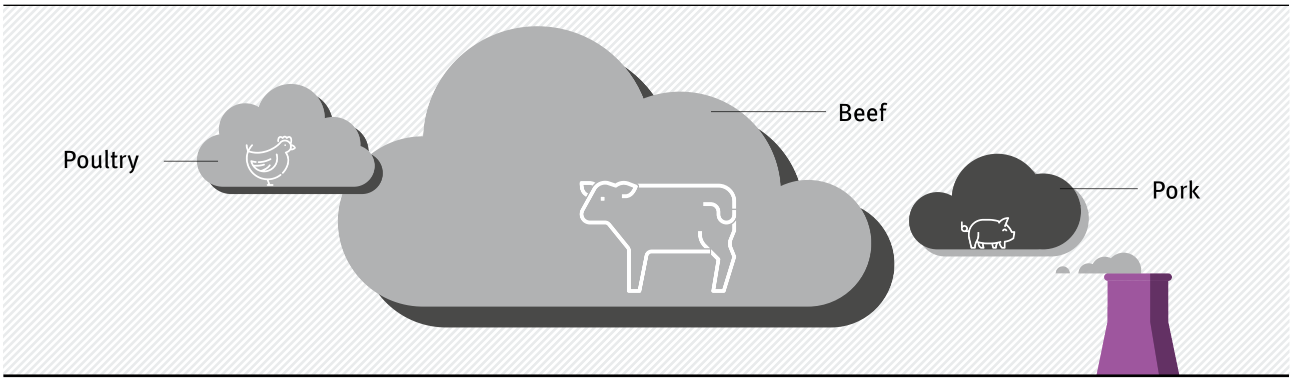


Source: World Resources Institute (WRI) (2019)

21 The terms animal production and livestock farming are used synonymously in this report.
22 The drainage of peatlands for agricultural use is another example of the development of greenhouse gas emissions related to a change in land use.
23 Methane is also produced during milk production. In this study, however, the focus is on meat production.
24 Reasons for this are, for example, that pigs or chickens are not ruminants and do not produce methane during digestion, but the use of different feedstuffs also plays a role.

Figure 21

Comparison of greenhouse gas emissions



Sources: Mattick et al. (2015c) and Smetana et al. (2015a)

pork and poultry (Oonincx und Boer, Imke J. M. de 2012). This means 3.05 kg CO_2 equivalent for 100 g beef, 0.41 kg CO_2 equivalent for 100 g pork (Mattick et al. 2015b) and 0.38 to 0.43 kg for 100 g of poultry (Smetana et al. 2015a) for a cradle-to-gate system boundary.[25] These differences also apply when considering how many CO_2 equivalents are produced for 100 g protein (Oonincx und Boer, Imke J. M. de 2012).[26] Furthermore, GHGs are not only generated in the country where the animals are kept, but also where feed is grown.

Nutrient inputs and surpluses

Fertilisation in excess of the nutrient requirements of crops results in nutrient surpluses in the soil.[27] According to the European Nitrogen Assessment (Sutton et al. 2011) 79 to 88 % of total emissions of ammonia, nitrate and nitrous oxide[28] from European agriculture are related to livestock production.

In Germany, nitrogen surpluses regularly occur, especially on farms with high livestock numbers. In 2016, this surplus of agricultural fertilisers amounted to around 102 kg per hectare of agricultural land (Kommission Landwirtschaft beim Umweltbundesamt (KLU) 2019). On other agricultural holdings, e.g. those which do not keep animals themselves and therefore do not produce liquid manure, mineral fertilisers such as phosphate fertilisers are used to increase the yield of the soil.

After the application of agricultural fertilisers on arable or grassland, nitrogen compounds – nitrates – are leached into groundwater and surface waters and can lead to their eutrophication. Phosphorus, on the other hand, remains in the soil, but can get into rivers, lakes and streams through erosion and cause excessive plant growth there (Umweltbundesamt (UBA) 2019). Nitrogen compounds reach the sea via rivers and, especially in enclosed and semi-enclosed seas with low water exchange, such as the Baltic Sea, they cause algae formation and oxygen deficiency and thus a reduction in water quality (Mayer et al. 2015).

The storage of liquid manure in intensive livestock farming is also a contamination risk for surface and ground water in many countries (Godfray et al. 2018). The pollution of water bodies with nitrogen or phosphorus has a negative impact on biodiversity (see section on biodiversity and land use change).

However, nitrogen compounds from farm manure do not only pollute water bodies, but also the air (atmosphere) in the form of ammonia (NH_3), especially in regions with an increased concentration of livestock farms. Nitrogen inputs from the air contribute to the acidification and eutrophication of soils and ecosystems, and in the long run they can lead to reduced plant growth and a loss of biodiversity (Bayerisches Landesamt

25 In the data of Smetana et al., as described above, the share of emissions for the preparation of the products was eliminated to ensure comparability of the data.
26 In the literature there are figures ranging from 75 to 175 kg CO_2 equivalents for beef, 20 to 55 kg CO_2 equivalents for pork and 20 to 40 kg for poultry: Oonincx und Boer, Imke J. M. de 2012.
27 If the balance between the production of manure through livestock farming and its use for crop production is reasonable, and if the manure is applied in a technically correct way, there will normally be no nutrient surpluses and environmentally harmful emissions.
28 Ammonia, nitrate and nitrous oxide are also called "reactive nitrogen compounds".

für Umwelt (LFU) 2018). For 100 g of in vitro meat produced, the generated eutrophication potential is of 0.75 PO_4-equivalents compared to 21.4 PO_4-equivalents for beef, 2.62 for pork and 0.64 for chicken (Mattick et al. 2015a).

However, animal production in Germany not only disrupts the nutrient cycles in this country, but also changes the cycles in the countries where the feed is grown. There, the natural balance of nitrogen or phosphorus release and fixation is disturbed by, among other things, the use of large quantities of artificial fertiliser, e.g. in soya cultivation.[29]

Fresh water consumption
From a global perspective, agriculture is the largest consumer of fresh water with a use of about 69 %. (Food and Agriculture Organization of the United Nations (FAO) 2016b). About one third of agricultural water consumption is attributed to meat production, especially the production of animal feed. Most of the water used comes from precipitation, also known as "green water"; a smaller proportion of 6.2 % is taken from rivers, lakes and groundwater, the so-called "blue water" (Godfray et al. 2018). However, the proportion of blue water abstracted is particularly critical, as it competes with "natural" water use, e.g. to preserve aquatic ecosystems (Mekonnen und Hoekstra 2010; Godfray et al. 2018).

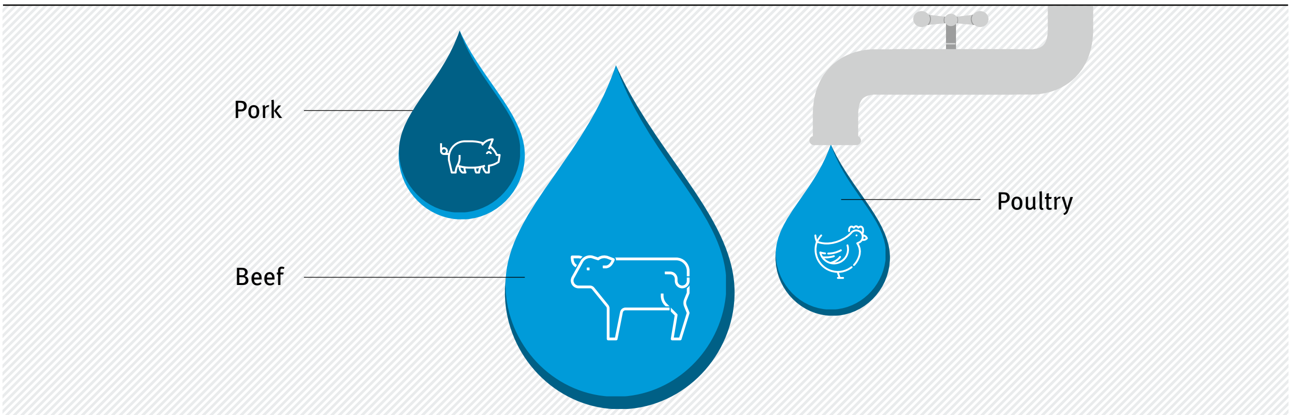
The average water footprint, i.e. the total water consumption required along the various production stages for the production of poultry and pigs, is around 340 litres and 380 litres respectively per 100 g of animal mass (Miglietta et al. 2015). The differences in water consumption become even more apparent when the edible portion, i.e. the portion minus skin, bones and other by-products of the respective farm animal species, is taken into account. For example, a good 1,500 litres of water are needed to produce 100 g of edible beef, just under 600 litres for 100 g of pork and 400 litres for poultry (Miglietta et al. 2015).[30]

The environmental impact of "green" water consumption, i.e. rainwater, is unproblematic in many regions, e.g. in Central Europe. The environmental impact of the use of "blue" surface water, e.g. for the artificial irrigation of animal feed crops, on the other hand, is heavily context-dependent, i.e. it depends on local water scarcity as well as on the characteristics of the ecosystem, e.g. specific vulnerabilities. However, with increasing fresh water scarcity worldwide, the pressure on ecosystems and the risks to water quality and stable water cycles are increasing (Hoekstra 2017).

Germany is one of the largest net importers of virtual water, i.e. it imports, for example, animal feed for animal husbandry from abroad, e.g. Brazil

Figure 22

Comparison of water consumption of conventional animal production



Source: Miglietta et al. (2015)

29 Imported soya, which is used as animal feed in Germany, also provides an import of nutrients or nitrogen and potentially leads to further nutrient surpluses.
30 The sharp differences are due to the fact that the edible portion of beef is much smaller than that of pork or poultry.

or Argentina, for which water was consumed outside Germany. Thus the environmental impacts of water consumption also occur in the respective exporting countries (Mekonnen und Hoekstra 2011; p. 21).

Biodiversity and land use change
Animal production can have both positive and negative effects on biodiversity (Food and Agriculture Organization of the United Nations (FAO) 2016a; p. 13). The Millennium Ecosystem Assessment identified the most important drivers of biodiversity loss: habitat change, climate change, invasive species, pollution and overuse (Millennium Ecosystem Assessment 2005; p. 8) . Animal production has both a reinforcing and a relieving effect on these drivers (Food and Agriculture Organization of the United Nations (FAO) 2016a; p. 13). Effects are also dependent on the type of animal production, i.e. whether it is intensive or extensive (Leip et al. 2015). For example, extensively grazed land in Europe is considered the most biodiverse in the agricultural landscape, while animal feed production for intensive livestock farming contributes to significant habitat loss and fragmentation, for example in South America (Food and Agriculture Organization of the United Nations (FAO) 2016a).

For 100 g of edible beef, the area used is between 2.7 and 4.9 m², about four times the area used for the same quantity of pork and almost five times that used for poultry (Vries und Boer, Imke J. M. de 2010). Reasons for the high figures in beef production include the fact that cows eat less concentrated and more green fodder and that fodder cultivation is more land intensive.

Almost half of the cultivated area required for domestic meat consumption is located outside Germany; this makes Germany a net importer of “virtual” arable land and grassland (Umweltbundesamt (UBA) 2017a; p. 35). This area, the size of Mecklenburg-Vorpommern, is mainly located in South America and is largely used for soya bean cultivation for animal feed (Witzke et al. 2011). The deforestation of tropical rainforests leads to the extinction of valuable and/or rare species.

The overgrazing of land also leads to a reduction in plant biodiversity at global level. In arid regions, reduced plant cover also leads to soil erosion (Godfray et al. 2018). Finally, animal production can also have an impact on biodiversity through disease transmission from farm animals to wildlife (Food and Agriculture Organization of the United Nations (FAO) 2016a; p. 13).

Figure 23

Land use in comparison

Source: Mattick et al. (2015c) and Smetana et al. (2015a)

6.1.2 Organic animal production and the environment

The impact of organic livestock production on the environment is highly dependent on the efficiency of the production system, in particular feed conversion, feeding – composition and production of feed – (Alig et al. 2012) and the type of meat under consideration. Overall, it can be stated that organic farming is more advantageous than conventional variants in terms of environmental and resource protection due to the systemic approach pursued (Sanders und Heß 2019).

The environmental effects of some organically produced types of meat have already been scientifically measured. For example, organic production of beef and lamb can have positive effects on biodiversity, the preservation of open landscapes and soil protection, e.g. by dispensing with pesticides and mineral fertilisers in organic production (Kumm 2002; Castellini et al. 2006; Alig et al. 2012). Organic poultry meat production may also have environmental advantages over conventional production methods, in particular as regards sulphur and nitrogen oxide emissions into the air, the consumption of non-renewable resources, greenhouse gas emissions and nitrogen emissions. CO_2 emissions account for the largest share of potential savings. Such emissions can be saved in the case of organic farming, as this largely dispenses with the use of fossil fuels in the production of fertilisers and the import of animal feed, such as soya from Latin America. (Hirschfeld et al. 2008)

The comparison of methane (CH_4) and nitrous oxide (N_2O) emissions from conventional and organic animal husbandry is particularly difficult for cattle farming, as the base data is not yet sufficient (Sanders und Heß 2019). In terms of greenhouse gas emissions, there is therefore no clear advantage over conventional livestock farming. Organic meat production requires more cultivated land than conventional production (Korbun 2004). However, the organically farmed land contributes to the preservation of biodiversity and open landscapes (Sanders und Heß 2019).

6.1.3 Animal welfare aspects of conventional and organic animal production

Anyone examining the consequences of conventional animal production must also consider questions of keeping, transporting and killing animals. The declared aim of livestock farming in Germany is the production of food and animal products (Bundesministerium für Ernährung und Landwirtschaft (BMEL) o. J.). Animal welfare is also relevant, but initially of secondary importance.

In a system characterised by specialisation, standardisation and automation, animals often adapt or are adapted to confined and productivity-oriented housing systems. This is done by removing horns from calves, docking tails from piglets or shortening the beaks of poultry in order to minimise mutual injuries in the confined space and to achieve productive and standardised animal performance (Dirscherl 2013).

In organic livestock production, the species-appropriate keeping of animals is an important aspect. For example, specifications are issued on the provision of outdoor areas in fresh air and space in the barn, but also on the use or non-use of pharmaceuticals when animals become ill. Hoof and limb health is also better in organic farms than in conventional ones (Sanders und Heß 2019). In practice, however, organic livestock production does not always generally perform better, as animal welfare is highly dependent on management. Variables such as animal behaviour and emotional state are covered in only a few studies, but these do indicate that organic farming is advantageous (March et al. 2019; Sanders und Heß 2019).

6.1.4 Health effects of increased meat consumption

In principle, meat consumption in Germany is above average in international comparison and above the recommendations of national and international health organisations. In 2016, more than 60 kg of meat per capita were consumed in Germany, while the recommendations are 15 to 30 kg (Deutsche Gesellschaft für Ernährung e. V. (DGE) 2017; Willett et al. 2019).

Assessing the health effects of excessive meat consumption is difficult and fraught with uncertainty. In industrialised countries, there are other risk factors besides high meat consumption, such as smoking, alcohol and obesity, which have an impact on health (Dannemann Purnat et al. 2019).

Red meat in particular, but also processed meat, is the focus of many studies on the health effects of increased meat consumption. The strongest link is between colorectal cancer and excessive consumption of red and processed meat (Stewart und Wild 2014; Bouvard et al. 2015; Godfray et al. 2018). Current recommendations for the maximum quantities of red and processed meat to be consumed vary between 100 g (Lim et al. 2012) and 350 to 500 g per week (World Cancer Research Fund (WCRF) und American Institute for Cancer Research 2018) but are regularly exceeded many times over by consumers (Bouvard et al. 2015). Other studies establish a link between excessive meat consumption and obesity, cardiovascular diseases, hypertension or type 2 diabetes (Crowe, Appleby, Travis & Key, 2013; Huang et al., 2012; Sinha, Cross, Graubard, Leitzmann & Schatzkin, 2009). The intake of animal fats, i.e. saturated fatty acids, and the method of preparation, such as smoking, pickling, salting and strong heating, are factors that can promote the above-mentioned disease patterns (World Cancer Research Fund (WCRF) und American Institute for Cancer Research 2018).

Numerous food scandals have highlighted the risks of poor food safety in animal production. Salmonellosis is a classic foodborne infection and is most frequently transmitted by raw meat or meat products that have not been heated or not heated sufficiently (Robert Koch-Institut (RKI) 2019). In addition, high levels of dioxins have been found in fish and animals kept outside, which are transmitted to humans through food consumption (Bundesamt für Strahlenschutz (BfS) et al. 2011). Dioxins are toxic pollutants which spread in ecosystems and organisms and put a considerable strain on the human body, particularly when deposited in fatty tissue and the liver (Bundesamt für Strahlenschutz (BfS) et al. 2011).

Another public health problem is the extensive use of antibiotics in animal husbandry. In 2017, the quantity of antibiotics supplied to veterinarians in Germany was 733 tonnes (Bundesamt für

Verbraucherschutz und Lebensmittelsicherheit (BVL) 2019). This high level of consumption can lead to the development of dangerous resistances to antibiotics in humans and animals, which makes the antibiotic treatment of diseases increasingly difficult (Bundesamt für Strahlenschutz (BfS) et al. 2011; Landers et al. 2012; Bundesamt für Strahlenschutz (BfS) et al. 2017).

6.2 Plant-based meat substitutes

6.2.1 Principles of environmental assessment

Meat substitutes based on processed vegetable proteins have become increasingly important in recent decades. These include products such as seitan (wheat protein), soya meat/tempeh (soya beans) and Quorn (fermented mycelium); also products based on lupins. The analysis of the environmental impact of plant-based meat substitutes is intended to help identify differences with respect to conventional meat and between the meat substitutes themselves. Where appropriate, results on tofu are also included, e.g. with regard to soya bean cultivation.

Wheat and soya beans, which are used for the plant-based meat substitutes, may be used directly for human consumption. This significantly reduces the environmental impact of the plant-based meat substitutes since the GHG emissions as well as the land and water consumption associated with the conversion of plant to animal food – and the associated calorie losses – are eliminated.

The question of substitution, i.e. whether the plant-based meat substitutes are actually meat substitutes or are eaten in addition to meat, is central to the environmental assessment. The resource savings achieved by plant-based meat substitutes are most effective if meat consumption is reduced accordingly. Currently, around 93 % of the soya in demand in Europe is used for animal feed (Europäische Kommission 2018). In the absence of substitution and with additional consumption of meat substitutes, the demand for soya will grow additionally. The way in which plants are used – whether as a substitute or "add-on" – must therefore always be considered in an environmental assessment.

Greenhouse gases

Overall, the production of soya-based products releases less CO_2 emissions compared to meat production, as various studies with different system boundaries and assumptions show (Smetana et al. 2015a; Fresán et al. 2019). While the production of 100 g of chicken meat (edible mass) generates 0.38 to 0.43 kg CO_2 equivalents, the production of 100 g of soya-based meat substitute releases only about one third of the GHG emissions, namely 0.111 to 0.117 kg CO_2 equivalents (Smetana et al. 2015a; Fresán et al. 2019).[31]

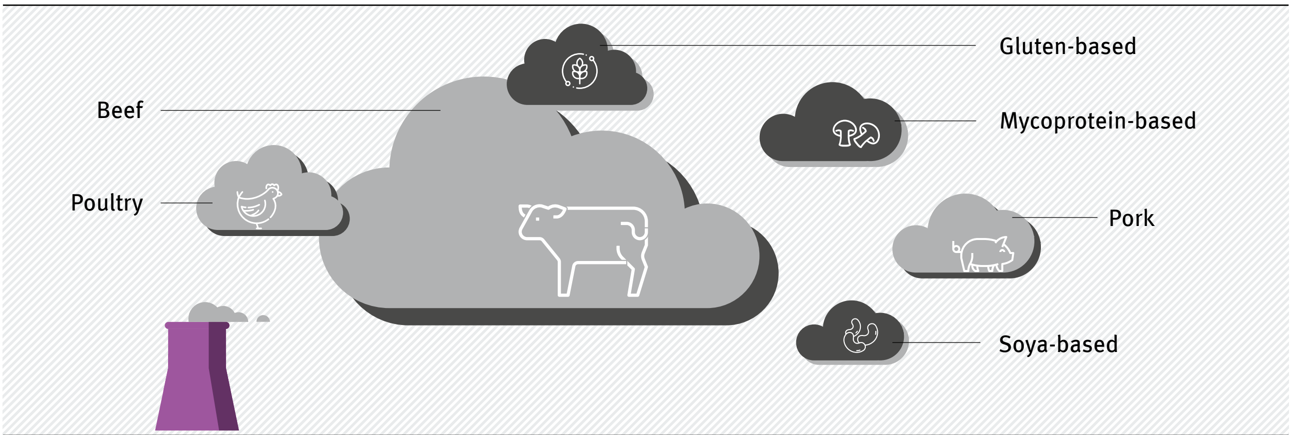
From research on tofu, it is known that the greatest impact occurs during the processing of soyabeans into tofu, namely a share of approx. 52 % of total emissions (Mejia et al. 2018). The size of the emission share resulting from cultivation and transport depends on the region of cultivation (Head et al. 2011).

For the above calculation of emissions per 100 g of soya-based product (Smetana et al. 2015a) no specific production region was supposed, but the average world soya bean area was used as the basis for the calculation.[32] However, most manufacturers of soya products for the German market currently obtain their non-genetically modified soya predominantly from EU countries (Albert Schweitzer Stiftung für unsere Mitwelt 2018).[33] This means that greenhouse gas emissions from transport are comparatively less significant for German production.[34] Furthermore, greenhouse gas emissions from organically produced soya products are up to 50 % lower than those from conventionally produced products (Sustainable Europe Research Institute (SERI) 2011b).

According to a study by the Sustainable European Research Institute(Sustainable Europe Research Institute (SERI) 2011a) on behalf of the Vegetarierbund (VeBu; now ProVeg Deutschland e. V.), seitan causes on average about 50 % more CO_2 emissions than tofu (0.23 to 0.25 kg CO_2 equivalents

Figure 24

Comparison of greenhouse gas emissions



Sources: Mattick et al. (2015c) and Smetana et al. (2015a)

31 To improve the comparability of the data, the share of emissions resulting from the preparation of the product was eliminated here (see above).
32 Indirect emissions due to land use change were not included.
33 To date, around 24,000 hectares of soya beans have been planted in Germany. The future (cautiously estimated) cultivation potential is 100,000 hectares (ökolandbau.de 2018). In 2017, the amount of land given over to soya bean cultivation in Europe was around 0.97 million hectares and strong growth is expected (The Sustainable Trade Initiative (IDH) und Dutch national committee of the International Union for the Conservation of Nature (IUCN NL) 2019)
34 If non-genetically modified soya were to be imported into the EU from overseas in the future, the GHG emissions for transport would become more important.

for the production of 100 g of soya-based product according to Smetana[35]), but the emissions are only about half as high compared to the production of 100 g of poultry. Quorn comes off worse than seitan in terms of CO_2 balance. The production of 100 g of Quorn releases 0.41 to 0.46 kg CO_2 equivalents – almost as much as the production of 100 g of pork. The high greenhouse gas balance of this product is due to the high energy consumption during production (Jungbluth et al. 2016; p. 17).

Nutrient inputs and surpluses

As agricultural products, soya and wheat – and thus also soya-based products and seitan – have an impact on nitrogen and phosphorus nutrient cycles. In general, as described for conventional animal production, the application of manure and mineral fertilisers on arable land leads to nitrogen and phosphorus compounds being released into groundwater and can have a negative impact on water quality. Depending on the place of cultivation, natural site factors and agricultural practice, the environmental impact varies.

In the form of plant-based meat substitutes, soyabeans and wheat serve directly for human nutrition. In animal husbandry, plants are used as animal feed, so the conversion rate from vegetable to animal calories is high, which is also called calorie loss. On average, a fattening pig consumes 250 kg of animal feed within five to six months until it reaches the slaughter weight of approximately 95 kg; the edible portion of a whole animal is around 62 %. (Heinze 2011; Heinrich-Böll-Stiftung et al. 2014b). In the case of a plant-based diet, therefore, a smaller overall quantity of agricultural products is needed to feed the same number of people. This also reduces the pollution of groundwater and soil through nutrient overload. This is shown, for example, by substitute products based on soya The total emissions of sulphur dioxide (SO_2), nitrogen oxides (NOx) and ammonia (NH_3) are seven times lower in a diet based on soya protein than for meat proteins (Reijnders und Soret 2003). Phosphorus emissions are also only one seventh of those of the production of proteins from meat (Reijnders und Soret 2003).

The soya bean is also a nitrogen-fixing protein plant (legume), which accumulates nitrogen in the soil, thus contributing to soil improvement and reducing the use of mineral fertilisers. In contrast to wheat, mineral nitrogen fertilisers can thus be saved (Bundesministerium für Ernährung und Landwirtschaft (BMEL) 2016).

Organic farming has advantages over conventional intensive cultivation for both soya beans and wheat. The omission of chemical synthetic pesticides helps to largely avoid pollution of water bodies by pesticides (Sanders und Heß 2019). For wheat, the balance is good, but not quite as positive as for soya beans, since the effect of nitrogen fixation is eliminated (Sanders and Heß 2019).

If conventional animal products were increasingly substituted by plant-based meat substitutes, emissions directly attributable to animal husbandry would also be increasingly eliminated. Livestock farming contributed 38 % of the nitrogen surplus in agriculture in 2015 (Umweltbundesamt (UBA) 2019). Animal husbandry accounts for 60 % of ammonia emissions from agriculture (Umweltbundesamt (UBA) 2017b). In addition, the risk of contamination of surface and groundwater from the storage of manure in intensive livestock farms would also be reduced if meat production were reduced. Thus plant-based meat substitutes have a considerable savings potential if meat is partially substituted.

Fresh water consumption

Research has shown that the water consumed for producing Quorn is the highest, for seitan the second highest and for soya-based products the lowest. In addition, all three products consume significantly, i.e. between 4 to 15 times less water than beef, pork and chicken.

From research on tofu, it is known that the largest share of the water footprint comes from soya cultivation (Ercin et al. 2012). Accordingly, and in the absence of concrete figures on the water footprint of the end products tempeh/soya meat, the water requirement for the cultivation of soya is considered here, i.e. the water requirement for the cultivation of the mass x of soya beans required to produce 100 g

35 Excluding the share of emissions for the preparation.

of tempeh/soya meat. For the production of 100 g of soya tempeh, approx. 63 g of soya beans are required (Shurtleff und Aoyagi 1986; p. 80). For the cultivation of 350 g of soya beans about 1,000 litres of water are needed (Ercin et al. 2012). The largest proportion of this, 65 %, is "green water", which comes from rainfall, 5 % is "blue water", i.e. additional irrigation water, and 30 % is "grey water", the proportion that is polluted by fertilisers and pesticides during cultivation and thus becomes unusable for other purposes (basis of calculation: Ercin et al. 2012). Since soya beans are cultivated in temperate zones as well as in dry climates, there are large regional differences in the proportions for "green" and "blue" water. The above figures are based on soya bean cultivation in Europe (France), reflecting the fact that most manufacturers of soya products for the German market source their soya predominantly from EU countries (see above). (Albert Schweitzer Stiftung für unsere Mitwelt 2018). This also means that, unlike conventional meat, under this assumption there are no or fewer imports of virtual water outside the EU. The proportion of "grey water" can be reduced by up to 98 % compared to conventional cultivation, according to various life cycle assessments of organic soya bean cultivation (Ercin et al. 2012). The input of water pollutants in organic soya bean cultivation is much lower than in conventional cultivation (Jungbluth et al. 2016).

For the production of 100 g of seitan approx. 0.16 kg of wheat is needed (Smetana et al. 2015b). This requires about 130 litres of water – based on wheat cultivation in Germany. 70 % of this is "green water", 19 % "blue water" and 11 % "grey water" (Vereinigung Deutscher Gewässerschutz e. V. 2019).

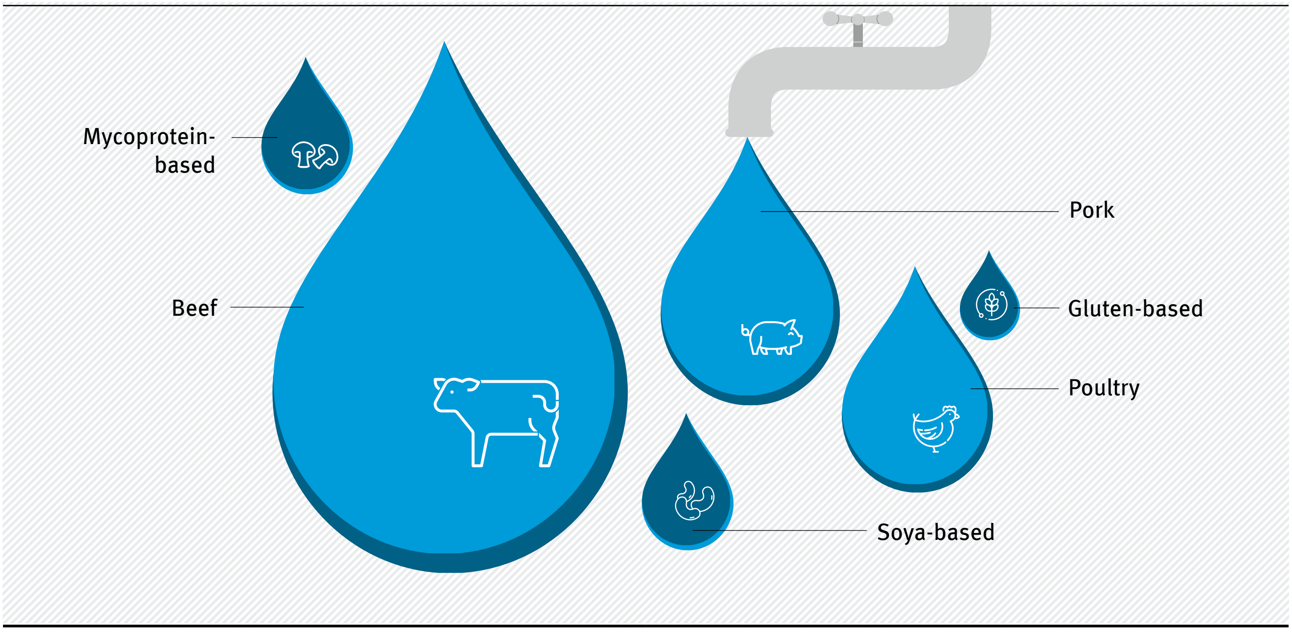
However, the two calculations above – due to the lack of data – do not include the processing of the raw materials soya and wheat into end products, which also consumes water, but significantly less than the cultivation of the raw materials (Sustainable Europe Research Institute (SERI) 2011a; Ercin et al. 2012).

For Quorn, figures are available for the finished, ready-to-sell product (cradle-to-gate approach). Depending on the product, approx. 1,700 to 1,900 litres of water per kg are consumed in the process (Carbon Trust 2014). Proportionally, 76 % of this is green water, only 4 % blue and 20 % grey water.

Plant-based meat substitutes therefore have advantages over conventional meat in terms of water consumption, which vary according to where cultivation take place, the type of cultivation (organic or conventional) and the substitute.

Figure 25

Comparison of water consumption



Sources: Miglietta et al. (2015) and Carbon Trust (2014); own calculation

Biodiversity and land use

For the production of plant-based meat substitutes such as tofu, tempeh, soya meat and seitan, agricultural land is needed for soya and wheat cultivation. At present, however, this area represents only a fraction of the global arable land. For example, only about 6 % of the soya beans grown worldwide are used for direct human consumption, while about 70 to 75 % are used as animal feed (Dutch Soy Coalition 2012). Cereals are also fed to animals to a large extent; in Germany approx. 40 % of the wheat harvested ends up in the feeding trough (Bundesanstalt für Landwirtschaft und Ernährung (BLE) 2018b). The great advantage of plant-based meat substitutes over conventional meat is that they are located at the lower end of the food chain. This means that fewer resource inputs and less land area are needed to produce the same nutrients. Instead of using soya or wheat for animal feed, it can be used directly for human consumption in processed form. In terms of protein content, six to seventeen times more land is needed to produce meat protein compared to soya protein (Reijnders und Soret 2003).

Looking at individual products, less agricultural land is required for plant-based meat substitutes than for conventional animal production. For 100 g of chicken meat, 0.385 to 0.389 m² of land is required (Head et al. 2011; Smetana et al. 2015a). The information varies slightly depending on the type of farming and the type of feed used. In comparison to chicken meat, a third less land is needed to produce 100 g of soya-based food (Smetana et al. 2015a). Wheat gluten requires between 0.55 and 0.582 m²/100 g (Smetana et al. 2015a). As already explained in the chapter on conventional livestock farming, the environmental impact of pork and beef is even greater, so the difference between them and plant-based meat substitutes is many times greater. Under the assumptions made in a cradle-to-gate system boundary, the land consumption for beef in terms of pasture and arable land is between 2.7 and 4.9 m²/100 g (Vries und Boer, Imke J. M. de 2010).

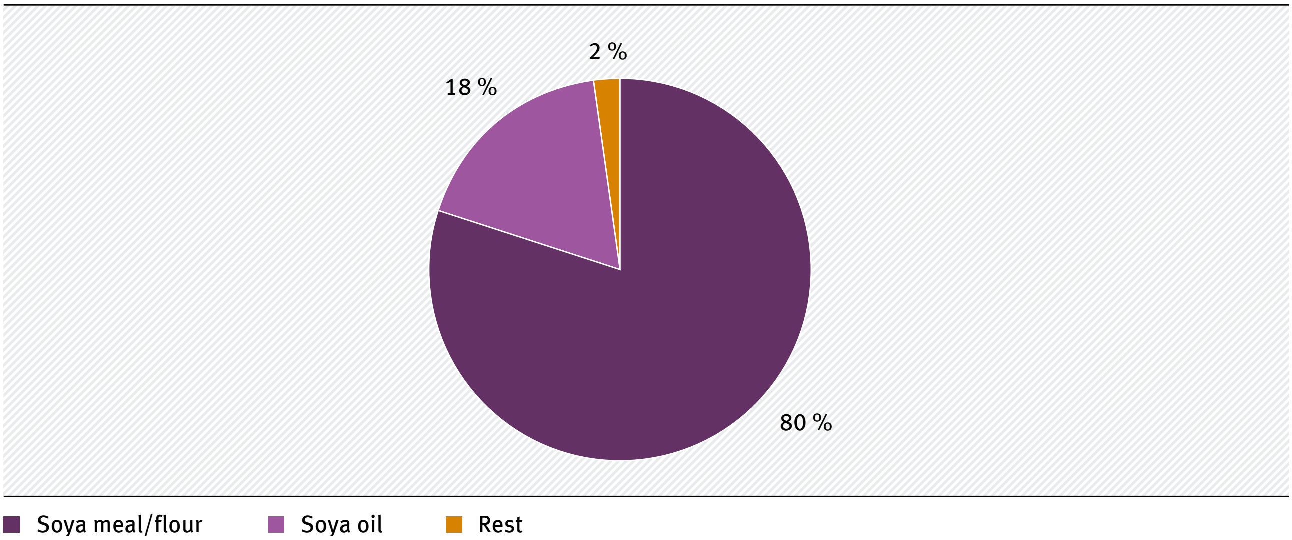
Due to the industrial production of Quorn, the land use of 0.079 to 0.084 m²/100 g is many times less than in conventional meat production. Quorn also performs best compared to soya and gluten-based meat substitutes (Smetana et al. 2015a).

Impacts on local biodiversity vary widely depending on the type of agricultural practices for soya bean and wheat cultivation. Monocultures as well as extensive fertiliser and pesticide application have significant negative impacts on biodiversity and soil quality due to the intensity of production. Organic farming, on the other hand, has a positive impact on biodiversity (Sanders und Heß 2019).

The origin of the plants also plays a role in assessing the impact on biodiversity. According to Regulation (EC) 1829/2003 genetically modified plants must

Figure 26

Use of soya



Source: Brack et al. (2016)

Figure 27

Land use in comparison

Sources: Mattick et al. (2015c) and Smetana et al. (2015a)

be labelled, which means that the seitan and tofu or soya-based products sold in Germany are made from non-genetically modified wheat or soya and come mainly from Europe or Canada (Stiftung Warentest 2016). In the production of conventional meat, however, genetically modified soya from South America is mainly used for animal feed (WWF International 2014).

6.2.2 Health effects

Plant-based meat substitutes can serve as sources of protein in human nutrition. The Protein Digestibility Corrected Amino Acid Score (PDCAAS) is used to show protein utilisation in the human body. Milk, soya and egg proteins are rated with the highest value of 1.0 (Biesalski et al. 2011). Mycoprotein, from which Quorn is produced, has a value of 0.996 and thus also has a very good protein quality (Edwards und Cummings 2010). Of the various types of meat, beef protein (0.9) is the best (Biesalski et al. 2011). Wheat protein has a protein quality of 0.4 (Biesalski et al. 2011). By combining legumes with cereals, protein utilisation can be increased.

Comparing the health effects of meat and plant-based meat substitutes is complex, as they depend strongly on the animal/plant type, the degree of processing and the preparation of the products. For example, the German Nutrition Society recommends low-fat meat and lean muscle meat (Deutsche Gesellschaft für Ernährung e. V. (DGE) 2017). An advantage of plant-based foods over meat products is that they contain almost no cholesterol (Heseker und Heseker 2015). In general, soya and gluten products that are not heavily processed have a low fat and increased nutrient content (Huber und Keller 2017). Quorn also contains a high protein content, a lot of fibre and little fat (Wiebe 2004).

One aspect of the impact on health is food safety. This is particularly important in the case of highly processed products, such as cutlets or sausages made from seitan, etc. Due to production processes, undesirable components may be present. For example, petroleum hydrocarbons have been detected, which have adverse health effects (Ökotest 2016). However, these substances were also found in products containing meat (o. A. 2016).

Another important aspect for the health effect is the additives used in the processed meat substitutes; these include artificial colouring, stabilisers, acidity regulators, emulsifiers and antioxidants (Huber und Keller 2017). Conventional meat substitutes contain on average more additives than their organic counterparts.

6.3 Insects

6.3.1 Principles of environmental assessment

In principle, various framework conditions must be looked at more closely/defined more precisely in the environmental assessment of insect-based meat substitutes. These include the place of production, the insect species considered and the type of feed used. The "place of production" can be defined both in terms of the climate prevailing there, e.g. tropical vs. continental temperate, and in terms of its closeness to or remoteness from nature. In this respect, a distinction should be made between:

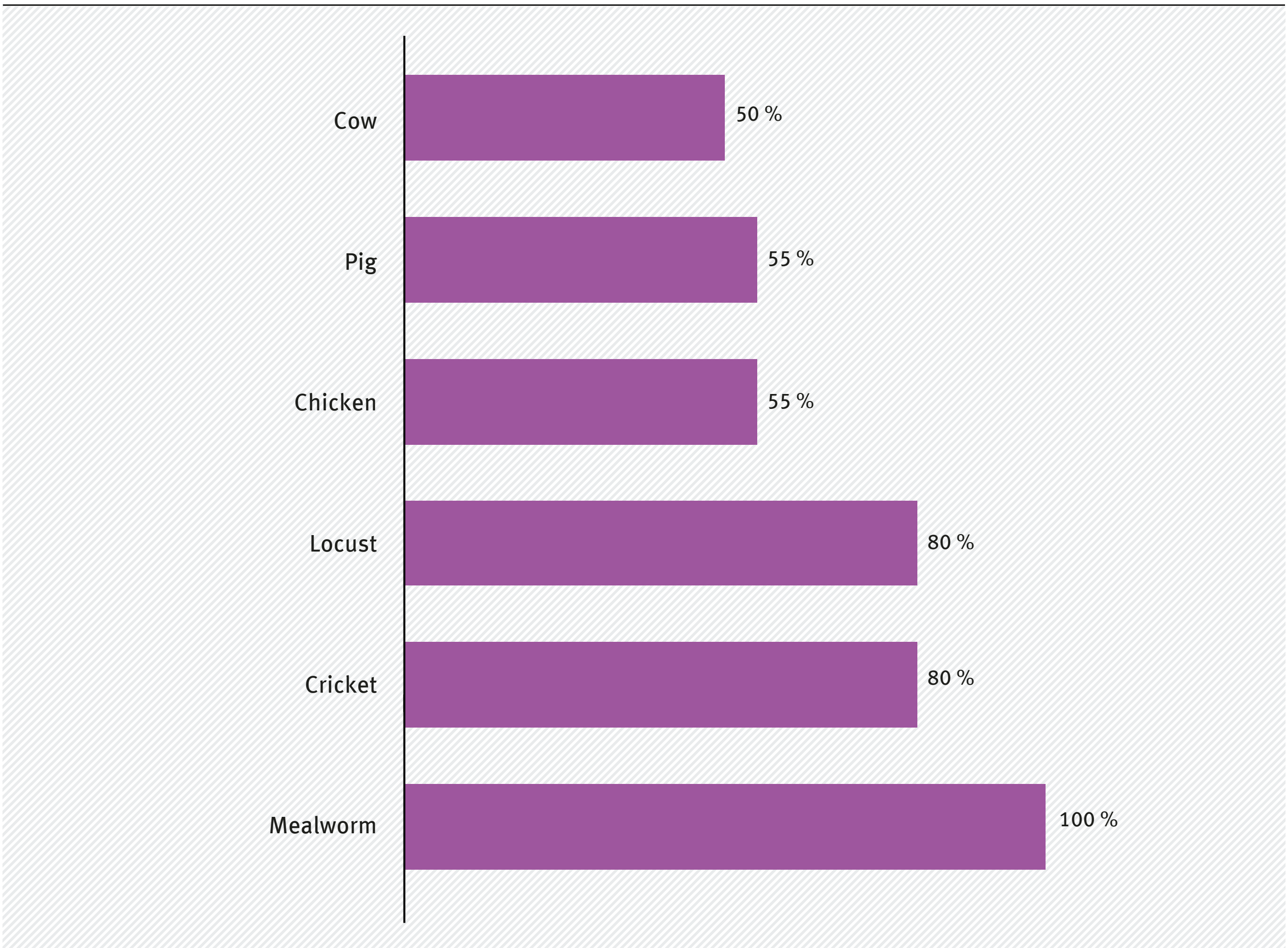
- removal of insects from natural habitats;
- removal of insects from modified habitats;
- "insect plagues", i.e. the collection of originally unwanted insects, e.g. from maize or millet fields in Mexico or the Sahel region;
- production in insect farms outside Germany/the EU;
- production in insect farms in Germany/the EU.

Life cycle assessments are currently only available for production on insect farms outside Germany/EU (Halloran et al. 2017).[36]

It also plays a role which insect species is considered and which feed is used. A distinction must be made, for example, between the use of chicken feed such as cereals, fish meal and soya meal as insect feed and feeding with waste or by-products.

Figure 28

Comparison of edible portion



Source: Fiebelkorn (2017)

36 The data are also still quite scant. ((oder: The data situation is also still quite patchy.))

Compared to conventional farm animals, the edible proportion of insects is much higher at 80 to 100 %. The edible proportion of conventional farm animals is 50 to 55 % (Fiebelkorn 2017). In addition, insects have a much better feed conversion rate than conventional farm animals, so they need much less feed for the same increase in mass. Insects are also poikilothermic, i.e. cold-blooded, in contrast to conventional farm animals, which are homoiothermic (warm-blooded) creatures. Because of this property, insects in certain regions, e.g. the tropics, do not need any additional (heat) energy supply to maintain their body temperature, but can use all their energy for growth (Fiebelkorn 2017). Overall, these characteristics of insects can positively influence their environmental impact during production compared to conventional animal production.

Below, the focus is on the – few – insect species that have already been studied with regard to their environmental impacts. These include mealworms, locusts and crickets. Furthermore, the focus is on insects grown in production plants rather than in the wild, as only large-scale production can produce significant and affordable quantities of insect meat that can replace conventional meat if necessary.

6.3.2 Currently observable environmental effects

Greenhouse gases

The production of 100 g of ready-to-eat insect-based end product generates approx. 0.14 to 0.15 kg CO_2 equivalents (Smetana et al. 2015a).[37] In this form of consideration within the cradle-to-gate system boundaries, in which not only feed production and transport for the insects but also processing (freeze-drying) is taken into account, only about one third of GHG emissions are produced compared to 100 g of chicken meat.

Direct GHG emissions from animals are composed of carbon dioxide, methane, nitrous oxide (N_2O) and ammonia (NH_3), which are released through the respiration and metabolism of insects and their faeces (van Huis und Oonincx 2017). As far as it is currently known, these GHG emissions are lower than those from conventional animal production (van Huis und Oonincx 2017). For example, mealworms, crickets and locusts emit up to 100 times less greenhouse gases per 1 kg increase in mass compared to pigs and cattle (Fiebelkorn 2017). This is mainly due to the absence of the highly climate-affecting methane gas and to the better feed conversion in insect production (Oonincx et al. 2010). Methane, which plays an important role in conventional animal production – in the digestive process of ruminants – is only produced in the production of a few insect species, such as cockroaches, termites and scarab beetles, and only in small quantities during the digestive process (Fiebelkorn 2017).

However, the greenhouse gas balance of insect production is influenced by other effects, similar to meat production, whose environmental impact is of greater relevance. For example, additional emissions are produced by the cultivation of animal feed or, if the insects are kept outside tropical areas, by heating the air-conditioned insect breeding facility (Oonincx und Boer, Imke J. M. de 2012).[38] The heating of the breeding facility accounts for about a quarter of the GHG emissions, taking a mealworm farm as an example (Oonincx und Boer, Imke J. M. de 2012).[39] Heating is necessary in cooler climates, e.g. in Central Europe, as the body temperature of poikilothermic insects adapts to the surrounding temperature and the metabolism only becomes active at higher temperatures. The advantage of heating the breeding facilities is that the energy in the feed is converted directly into growth and does not have to be used to maintain body temperature (Fiebelkorn 2017; van Huis und Oonincx 2017).

As mentioned above, the feed used in an insect production system is a significant factor when it comes to the environmental impact and GHG emissions (van Huis und Oonincx 2017). In a mealworm farm, for example, the production and transport of feed grain accounts for 42 % of total emissions (Oonincx und Boer, Imke J. M. de 2012). Mealworms and house crickets need about 2.2 kg of

37 To improve the comparability of the data, the share of emissions resulting from the preparation of the product was eliminated here (see above).
38 In this example the rearing facility was located in the Netherlands.
39 In the study by (Oonincx und Boer, Imke J. M. de) the cradle-to-gate system boundary was used.

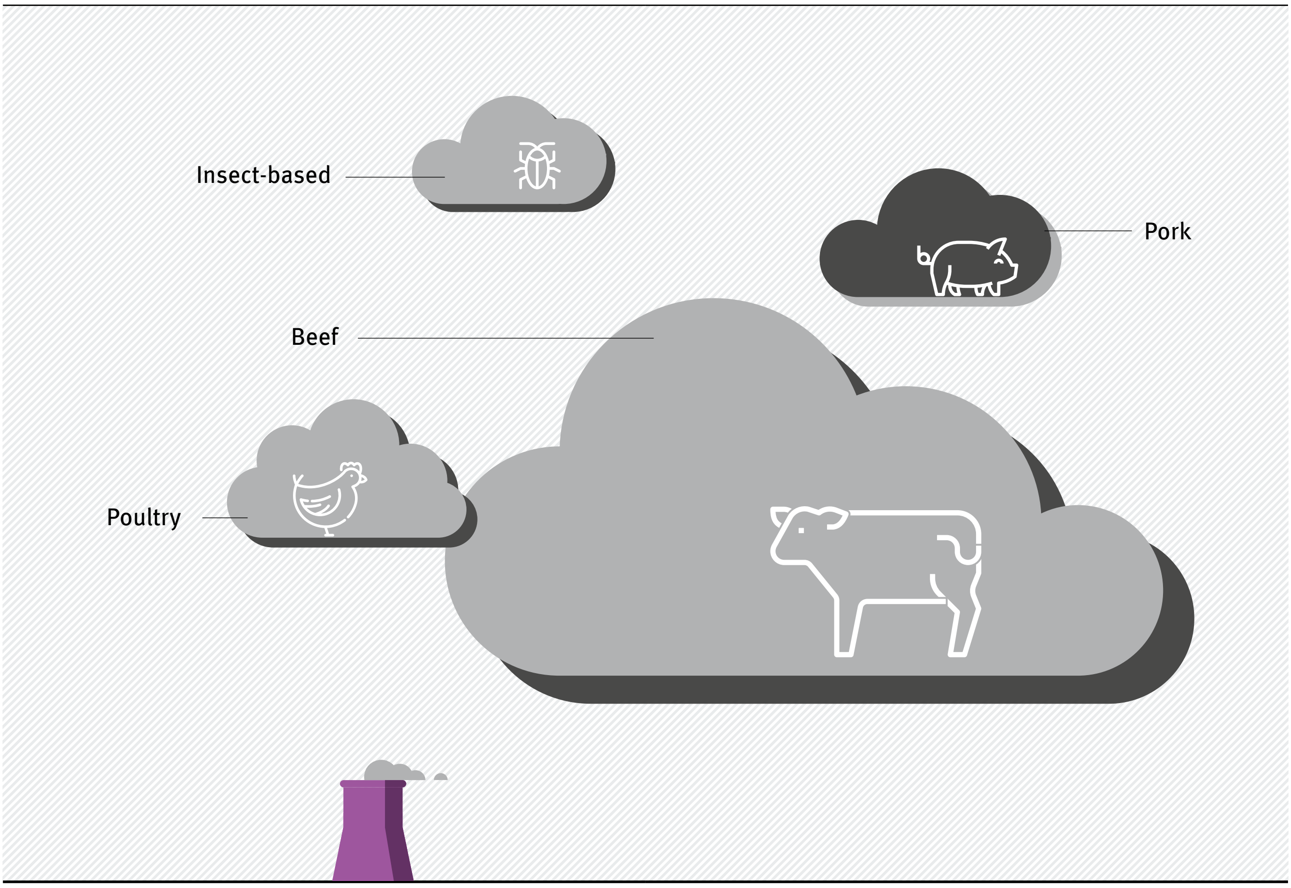
feed to produce 1 kg of weight. For chickens it is a good 4.5 kg of feed, for pigs 9 kg and for cattle 25 kg (Fiebelkorn 2017). If soya or fishmeal is used, this has a negative impact on the GHG balance, as soya cultivation leads to land conversion and deforestation of rainforests, or a relatively large amount of energy has to be used to produce fishmeal (van Huis und Oonincx 2017). Dried stillage (DDGS)[40] is also used as feed and has a lower environmental impact (van Huis und Oonincx 2017).

Overall, current research results indicate that the production of insects generates less greenhouse gases than conventional pig or cattle farming (Dobermann et al. 2017) and poultry production (Halloran et al. 2017).[41] The production of the required cereal feed was identified as the largest hotspot[42] for both systems, in contrast to other possible feeds such as organic waste (Dobermann et al. 2017; Halloran et al. 2017).

In summary, there is great potential to further optimise insect breeding in terms of GHG potential by using feed from waste or by-products (Alexander et al. 2017; Dobermann et al. 2017). Certain species, e.g. the mealworm, can be easily fed with waste products from the food industry, which reduces the environmental impact of feeding. However, they then grow somewhat slower, which leads to longer and therefore more "inefficient" production cycles (van Huis und Tomberlin 2017b). Insect species such as crickets are less flexible with regard to their food, while others, e.g. certain types of flies, can also be reared on liquid manure or household waste, but cannot then be used as feed or food (van Huis und Tomberlin 2017b).

Figure 29

Comparison of greenhouse gas emissions



Sources: Mattick et al. (2015c) and Smetana et al. (2015a)

40 Dried stillage is produced during the production of bioethanol and is a high-quality protein-energy feed, which is also used for dairy cows, for example.
41 Based on the production of 100 g of meat.
42 Hotspots are "life cycle phases, processes or material flows identified in an LCA which are responsible for a significant proportion of the impacts of the functional unit" (UN Environment 2017; p. 7); translation by the authors).

Nutrient inputs and surpluses
As outlined in Chapter 6.1, some of the problems of conventional meat production in this country are the production, storage and application of far too much manure on far too few and small areas, and the associated environmental impacts on water, air, soil and biodiversity.

Insects also produce excrements containing nitrogen and phosphorus. For example, the eutrophication potential was recorded in the life cycle assessment of a Thai cricket farm (Halloran et al. 2017). The results showed that the resulting eutrophication of soil and water (salt and fresh water) was up to one third lower in the production of 100 g crickets compared to 100 g broilers (Halloran et al. 2017).

The study was based on the following assumptions: firstly, that ammonia emissions from the crickets' manure (mixed with other waste materials[43]) after application and during storage are low, as insect dung is by nature relatively dry (Halloran et al. 2017; van Huis und Tomberlin 2017b). Secondly, that during cricket production, ammonia emissions are similar to those during broiler production, so there is no advantage for insects. Thirdly, that cricket dung replaces the use of artificial fertilisers in the region (Halloran et al. 2017) which, however, if transferred to Germany, would fail due to the surplus problem of farm manure. In a future – more efficient and enlarged – cricket production scenario, however, the eutrophication potential on water and soil was further reduced, in some cases even more than halved, compared to broiler production.

Ammonia emissions contribute to acid rain and soil acidification, as already described in the chapter on conventional meat. However, initial research results show an advantage of insect production over meat production. A comparison of ammonia emissions from pigs with those from mealworms, crickets and migratory locusts showed that insect emissions are between 13 and 1,900 times lower (Fiebelkorn 2017). In an experiment with five different insect species[44] the measured NH_3 emission values of all insect species were below the NH_3 emission values of conventional farm animals (Oonincx et al. 2010).

In industrial production, good waste management is necessary to clean the exhaust gas stream, which contains sulphur compounds, ammonia and carbon dioxide (Kok 2017).

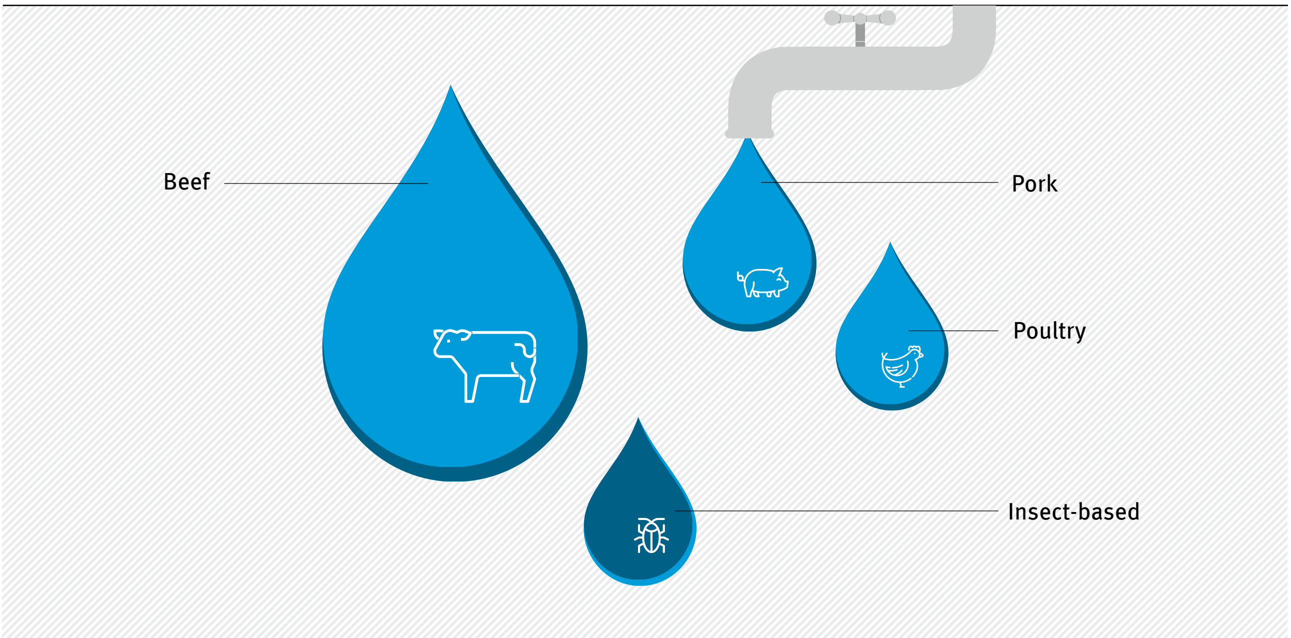
Fresh water consumption
In order to calculate the water footprint of insect production, all water consumption and contamination that occurs during the various production steps is taken into account. This includes consumption during feed production, for animal growth and for cleaning the production facilities. The most significant influence on water consumption in insect production, as in conventional animal production, is the production of the respective feed (Miglietta et al. 2015). Water consumption during the feed production process depends on the amount of feed consumed, its composition and its origin (Halloran et al. 2016). Different feedstuffs have different water consumption rates. For example, mixed grain feed has a higher water footprint than carrots (Miglietta et al. 2015). The current discussion on biological waste as animal feed can be found in the spotlight Waste to feed.

In the existing analyses, the production of 100 g of edible mealworms shows a lower water consumption, at around 434 litres per 100 g, than the conventional production of beef and pork, at around 1,540 litres per 100 g and 600 litres respectively. The water consumption for producing 100 g of edible chicken meat, at around 433 litres per 100 g, is similar to that of mealworms (Miglietta et al. 2015). The lower water consumption for insect production compared to conventional beef and pork production can be explained by the fact that insects are poikilothermic creatures. Therefore, they produce more edible mass than conventional species for the same amount of feed. As a consequence, less feed is needed to produce the same amount of "meat", which leads to lower water consumption for feed production per kg of insect meat and thus to a smaller water footprint (Oonincx 2017). In addition, insects are able to cover their entire water requirements through their food (Miglietta et al. 2015). In a practical trial, it has already been

43 This includes insect parts, food remains and egg carton parts.
44 These included crickets, mealworms and locusts.

Figure 30

Comparison of water consumption



Source: Miglietta et al. (2015)

established that no additional drinking water had to be added to an insect production system as long as adequate humidity was available and a feed mix of carrots, bran and grains was chosen (Miglietta et al. 2015).

The lower water consumption for mealworms compared to beef and pork production becomes clear when considering the water footprint per edible 100 g. If the edible part of the species studied is not taken into account and only the water footprint of a living animal at the end of its life is considered, the water consumption per 100 g of animal mass for mealworms would even exceed that of chickens and pigs (see Table 2) (Miglietta et al. 2015). The smaller water footprint per consumable 100 g of mealworms can be explained by the fact that their edible portion is 80–100 % and that only a smaller proportion of the total animal is generally consumed in the case of pigs and cattle.

However, it should also be noted that there are differences in water consumption between different insect species. For example, one study found that

Table 02

Water footprints of different types of meat and mealworms

Product	Water footprint of a living animal at the end of its life (litres/100 g)	Water footprint per edible 100 g (litres/100 g)
Mealworms	434	434
Pigs	383	599
Chickens	336	433
Cows	748	1,542

Source: Miglietta et al. (2015); adapted to 100 g ten times more water is used in the production of mealworms than in production on a cricket farm in Thailand (Halloran et al. 2017).

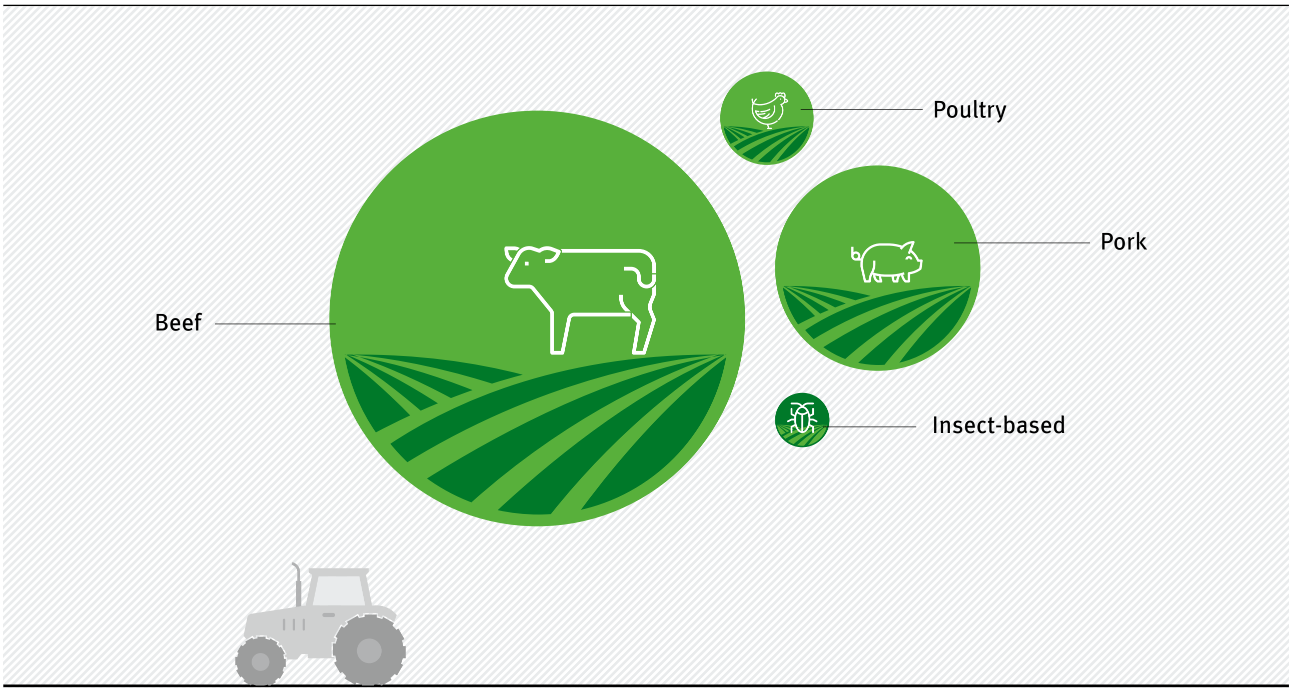
Land use and biodiversity
There is also limited data available on land use for insect production (Dobermann et al. 2017). It was found that a large part of the land required for insect production is also closely related to feed production. For example, one study found that the production site for mealworms represented only 0.2 % of the total land use, whereas the feed used in this plant was associated with 99 % of the land use (Oonincx und Boer, Imke J. M. de 2012; van Huis und Oonincx 2017).[45]

Since a large part of the land required for insect production is directly related to feed production, more efficient feed conversion by insects plays an important role when considering land requirements. For example, less land is required for insect feed production than for conventional feed production (van Huis und Oonincx 2017). For the production of 100 g of edible insect mass, 0.15 to 0.152 m² of land is needed. For the production of the same edible mass of chicken meat, this is between 0.385 and 0.389 m² (Smetana et al. 2015a).

As land availability is a critical factor in the food security of the world's population, the production of mealworms has the potential to be a sustainable

Figure 31

Land use comparison



Source: Mattick et al. (2015c) and Smetana et al. (2015a)

Table 03

Land use per edible gram of protein in comparison

	Mealworm	Chicken	Cow
Land use/edible protein (1 g)	1	2 bis 3	8 to 14

Quelle: van Huis und Oonincx (2017)

45 The defined system boundary for the study is cradle to gate.

alternative to poultry, pork and beef, depending on the use of the land saved (Oonincx und Boer, Imke J. M. de 2012).

Mass production favours insects with rapid growth, large body mass and a high reproduction rate. Selective breeding of insects could lead to modified insect populations adapted to the conditions of domestication. The disadvantage of a constant food supply in an insect production plant would be a lower starvation tolerance and an inferior feed conversion (Jensen et al. 2017). The domesticated insects would thus be less able to adapt to conditions in the wild.

Animal welfare

Challenges in terms of animal welfare also arise from the production and consumption of insects.

Currently, insects are not mentioned in EU animal welfare legislation, including the EU Directive 2010/63/EU on animals used in research (2010). One reason for this is the question of whether insects can feel pain. Experiments have shown that insects react to impulses that pose possible dangers. However, it is not clear whether this is only a reflex or whether it is associated with an "actual" sensation of pain (Erens et al. 2012). This question is difficult to answer, since the physiology of insects is not comparable to that of humans and research in this area is not yet very advanced (Pali-Schöll et al. 2019). Furthermore, there are more than one million species of insects. It is therefore not possible to make a general statement about whether insects feel pain (Gjerris et al. 2016).

Various authors, however, argue that the lack of evidence should not be taken as a reason to deny insects the sensation of pain per se, but rather to advocate species-appropriate animal husbandry (Erens et al. 2012; Gjerris et al. 2016; Pali-Schöll et al. 2019).

In accordance with this system, it is recommended that husbandry is based on natural environmental conditions and that external factors such as temperature and humidity are adapted to the insect species concerned (Erens et al. 2012). There is a need for research, especially with regard to species-specific needs and the resulting type of rearing and processing (Erens et al. 2012). Killing the insects should be quick, reliable and painless (Erens et al. 2012). Deep-freezing is one of the preferred options, although the recommended methods differ depending on the species and stage of development and further research is needed (Pali-Schöll et al. 2019).

Even if the question of how insects feel pain has not yet been answered, from an ethical point of view, insect husbandry is preferable to conventional animal husbandry, since according to current knowledge insects feel less pain than mammals (Pali-Schöll et al. 2019). Similar to animal experiments, where the principle is to use the animals which are least sensitive to pain and stress (Europäische Kommission 2010) this criterion could also be used for (insect) meat production. In this context, it must also be considered whether a shift in animal husbandry to "lower" animal species is necessary at all if plant-based alternatives are available.

6.3.3 Currently observable health effects

From a nutritional point of view, insects are a good alternative to meat. In terms of dry matter, insects have an average protein content of between 25 and 75 % and a fat content (including fat-soluble molecules) of 10 to 70 %. (Finke und Oonincx 2017). Meat foods have a protein content of 20 to 30 %,

the fat content varies greatly with the method of preparation (Max Rubner-Institut 2019). Depending on the species, feed and conditions in which they are kept, insects contain, in addition to proteins, other nutrients, minerals, vitamins and trace elements which are important for humans as well as dietary fibre(Payne et al. 2016b). An exception is calcium, which is present in higher concentrations in vertebrates (Finke und Oonincx 2017).

In a relatively new field of research, few studies have so far been conducted on the link between insect consumption and individual diseases, such as colon cancer, obesity or cardiovascular disease. However, the reasons for these diseases are often animal fats, i.e. saturated fatty acids, and intensive frying and salting (World Cancer Research Fund (WCRF) and American Institute for Cancer Research 2018). Since insects have a high proportion of mono- and polyunsaturated fatty acids, the risk of disease could be reduced (Fiebelkorn 2017).

Other aspects are also relevant for health effects. For example, the potential allergic reactions that the consumption of insects, in particular mealworms, locusts and crickets, can cause in people with crustacean and house dust mite allergies (Ribeiro et al. 2018). This effect could also occur in humans working on insect farms. Therefore, adequate occupational safety must be ensured (Dobermann et al. 2017).

Potentially pathogenic microorganisms from the intestinal flora of insects can usually be reduced by simple processing steps, such as thorough washing and heating, so that the microbial risk of insects is comparable to that of other animal proteins, depending on the preparation (Dobermann et al. 2017). Contaminants, such as heavy metals, dioxins and polychlorinated biphenyls, which can be produced by breeding, insect feed and packaging, do not pose a higher risk than other animal products, provided that the insects are correctly bred and processed (Dobermann et al. 2017).

Insect feed can also have an impact on human health. Some insects that are collected in agricultural habitats and have fed on plants there have had a high pesticide load (Rumpold und Schlüter 2013).

Overall, there is still a need for research on the health effects of insect consumption. Further investigations into the possible microbial and pathogenic risk potential of edible insects are desirable (Roos und van Huis 2017). Whether insects act as vectors of pathogens has not yet been sufficiently researched (van Huis et al. 2013). Finally, studies on the hygienic and risk-minimising keeping and storage of insects would be interesting.

6.4 In vitro meat

6.4.1 Principles of environmental assessment

At present, environmental effects of in vitro meat can only be estimated hypothetically, as large-scale production is not (yet) possible. For a more precise assessment of the environmental impact, important technical steps of the production process must first be further clarified, such as in particular the production of an alternative culture medium to foetal calf serum – or an animal-free culture medium – for the cells, the efficient establishment of stem cell lines and the production of bioreactors for large-scale production of in vitro meat (Pandurangan and Kim 2015; Mattick et al. 2015a; Mattick 2018; Mattick et al. 2015b; Tuomisto 2019). It should also be noted that when producing in vitro meat a controlled production environment must be maintained which can replace the biological functions of animals (Mattick et al. 2015b). Therefore, only so-called anticipatory life cycle assessments can be used for assessing innovations, which are, however, associated with a high degree of uncertainty. Ultimately, they depend on assumptions about resource inputs and occurring emissions (Mattick et al. 2015d).

The LCAs should therefore be understood as well-reasoned scenarios with little validity and not as predictions. However, this is rarely clearly communicated by the innovators.

6.4.2 Differences in the initial parameters of the studies

The previous anticipatory life cycle assessments for in vitro meat differ greatly in the selection of the initial parameters for comparison with traditional animal production (see also the introduction in the chapter on effects on the environment, health and animal welfare). The most important differences are explained below.

Culture medium

Tuomisto und Teixeira de Mattos (2011) assumed for the first life cycle assessment of in vitro meat that cyanobacteria hydrolysate serves as a culture medium for the muscle cells. The hydrolysate is produced from blue algae and is considered a very efficient culture medium. However, since a method for the large-scale production of these bacteria as culture medium does not yet exist, the study was more strongly criticised (Mattick et al. 2015b; Alexander et al. 2017; Röös et al. 2017). Tuomisto and her research group changed this assumption for a further life cycle assessment and instead used a "mixed" form of culture medium for the environmental assessment, in which – together with cyanobacteria hydrolysate – processed wheat and maize are also used as growth factors. On the basis of existing data on wheat and maize production, it was estimated that 200 g of wheat or maize are needed to produce 100 g of in vitro meat. Cyanobacteria showed the lowest greenhouse gas emissions and land use; wheat had the lowest water footprint and maize the lowest energy requirements. This study also calculated the resource input for the sterilisation and hydrolysis of maize and wheat (Tuomisto et al. 2014). Mattick and her group (Mattick et al. 2015a; Mattick et al. 2015b) use in their estimation a culture medium consisting of peptides and amino acids from soya hydrolysis and glucose from maize starch. This is based on cell proliferation data from the ovary of the Chinese hamster (CHO) (Sung et al. 2004).

Modelling of the bioreactors

In the studies of Tuomisto and Teixeira de Mattos (2011) and Tuomisto and Roy (2012), the mode of operation and design of the bioreactors was modelled less precisely than in later studies. Energy consumption for the bioreactors was assumed to be mainly for maintaining the growth temperature of 37 °C for the cultivation of the cell. A stirring cylinder was used as bioreactor design. In Tuomisto et al. (2014) a scenario based on a hollow capillary bioreactor was presented. However, the energy consumption was modelled according to the previous approach in Tuomisto and Teixeira de Mattos (2011). According to later studies, the cell scaffold consists of maize starch microcarrier beads and the process takes place in stirred tank bioreactors (Mattick et al. 2015d; Mattick et al. 2015b). Finally, the bioreactors in these studies are cleaned between each culture batch by rinsing with sodium hydroxide and heating to 77.5 °C.

Functional unit (FU)

Smetana and his colleagues (2015a; 2015b) developed a life cycle assessment that takes into account the supply chain from the extraction of the raw materials (cradle) to the use of the product by the consumer or preparation (plate). As described above, the emission share for the preparation was eliminated at this point to ensure the comparability of the data. In Smetana et al. (2015a) the different products are compared on the basis of three functional units (FU): 1 kg of product prepared ready for consumption, the supply of the consumer with 3.75 MJ of caloric content and the supply of the consumer with 0.3 kg of digested protein. Here, in vitro meat – together with other meat alternatives – is compared only with chicken meat, as chicken meat is the "most efficient" type of meat (Roy et al. 2009). Lynch and Pierrehumbert (2019) emphasise that the type of FU used in estimating GHG emissions varies widely in existing LCA studies. If protein rather than meat is considered a functional output, the footprints would vary within the studies: Mattick et al. (2015b), for example, estimate a protein content of 7 % per weight of meat mass for in vitro meat, while Tuomisto and Teixeira de Mattos (2011) and Tuomisto et al. (2014) calculate 19 % for this. The studies also compare different types of cell biomasses: in Mattick et al. (2015b), the FU represents 1 kg of cell biomass, with no estimate for any further processing or additional ingredients required to convert this biomass into an edible form or a conventional meat analogue product. Tuomisto and Teixeira de Mattos (2011) calculate the FU of a "minced meat product" without including the other necessary processing steps (which was not possible due to the early stage of innovation). The impact of the processes used to produce various meat products, such as steaks, can be even greater (Stephens et al. 2018).

6.4.3 Future potential environmental impacts compared to conventional animal production

The previous anticipatory life cycle assessments of in vitro meat differ greatly in the selection of the starting parameters for comparison with traditional animal production (see also the introduction in Chapter 6).

Figure 32

Comparison of greenhouse gas emissions

Sources: Mattick et al. (2015c) and Smetana et al. (2015a)

Greenhouse gases

Greenhouse gas emissions result from the production of in vitro meat, among other things from the operation of bioreactors and the production of culture medium. The studies are based on different parameters concerning the size, the operation of the bioreactors as well as the type of culture medium used (see Chapter 6.4.2), as no bioreactors for large-scale production currently exist. The first studies on the environmental impact of in vitro meat showed extremely positive results regarding GHG emissions. Tuomisto and Teixeira de Mattos (2011) calculate savings of between 78 and 96 % in GHG emissions compared to conventional meat production, depending on whether best-case or worst-case scenarios are considered in terms of bioreactor efficiency and growth factor. They estimate an average GHG footprint of 2.2 kg CO_2 equivalents per kg of in vitro meat. Using the same parameters, the estimation was carried out for 27 countries of the European Union (Tuomisto and Roy 2012). The result was also a saving of up to 43 % in GHG emissions compared to conventional animal products.

More recent studies assume significantly higher GHG emissions. Previously optimistic assumptions regarding the culture medium and the modelling of the bioreactors have now been modified. This results in a footprint of 0.75 kg CO_2 equivalents per 100 g of in vitro meat (Mattick et al. 2015b). This value is higher than for pork (0.41 kg CO_2 equivalents per 100 g) and chicken (0.23 kg), but significantly lower than for beef at 3.5 kg CO_2 equivalents per 100 g. A sensitivity analysis also shows that, depending on the initial parameters, the values vary more and may even increase.

In some cases, there are even higher GHG emissions. In a scenario where the upper end of the sensitivity analysis in Mattick et al. (2015b) is modelled, the resulting footprint is 25 CO_2 equivalents per 100 g of in vitro meat (Lynch and Pierrehumbert 2019). Assumptions include that lower cell densities are achieved at the end of the proliferation phase than during the proliferation phase; that no further growth of biomass is achieved in the differentiation phase; that the building size and energy footprint of the bioproduction plant is more comparable to a pharmaceutical plant than a brewery. These assumptions are also consistent with figures from other anticipatory life cycle assessments, which calculate that 100 g of in vitro meat yields approximately 2.3 kg CO_2 equivalents, which is significantly higher than chicken meat, where the value is between 0.38 and 0.43 kg CO_2 equivalents (Smetana et al. 2015a).[46]

46 See above: the share of emissions resulting from the preparation of the products was eliminated in each case.

So far, these comparisons have been based on CO_2 equivalents, which relate the emissions of various greenhouse gases to carbon dioxide. In addition, the potential climate impact of in vitro meat and beef has also been calculated using an atmospheric modelling approach – a simple climate model that simulates the different behaviour of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Lynch and Pierrehumbert (2019). The authors assume that CO_2 equivalents are inadequate as a basis for comparison: individual gases differ both in the quantity in which they change the atmospheric energy balance (radiative forcing) and in the time span over which they remain in the atmosphere. In their model, different footprints of the breeding of meat and beef systems are tested under three alternative consumption paths and the temperature influences are compared under different production and consumption scenarios in all time periods of 1,000 years (Lynch und Pierrehumbert 2019). Overall, it can be seen that the effect of the production of in vitro meat is not per se always more efficient than the production of beef: while the contribution of in vitro meat to global warming depends solely on the production of CO_2 that accumulates in the atmosphere, the contribution of beef also depends strongly on the production of CH_4 that does not accumulate: in many scenarios, the GHG potential of in vitro meat overtakes that of beef.

Energy

Almost all the energy used in the production of in vitro meat is used for industrial processes, i.e. for ventilation, mixing and temperature regulation during the culture phase (Tuomisto et al. 2014; Mattick et al. 2015a). Initially, energy savings of between 7 and 45 % were calculated for the production of in vitro meat compared with conventional meat (Tuomisto und Teixeira de Mattos 2011). Recent studies see this in a very different light. Here, the consumption of non-renewable energies for the production of 100 g of in vitro meat (FU) is between 29.07 and 37.3 MJ, higher than for the production of chicken meat (between 5.164 and 6.34 MJ) (Smetana et al. 2015a; Smetana et al. 2015b). Other studies also calculate that the energy consumption in the production of in vitro meat is 35 % higher than in the production of beef and almost four times higher than in the production of poultry meat (Mattick et al. 2015b). These calculations are based on the assumption that production plants would use a similar mix of fuels as those used in the malt beverage industry. This fuel mix consists mainly of natural gas (43 %), coal (33 %) and electricity from the US electricity grid (16 %) (Galitsky et al. 2003). If renewable or lower carbons were used, in vitro meat production would contribute less to global warming.

Nutrient inputs and surpluses

The eutrophication potential due to the release of nitrogen and phosphorus from agricultural waste water results mainly from the production of the culture medium used. For this reason, the potential for in vitro meat is only calculable to a limited extent. Studies on conventional meat production consider their waste streams (Pelletier 2008; Pelletier et al. 2010b; Pelletier et al. 2010a) whereas this is not the case for in vitro meat (Mattick et al. 2015a). Existing studies assume a lower eutrophication potential[47] than in cattle and pigs. For example, for 100 g of in vitro meat produced, the eutrophication potential is 0.75 PO_4 equivalents compared to 21.4 PO_4 equivalents for beef, 2.62 for pork and 0.64 for chicken (Mattick et al. 2015a). In a later paper Mattick (2018) arrives at the somewhat more optimistic estimate that in vitro meat contributes to eutrophication to about the same extent as conventional poultry production and to a much lesser extent than beef or pork.

Fresh water consumption

In the study by Tuomisto and Teixeira de Mattos (2011) only the consumption of "blue" water was considered and a saving of between 82 and 96 % was calculated. However, it should be noted that conventional meat production has a large "green" water footprint and only a relatively small "blue" water footprint. Smetana et al. (2015a; 2015b) estimate a consumption of tap water of about 42 kg for the production of 100 g of in vitro meat, which is significantly less than for the production of chicken meat (85 kg). A later study by Tuomisto et al. (2014) which also considered the green water footprint, concluded that the water footprint for in vitro meat is at the same level as for conventional meat production.

47 Eutrophication potential is an indicator for the eutrophication impact category in the life cycle assessment.

Land use change

Research presents in vitro meat as, overall, more beneficial for land use, compared to conventional meat. In the literature, land consumption is assumed to be between 0.18 and 0.77 m^2 per kg of in vitro meat produced. This is lower than for chicken meat, for which the value is between 3.85 and 3.89 m^2 per kg (Mattick et al. 2015b; Smetana et al. 2015a; Smetana et al. 2015b).[48] Earlier studies assumed even lower values (Tuomisto und Teixeira de Mattos 2011; Tuomisto und Roy 2012) and estimate a land consumption of between 0.18 and 0.23 m^2 per kg of in vitro meat produced.

Animal welfare

Very little literature deals with the issue of future husbandry conditions of animals used for the production of in vitro meat. The innovators assume a general benefit for animals, as the number of animals kept for meat production will be significantly reduced (Bhat et al. 2015) – with the exception of animals required for stem cell collection and as a source of culture medium.

However, there is no estimation in the literature on how many stem cells are needed for in vitro meat products, how much muscle material is needed from the animal to obtain the stem cells and how often cells need to be harvested and from how many animals for the production of in vitro meat. This lack of data also has to do with the fact that stem cell lines in research are optimised for humans and mice and not for the usual types of farm animals. In this context, it is worth remembering that in vitro meat uses a technique from the medical field: tissue engineering.

The collection of foetal calf serum is another cause of suffering for calves. It is performed by puncturing the middle of the heart of unborn calves that are still alive, without anaesthesia (Jochems et al. 2002). Until now, the implications of other culture media with animal components on animal welfare remain unknown in the literature.

Even the innovators themselves hardly discuss how animals will live in a future with in vitro meat. Post (2012) wrote, for example, that one of

Figure 33

Land use in comparison

Sources: Mattick et al. (2015c) and Smetana et al. (2015a)

48 Mattick et al. (2015a) and Mattick et al. (2015b) estimate a consumption of 717 m^2 per year for each bioreactor, i.e. on average 0.7 m^2 per kg of in vitro meat produced. Smetana et al. (2015a; 2015b) calculate a land consumption of between 0.39 and 0.77 m^2 per kg of in vitro meat.

the most important challenges for this innovation is the special breeding of animals, which are then optimised as stem cell suppliers. In contrast, Forgacs of Modern Meadow spoke in 2014 about Daisy, a cow that lives naturally and is occasionally given a muscle biopsy (Forgacs 2013). As long as this is not clarified, in vitro meat as a vision remains a means of different ethical strategies, which define the human-animal relationship in different ways: either as an incremental step towards an improvement in the conditions of animal husbandry or as a means for a radical change in such relationships (Ferrari 2016).

6.4.4 Future potential health effects compared to conventional animal production

In vitro meat is presented by innovators as healthier meat because it is produced in the laboratory under controlled conditions (Post 2012). A reduction in the risk of zoonoses, i.e. the transmission of disease from animals to humans, can be expected, since this innovation does not involve contact with whole animals. However, there are a number of unresolved issues that could potentially have an impact on human health and will need to be further researched in the future:

Antibiotics: It is often assumed that animals are reared differently for in vitro meat compared to conventional meat production and that they are not given antibiotics (Bhat und Bhat 2011; Mattick und Allenby 2013). Even if antibiotics are not used, it remains unclear whether and to what extent antibiotics are necessary for cell cultures. Antibiotics were used in the production of the first in vitro burger made from bovine stem cells, which was presented in London in August 2013. Post assumes that antibiotics will no longer be needed once large-scale production in sterile systems has become possible (Zaraska 2013).

Transmission of diseases and germs: Foetal calf serum, still the most efficient culture medium to date, may contain germs for infectious diseases (Girón-Calle et al. 2008; Brunner et al. 2010). Such diseases are difficult to rule out because the health status and husbandry conditions of suckler cows are difficult to control. The innovators are working on the production of alternative – animal-free – culture media.

Meat consumption and preparation: Many studies prove the connection between excessive meat consumption and obesity, cardiovascular diseases, high blood pressure, autochthonous hepatitis E virus, some types of cancer or type 2 diabetes (IARC 2015; Lippi et al. 2015; Farvid et al. 2018). However, it is not yet known whether these health risks are intrinsically related to meat consumption, whether they rather result from the way animals are kept (feed and medication) or how meat is subsequently prepared and cooked. It is therefore unclear whether and to what extent such health risks would also arise in the case of (broad) consumption of in vitro meat.

Smetana et al. (2015a) calculated the effects on human health and concluded that in vitro meat has the most negative effects, at least as far as indirect effects on health are concerned (ecotoxicity during production; the authors compare it to chicken meat and other alternative products).

Potential to serve as functional food: In vitro meat could become a food fortified with additional nutrients such as vitamins or omega-3 fatty acids, which are said to have a positive effect on health. This is what the innovators are speculating on, but the area remains controversial in social terms as well. For example, there is a debate about whether in vitro meat is at all desirable and necessary.

6.5 Conclusion

In order to be able to adequately address the existing differences between meat and alternative products, 100 g of unprocessed, edible mass without additives was chosen as a benchmark, which, depending on the product, corresponds approximately to the weight of a burger patty. Available data allow a uniform and consistent comparison of all meat types considered. In addition, the product of the burger patty was used for a concrete, consumer-oriented illustration.

From an environmental point of view, plant-based meat substitutes are the best meat alternative. This is mainly due to the fact that plants can directly serve human nutrition "without detour". This eliminates the calorie conversion of plant-based feed into animal meat, which is necessary in animal production and is accompanied by a high calorie loss. In addition, direct consumption of plants results in a much lower demand for land and water. Six to seven times more land is needed to produce 100 g of meat protein than to produce 100 g of soya protein (Reijnders and Soret 2003). At the same time, the pollution of groundwater and soil by nutrient overload is lower for plant-based meat substitutes. The GHG emissions of soya-based meat substitutes are also 75 % lower than those of chicken meat, the type of meat with the relatively lowest GHG emissions (Smetana et al. 2015a). Compared to beef, the most greenhouse gas-intensive type of meat, GHG emissions are actually 27 times lower. At the same time, however, these reductions only occur if soya-based products are not consumed in addition to existing demand. If it is assumed in the future that plant-based meat substitutes will remain the most important alternative to meat, but are more of a niche in terms of market share, then the overall environmental benefits will also remain lower than if plant-based meat substitutes replace conventional animal products to a larger extent (see Chapter 6.2 and Chapter 5).

Various advantages of plant-based meat substitutes compared to conventional meat also result from a health and ethical point of view (however, differences in plant-based meat substitutes, for example between wheat and soya, must be taken into account; see Chapter 6.2). Plant-based meat substitutes are rich in protein, but do not contain cholesterol, which can have negative effects on health if consumed in excess. The health benefits of plant-based meat substitutes are also influenced by the degree of processing of the products. They can be significantly reduced if stabilisers, colourings etc. are added excessively. In addition, according to the recommendations of the German Nutrition Society, care must be taken to ensure a nutritious and balanced diet; this applies in particular to children and pregnant women (Deutsche Gesellschaft für Ernährung e. V. (DGE) 2017).

Aspects of animal welfare, e.g. species-inappropriate husbandry or the use of antibiotics, which are sufficiently well known in conventional meat and also play an important role in insect meat or in vitro meat, are omitted in the case of plant-based meat substitutes.

In a ranking of the investigated meat or meat substitute products, insect-based products are ranked **second behind plant-based meat substitutes with regard to their environmental and health effects**. Insect production accounts for only about one third of GHG emissions compared to 100 g of chicken meat (Smetana et al. 2015a). Compared to the other conventional types of meat, the savings in CO_2 are much higher. There are also advantages when it comes to water consumption in insect production. The nutrient input into soil and water is also lower than in conventional animal husbandry. The savings in terms of land consumption are up to 50 % in insect production compared to chicken meat (Smetana et al. 2015a).

Insects have a positive effect on health. The risk of disease arising from the increased intake of saturated fatty acids in meat products can be minimised by eating insects, as they have a high proportion of mono- and polyunsaturated fatty acids (Fiebelkorn 2017). Insects have a high protein content and are therefore in no way inferior to conventional meat in terms of meeting human protein requirements.

Animal welfare aspects must also be taken into account in the case of large-scale production of insects. For example, keeping them in masses is potentially problematic. Associated with this is the question of whether such a large-scale production can still be based on the natural environmental conditions of the insects in order to guarantee species-appropriate husbandry. In addition, the question whether insects feel pain has not yet been sufficiently researched in order to be able to make general and scientifically sound statements on appropriate and painless killing methods for the various species.

If edible insects remain a niche product in the future, their potential will not be able to develop accordingly.

In vitro meat and its potential advantages over conventionally produced meat are currently the subject of widespread debate. **However, it is not yet possible to make reliable statements about positive environmental or health effects from in vitro meat.** Current evaluations of laboratory tests and anticipatory calculations assume reductions in land and water consumption compared to all conventional types of meat, but at the same time show energy consumption that exceeds that of conventional meat production. Meat production in the laboratory would still have to be comprehensively designed and developed in order to realise the currently praised potential benefits, such as less animal suffering, the possible avoidance of antibiotics, etc. As things stand, in vitro meat faces the following major challenges: the currently very high energy consumption during production, the culture medium or rather the development of alternatives to foetal calf serum and the use of antibiotics, which has been indispensable up to now. If in vitro meat becomes established as a real meat alternative in the future through further research and development, large environmental benefits will most likely be achieved, but only if the existing environmental risks are addressed simultaneously.

7 Political entry points and research questions

When identifying political entry points and research questions that are relevant in terms of the environmentally friendly development of meat alternatives, three areas can be distinguished:

- Entry points that refer specifically to one of the three developments examined (see Chapter 7.1).
- Entry points that refer to two or more of the alternatives mentioned (so-called cross-sectional approaches; see Chapters 7.2 and 7.3).
- Entry points that refer to the necessary environmental and promotional integration of meat alternatives in the overarching political framework of nutrition systems or changes in nutrition (see Chapter 7.4).

The following subchapters are preceded by short summaries, highlighted in boxes.

The focus is on policy options that improve the ecological balance sheet of the products. To a lesser extent, the effects in the areas of health, ethics and animal welfare that are indirectly relevant to the UBA and the BMU are also discussed, in order to highlight where synergies exist with other goals of more sustainable nutrition and where areas of conflict might arise. If no policy options for action can be derived in relevant areas due to the poor data situation, the most important research needs that are necessary for shaping the political framework will be addressed. The need for research and political recommendations for action are strongly interlinked. For example, some political recommendations for action only apply if certain environmental or health impacts can be substantiated by further research.

7.1 Political entry points for meat substitutes

7.1.1 Plant-based meat substitutes

As the studies of the life cycle assessments have shown, plant-based meat substitutes performed best in comparison with meat. Given the level of technological maturity, there are only a few critical (research) questions whose answers could significantly change the assessment of environmental and health impacts. It therefore makes sense to rely on plant-based meat substitutes instead of meat and other animal products. The areas of activity "regional raw materials" and "degree of processing" are particularly relevant here, as are the aspects of labelling, public procurement, education and training and acceptance described in the chapter "Cross-sectional approaches".

Improvement of the environmental balance sheet through regional, diverse raw materials

Promotion of regional, diverse raw materials, especially legumes (based, among other things, on the protein plant strategy of the Federal Ministry of Food and Agriculture (BMEL)

An important entry point for improving the environmental balance sheet of plant-based meat substitutes is the raw materials. Currently, mainly wheat, soya, peas and lupins from domestic production, but also from imports, are used. The use of regionally sourced raw materials is recommended in order to contribute to the reduction of transport-related greenhouse gas emissions, to avoid the negative effects of overseas soya bean cultivation[49], to improve soil fertility and to promote positive rural development.

49 The cultivation of soya for animal feed is one of the main causes of deforestation in South America.

This is where political strategies come in, such as the BMEL's protein plant strategy (Bundesministerium für Ernährung und Landwirtschaft (BMEL) 2016) and the European Soya Declaration (European Soya Declaration 2017), whose implementation should also be further supported for the purpose of promoting plant-based meat alternatives. In order to increase resource efficiency, it is also necessary to examine which by-products of vegetable oil production – residues from e.g. sunflower oil and pumpkin oil production – are suitable for use in the production of plant-based meat substitutes, and to analyse whether this use is ecologically advantageous compared to use as animal feed.

Environmental benefits and positive health effects can be further enhanced not only due to the aspect of regionality but also by implementing organic farming methods.

Degree of processing and packaging

Promotion of low-processed and light-packaged products in the interests of resource efficiency and healthy nutrition

Most plant-based meat substitutes are highly processed foods, usually packaged in single portions. Heavily processed foods are less recommendable from a health point of view than lightly processed or fresh products. However, what is missing for an evaluation of the health effect is a comparison of meat products and their meat-free alternatives adapted to the current market. Such an investigation does not yet exist, but should be carried out. The results should form the basis for entering into dialogue with producers in the food industry with the aim of reducing the degree of processing as well as the proportion of additives that may be harmful to health, such as artificial flavourings, preservatives and saturated fats. This is intended to prevent possible positive effects in environmental compatibility from being accompanied by negative health effects. Finally, differences in quality and health effects must be communicated to consumers, restaurateurs and all relevant users by means of education and appropriate labelling.

Processing and packaging are associated with high consumption of resources, greenhouse gas emissions, energy and water consumption, plastic waste, etc. (Wissenschaftlicher Beirat Agrarpolitik, Ernährung und gesundheitlicher Verbraucherschutz und Wissenschaftlicher Beirat Waldpolitik beim BMEL 2016). The influence of the degree of processing and packaging on the environmental performance of meat substitutes needs to be further investigated. General statements can hardly be made. What is decisive is the overall balance, which is determined by, among other things, the means of transport used and the transport distance, the efficiency of logistics, the production technology and the type and duration of cooling or storage (Eberle und Hayn 2007).

7.1.2 Entry points regarding insects as food

Edible insects also have great potential as an alternative protein supply and are particularly interesting from an environmental point of view because of their ability to use natural resources efficiently. The two most important approaches – testing the feeding of organic residues to insects and the approval of insects as animal feed – are described below. In addition, the topics listed in the chapter "Cross-sectional approaches" are relevant: acceptance, building permit, the obligation to inspect plants in accordance with the Environmental Impact Assessment Act (UVPG) and the Federal Immission Control Act (BImSchG), energy consumption and the choice of location for production plants, organic certification, training and further training, and (in the long term) public procurement.

There is also a need for research into the keeping and killing of insects, as the capacity of so-called lower animal groups to suffer has not yet been studied much.

Testing the feeding of organic residues

(Re-)evaluation of the usable feed for insects for the use of resource-saving raw materials from organic residues

According to a survey of insect producers, the European regulatory framework plays a key role in the development of the market for edible insects.[50] This includes the fact that the feeding of insects with "former foodstuffs"[51] containing animal products and/or "catering reflux"[52] is not allowed, whether used as feed or food. [53]

The introduction of the feed ban on former foodstuffs, which may also contain animal products and catering reflux, in the EU is attributed to the BSE crisis. The cause of "mad cow disease" was identified as the feeding of insufficiently heated meat and bone meal from sheep carcasses infected with the scrapie pathogen. As a result, the feeding of products of animal origin, including meat and bone meal, to food-producing animals has been generally prohibited throughout the EU since 2001 (Regulation 999/2001). Later, the ban was relaxed for use in aquaculture.

In recent years, feeding food waste to naturally omnivorous animals, has been under consideration again. Feeding food waste to insects, pigs or poultry is one way of making sensible use of food waste and returning it to the nutrient cycle.

The European Commission announced the EU action plan for the circular economy in 2015 and announced within the chapter on food waste, "to take measures to clarify EU legislation relating to waste, food and feed and facilitate food donation and the use of former foodstuffs and by-products from the food chain in feed production without compromising food and feed safety" (Europäische Kommission 2015). The European Parliament's 2017 report "Report on Resource Efficiency: Reducing Food Waste, Improving Food Safety" (Borzan 2017) calls on the Commission to analyse the legal obstacles to the use of former foodstuffs and residues as animal feed and to support research in this area, and points to the potential for feed conversion and the need to reconcile this potential with high food safety standards.[54] In 2019, the EU research project against food waste "REFRESH", funded by the European Commission, presented a technical report, which has received much attention in EU policy and the European feed industry, which sets out how, under strict food safety standards, surplus food, which also contains animal products, can be used as feed (Luyckx et al.). A change in the corresponding European legal basis for the use of these resource flows could make 16 % of the 88 million tonnes of food in Europe, which are currently disposed of annually as waste, usable as animal feed (Bowman und Luyckx 2019). The most important EU legal bases that would have to be amended for this purpose are the following regulations (Bowman und Luyckx 2019):

- Regulation 999/2001 on the prevention, control and eradication of certain transmissible spongiform encephalopathies,
- Regulation 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption,

50 Survey of the "International Platform of Insects for Food & Feed" among its members (IPIFF 2018).
51 Foodstuffs which are no longer fit for human consumption.
52 For the definition of "former foodstuffs" and "catering reflux" see Regulation (EU) 2017/1017 amending Regulation (EU) No 68/2013 on the Catalogue of Feed Materials.
53 In accordance with the definition of ‚farmed animal' in point 6 of Article 3 of Regulation (EC) No 1069/2009, insects bred for the production of processed animal protein are considered as farmed animals and are therefore subject to the feed ban provided for in Article 7 of and Annex IV to Regulation (EC) No 999/2001 and the feeding rules laid down in Regulation (EC) No 1069/2009. Consequently, the use of ruminant protein, catering waste, meat and bone meal and manure as feed for insects is prohibited. In addition, Annex III to Regulation (EC) No 767/2009 provides that the use of faeces in animal feed is prohibited.
54 The original quote states: "to analyse legal barriers to the use of former foodstuffs in feed production and to promote research in this area, while also bringing food safety risk down to zero" and refers to "the potential for optimisation of use of food unavoidably lost or discarded and by-products from the food chain, in particular those of animal origin, in feed production" (Borzan 2017).

which covers the use of catering waste and catering residues, and

- Regulation 142/2011 on health rules as regards animal by-products and derived products not intended for human consumption, into which a method for further processing of certain by-products could be added to Annex IV.

However, an updated risk assessment by the European Food Safety Authority (EFSA) or other institutions for the re-authorisation of these feeds is not yet available and it is not yet possible to assess the momentum that can be expected to result in changes to the legal bases at European level. For a well-founded assessment, the possible benefits and effects of the use of reintroduced organic feed should be tested and evaluated in research projects. At the same time, it should be examined what influence a minor contamination of surplus food by packaging residues could have on animal and human health. If there are no adverse effects, the introduction of tolerated minor tolerances for animal feed should be discussed in order to allow the use of resource streams that are currently still being disposed of as waste: for example, baked goods in the retail trade from the previous day that also contain a small amount of animal protein, e.g. ham rolls, or packaging residues (food from damaged packaging). Such tolerances are often already part of the inspection of pig feed, for example.

While the above-mentioned discourse on the re-authorisation of feeding certain organic residues to pigs, poultry and insects is ongoing, there is currently a concrete proposal for the modification of the EU insect health legislation, especially for the feeding of insects.[55] The proposal provides for the definition of conditions that should apply to all insects fit for human consumption.

There are four concrete subareas:

1. The insects must belong to a species approved by the Novel Food Regulation.[56]

2. The permitted substrates for feeding the insects are named: substrates of non-animal origin, but also of various animal origin, such as blood products of non-ruminants.

3. It stipulates that feed must not come into contact with feed other than that permitted.

4. According to the proposal, the substrate for insect feeding must not contain manure, catering waste or other waste (Shungham 2019).

However, on 4 July 2019, this proposal was postponed, as some member states still want to assess the appropriateness of the planned amendments concerning the allergenic potential of insects, food hygiene standards, the rules on animal nutrition and novel food (Shungham 2019).

A presumably lower food safety risk would be associated with a change in the regulations that provide for the feeding of former foodstuffs to insects that do not contain animal products – and are therefore approved as insect feed, but may contain packaging residues. Here the European insect association IPIFF demands that tolerance limits for packaging residues be defined. At present, there are still differences in the application of the existing rules in the Member States with regard to controls and the punishment of violations.[57] As early as 2018, the European Commission had published guidelines for the use of food that is no longer intended for human consumption but is suitable as animal

55 EU Regulation 853/2004 on specific hygiene rules for food of animal origin.
56 As of July 2019, none of the existing applications for approval of insects as food on the EU market have been approved.
57 Interview with Christopher Derrien.

feed, which clarified numerous legal questions of interpretation. Making these resources accessible to insects is the aim of an initiative by IPIFF at the European Commission (status July 2019).

A change in European regulations to allow catering reflux, organic waste and/or former foodstuffs to be fed to insects – provided that this is possible while maintaining strict food safety standards – would probably have a major impact on the growth of the industry in Europe and would also have a beneficial effect on the environmental balance sheet of insect production.

Spotlight: Review of the authorisation of insects as feed

A possible extension of the feed allowed for insect production (see above) has the potential not only to improve the environmental performance of insect production but also the competitiveness of insect producers. The situation is similar with the approval of insects as animal feed. Currently, insects (or rather some defined species) may only be fed in aquaculture and to pets, e.g. dogs. Approval of insect meal for omnivorous farm animals such as pigs, chickens, etc., which naturally ingest animal proteins, would probably have repercussions on market growth for insects.[58] From an environmental point of view, the decisive factor here too is what these insects are fed. Ecological advantages to plant-based feeds can be achieved above all if residual resource streams that have not been used elsewhere are used for feeding, e.g. old bread from bakeries, wrongly declared food, catering waste, etc. However, since this project focuses on insects as an alternative to meat for human consumption, this type of insect use and necessary political options for action will not be discussed in greater detail here.

7.1.3 Entry points regarding in vitro meat production

Compared to plant-based meat alternatives and edible insects, studies on in vitro meat are marked with the greatest uncertainties, both in terms of opportunities and potential risks to the environment and health. Therefore, as an improved information basis for policy makers, research policy conclusions regarding culture media for meat production and the preparation of (extended) life cycle analyses are outlined in particular. In addition, as addressed in the “Cross-sectional approaches” section, the topics of acceptance, labelling, building permit, the obligation to inspect plants under the UVPG and BImSchG, energy consumption and the choice of location for production plants, organic certification, and training and further education are relevant.

Research on culture media and preparation of (extended) life cycle analyses

Research on competitive, serum-free culture media for the production of cell cultures suitable for in vitro meat production as food

Preparation of further comparative life cycle analyses, taking into account the parameters that are important from an environmental point of view: selection of the culture medium, (re)use and cleaning of the culture medium, use of antibiotics, energy consumption and energy source (fossil or renewable), size of the production plant

Currently, in vitro meat is produced for research purposes in culture media containing foetal calf serum, i.e. the blood of unborn calves. The development of a serum-free, i.e. animal-free, culture medium is crucial to the question of whether in vitro meat can be advantageous over other meat-like products and over meat from an ecological, ethical and health point of view. The existing life cycle analyses refer to serum-free culture media that will be available in the future and are not based on the use of FCS.

58 Interview with Heinrich Katz.

Further comparative life cycle analyses are therefore required, taking into account the different culture media used in each case and the necessary land, energy and water requirements for their production. Where FCS is used as a component of the culture medium for the production of in vitro meat, the possible health risks associated with its use need to be further investigated.

The claim to be able to produce "meat without animal suffering" depends largely on the use of alternative, serum-free culture media in in vitro meat production. Of the existing producers on the market, the manufacturer Aleph Farms advertises that "the stem cells from which the meat develops are taken from living animals" and that "the culture solution is free of animal components" (Ksienrzyk 2019). Innocent Meat, which is the first German start-up aiming at the production of in vitro meat, states that serum-free culture media are still expensive, but – due to the existing medical use – are already available in principle and assumes that further development will bring cost savings in the coming years.[59] According to statements by innovators in this field, providing the culture medium accounts for around 80 to 85 %[60] of the costs of in vitro meat. The reduction of these costs through an alternative culture medium is a crucial factor in competitiveness.

Competitive and environmentally friendly large-scale production of in vitro meat in bioreactors also depends on the question of whether and how the culture medium can be further used or recycled (agriculturally, energetically, etc.) and how often the culture medium has to be replaced.

The question of how to separate the meat cells from the culture medium and how to remove cell metabolic products from the culture medium must also be clarified.[61] The known medical technology solutions are designed for a smaller production scale and are very cost-intensive. A scientific investigation of these aspects is therefore worthwhile.

7.2 Cross-sectional approaches for meat substitutes

Some potentials for governance affect several, i.e. two or all of the named meat alternatives and thus represent cross-sectional approaches.

Labelling

For plant-based meat substitutes: ensuring that clear consumer labelling is found at European level to promote consumer choice of meat substitutes.

For in vitro meat: establishing guidelines and rules that provide clarity on whether in vitro meat can be labelled as meat and whether the method of cell collection (punch biopsy from live animal and removal from slaughtered animal) has an influence on this labelling.

In the spread of meat alternatives – especially plant-based meat alternatives – the label that the product bears plays a major role, for example whether it may be marketed as "vegetarian schnitzel", "vegetarian burger" or "vegan salami". Since the designation also gives an indication of the expected taste, the type of use etc., it is likely that consumers are more likely to choose meat alternatives if the designation indicates which meat or sausage product they imitate.

59 Interview with Laura Gertenbach.
60 80 % was mentioned in relation to the start-up Mosa Meat (Ksienrzyk 2018). Laura Gertenbach from Innocent Meat assumes up to 85 % of the current costs (interview with Laura Gertenbach).
61 Interview with Prof. Dr. Hans-Wilhelm Windhorst.

The German Food Book Commission (DLMBK) published the "Guidelines for vegan and vegetarian foods similar to foods of animal origin" in December 2018 (Deutsche Lebensmittelbuch-Kommission (DLMBK) 2018). Although the guidelines do not form a legal basis, they play an important role as expert opinions and serve as a guide for food manufacturers, processors, the courts and supervisory authorities. In practice, however, the lack of clarity of the new rules is criticised, leaving uncertainty as to their correct application. This is shown among other things by a statement of 18 food producers together with ProVeg e. V. in which the signatories criticise the incomprehensible and inconsistent use of meat terms, which is permitted for some product groups and not for others. (ProVeg Deutschland e. V. 2019). Participants in training courses organised by the German Agricultural Society (DLG) and the Federal Office of Consumer Protection and Food Safety (BVL) for food producers and other stakeholders also confirmed the lack of clarity in how to deal with the rules.[62] The aim of political action should be to achieve this clarity.

Due to the relevance of the question of labelling and the DLMBK's guidelines being non-legally binding, a current legal initiative at European level is of particular importance. In April 2019, the Agricultural Committee of the European Parliament voted by a large majority in favour of an amendment to EU Regulation 1308/2013, Proposal for a Regulation establishing a common organisation of the markets in agricultural products, which stipulates that terms and designations referring to "meat" may only be used for "those parts of the animal which are fit for human consumption". It is still uncertain how and whether this initiative will be further pursued – also due to the newly constituted European Parliament – but it can be assumed that it is time critical to react to this initiative, which aims to ban terms referring to "meat". Should a ban on terms referring to "meat" prevail, it is to be expected that the marketing of plant-based meat alternatives will be made considerably more difficult. In June 2019, a European petition against the planned restrictions on labelling was being conducted by ProVeg International (ProVeg International 2019).[63]

So far, only a few studies show that consumers lack clarity in product classification. It is therefore unclear whether a ban on the use of terms with similarity to meat and sausage is necessary. A forsa survey conducted by the Federation of German Consumer Organisations in 2015 showed that only 4 % of consumers stated that they had accidentally bought vegetarian products (Verbraucherzentrale Bundesverband e. V. 2015). Nevertheless, a designation of meat-imitating products as meat or schnitzel could be perceived by consumers as deceiving them, as a study commissioned by the DLG found (Buxel und Auler 2017). Clear labelling beyond the product name to indicate that it is a vegetarian or vegan product therefore seems to be of particular importance.[64]

Not only the use of meat terms is relevant for the marketing and spread of plant-based meat alternatives, but the use of the terms "vegan" and "vegetarian" also plays a role. Neither at federal nor at European level do legal definitions exist as regards exactly what is meant by "vegan" and "vegetarian". This can lead to uncertainties among consumers and manufacturers, who sometimes have different interpretations of such criteria. Therefore, a passage in the European Food Information Regulation provides that the European Commission shall adopt an implementing act to define the terms "vegan" and "vegetarian" in food labelling (Article 36(3) point b of Regulation (EU) No 1169/2011, also referred to as the "Food Information Regulation"). However, the European Commission has not complied with this since 2011, so a regulation is still pending. At national level, the Conference of Ministers for Consumer Protection (VSMK) has drawn up a proposed legal definition for the Food Information Regulation in 2016.[65]

The question of labelling requirements and options also plays an important role for in vitro meat, at

62 Interview with Stephan Zwoll and Simone Schiller.
63 As at August 2019: 72,000 signatures (ProVeg International 2019).
64 It is also important for the consumer that it is clearly recognisable, e.g. by means of appropriate labels, whether the products are vegetarian or vegan.
65 It was also agreed that the unanimously adopted proposal for a definition, which corresponds to the ideas of the European Vegetarian Union (ProVeg 2018), should also be "taken as a basis in the future" (VSMK 2016) by food control when assessing food labelling.

least in the medium and long term. In concrete terms, investors in the in vitro meat sector are faced with the question of whether meat produced using in vitro technology can also be labelled as meat.[66] The European Commission and the EFSA are initially responsible for the sale of in vitro meat in the EU within the framework of the approval of the Novel Food Regulation. According to Article 10 of the Novel Food Regulation, corresponding applications must also contain a "description of the production process" (presumably including information on how the cells were removed from the animal) and a "proposal for specific labelling requirements". As no application has yet been submitted for the production of in vitro meat in the EU, this question cannot yet be answered.[67]

To answer this question it may play a role how stem cells are taken from the animal. There are two possibilities: firstly, by punch biopsy from a living animal (which in Germany must first be approved by the veterinary offices of the administrative districts) or by removal from a slaughtered animal. A European regulation on the possibility of being labelled as "meat", which is presumably easier to market, could thus also have repercussions on the type of cell removal – from the dead or living animal – and thus play a role in the marketing of in vitro meat.

Relevant public parties using the scope they have for public procurement in catering

Public procurement
Public procurement is an important overarching entry point when it comes to political decision-makers being able to influence nutritional practices. Incentives for environmentally friendly and healthy nutrition can be created by setting purchasing standards for community catering in public institutions such as schools, hospitals, prisons, day-care centres and public canteens. This primarily concerns the possibilities of promoting the variety and attractiveness of plant-based foods and meat alternatives in community catering or reducing meat consumption. In the future, this ability to influence also theoretically applies to insects as food and to in vitro meat, as long as there is a stronger demand and supply on the market and the potentials of the ecological and health benefits can be put into practice. In principle, it should be noted for all potentials of public procurement practice that the public procurement criteria can include sustainability, but that many other criteria also play a central role, especially price.

66 Interview with Laura Gertenbach.
67 At the national level, the "Working Group of Experts in the Field of Food Hygiene and Food of Animal Origin" (ALTS) of the Federal Office for Consumer Protection and Food Safety deals with the question of the necessary labelling of in vitro meat.

Cost saving potential is offered by the increased use of legumes as a substitute for animal protein. In order to promote plant-based meat alternatives in community catering, it is important that these are also advertised in a way that makes them more attractive. There are only a few studies in this area at German level, such as the NAHGAST[68] project of the Federal Ministry of Education and Research (BMBF). However, comprehensive studies and practical tests conducted by the World Resources Institute's "Better Buying Labs" in canteens in the USA and the UK on the promotion of plant-based foods in meals suggest that a change in the choice of name can have a major influence on consumer decisions (Wise und Vennard 2019).[69] In addition, it was shown that after doubling vegetarian dishes on the menus of refectories and canteens, the demand for meatless dishes increased dramatically (Garnett et al. 2019).

Organic certification

Creation of uniform EU rules and guidelines for the production and distribution of insects and in vitro meat according to organic standards.

With the growth of the organic sector and the marketing potential that this opens up, the question of the possibility of organic certification, which already exists in the area of plant-based meat alternatives, arises in the insect and in vitro meat sector.

Since there are currently no organic standards[70] for insects in the EU, insect products from the EU cannot yet bear an organic seal. However, in the course of the amendments to the EU framework for organic production (Regulation 2018/848), the definition of organic standards for insects is being planned (International Platform of Insects for Food and Feed (IPIFF) 2019). Nevertheless, organic insect products are already on the European market, as there is an insect organic standard in Canada and products can also be sold in the EU through an EU-Canada organic equivalence agreement.

Whether and under what conditions – use of antibiotics, use of genetic engineering conditions in which the donor animal is kept, circular use of the culture medium etc. – in vitro meat could be certified as organic meat is still unclear.

Uniform EU rules and guidelines should be established to address these issues.

Education and training

With regard to plant-based meat substitutes: integration of findings on possible applications, on the environmental and health effects and on the communication of plant-based meat alternatives (as well as a more plant-based, nutritionally complete diet) into relevant professions and training regulations (chefs, gastronomy personnel, in some cases also pedagogical and health care personnel), increase in the attractiveness of these professions, creation of financial support opportunities.

In relation to edible insects and in vitro meat: extending the capacity of regulatory authorities, developing skills on insect husbandry and certification issues, e.g. zoo technicians, regulatory authorities for production facilities, veterinary offices, feed control institutions, etc.

For a broader introduction of tasty, ecologically beneficial and healthy food products that make greater use of plant-based meat alternatives and, in the future, in vitro meat and insects, it is crucial that the training of the relevant professional groups – especially in the catering trade – is sufficiently well organised. Ensuring this is also a political task by establishing training curricula and ensuring their implementation, as well as by providing financial support. In addition, many catering professions suffer from a lack of young professionals. Increasing the attractiveness of these occupations is also a possible field of political action.

With regard to the outstanding need for regulation in the promotion of meat alternatives, the need to

68 Further information is available at: https://www.nahgast.de/
69 Names that refer to taste, appearance, emotions or regional characteristics have proven to be advantageous. Not recommended, however, are names that refer to the health value, e.g. "free of", "low fat" etc. Nor should the terms vegan, vegetarian and meat-free be used, rather symbols indicating that something is vegetarian or terms such as "also suitable for vegetarians". The investigation of the influence of different descrptionss and linguistic solutions for the German-speaking countries is a relevant field of research. Existing initiatives such as "Klimateller" (www.klimateller.de) should also be examined for their linguistic suitability to describe their offers and activities.
70 EU Regulation 2018/848 on organic production and labelling of organic products.

prepare staff at the relevant bodies (such as licensing authorities for production facilities, veterinary offices, chefs in community catering, etc.) for the new requirements is repeatedly mentioned, as well as the need to support potentially growing production of meat alternatives and their consumption, by adapting training and further training curricula.

Acceptance for meat substitutes

> Investigation of which factors influence consumer acceptance of novel meat alternatives and how this can be promoted, as this in turn is an important aspect for the spread of meat alternatives.

The use of meat alternatives is still met with reservations and a lack of acceptance in the population. There is a need for research on the underlying causes of this lack of acceptance and on strategies to overcome it: the role of language, presentation, differences between genders, age groups, social milieus; influence of the cultural context, role of meat and meat alternatives as status symbols, etc.

Measures to increase the acceptance of alternatives to meat should always be embedded in basic recommendations on a healthy, environmentally friendly and ethically acceptable diet, e.g. recommendations on meat consumption as a whole, on the role of (heavily) processed foods, plant-based foods etc., in order to approach consumers with uniform messages.

For consumer acceptance, but also for the health policy assessment of in vitro meat, it will be decisive which techniques become established for the production of in vitro meat and how transparently consumers are informed about ingredients and production processes. The use of antibiotics is an issue of relevance to acceptance.[71] Similarly, the answers to the questions of the extent to which the cells removed are genetically modified and whether these interventions mean that the meat has to be declared as genetically modified are important for the further development of production techniques.

For all three areas it is also relevant what influence labelling and naming has on the spread of the products and whether it is possible to make meat alternatives even more meat-like in sensory terms.

Production facilities and building law issues

> Clarification of the question whether production facilities for insects and in vitro meat are among the privileged agricultural operations under Section 35(1) of the Building Code and therefore buildings may also be erected here in the so-called “outlying area”.

The production of insects and in vitro meat is still not very common. As the market grows, demand is expected to increase, requiring land to build bioreactors and larger production facilities. This raises the question of whether large-scale insect production facilities and/or in vitro meat production in bioreactors can also be classified as “agricultural operations”. This classification has consequences for the permissible locations where these buildings may be erected and what costs arise.[72] While building in so-called undesignated “outlying areas” is restricted by the legislator in principle, Section 35(1) of the German Building Code (BauGB) provides for the privileging of agricultural operations, so that they may also erect buildings in outlying areas.[73]

Duty of inspection within the context of the environmental impact assessment, obligation to obtain a permit within the context of the BImSchG

> Clarification of the question of whether the special production conditions of plants for breeding insects and producing in vitro meat give rise to requirements which result in changes to the plants subject to environmental impact assessment or plants subject to approval under the Federal Immission Control Act.
>
> Need for research on new risks and consequences of microbial contamination by large insect breeding facilities

71 In vitro meat can be produced under sterile conditions without the addition of antibiotics. Antibiotics are still widely used in (research) practice.
72 The purchase of agricultural land is usually considerably cheaper than the purchase of commercial land.
73 Section 35(1) point 1: ”A project is only permissible in the undesignated outlying area if there are no public interests opposed to it, if sufficient development is ensured and if it serves an agricultural or forestry operation.”

At present, neither insect rearing facilities nor in vitro meat production facilities are specifically included in the list of facilities subject to mandatory inspection in Annex 1 of the Environmental Impact Assessment Act (UVPG) or in facilities subject to approval under § 4 of the Federal Immission Control Act (BImSchG). It should be checked whether the special production conditions here may result in adjustments with regard to the obligation to inspect or obtain a permit.

Under the UVPG, the possibility of a duty of inspection could be derived from No. 18.5 of the projects subject to an EIA for the "construction of an industrial zone for industrial plants, for which a development plan is drawn up in the existing outlying area in accordance with Section 35 of the Building Code, with an admissible floor area in accordance with Section 19(2) of the Building Utilisation Ordinance or a fixed size of the floor area of 100,000 m^2 or more in total and a general preliminary examination of the individual case for 20,000 m^2 to less than 100,000 m^2".

No. 7.13.1 of Annex 1 to the UVPG on "Construction and operation of a plant for the slaughter of animals with a capacity of 50 t live weight or more per day", on the other hand, seems to suggest a possible duty of inspection for large plants. However, since "slaughter" according to Section 1 and Section 3 of the Meat Hygiene Act refers to the bleeding of the vertebrates mentioned there, and insects are not mentioned there as an animal group, it is to be assumed that such a duty of inspection does not exist, even if plants with more than 50 tonnes live weight of insects are already in the planning.

In the case of an EIA obligation, an EIA assessment report must also be prepared. The EIA report is an important element in evaluating the approval of plants. According to Article 4 UVPG, the EIA report includes, among other things, a description of the project, in terms of energy demand and consumption and expected residues and emissions, as well as a description of the reasonable alternatives examined by the developer. For insect-producing facilities, the passage on the assessment of impacts on biodiversity is relevant, as some insect species in Europe are potentially invasive and can damage domestic biodiversity by "escaping" from the facilities.

Due to the high energy input needed to supply heat in insect breeding facilities and in vitro meat production plants, it may also be necessary, if large-scale insect production facilities are to be supported, to examine whether a subsidy should be granted specifically for particularly environmentally friendly and energy-efficient plants. Unless otherwise publicly available, the EIA reports can provide a good basis of information in this respect.

Energy supply and production site

Examination of the possibilities for reducing energy supply (choice of location), waste heat utilisation and integration of renewable energies

The production of in vitro meat and insects is more energy-intensive compared to meat production from conventional animal farming, as the growth of cells in the culture medium requires a constant supply of heat or, for insect breeding, heat and cold depending on the farm, phase and breeding line. A reduction in the energy required for insect and in vitro meat production, the use of excess heat and the use of renewable instead of fossil energy sources therefore represent an area of research and support to make production more environmentally friendly.

In the field of renewable energies, the use of solar thermal and photovoltaic systems is a good way to cover the heat demand using renewable energy sources as well. Depending on the type of use, e.g. on-site generation, supply from the grid, the question of the use of renewable energies has possible repercussions on the location of production plants and bioreactors. If current meat production is still often linked to fertile soils and pastures, solar radiation could become an important location factor for insects and in vitro meat production.

7.3 Indirect effects: cross-sectional research topics

In order to promote the substitution of meat with meat alternatives, which is recommendable from an environmental point of view, indirect effects must also be investigated and solutions must be provided. This should be the subject of future research projects. The research questions include the following:

- What **employment effects** are shown with a change in production and consumption of meat/meat alternatives? In which areas are jobs created, where do they disappear? Do new **production structures** emerge or do they dock onto existing agricultural structures? Where are the new companies based? What are the effects of large meat producers investing heavily/holding shares in in vitro production start-ups? Does in vitro meat production lead to a **diversification of suppliers** on the meat market or to a concentration? What is the ownership structure?

- What effects does growth in the sector have on the **agricultural production structure and rural areas**?

- Can the growing supply of meat alternatives and increasing consumption of these products be a "**bridge**" to the reduction of meat consumption and the conversion of culturally embedded eating habits? Does consumption have an influence on "**nutrition education**" in society? Are there **gender- and milieu-specific differences** between consumers? Are consumers more concerned with the principles of the food system and agricultural production or does production in in vitro meat bioreactors and insect farms lead to a loss of knowledge and (further)[74] alienation from agricultural production systems?

7.4 The role of meat substitutes for the transformation of the food system and overarching policy options for action

The political shaping of the development of meat alternatives in terms of environmental protection is closely linked to the accompanying framework conditions of agricultural and food policies and other policy areas.

The preceding explanations have shown that options for action are often not directly found in the field of environmental policy. Rather, a large number of regulatory areas interact. The possible use of organic residues, former foodstuffs and catering waste as feed for insects, for example, is regulated to a very large extent by food safety and EU regulations on food hygiene. The assessment of in vitro meat production facilities is closely linked to energy policy and has numerous points of contact with animal welfare, consumer protection and rural development strategies. The favourable or inhibiting framework conditions for meat production – support for new livestock buildings, slaughterhouses etc. – in Europe are in turn closely linked to EU agricultural policy. In addition, there are numerous other points of contact with trade, education and economic policy, the promotion of innovation etc.

It is therefore important to define a strategy on the role of meat substitutes in nutrition, which, in order to ensure coherence and efficiency of the measures, is developed in cooperation with all relevant political stakeholders.

The design of these policy areas was not the focus of the trend report. Nevertheless, the most important aspects that are key for the development of sustainable and environmentally friendly nutritional practices and the potentially increasing role of meat alternatives in them will be pointed out below.

74 The dominant part of the traditional food supply is also currently "decoupled" from the consumer: no access to large animal-keeping units, slaughterhouses, processing plants etc. for the general population, but to smaller production units.

Reduction of meat consumption, internalisation of external costs

Since meat alternatives also compete directly with meat on the market, it is important, when deriving policy options, not only to concentrate on the promotion of meat alternatives, but also to take into account the political framework conditions for meat production and to put these into a desired relationship. In view of the negative effects of meat consumption on the environment and cost developments in the health care system, it is therefore important to consider how the negative effects of meat consumption are also reflected in the price ("internalisation of external effects"), thus enabling fair competition between meat and meat alternatives that are more resource- and health-friendly.

Possible entry points, which are being discussed in various contexts, include the abolition of the VAT privilege (increase from currently 7 % to the standard rate of 19 %) with simultaneous tax privileges for plant-based foodstuffs, (re-) introduction of land coupling/area-based livestock farming, a levy on meat/sausage based on weight or greenhouse gas emissions, taxes and levies – in relation to greenhouse gas emissions, nitrogen surpluses, animal feed imports, animal welfare, etc. –, climate tax, levy on animal welfare depending on the production system, nitrogen surplus levy, animal feed import levy etc., but also campaigns and measures for nutrition education in schools and the promotion of environmentally friendly meat products with high animal welfare standards.

Promotion of a more plant-based diet

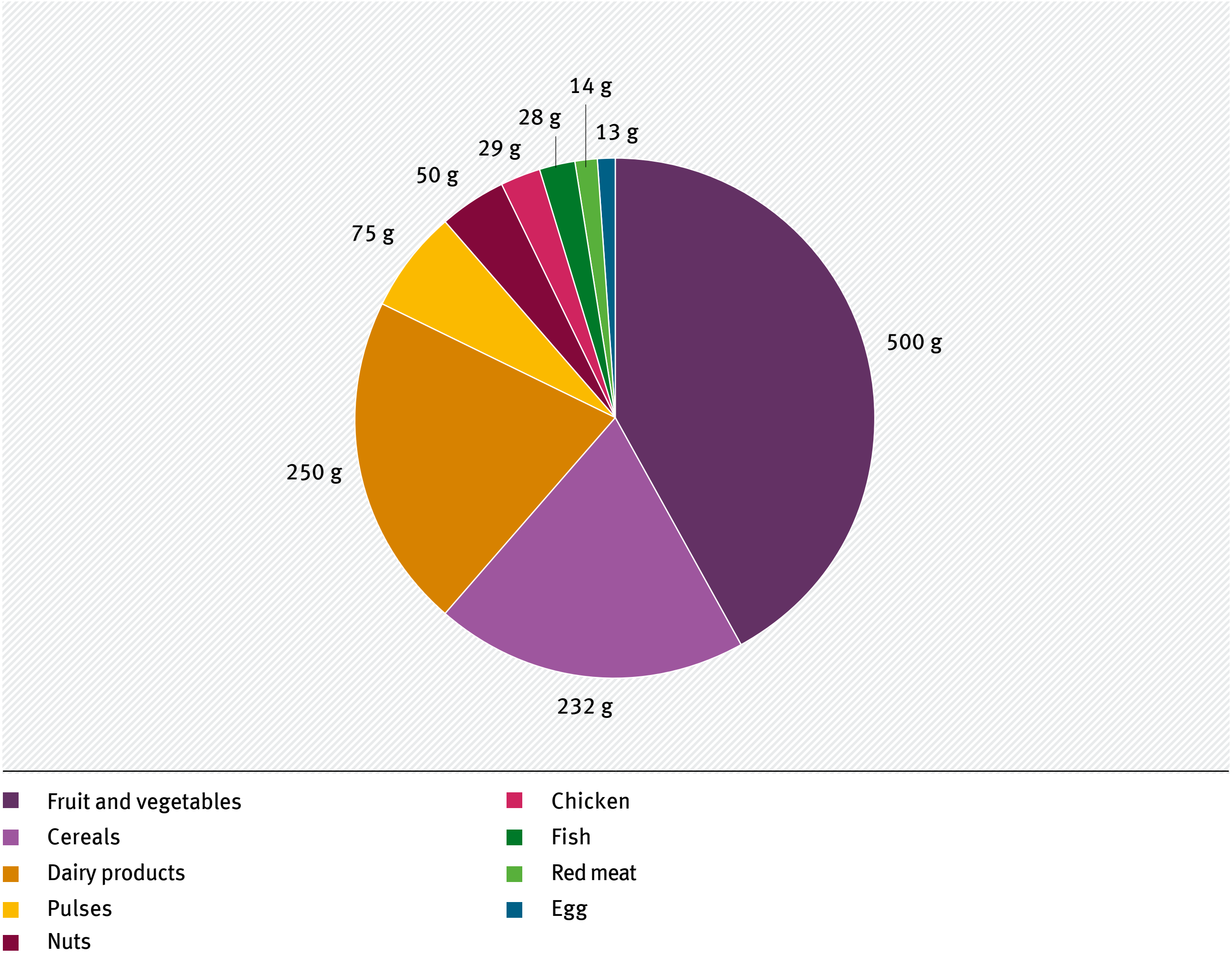
In promoting a more plant-based diet, public procurement/promotion in community catering is of particular importance. In addition, measures to educate about nutrition, to influence nutritional practices and habits, especially in schools, to use so-called nudging to guide consumer decisions (without coercion and with full freedom of choice), and a stronger anchoring of plant-based nutrition in health guidelines are important and helpful.

Development of an approach across policy areas and an agricultural and food strategy

In order to avoid inconsistencies with other policy areas, a coordinated approach to the development of environmentally friendly and sustainable diets and the definition of the role of meat alternatives is necessary (Wunder et al. 2018). This applies, among other things, to the use of agricultural biomass and residual materials, for which there is already strong competition: bioenergy, animal feed, bioeconomy, food production, compost production etc. Within the framework of a nutrition strategy, compromises must also be found in dealing with the contradictions in the environmental impacts of different meat substitutes, since the assessment of the effects in the areas of land use, energy balance and species protection often varies greatly. In contrast to the energy sector, for example, a strategy on meat consumption and meat alternatives cannot be based on a sustainable "mix" or minimum proportion of meat or meat substitutes, since there is no minimum value of a necessary meat consumption that would have to be substituted. The orientation framework for sustainable nutrition from an environmental perspective must primarily be the planetary boundaries, but also the availability of agricultural land per person and the necessary supply of nutrients and calories. Thus, measures to meet climate targets and emission limits can have repercussions on the available arable and pasture land through the renaturation of peatland sites, the promotion of permanent humus formation in arable soils and afforestation (carbon sequestration). Further topics of such a strategy also include the re-regionalisation of nutrition or of production and consumption, with closed nutrient cycles and the derivation of conclusions for other policy areas such as research and education, economic development, energy etc. To date, national nutrition strategies exist in only a few countries worldwide. An evaluation of these nutrition strategies, their contents and effects on economic activities and consumption habits is therefore an important research topic.

Figure 34

Possible planetary health diet per person and day according to the EAT-Lancet Commission



Source: Own illustration according to Willett et al. (2019)

The proposals of the EAT-Lancet Commission, published in 2019, are groundbreaking for the design of a healthy and environmentally compatible diet (Willett et al. 2019). For the first time, the report provides an estimate of the meat consumption per person that can meet the requirements of a "Planetary Health Diet", thus combining the demands of a growing world population, planetary boundaries and a healthy diet.

Compared to the existing national consumption[75] of meat of 88.6 kg per person (2018) in Germany and a per capita consumption of about 60 kg (Bundesanstalt für Landwirtschaft und Ernährung (BLE) 2018a; Newmiwaka und Mackensen 2019) the amount recommended by the EAT-Lancet Commission corresponds to a quarter of the German consumption or the available meat quantity of 300 g per person per week, i.e. about 15 kg per year.

Joint funding initiative for researching meat alternatives

To examine the technology-specific issues and cross-sectional topics mentioned, a joint research and funding initiative by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, the Federal Ministry of Education and Research, the Federal Ministry of Economics

75 The quantity available for consumption includes not only food consumption but also consumption for animal feed, industrial use and all losses, e.g. unused portions. Consumption is calculated from net production plus imports and minus exports.

and Energy and the Federal Ministry of Food and Agriculture on the contribution of meat alternatives and the substitution of animal proteins with plant proteins would be an approach that could bring together innovation, food safety, healthy nutrition, environmental protection, food education and animal welfare. This can directly tie in with the corresponding preliminary work of the departments, especially the “Nutrition of the Future” division in the BMEL. An improved research basis on the possible positive and negative – also indirect – impacts and the identification of ways to further develop the technologies in a targeted way towards sustainability and environmental protection is in turn a prerequisite for the further development of suitable (funding) policy frameworks.

Research projects can make the generated data publicly available (“open access”) so that companies can use it for approval under the Novel Food Regulation. This would also reduce the financial investment risk[76] currently borne by companies and start-ups to demonstrate the safety of food products whose marketing authorisation in the EU is partly in the public interest. This applies above all to the approval of insects and in vitro meat, but also to various plant-based products, such as isolated proteins from the mung bean, which, as an important component of the egg replacement product “Just Egg”, for example, are also subject to the Novel Food Regulation.

Due to the diversity of necessary innovations in the food system, the promotion of a positive innovation culture is becoming increasingly important. This includes the creation of rule-based “innovation spaces” in which regulatory freedoms are created in pilot projects, e.g. in the context of a feeding study of previously non-permissible feeding substrates for insects, and these are tested and evaluated for a limited period of time under official supervision.

Internationally coordinated action and change in EU agricultural policy
Finally, it is important to establish regulations in the overall global and European context in order to exclude distortions of competition and relocation effects, for example in meat production. The most important entry point for this is the redesign of the European Common Agricultural Policy, which has been under negotiation since autumn 2019 for the period from 2020 onwards.

Making conflicts of interest transparent
Strong structural changes in production and consumption behaviour will also meet with resistance, as there will be losers from the change as well as winners. These changes are an inherent part of social transformation processes. In agricultural policy in particular, the influence of some interest groups is very high, who are fighting against far-reaching changes in agricultural and food policy and the reduction of meat consumption (Nischwitz und Chojnowski 2019). The introduction of a transparency or lobbying register can be helpful in identifying hidden influence and interdependencies and bringing them into the public debate.

Participative multi-stakeholder processes
In order to cope with the complexity involved in drawing up a nutrition strategy, it is important to incorporate different perspectives, areas of expertise and types of knowledge, i.e. inter- and transdisciplinary cooperation, into the process and to initiate participative multi-stakeholder processes. In the field of meat production and meat alternatives, new alliances are potentially emerging.

In summary, it can be said that a reduction in meat consumption and the promotion of meat alternatives are indeed a major environmental policy concern. However, the options for action to create suitable framework conditions lie essentially in other political fields of action. Therefore, overarching cooperation between the stakeholders concerned, whether within the framework of a joint research and funding initiative, the coordination of agricultural policy innovations or the drafting of a nutrition strategy for the consistent design of political framework conditions, is of particular importance.

76 Applicants often quote costs of between 40,000 and several hundred thousand euros for the submission of all documents required for approval under the Novel Food Regulation for a product.

8 Summary and outlook

For a sustainable, healthy and environmentally friendly diet it is necessary to considerably reduce the excessive consumption of conventional meat in Germany.

The trend report has shown that alternative meat products already exist today. These are mainly made from plant-based raw materials and are achieving an ever-higher degree of imitation of conventional meat products. Apart from plant-based meat substitutes, meat substitutes made from edible insects also have some potential, but are still subject to high acceptance hurdles. The future development of in vitro meat is currently subject to greater uncertainties due to development constraints.

Future scenarios for possible alternative products depend on the development of the global and German meat markets. So far, there are no signs of a slowdown in the strong growth in the global meat market. Compared to conventional meat products, alternative meat products do still occupy niches only. Although Germany can be characterised in this respect as a growing market with increased consumer interest in meat substitutes, the average meat consumption of the German population has hardly fallen at all over the past thirty years.

Meat substitutes made from plants, insects and in vitro meat can nevertheless play an important role in reducing meat consumption and facilitate the adjustment of culturally embedded eating habits. Meat substitutes are thus a possible element on the way to a diet with less meat, even if they are not necessarily an essential part of an environmentally conscious and healthy diet.

As the analysis of the life cycle assessments has shown, plant-based meat alternatives performed best in comparison with conventional meat. In addition, the underlying production processes are already relatively mature. The promotion of a more plant-based diet should therefore be the focus of political action, especially if these products have a low degree of processing. Unprocessed plant products such as legumes are immediately available to the market with low risk and immediate benefits.

Edible insects also have great potential as an alternative supply of protein and are particularly interesting from an environmental point of view because of their ability to use natural resources efficiently. The most important entry point for improving the environmental balance is to re-evaluate the feeding of organic residues to insects.

Compared to plant-based meat alternatives and edible insects, studies concerning in vitro meat production are subject to the greatest uncertainties both in terms of opportunities and potential risks to the environment and health. This has implications especially for research policy. The development of culture media free of animal components and the preparation of (extended) life cycle analyses are two central research questions. An improved information basis based on the findings of such analyses will enable decision makers to shape future developments in line with sustainability criteria.

The following three aspects are important cross-sectional approaches, which prove to be highly relevant for the future development of the market for all three of the analysed meat substitutes:

1. Social acceptance of the food.

2. The revision of education curricula and training curricula to build up knowledge and skills on issues related to market development for meat alternatives.

3. The scope of the permissible labelling of products (in essence: whether meat substitutes may be marketed as products reminiscent of meat, e.g. as "vegetarian schnitzel" or "vegan salami").

When developing policy measures to promote environmentally friendly and sustainable food, it is necessary to integrate a wide range of policy areas (health, food safety, animal welfare, agricultural policy, economic development and innovation culture, research and education policy, consumer protection, energy policy, etc.) in order to take account of indirect effects of developments. The type and scope of support for new food technologies for the production of products from edible insects, alternative plant-based raw materials and in vitro meat should therefore be defined and implemented within the framework of an interministerial national food strategy.

Finally, it is important to establish regulations in a global and European context in order to exclude distortions of competition and relocation effects (e.g. of meat production). The most important entry point for this is the restructuring of the European Common Agricultural Policy for the period from 2020 onwards, which has been under negotiation since autumn 2019.

This trend report provides a small insight into the complex topic of future nutrition. Meat of the future represents only a part of the changing nutrition system. Under the assumption that, on the one hand, the current food system is not sustainable, but leads to environmental problems, and, on the other hand, can be shaped to a certain extent, the reduction of meat consumption will become a central lever in solving environmental problems. This should not be about motivating people to forgo something. Rather, there are numerous alternatives available that can solve some of the problems associated with high meat consumption. This trend report sheds light on these alternatives and their environmental impact. In addition, it outlines initial governance approaches which can be implemented within the framework of a future-oriented and sustainable environmental and nutrition policy and which can drive forward a transformation of the food system.

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A Annex

A.1.1 Keywords for Google search

Meat alternative	Search terms
In vitro meat	“cultur* meat”; “clean meat”; “in vitro meat”
Edible insects	“edible insect*”; “entomophag*”
Plant-based meat alternatives	“meat analogue”; “vegetarian meat alternative”; “meat substitutes”; “meat alternates”; “meatless meats”; “meat replacers”; “simulated meat”; “meat analogs”; “meat-free meats”; “vegetable meats”; “vegetable substitutes for meat”; “soy meats”; “soya meat”; “soy-based meats”; “plant-based meat”

A.1.2 Keywords for Scopus search

Meat alternative	Suchbegriffe
In vitro meat	“cultur* meat”; “clean meat”; “in vitro meat”
Edible insects	“edible insect*”; “entomophag*”
Plant-based meat alternatives	“meat analogue*”; “meat analog*”; “meat alternative*”; “meat substitute*”; “meat alternate*”; “meat replacer*”; “simulated meat”; “vegetable meat”; “soy* meat”; “plant based meat”

A.1.3 Interview partners

Name	Organisation
Christophe Derrien	Secretary General, IPIFF (International Platform of Insects for Food & Feed)
Prof. Dr. Jana Rückert-John	Professor for “Sociology of Eating”, University of Applied Sciences Fulda
Ronja Berthold	Consultant for politics, ProVeg
Prof. Dr. Hans-Wilhelm Windhorst	Science and Information Centre for Sustainable Poultry Management (WING), University of Vechta
Laura Gertenbach	Co-Founder/CEO, Innocent Meat
Carina Millstone	Director, Feedback Global
Dr. Niels Bandick	Head of Division 41 “Food Technology Processes, Product Chains and Product Protection”, BfR (Federal Institute for Risk Assessment)
Martin Hofstetter	Political Advisor Biodiversity and Agriculture, Greenpeace
Stefan Zwoll	Head of DLG Office Berlin, German Agricultural Society
Simone Schiller	Managing Director of the DLG Specialist Centre for Food
Marek Witkowski	Head of Communication, DIL (German Institute of Food Technologies)
Dr. Kerstin Anders	BMU
Dr. Peter Loosen	Managing Director and Head of the Brussels Office of the BLL (Bund für Lebensmittelrecht und Lebensmittelkunde e.V.)
Heinrich Katz	Hermetia Group and Chairman of the Supervisory Board of Katz Biotech AG

A.1.4 Workshops held

Workshop title	Date and place	Number of participants
Expert Workshop “Meat of the Future”	18/10/2018 at the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin, Stresemannstraße 128–130	28
Expert workshop: Environmental policy options for action regarding the design of insect-based, plant-based and in vitro produced meat substitutes	17/09/2019; Design Offices at EUREF Campus | EUREF Campus 22 | 10829 Berlin	44