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Sustainability innovations in agriculture:

A systems perspective on insect feed as an alternative protein resource in German animal production

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List of abbreviations

ABP	Animal by-products
ATB	Leibniz- Institut für Agrartechnik und Bioökonomie
BfR	Bundesinstitut für Risikobewertung
BLE	Bundesanstalt für Landwirtschaft und Ernährung
BMBF	Bundesministerium für Bildung und Forschung
BMEL	Bundesministerium für Ernährung und Landwirtschaft
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit
BSE	Bovine spongiforme Enzephalopathie
BSF	Black Soldier Fly
BVL	Bundesamt für Verbraucherschutz und Lebensmittelsicherheit
DAFA	Deutsche Agrarforschungsallianz
DBV	Deutscher Bauernverband
DG Sante	Directorate General Health and Food Safety
DLG	Deutsche Landwirtschafts- Gesellschaft
drv	Deutscher Raiffeisenverband
EC	European Commission
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FiBL	Forschungsinstitut für biologischen Landbau
FMV	Futtermittelverordnung
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
HACCP	Hazard Analysis and Critical Control Points
IPIFF	International Platform of Insects for Food and Feed
LCA	Life Cycle Assessment
LFGB	Lebensmittel- und Futtermittelgesetzbuch
MLP	Multiple Level Perspective
OECD	Organization for Economic Co-operation and Development
OVID	Verband der ölsaatenverarbeitenden Industrie in Deutschland
PAP	Processed animal protein
PCR	Polymerase Chain Reaction
PHW	Paul-Heinz Wesjohann

SDG	Sustainable Development Goals
TIS	Technical Innovation System
TSE	Transmissible Spongiforme Enzephalopathie
UN	United Nations
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
WEF	World Economic Forum
WUR	Wageningen University & Research
QS	Quality and Safety

1. Introduction and research aim

By the year 2050, the world population of currently 7,6 billion is expected to grow to 9,8 billion people (UN, 2019). This population growth is accompanied by an increasing demand in the necessities of life (food, feed, fuel, fibre & fun) and subsequently an aggravation of land-use and resource competition. To ensure the food security of this many people, FAO forecasts determine that global food supply will need to increase by about 70% of today's production volume (base period 2007) (FAO, 2009). Moreover, changes in the demographic composition, like growing income levels, urbanization trends and the globalization of food markets also result in changing dietary preferences with increased proportions of animal-based products (Alexander et al., 2017; Kearney, 2010; Keyzer et al., 2005; McMichael et al., 2007). By 2050, the global demand in meat is expected to be 73% higher than it was in 2010 (FAO, 2011). Accounting for nearly half of all the additional meats expected to be produced over the next decade, poultry meat is the dominant driver of the growth rates within the meat complex (FAO, 2018). These growth predictions make the livestock sector one of the fastest growing sectors in the agricultural economy (WEF, 2018). Still, responding to the growing demand in animal-sourced foods will become a daunting challenge for the world's agricultural systems. Industrial livestock production, which relies on concentrated protein feed, is a resource intensive and environmentally burdensome activity. Today, 72% of cropland is occupied by livestock feed production (Raschka et al., 2012), 22% of wild caught fish (FAO, 2016) is used as an animal feed ingredient and about 70% of the global freshwater resources is used by the agricultural industry (FAO, 2017). In addition, it is estimated that 45% of greenhouse gas emissions caused by the livestock industry can be attributed to feed production alone (Garnett et al., 2017). As livestock production intensifies and feed production continues to outpace plant-based food production (OECD & FAO, 2018), the animal production sector is under increasing pressure to address its environmental and societal costs (Godfray et al., 2010; Harry Aiking, 2011).

By implementing international agreements, such as the 'Paris Climate Treaty' and the 'Sustainability Development Goals' (SDG's), the international community set a blueprint for action. Producing up to 73% (FAO, 2011) more meat, simply by maintaining current modes of production and consumption, is not a credible option to achieve a resilient and sustainable food system (Rockström et al., 2009; Alexander et al., 2017; Aiking, 2011; Springmann et al., 2018). However, more responsible and environmentally sensitive ways of consumption and production are possible (Smil, 2014). Currently discussed strategies to source future-fit protein aim at improving the overall efficiency of existing production schemes, but also include innovative approaches to moderate or shift the overall demand towards less resource-intensive alternatives like waste streams or protein novelties.

With one third of all food produced (1,3 billion tonnes per year) being lost before it reaches the market (unintended food loss) or wasted on household level (as a result of negligence or decision to throw food away) (Gustavsson et al., 2011), food loss and waste are significant factors undermining the sustainability of the current food system. On an annual basis, the production of food that is never being consumed requires 250 billion liters of water, 200 million barrels of oil (FAO, 2013), occupies 198 million hectares of land (Lipinski et al., 2013) and causes 3,300-5,600 million metric tons of greenhouse gas emissions (Lipinski et al., 2013). Despite the UN target to *'halve per capita global food waste at the retail and consumer level, and reduce food losses along the production and supply chains'* by 2030 (SDG 12), projected changes in the demographic composition and social drivers are also expected to aggravate the waste burden of the food supply chain and their negative environmental and economic impacts. While food waste cannot be prevented completely, global recognition of the 'waste hierarchy' opens new opportunities to better incorporate underutilized waste streams in the feed supply scheme. Residues, co- and by-products of food production currently only account for 30% of global livestock feed intake (Mottet et al., 2017).

At the same time, with the recognition that '*the opportunity cost of animal- based diets exceeds all food losses'* (Shepon et al., 2018) another strategy, focusing on dissolving land-use competitions and addressing the sustainability of the food system, is aimed at decreasing the per capita meat consumption and thus reducing the overall demand in animal feed. As animal products in general require more land per unit of protein than the plant based equivalent (Shepon et al., 2018), a shift towards increased proportions of plant-based protein sources in human diets could alleviate the demand in animal-sourced products and moderate the overall demand in feedstuff (Stehfest et al., 2009; Grethe et al., 2011; Shepon et al., 2018). However, despite growing awareness and concern for the impacts of today's food production system, societal appreciation of animal-based products seems uncontested. When it comes to culinary choices, many consumers still tend to look for products that fit their specific dietary preferences, rather than being guided by their concern for the environment, personal health or animal welfare (Shockley et al., 2017). The global shift towards diets with increased consumption of animal-based products shows that many people still consider these products the most desirable way to access nutrient rich and tasty protein (WEF, 2018).

It is therefore that new technical solutions and sustainability-driven feed innovations to address the deficiencies of feed production have built momentum. Feed optimization (e.g. essential amino acid supplements) and the sourcing of alternative proteins (e.g. insects, algae, yeast, seaweed, bacteria) are promising approaches to increase land-use and resource efficiency of the supply scheme. A favorable performance in terms of feed conversion, land and water usage currently attributes to the production of insect protein. A great deal of focus on this novelty arose with the recognition that insects display high efficiencies in converting waste streams and underutilized by-products into high quality feed (van Huis, 2013; Vantomme, 2017). Integrating insect protein in the diets of livestock animals like fish, poultry and pigs (as part of the primal diet of these species) could therefore ‘close the loop’ towards a more circular food system and simultaneously address sustainability and waste problems (van Huis, 2013; PROteINSECT, 2016).

However, since the FAO publication ‘Edible Insects - future prospects for food and feed security’ (van Huis et al., 2013) brought serious global attention to the topic (Vantomme, 2017), the implementation of insect proteins has developed quite differently throughout the world (Reverberi, 2017; Van Huis, 2017). In the European Union, where the use of insect protein feed is also coupled with the hope to reduce imports of high protein feeds and thus diminishing what is described as the ‘protein gap’ or ‘protein deficit’, actual practical integration of the insect protein novelty into the existing agricultural systems is still in its infancy. Despite a communal food policy and seemingly similar basic conditions, development of the insect protein niche differs among the Member States. While the Netherlands, for example, earned a reputation as a pioneer in the field of insect innovation and research, the German market seems to take a more reluctant stance (Reverberi, 2017; Shockley et al., 2017). This development leads to the assumption that there might be national differences in the support and in the dynamics of sustainable innovation processes. It also raises the question, in what way national innovation structures or processes hinder or enable successful implementation of innovations. With the aim to answer these questions and to contribute to gaining structural knowledge of the insect protein novelty, this master thesis directs its focus on the German insect protein feed niche and answers the following research questions:

1.What are the current structural components (actors, institutions, networks and technological structures) and what are the functional processes of the German ‘insect protein solution’ for animal feed?

2.Which opportunities does the German Insect Industry provide that could help the sector to develop? What are the obstacles the German Insect Industry faces and how can the sector transform or cope with them?

3.What kind of structural effort (enabling conditions) is needed to design and deliver a legitimate and trusted ‘Insect protein solution’ as an agricultural niche to ultimately challenge the current protein provision sector?

2. THEORETICAL FRAMEWORK - STATE OF RESEARCH

2.1 Sustainability innovations and the systems perspective

With the assumption that divergences in the development of the insect protein novelty might be attributed to national differences in the support and in the dynamics of sustainable innovation processes, this section takes a closer look at the criteria and special characteristics of sustainable development and introduces the theoretical foundations and prevailing analytical approaches to analyze and understand the processes underlying innovations.

2.1.1 Sustainability transitions and innovations

Increasing awareness and understanding of the planetary boundaries (Rockström et al., 2009) and the realization that growing demand pressures cannot be sustained by additional exploitation of depleted natural resources, have led to a call for a transformation towards a '*sustainable society'* (UN, 2018). To move towards the envisaged sustainable society, a society that '*meets the needs of the present without compromising the ability of future generations to meet their own needs'* (WCED, 1987: 41), Kemp et al. (2007) argue that managing change processes towards sustainability will need *'structural changes in social-technical systems and wider societal change, in beliefs, values and governance that co-evolve with technology changes'* (Kemp et al., 2007: 78). With this scope, 'innovation' moves beyond the focus of incremental sustainability advances and determines fundamental societal change as the path to ensure future sustainability.

The transformational process towards more sustainable modes of production and consumption also involves *'major transformations in agriculture practices and global food systems'* (FAO, 2018). As a core aspect of the UN's Sustainable Development Goals, the sustainable food system, a '*food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised*' (FAO, 2018), shall ensure food security, improved nutrition and the end of hunger by 2030 (FAO, 2018). Numerous strategic reports and policy papers dealing with sustainable development emphasize the role of innovation in order to implement these goals (El Bilali, 2018). According to FAO (2019), agricultural innovation means *'the process* *whereby individuals or organizations bring new or existing products, processes or ways of organization into use for the first time in a specific context, to increase effectiveness, competitiveness and resilience with the goal of solving a problem.'*

Sustainability innovations display a number of special characteristics and distinctive features. In contrast to market- driven innovations, which often emerge out of commercial motivations and co- evolutionary processes surrounding technical inventions (Darnhofer, 2015; Geels, 2011; El Bilali, 2018), sustainability innovations refer to a purposive (Smith et al., 2005), goal-oriented and therefore normative approach, that evolves with changing social demands (Geels, 2005).

Despite the broad consensus for the need of sustainable development (UN, 2012), its normative character with the focus on 'what should be', gives cause to subjective ideas and thus different interpretations of what is understood as a sustainable practice. The lack of definitional clarity involves the risk that due to negotiation, debate and compromising, final outcomes and pre-defined explicit goals might not correspond with each other (Loorbach, 2007; Rauchmeyer et al., 2015). Rauschmeyer et al. (2015) therefore emphasize the importance of quality criteria regarding the process rather than pre-defined objectives of sustainability. Another particularity regarding sustainability innovations is that the cause for structural changes does not arise from direct and obvious monetary or user benefits but from the intention to address persisting sustainability deficiencies (Geels, 2011). According to Geels (2011), this results in limited privately- driven incentives to implement sustainable changes and implies challenges such as the 'free rider problem' or 'prisoner's dilemma'[1]. When reviewing innovation studies and sustainability transitions, with reference to Pearce et al. (1989), Smith et al. (2010) recognized that within sustainable transition literature, existing market structures are criticized for poorly serving environmental considerations, as '*costs and prices fail to internalise environmental externalities, and consequently fail to generate effective demand for cleaner innovations'* (Smith et al., 2010: 437). While environmental economists advocate the internalization of negative external effects (e.g. environmental degradation) in order to improve market- based incentives for sustainable innovations, recent currents of innovation studies argue that prevailing innovation

[1] The 'free rider problem' and the 'prisoner's dilemma' are challenges associated with collective action and the provision of collective goods. While the 'free rider problem' refers to the challenge of users profiting from a collective good while refraining or failing to contribute to its operating and maintenance costs, the 'prisoner's dilemma' refers to a social dilemma of decision making in which rational decisions of individual group members do not result in the pareto- optimal situation of the group.

policy frameworks should focus on integrating other policy fields (e.g. trade, environmental, agricultural, energy) as well as non-market considerations in order to pursue a more long-term strategic orientation to face the challenges of sustainable development (Smith et al., 2010; Weber and Rohracher, 2012; Alkemade et al., 2011). In order to derive appropriate measures in support of sustainability innovations, literature on innovation and transition theory suggests employing a systems perspective on innovational processes that departs from an innovation concept primarily focused on research, to one that regards the interaction and interlinkages of actors as the driver for innovation (World Bank, 2006).

2.1.2 Systems perspectives on innovation

Following the systems approach, sectors fulfilling societal functions, such as the energy supply, food supply or transportation sector, can be conceptualized as socio-technical systems (Breschi and Malerba, 1997; Geels, 2005; Markard et al., 2012). While the social component of the system refers to the human agents, the actors, active and interacting within the system, the technical component refers to its material and immaterial artefacts (e.g. technologies, infrastructure, rules) (Geels, 2005). With the understanding of innovation processes as collective and co-evolutionary endeavors that emerge from the interaction of multiple actors and aligned activities among them (Geels, 2005; Schot and Geels; 2008; Markard et al., 2012), systems of innovation literature envisions (socio-) technical innovation systems (TIS) as (more or less) stable configurations of structural components of (Marletto et al., 2016; Carlson and Stankiewicz, 1991; Hekkert et al., 2007): (1) The actors (e.g. individuals, firms, organizations, universities, research institutes, consumers), (2) the networks (e.g. established linkages between the actors- coalitions, cooperation and collaboration-), (3) the institutions (e.g. formal and informal institutions that structure the activities of actors) and (4) the technology (e.g. material and immaterial artefacts that enable or constrain action). Analyzing the structural components of a specific innovation system therefore unveils valuable indications to assess its composition and the heuristics of collective action, however, it falls short in giving insight into the actual processes that determine the successful diffusion or failure of a novelty.

2.1.2.1 Functional dynamics of technological innovation systems

As innovation processes in general are *‘characterized by uncertainties, high risks, large investments and late return on investments’* (Alkemade & Suurs, 2012: 448) and with the understanding that this is particularly true for sustainability innovations, successful emergence and implementation of sustainable innovations depend on the identification and utilization of inducement processes. Based on the theoretical foundations of the systems of innovation thinking of the 2000s, Bergek et al. (2008) therefore suggested an analytical framework that extends the components of the structural analysis by an analysis of the functional dynamics that prove to be essential for the emergence and successful growth of the innovation. By doing so, Bergek et al. (2008) established a framework that helps to gain better insight into the performance of technical innovation systems (Bergek et al., 2008). The functional approach seeks to 'break down' the complex dynamics within TIS by systematically identifying and analyzing seven key processes, which stem from innovation theory and are empirically validated (see: Bergek et al., 2008; Hekkert et al., 2007):

1. Entrepreneurial activities
2. Knowledge development
3. Knowledge exchange
4. Guidance of the search
5. Formation of markets
6. Mobilization of resources
7. Legitimation

With the help of 'diagnostic questions' (see Annex 3: 'Guiding questions for expert interviews') and indicators that reflect to what extent a functional process is fulfilled or disregarded, the functional approach provides increased insight into the system behavior and generates more practical guidelines on how to support and direct its development. While this approach is particularly helpful to evaluate the structural setting and immediate functional environment of a specific novelty, it falls short in depicting the relevance of a novelty in the broader societal context and for the long- term transformational process towards sustainability (Weber & Rohracher, 2012).

2.1.2.2 Multi-level perspective

An analytical framework that takes a more holistic approach, by including the dynamics of fundamental societal change, is the multi- level perspective (MLP) shaped by Rip and Kemp (1998), Geels (2005) and Geels & Schot (2007). The MLP takes co-evolutionary processes on three different levels (the landscape level, the regime level and the niche level) as the basis of long-term socio-technical transitions. By regarding the broader societal context and highlighting the interactions and linkages of the different levels, the MLP perspective sets a wider scope on innovations and functions as a suitable approach to understand the emergence and further diffusion of novelties and their contribution to socio-technical transformations.

Figure 1, 'A dynamic multi-level perspective on system innovation' (Source: Geels 2002: 1263), outlines the dynamic processes behind socio- technical transformations. The core notion of the MLP approach is that:

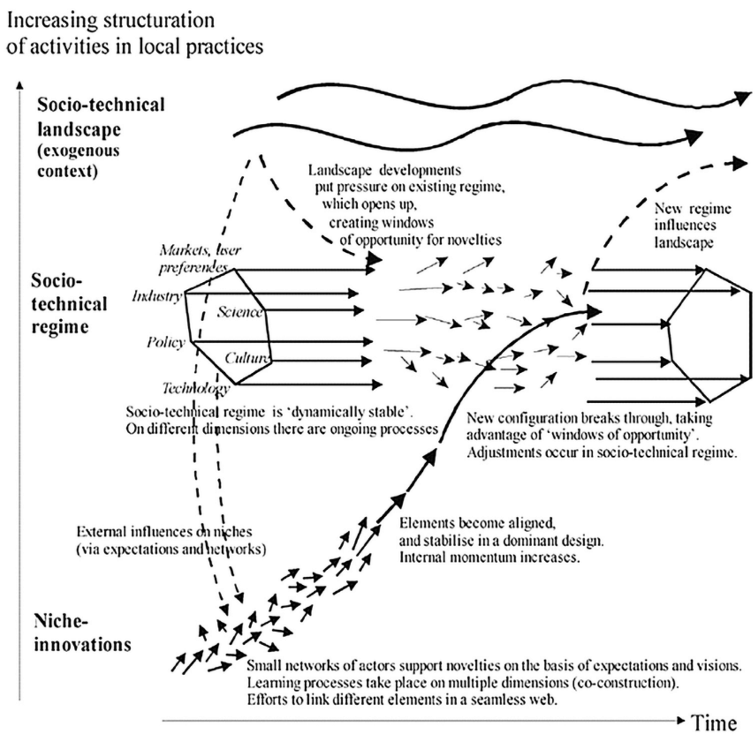
(1) Within innovation niches, processes of experimentation, innovation and creation, continuously generate novelties. These novelties are not only based on technical advancements but include new ideas, new belief and value systems, new technologies and practices, new networks and policies and new configurations of actor groups (Darnhofer, 2015), thus all activities and views differing from the mainstream logic of the incumbent socio-technical regime level. As most novelties are relatively '*crude and inefficient'* in the early phases of their invention and display traits that are '*badly adapted to many of the ultimate uses to which they are eventually be put*' (Schot & Geels, 2008: 537), innovation niches act as 'incubation rooms' protecting novelties against the selection bias of the mainstream market (Geels & Schot, 2007). With the freedom to experiment, niche actors, sharing a common vision or objective, engage and form networks of actors in support of the novelty. By doing so, niche activities become more aligned and the momentum for the novelty to manifest in the socio-technical regime increases.

(2) Changes and developments on the 'landscape level', the exogenous environment (e.g. deep cultural patterns or demographic composition) to the 'niche' and 'regime level', put pressure on the socio-technical regime and open 'windows of opportunity' for novelties of the 'niche level' to break through.

(3) Over time, the 'regime level', which refers to the prevailing regulative, normative and cognitive rules that stabilize and secure the functioning of a socio-technical system, displays insufficiencies and weaknesses (e.g. through internal conflict or unintended side- effects) that, with pressure from the landscape level, destabilize otherwise stable trajectories (Nelson and Winter, 1982). This gives impetus for niche innovations to gain

support and to take further advantage of the ‘window of opportunity’. Regime level adjustments towards the niche innovation accelerate its ‘out- of- the- niche’ development and initiate regime shifts. Yet, the common institutional structures of the regime level also entail the risk of ‘lock-in’ effects (e.g. through sunk investments, power relations and institutional commitments) or ‘path-depended development’ (e.g. existing infrastructures or previous investments) (Geels and Schot, 2007; Darnhofer, 2015). As actors align and coordinate their activities towards the incumbent socio-technical ‘regime level’, as their ‘shared belief system’, they reproduce and further stabilize it. While these dynamics govern the social function, they can also manifest in the maintenance of sub-optimal regime structures and to the detriment of niche innovations. Yet, the socio-technical regime structures are both, ‘*the context and outcome of action’* (Geels, 2005: 43) and thus display a ‘duality of structure’. Although rules, cognitions and prevailing norms of the incumbent regime are the framework for action, their evaluation and assessment can also result in changing them (Geels, 2005).

Figure 1: ‘A dynamic multi-level perspective on system innovation’



(Source: Geels 2002: 1263)

2.2 Status quo: Insect protein solution

The following section introduces the insect protein solution as the object of research. It examines the historical context in which the novelty evolved and outlines the anticipated benefits. To better understand the opportunities and obstacles the innovation faces, this chapter also gives an overview on the current state of research.

2.2.1 History

The practice of eating insects and using their products has a long history. It can be assumed that the consumption of insects, as part of a 'faunivory' diet, has played a key role in human evolution (McGrew, 2001). Evidence of humans considering insects a valuable food choice can be found in the Old and New Testament; in descriptions of Aristotle and accounts on ancient Greek and Roman lifestyles (Harris, 1985; Evans et al., 2015; Meyer-Rochow, 2004). For the purpose of sourcing valuable products like silk, shellac and honey, the domestic rearing of insects has been practiced for over 7000 years (Rumpold & Schlüter, 2012). Reports dating back to antiquity also highlight the use of insects in medical products and therapeutic treatments (Meyer-Rochow, 2017). But despite the apparent historical importance of insect products, only little scientific research and data is available to help fully understand their historical course and application in different regional contexts and cultural settings.

Today, anthropologists try to understand the culturally acquired aversion of Western societies towards insects in general and towards their use as human food specifically. It is unclear how the negative associations and attitudes manifested themselves so deeply in the Western world while responses in other regions are far more open-minded or even appreciative. While some researchers argue that eating insects might never have played a substantial role in Europe (Bennett and Zeleznik, 1991; Harris, 1985), others argue that the knowledge of insect consumption merely got lost in the industrialized countries (Rumpold and Schlüter, 2012).

The idea of using insects as a food and feed source is not new ('Why not eat insects?', Vincent Holt, 1885; 'Butterflies in my stomach: Insects in Human Nutrition', Ronald Taylor, 1975). Yet, it is only recently that the topic was able to gain global attention among scientists, industry experts and policy makers. Serious interest for the topic emerged out of the 2008 collaboration between the FAO and the Wageningen University & Research (WUR). When analyzing the creation of an enabling environment for the insect food and feed sector, Vantomme (2017) highlights the 2013

FAO and WUR publication 'Edible insects: Future Prospects for Food and Feed Security' (van Huis et al., 2013) and its enormous reception[2] as the landmark for increasing research interest and public awareness. The reality of current land-use constraints and sustainability deficits of the food production system spurred the interest in alternative protein resources and provided a critical platform for the novelty (Vantomme, 2017; PROteINSECT, 2015). Campaigns of the insect protein food and feed niche evolve around the ideas that using insects as a bioresource for protein would reduce the land- and water usage and reduce the release of emissions, while converting less competitive feed sources more efficiently than the traditional protein supply scheme (van Huis et al., 2013; Vantomme, 2017; PROteINSECT, 2016).

2.2.2 Insects as a bio-resource

With about one million types described, insects form the largest group of invertebrate animals classified as arthropods. This makes them the most speciose class of animals. Insects display enormous variations in almost any aspect of their biology (Gullan and Cranston, 2010). Given this diversity, they can be considered a promising, yet underestimated and underutilized bioresource (Payne et al., 2016). When cataloguing edible insects, Jongema (2017) found more than 2000 species to be considered a safe and valuable food choice for human diets. Globally, the consumption of insects is not uncommon. It is estimated that insects supplement the diets of approximately 2 billion people worldwide (Makkar et al., 2014). Especially in the tropical countries of Asia, Latin America and Africa (Bukkens, 1997), different insect species are considered a valuable food choice. Yet, dietary habits are embedded in a complex system of social, cultural and geographical drivers and are influenced by socio-economic trends (Payne et al., 2016). In many 'western cultures', the idea of eating insects is not prevalent and often evokes feelings of fear and disgust which can be explained by a culturally acquired aversion (Rozin et al., 2008). Due to this cultural stigma, the EU funded research project 'PROteINSECT' (2013-2016) concluded that a significant global switch from meat to insect consumption cannot be anticipated and '*that sustainably producing additional protein that can be fed to livestock and fish constitutes a strategy that is not only more realistic, but also one that stands a better chance of increasing food security.'* (PROteINSECT, 2015: 14). Consumer acceptance studies support this

[2] 2,3 million downloads and more than 10 million tweeds in the first 24 hours of its launch (Vantomme, 2017)

idea and indicate a positive attitude towards insects as feed ingredients (PROteINSECT, 2016; Verbeke et al., 2015).

2.2.3 Insects as a feed ingredient

In a comprehensive study, Makkar et al. (2014) reviewed the '*state- of- the- art on use of insects as animal feed'* by collating and discussing the available information of five insect species[3] and their application as a feed ingredient in the diets of diverse target species. They concluded that the feeding studies conducted so far confirm the feasibility of using insect meal as a suitable replacement or supplement for soymeal and fishmeal in livestock diets. Depending on the animal species, insect meal can replace 25-100% of traditional protein sources. The same was determined by a recent study of the Georg-August-University of Göttingen in which defatted black soldier fly (Hermetcia illucens) meal could replace 50-100% of soy meal in the diets of pigs and poultry without any adverse nutritional or physiological effects (Velten and Liebert, 2018). Good tolerability in poultry and certain fish species might be attributed to the fact that in their natural habitat, insects supplement the diets of free- range poultry and fish species as part of their natural feed choice (Rumpold & Schlüter, 2012). With protein contents between 42-63% (Makkar et al., 2014), insect protein levels are higher than those in soy meal and in some species even similar to that of fish meal (Sánchez-Muros et al.,2014). Still, due to a limited availability of insect meal (Makkar et al., 2014), feeding trials among livestock animals mainly concentrated on poultry, fish and pigs and are of limited scope. Factors like the optimal levels of inclusion and how to deal with deficiencies in amino acids (Makkar et al., 2014), as well as potential antinutrient components (Rumpold et al., 2016) have yet to be resolved.

2.2.4 Resource efficiency and environmental impacts

A majority of insect species is omnivorous and has small requirements with regard to their feedstuff (Rumpold and Schlüter 2012). Furthermore, they have the potential to convert low-grade biomass sources, such as organic waste and agricultural by-products into high quality proteins (Lundy and Parrella, 2015; van Huis et al., 2013). On that basis, they are discussed as the 'missing link' in designing a circular food production system (van Huis et al., 2013). Being cold- blooded, a majority of insect species also displays significantly higher feed conversion efficiencies than traditional livestock

[3] Black soldier fly larvae, house fly maggots, mealworm, locusts–grasshoppers–crickets, and silkworm

animals (van Huis, 2013; Dobermann et al., 2017; Rumpold and Schlüter, 2012), and has no need of drinking water as they absorb necessary water from their food and surroundings (Rumpold and Schlüter, 2012). While less water consumption is often mentioned as an environmental advantage of insect farming compared to livestock production (van Huis and Oonincx, 2017), so far only one 'water- footprint' study confirms a better water efficiency in liters/ gram protein of mealworm production compared with pig meat, poultry meat and beef production (Miglietta et al., 2015). However, life-cycle assessments (LCAs) that were conducted support that insect production does have a smaller environmental footprint compared to the production of different livestock animals (Halloran et al., 2017; Oonincx, 2010, Oonincx and de Boer 2012; Roffeis et al., 2015; Van Zanten et al., 2015; Smetana et al., 2016). Van Huis and Oonincx, (2017) observed that within these LCAs, the production of insect feed has the strongest impact on the environmental performance of insect production. Assessments of direct emission levels of insect production have been conducted with five insect species and indicate that from a perspective of GHG (they are lower by a factor of about 100) and NH3 (about a tenfold difference) emissions, insects could serve as a more sustainable protein source (Oonincx, 2010). However, due to the limited scope and data availability, Dobermann et al., (2017) argue that it is currently not possible to make general statements on the environmental impact of insects. The many application examples of insect production demonstrate that it can be practiced in different settings and scales (van Huis, 2013). Their ability to live in high densities (Rumpold and Schlüter, 2013) makes a large number of insect species suitable for mass-scale rearing without compromising on animal welfare (Berggreen et al., 2018). However, there is still uncertainty on the question if and to which degree insects can experience pain (van Huis et al., 2013). Looking at different rearing techniques, van Huis and Tomberlin (2017) discovered that insect rearing is often based on simple techniques but that these techniques are a matter of trial and error attempts by insect producing companies, which explains why companies are very secretive about their production specifications and often file patents (van Huis and Tomberlin, 2017).

2.2.5 Status quo insect production

Globally, there are significant differences and much ambiguity with regard to the legal status of using insect proteins (van Huis, 2013). When exploring the variations among regulative frameworks, Reverberi (2017) discovered that regulations *'pertaining insect* *farming, selling or marketing insect food products is either being embraced, delayed or haltered altogether'* (Shockley et al., 2017: 403). He discovered that following an assessment of the European Food Safety Agency (EFSA), which determined that edible insects fall in the category of 'novel foods' (see Chapter 2.4 'EU regulatory framework'), many countries of the European Union opted to establish a regulatory framework before allowing edible insect products. However, despite the common food policy within the EU, he also discovered that Member States in fact handle approvals differently. While Belgium, Britain, Denmark and the Netherlands explicitly permit insect products, countries like Italy and Germany declared a 'zero tolerance' policy (Reverberi, 2017).

2.2.6 Outlook

Despite a number of promising results and attested potentials, the outlook on the utilization of insect proteins is not uniformly optimistic (Payne et al., 2016). In 'Insects as food and feed: can research and business work together' Dobermann (2017) discussed incongruences and tensions among insect stakeholders and insect researchers and in 'Entomophagy and Power', Müller et al. (2016) criticized that the persistent '*solution narrative'*, especially regarding the '*universalized sustainability*' effects, lacks sufficient evidence.

2.3 German agricultural and animal production sector

For a better understanding of the developments and systemic structures of the German agricultural sector as the object of investigation, the following section gives an overview on the parameters of the German agricultural and food policy and outlines the current market structures of the feed, pig and poultry sector, as the envisioned markets for insect proteins.

2.3.1 Parameters of German agricultural and food policy

Agricultural paradigm

After World War II, European governments set self-sufficiency with regard to food as a main priority of their political agendas (BMEL, 2014). Emphasis in European agriculture was therefore clearly focused on productivity enhancements and stability in food markets. Government-packed investments in R&D activities enabled a rapid technological and organizational modernization of agricultural production modes (BMEL, 2014). Increased use of agricultural machinery, new breeding and cultivation techniques and the development and use of synthetic inputs (fertilizers, pesticides) allowed significant increases in agricultural productivity. The success in fulfilling the post-war political agenda and the societal appreciation of food supply with an extensive choice of safe and affordable food, led to a manifestation of the '*short-run productivity objective*' (see Prost et al., 2017) as what is also described as the 'industrial agricultural paradigm' (Pigford et al., 2018; Prost et al., 2017). Yet, changing societal demands (e.g. animal welfare, environmental concerns) and the realization that current production schemes in sum exceed the capacities of natural resources (Rockström et al., 2009) created new layers of obligations and commitments.

German commitments and support for sustainability

Since 2015, Germany is committed to the *'2030 Agenda for Sustainable Development'* and the implementation of the *'Paris Climate Treaty'* within the UN Framework Convention on Climate Change. In 2016, the German government adopted the 'Climate Plan 2050' (BMU, 2016) to confirm and clarify efforts in setting national climate protection targets. In order to achieve the overall objective of greenhouse gas neutrality by 2050 and a 55% reduction of greenhouse gas emissions by 2030 (compared to the base period 1990), the 'Climate Plan 2050' determines sector-specific targets and measures. As a main area of action, the combined agricultural division (agriculture, land-use and forestry) is designated to reduce 31-34% of its GHG[4] emissions by 2030 (compared to the base period 1990). Another policy strategy currently pursued by the German government to enhance resource efficiencies is the implementation of a 'bioeconomy'. As a holistic approach that is aimed at the *'knowledge-based production and use of renewable resources, in order to provide products, practices and services in all economic sectors within the framework of a sustainable/ future-oriented economic system'* (BMEL, 2018a), the bioeconomy concept envisions an economy that is completely based on biodegradable and renewable resources. While this approach involves all sectors of the economy and requires closer linkages between them, the agricultural and forestry sector will play a significant role in providing many of the raw materials necessary (BMEL, 2018a). Key element of the 2010 'National research strategy for bio-economy 2030 - our way for a bio-based economy' is the support for

[4] This equals a reduction of about 58-61 million tonnes of CO2 equivalent (BMU, 2016)

innovations by research and development. The ‘National policy strategy bio- economy’, also mentions feed production as an area to implement innovative technologies and products and emphasizes enhancements of cascaded utilization or coupled production (utilization of side streams) (BMBF, 2014: 67).

Food policy

With the single market, the EU also agreed on establishing a common food safety policy to ensure the safety of all goods being traded within the market or being imported and exported. An extensive body of EU legislation therefore covers aspects like (a) the food hygiene, (b) animal health, (c) plant health and (d) contaminants and residues, thus aspects of the entire food production and processing chain (EU, 2019). EU Member States are obliged to implement common food safety laws and to take legal measures to enforce them on the domestic market, which is then closely monitored by the EU. To provide independent risk assessments and to advise EU institutions on existing and emerging risks within the agri- food supply chain, the EU established the European Food and Safety Agency (EFSA).

On German national level, food and feed legislation is implemented and regulated by the ‘Food and Feed Code’ (LFGB- Lebensmittel- und Futtermittelgesetzbuch) under the competence of the ‘Federal Office of Consumer Protection and Food Safety’ (BVL- Bundesamt für Verbraucherschutz und Lebensmittelsicherheit) and the ‘Federal Ministry for Food and Agriculture’ (BMEL- Bundesministerium für Ernährung und Landwirtschaft). The ‘Federal Institute for Risk Assessment’ (BfR- Bundesinstitut für Risikobewertung) is the national body for risk assessments regarding the food and feed sector. National legislation on feedstuff is additionally regulated by the ‘Feed Regulation’ (FMV- Futtermittelverordnung)’.

2.3.2 Insect protein in Germany

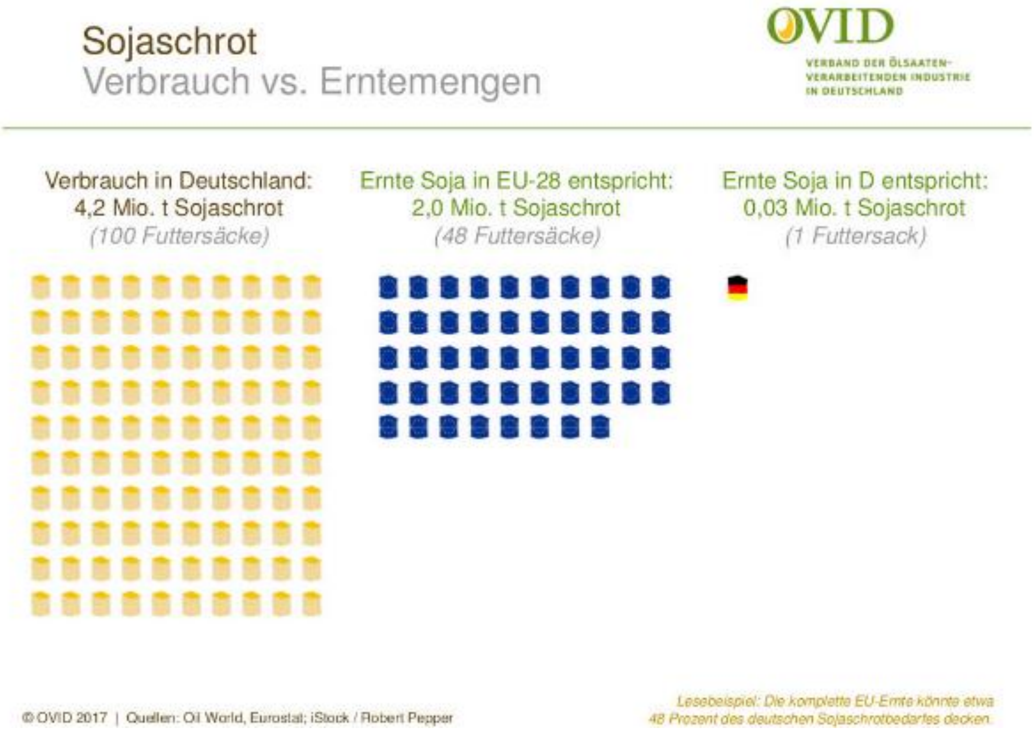
With the emergence of insect food products on the European market and subsequent risk assessment of the EFSA that determined that insect products fall into the ‘novel foods’ category, the BVL aligned with the EFSA and EU commission decision and took the stance that insects and insect derived products are novel food and cannot be sold in Germany until a procedure for novel food has been finalized (Reverberi, 2017). With a new regulatory framework that became effective in 2018 (see Chapter 2.4 ‘EU regulatory framework’) and related approval procedures, the German market has been opened for insects as ‘novel food products’. Due to the applicable regulations of the

‘TSE-Regulation’(see Chapter 2.4 ‘EU regulatory framework’), insect protein feed is not authorized to feed food-producing livestock animals other than farmed fish and other aquaculture animals.

Protein feed production and protein feed deficit- ‘protein gap’

Depending on the protein levels, the European Union differentiates between four categories of feed sources: (1) Low-Pro: less than 15% protein content, (2) Medium-Pro: 15-30% protein content, (3) High-Pro: 30-50% protein content (e.g. soy & rapeseed) and (4) Super-Pro: Over 50% protein content (e.g. fish meal & processed animal proteins) (EC, 2019). Due to their physiological demands and their limited ability to recover essential amino acids, pig and poultry feeding is dependent on high protein feeds. In Germany, the domestic production of protein crops cannot cover the protein feed demand of domestic livestock production, especially that of pig and poultry. To close this ‘protein gap’, about 26% (BLE, 2019) of German protein feed demand is therefore met by imports. Soy (including oil cake and oil groats) accounts for 62% of the net imports (BLE, 2018). Due to environmental and social costs of soy production systems in the main exporting countries like the US, Brazil and Argentina and an increasingly competitive world market, the German protein supply scheme is under pressure (PROteINSECT, 2015). It is expected that due to climate change and increasing overall feed demands, with shifting market powers (e.g. increasing livestock production in China) competition and feed price volatility of the global feed market will increase (PROteINSECT, 2015). At the same time it becomes increasingly difficult to source GMO- free soy on the world market, which does not resonate with the negative attitude of German consumers towards GMO products (OVID, 2018b; BLE, 2019). Estimates that out ‘*of the 256 million tonnes of soy used in animal feed on an annual basis, only 2,2 million tonnes is certified as sustainable soy’* (Koeleman, 2019: 11), illustrate the difficulties regarding the dependence on third countries that are not bound to the same production standards, health and environmental requirements. In order to reduce import dependencies, in 2012 the BMEL developed a ‘Protein Crop Strategy’ (Eiweißpflanzenstrategie) to support the domestic cultivation of protein crops. As a result, the cultivated area of protein rich leguminous crops increased by about 80.000 hectares (between 2014-2016). However, current domestic soy production levels only meet a fraction of the demand and account for only 1-2% (Deutscher Sojaförderring e.V., 2019), see figure 2: ‘Soy meal demand vs. supply’. With respect to the global developments and limited options to close the protein gap by cultivating domestic protein crops, the German government and agricultural sector is also focusing on supporting innovation and novelties in the field of protein products.

Figure 2: ‘Soy meal, demand vs. supply’



(Source: OVID, 2018a. Sojaanbau in Deutschland auf Erfolgskurs: Importe weiter unverzichtbar. Verband der Ölsaatenverarbeitenden Industrie in Deutschland (OVID)).

2.3.3 German poultry and pig market

Over the last eight years, Germany transitioned from a net importer to a net exporter of poultry and pork meat (Thünen Institute, 2019). With an annual export volume of more than 2 million tons, Germany even ranks as the single largest pork exporter (Thünen Institute, 2019).

Poultry and egg production

Poultry meat holds a dominant position on current and future global meat markets. It is expected that poultry meat will account for nearly half of all the additional meats to be produced over the next decade (OECD- FAO, 2016). The German poultry sector produces about 1,5 million tonnes of poultry meat and approximately 14,3 billion eggs (BMEL, 2018b). It generates an annual average of 3,6 billion Euros (between 2014-2016) (BMEL, 2018b). To achieve this production volume, the current number of 49.100 German poultry farmers keep 174 million animals and slaughter 689 million animals on an annual basis (BMEL, 2018b). Organic production accounts for only 1% of poultry meat and 10,5% of egg production.

Similar to the global market trend, German demand in poultry meat is steadily increasing, from an average per-capita consumption of 5,6 kg in 1985 to 12,4 kg in 2017 (BMEL, 2018b). Between 2014 to 2016, the domestic self-sufficiency rate of poultry meat reached 110%, while domestic egg production reached 72% (BMEL, 2018b). This makes Germany a net exporter of poultry meat and net importer of eggs. Market data on the self-sufficiency in organic eggs and poultry is not readily available.

Pig production

Pig production is the core business of the German farming sector. With an annual slaughter of 59 million animals and an average pig population of about 28 Million animals (BMEL, 2018b), Germany is the third largest pig producer in the world. German consumers consider pig meat their meat of choice. However, domestic per capita pig meat consumption is decreasing. In 2017 German consumers displayed an average per-capita consumption of 59,7 kg of pig meat, which is 800 grams less than in 2016 and 2,7 kg less than in 2007. At the same time, domestic pig production increased (by 9,5% compared to the level reached in 2007). With a production volume of approximately 5,6 tonnes (BMEL, 2018b) the sector generates a self-sufficiency rate of 118% (BMEL, 2018b). The annual export volume of more than 2 million tonnes makes Germany the world’s largest pork exporter (Thünen Institute, 2019). Organic pig meat accounts for only 0,4% of the domestic production volume. The organic pig population comprises about 250.000 animals (Naturland, 2019a). The self-sufficiency rate of organically produced pork stands at 72% (Tölle, 2018). Yet, the willingness of conventional farmers to convert to organic farming is hesitant, due to high investments in stable modifications, uncertainty of future changes in the standards and skepticism regarding the feed supply with 100% organic feedstuff (Tölle, 2018).

Admixture quota for organically produced poultry and pig products

Due to shortcomings in the supply of organically produced protein feed for poultry and pig production, the EU regulation on organic farming ((EU) 889/2008: Article 43) introduced a three-year transitional period that allowed the admixture of non-organic feed. The regulation provided a phased plan that for the time period 1.1.2009- 31.1.2009 allowed an admixture of 10% non- organic feed produce and for the time period of 1.1.2010- 31.12.2011 an admixture of 5% non-organic feed produce. Due to the fact that organically produced feed supply could not keep up with its demand, the admixture quota of 5% of non-organic feed produce in poultry and pig products has since been extended. Yet, the next amendment of the EU regulation on organic farming in 2021 is aimed at ending the derogations concerning the use of non-organic feed products in organic produce (Regulation (EU) 2018/848).

2.4 EU regulatory framework

To understand the context in which the insect feed niche evolves, this chapter gives an overview on the current regulatory setting the insect niche is embedded in. Within the history of European food culture, the consumption of insects never played a significant role. This is why the idea of producing, processing and using insect ingredients in food and feed products was not an aspect to be considered when current European food and feed legislation was established. With the occurrence of insect- based feed and food products on the European market, especially within the last five years, relevant legislation was reviewed and amended to suit the policy strategy of the European Union. The following chapter gives an overview on current legal requirements regarding the production, the processing and marketing of insect protein in the European Union. For a better overview of the applicable regulations relevant to insect production, processing and marketing, this chapter also provides a tabular summary which can be found in the annex of this work (Annex 1: ‘Summary of the legal requirements for insect proteins’).

2.4.1 Statutory provisions on the use and marketing of insects and insect derived feed products

According to the 'General Food Law' (Regulation (EC) No 178/2002), which forms the foundation of the European food and feed regulation, a 'feed business' is defined as *'any undertaking whether for profit or not and whether public or private, carrying out any operation of production, manufacture, processing, storage, transport or distribution of feed including any producer producing, processing or storing feed for feeding to animals on his own holding'* (Article 3 (5) of Regulation (EC) No 178/2002) and 'feed business operators' are defined as '*the natural or legal persons responsible for ensuring that the requirements of food law are met within the feed business under their control'* (Article 3 (6) of Regulation (EC) No 178/2002). Following these definitions, insect feed production can be categorized as a 'feed business' and actors involved in the breeding, rearing, processing and marketing of insect feed can be defined as 'feed business operators'. The 'General Food Law' also specifies 'feed' as *'any substance or product, including additives, whether processed or unprocessed, partially processed or unprocessed, intended to be used for oral feeding to animals'* (Article 3 (4) Regulation (EC) No 178/2002). Specifications laid down in the 'General Food Law' and in the 'Feed Marketing Regulation' require animal feeds to be safe and to not have adverse effects on the environment or animal welfare (Article 15 of Regulation (EC) No 178/2002; Article 4 (1) of Regulation (EC) No767/2009). European feed law distinguished four categories of animal feed: feed materials, compound feed including pet food, feed additives and medicated feed. While feed additives and medicated feeds are regulated under separate legislative provisions, feed materials and compound feed recognized under the 'Feed Marketing Regulatory' are listed in the 'Catalogue of feed materials' (Regulation (EU) 2017/1017 amending Regulation (EU) No 68/2013). Since the introduction of an amendment in 2017, four entries on the 'list of feed materials' under the classification '*Land animal products and products derived hereof*' refer to insects or insect derived products:

1. Animal fat (entry 9.2.1): Product composed of fat from land animals, including invertebrates other than species pathogenic to humans and animals in all their life stages.

2. Processed animal protein (entry 9.4.1): Product obtained by heating, drying and grinding whole or parts of land animals, including invertebrates other than species

pathogenic to humans and animals in all their life stages from which the fat may have been partially extracted or physically removed.

3. Terrestrial invertebrates, live (entry 9.16.1): Live terrestrial invertebrates, in all their life stages, other than species having adverse effects on plant, animals and human health.

4. Terrestrial invertebrates, dead (entry 9.16.2): Dead terrestrial invertebrates, other than species having adverse effects on plant, animals and human health, in all their life stages, with or without treatment but not processed as referred to in Regulation (EC) No 1069/2009.

Within the 'Catalogue of feed materials' it is further specified that marketing of these feed materials requires compliance with the 'Animal By-products Regulation' (Regulation (EC) No 1069/2009) and Regulation (EU) No 142/2011) and that they may be subject to the restrictions imposed by the 'TSE- Regulation' **(**Regulation (EC) No 999/2001)**.**

The ABP Regulation determines the animal feed hygiene and safety requirements for animal by-products and derived products. Based on risk assessment that identifies the risk that they pose to the public and animal health, the ABP Regulation categorizes feed materials into three categories, with category 1 containing feed materials with a very high risk; category 2 containing feed materials with a high risk and category 3 containing feed materials with a low risk. Article 10 (l) of the ABP Regulation classifies 'aquatic and terrestrial invertebrates other than species pathogenic to humans or animals' as a category 3 material. As a category 3 material, insects can be used as feed ingredient for farmed and pet animals if they do not pose an unacceptable risk to public or animal health. To eliminate such unacceptable risks and following the above mentioned specifications of the 'Feed Marketing Regulation' with the basic principle that *'animal feed may only be marketed and fed to animals if it is safe and if it does not have a direct adverse effect on the environment or on animal welfare'* (Article 4 (1) of Regulation (EC) No767/2009), authorization of insect species reared in the EU for food or feed products is based on three criteria:

1. The insect species shall not be pathogenic or have any adverse effects on plant, animal or human health.

2. The insect species shall not be recognized as vectors of human, animal or plant pathogens.

3. The insect species shall not be protected or defined as an invasive alien species.

Insect species that fulfill these safety conditions are listed on a newly established positive list in the annex X (Regulation (EU) No. 2017/893) of the ABP Regulation. This currently applies to seven insect species: Black soldier fly (Hermetia illucens), house fly (Musca domestica), yellow mealworm (Tenebrio molitor), lesser mealworm (Alphitobius diaperinus), house cricket (Acheta domesticus), banded cricket (Gryllodes sigillatus) and field cricket (Gryllus assimilis).

Transmissible Spongiform Encephalopathy (TSE) 'TSE- Regulation' (Regulation (EC) No 999/2001)

Following the Bovine Spongiform Encephalopathy (BSE) scandals of the late 1980s and the findings that linked emerging BSE cases to contaminated feed with infected ruminant protein in the form of processed animal protein (PAP), a ban on feeding ruminant protein to ruminants was adopted in 1994. BSE cases dropped significantly but still occurred due to cases of cross-contamination between ruminant, pig and poultry feed. As a consequence, a general PAP feed ban for 'farmed animals' (animals that are kept for the production of food, feed or other derived products) was adopted in 2001. Today, legal basis of the general feed ban rules and all legislative actions on Transmissible Spongiform Encephalopathy (TSE) are laid down in Regulation (EC) No 999/2001, also known as 'TSE- Regulation'. As protein derived from insects is defined as processed animal protein (Entry 9.4.1 of the 'Catalogue of feed materials'), the 'feed ban' provisions contained in the TSE Regulation do not allow the use of insect derived protein to be used in feed for 'farmed animals' (e.g. pigs, poultry, cattle, sheep). In 2013, with the amendment of Regulation (EU) No 56/2013, the feed ban was partially lifted. With this amendment, the European Commission re-authorized the use of PAPs derived from non-ruminant farmed animals (e.g. pig and poultry) in fish feed for farmed fish and other aquaculture animals. However, due to the wording of the regulation the opening did not apply to insect PAP. After a second amendment in 2017, with a revision of the legal text, PAP derived from insects and compound feed containing such processed animal protein are now authorized for feeding of aquaculture animals (Regulation (EU) 2017/893).

As living insects are not defined as an ‘animal-by product’ and are thus not regulated under the ‘Animal By-products Regulation’, they may be fed to non-ruminant animals if authorized by the competent authority of the Member State. However, live insects may not be fed to ruminants as Article 7(1) of the ‘TSE Regulation’ prohibits the use of any animal proteins in feed for ruminants (e.g. cattle, goats, sheep). The exceptional case for live insects does not apply to dead insects not processed as referred to in Regulation (EC) No 1069/2009 (e.g. whole insects, dry frozen insects). These insects are only approved for pet food and as feed for fur animals. With authorization of the competent authority of the Member State, it is allowed to use living insects as feed for non-ruminant (e.g. poultry and pigs), if they are reared on authorized substrates. It is not allowed to feed living insects to ruminants (e.g. cattle, goats, sheep). The general feed ban also doesn’t apply to fat and oils derived from insects, which listed as ‘animal fat’ (Entry 9.2.1 of the ‘Catalogue of feed materials’) can be marketed as feed ingredient for all animal species.

Article 14 (ii) and (iii) and Article 18 (1) of the ABP Regulation do allow insects and insect derived products to be used in feedstuff for fur animals (e.g. mink), pet animals (e.g. cats and dogs), for zoo and circus animals as well as for wild animals (e.g. birds, fish).

2.4.2 Statutory provisions on the feedstock applicable as feeding substrate for insects

In 2015, upon request of the European Commission, the European Food Safety Authority (EFSA) conducted a risk profile assessment of the microbiological, chemical and environmental risks arising from the production and consumption of insects as food and feed. In this risk assessment, the EFSA concluded that ‘*when currently allowed feed materials are used as substrate to feed insects, the possible occurrence of microbiological hazards is expected to be comparable to their occurrence in other non-processed sources of protein of animal origin’* (EFSA, 2015: 1).

According to Article 3 (6) of the ABP Regulation, insects intended for food or feed production are defined as ‘farmed animals’. With this classification, EU feed material provisions of the ‘Animal By-products Regulation’ and the ‘Feed Marketing Regulation’ not only regulate the use of insects and their derived products but also apply to define which feedstocks are suitable to feed them. As laid down in the ABP Regulation, the use of category 1 (inter alia: catering waste) and category 2 (inter alia:

manure) feed materials is not permitted as feeding substrate for insects. In addition, Annex III of the 'Feed Marketing Regulation', which lists the '*materials whose placing on the market or use for animal nutritional purposes is restricted or prohibited'*, prohibits the use of the following materials as feed material for 'farmed animals':

> *1. Faeces, urine and separated digestive tract content resulting from the emptying or removal of digestive tract, irrespective of any form of treatment or admixture.*
>
> *2. Hide treated with tanning substances, including its waste.*
>
> *3. Seeds and other plant-propagating materials which, after harvest, have undergone specific treatment with plant- protection products for their intended use (propagation), and any by-products derived therefrom.*
>
> *4. Wood, including sawdust or other materials derived from wood, which has been treated with wood preservatives as defined in Annex V to Directive 98/8/EC of the European Parliament and of the Council of 16 February 1998 concerning the placing of biocidal products on the market (1).*
>
> *5. All waste obtained from the various phases of the urban, domestic and industrial waste water as defined in Article 2 of Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (2), irrespective of any further processing of such waste and irrespective also of the origin of the water.*
>
> *6. Solid urban waste, such as household waste.*
>
> *7. Packaging from the use of products from the agri-food industry, and parts thereof.*[5]

As 'farmed animals', insects are also subject to the feed ban rules provided by the TSE-Regulation (Regulation (EC) No. 999/2001) and may not be fed with any form of PAPs other than fishmeal. Annex II of Regulation (EU) 2017/893 (which authorizes the use of PAPs in aquaculture) specifies that feeding substrate of insects *'may only contain products of non-animal origin or the following products of animal origin of Category 3 material:'*

> *-fishmeal,*

[5] Annex III of Regulation (EC) No 767/ 2009

-blood products from non-ruminants,

-di- and tricalcium phosphate of animal origin,

-hydrolysed proteins from non-ruminants,

-hydrolysed proteins from hides and skins of ruminants,

-gelatine and collagen from non-ruminants,

-eggs and egg products,

-milk, milk based-products, milk-derived products and colostrum,

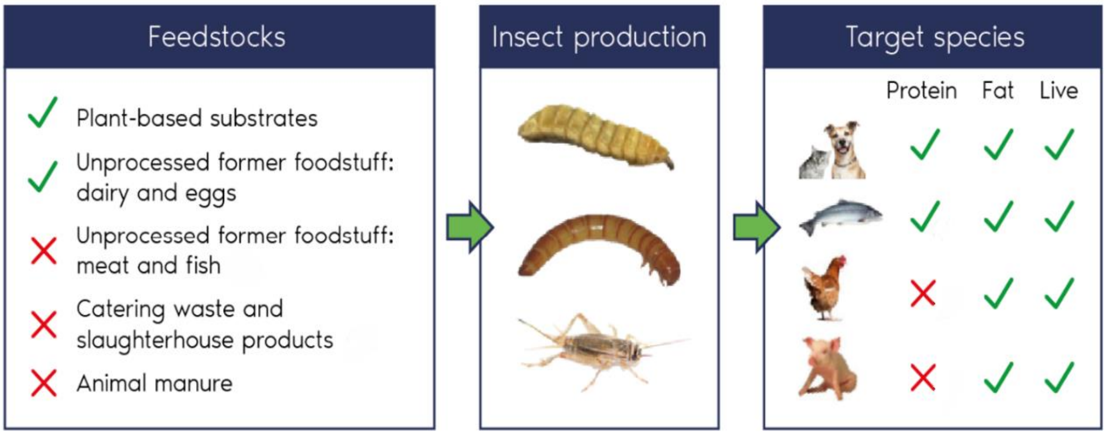
-honey,

-rendered fats.[6]

Section 10 of Regulation (EU) No 142/2011 (implementing the ABP Regulation) also includes the use of unprocessed former foodstuffs[7] as a feed material for 'farmed animals'. Yet, to eliminate any form of PAPs in insect feeding substrate**,** this approval is not valid for the use of unprocessed former foodstuffs containing meat or fish components.

Figure 3 'Overview legal authorization and restrictions regarding insect production' summarizes the main provisions of the 'TSE-Regulation' and 'Feed Marketing Regulation'.

Figure 3: 'Overview legal authorizations and restrictions regarding insect production'



(Source: IPIFF, 2018: 12)

[6] Annex II of Regulation (EU) 2017/893
[7] Foods produced for human consumption but which is no longer intended for human consumption for reasons such as expired use-by date or due to problems of manufacturing or packaging defects.

2.4.3 Statutory provisions on the production and processing of insects

As a ‘feed business’, insect feed production is subject to the ‘General Food Law Regulation’, as well as the requirements of the ‘Feed Hygiene Regulation’ (Regulation 183/2005 EC). These regulations determine the safety, traceability and manufacturing requirements the insect business must comply with. Under the current regulative setting, animal feed products are considered safe and marketable, when they comply with the feed hygiene standards (Regulation 183/2005 EC), with the rules for feed marketing (EC Regulation 767/2009), the rules for feed additives (Regulation (EC) No 1831/2003), the rules for medicated feed (Directive 90/167/EEC) and if they are free from undesirable substances as laid down in Directive 2002/32/EC. Besides fulfilling these general hygiene and safety requirements, the production of insects, as a ‘category 3’ material, urges insect producers to also comply with the legal obligations of the ABP-Regulation (and its implementing Regulation (EU) No 142). The ABP Regulation requests:

-the insect processing establishment to be approved by the competent authority of the Member State,

-the insect producer to be registered as a ‘feed business operator’,

-the insect to be processed according to processing method 1-5 or processing method 7.

Particularities of the processing methods 1-5 and processing method 7 are given in Annex IV of Regulation (EU) No 142/2011 (implementing the ABP Regulation) and refer to the particle size of the animal by-product to be processed and the different forms of pressure sterilization applicable. As insects intended for food or feed production fall within the definition of ‘farmed animals’, insect production is also subject to Article 10 of the ‘Animal Health Law’ (Regulation (EU) 2016/429) and must comply with physical measures concerning insect farms and management measures to ensure animal health and biosecurity at the rearing plants. Yet, as invertebrates, insects are excluded from Directive 98/58/EC concerning the protection of animals kept for farming purposes (Article 1 (2) of Directive 98/58/EC). Insect farming is therefore not subject to specific animal welfare rules.

2.4.4 Statutory provisions on the marketing of food products containing insects

In addition to the general regulatory framework applicable to all EU food businesses, the production and marketing of food products containing insects or insect ingredients is regulated under the 'Novel Foods' legislation. The regulatory framework of the 'Novel Food Regulation' was adjusted and revised in 2015 and became effective in 2018. Following this revision, food that had not yet been used or consumed within the EU before 15th May 1997 and food falling under one of ten newly specified food categories is now defined as 'Novel food'. Pursuant to Article 3.2 (a) vii and preamble 8 of the 'Novel Foods Regulation' ((EU) No 2015/2283), insects and insect parts are now explicitly covered by the regulatory framework. Since 1st January 2018, insect products are now admitted for sale on the European market under the condition that the specific product is listed on the positive list of authorized novel foods (Union list of novel foods-Regulation (EU) 2017/2470). Companies producing or marketing a food product containing insects or insect ingredients that is not yet established on this list need to receive a priori authorization for commercialization, which is granted or denied based on a product related risk assessment conducted by the European Food Safety Authority (EFSA). This authorization process is not related to the applicant, once a novel food is added onto the Union list, it is automatically considered as being authorized and any food business operator can place the 'novel food' on the market.

3. METHODOLOGY

The following section gives an overview on the research objective and research process of this work. It illustrates how the analytical framework was developed and how significant materials and data were collected.

3.1 Research objective

The need to resolve persistent sustainability deficiencies of agricultural production systems, while simultaneously having to comply with increasing demand pressures, has led to an emphasis on sustainability innovations and sustainability transitions as a high-priority topic in science, politics and economics (Markarrd, 2012; OECD, 2011; UNEP, 2011, Frantzeskaki and Loorbach, 2010; Grin et al., 2010; Smith et al., 2005). With the understanding that global animal feed production proves to be a defining issue to resolve sustainability deficiencies of the agricultural sector (Koeleman, 2019; Forum for the Future, 2017), feed novelties as insects, algae and single cell proteins have built momentum. Low land and water requirements and the ability to convert unused organic waste and side-steams into valuable protein ingredient particularly drew attention towards insect feed innovations. However, notwithstanding considerable attention, the actual practical integration of insect protein feeds into existing agricultural systems is still in its infancy. On the European market, diffusion varies from country to country. While the Netherlands earned a reputation as a pioneer in the field of insect protein innovations, the German involvement in the field is rather low. National differences in the development of the insect protein novelty, despite a communal regulative setting on EU level, indicate that successful 'out-of-the-niche' development is depending on context specific enabling conditions. With the intention to explore specific determinants for the 'out-of-the-niche' development of the insect protein novelty on the seemingly inert German market, this thesis directs its focus on the following research questions:

1.What are the current structural components (actors, institutions, networks and technological structures) and what are the functional processes of the German 'insect protein solution' for animal feed?

2.Which opportunities does the German Insect Industry provide that could help the sector to develop? What are the obstacles the German Insect Industry faces and how can the sector transform or cope with them?

3.What kind of structural effort (enabling conditions) is needed to design and deliver a legitimate and trusted 'Insect protein solution' as an agricultural niche to ultimately challenge the current protein provision sector?

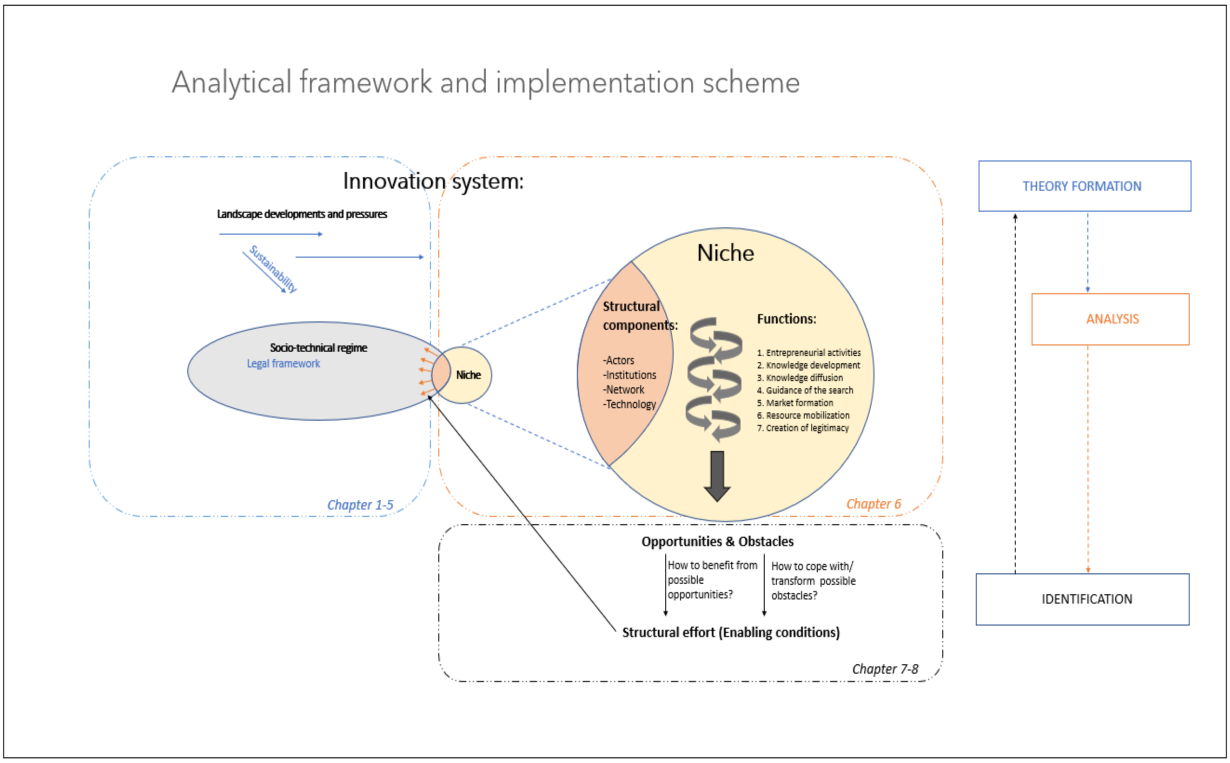
By answering these research questions, the work shall give insight into the innovation system's behavior and performance and shall contribute to a better understanding of sustainability innovations in agriculture.

3.2 Analytical concept

The research approach of this master thesis is embedded in an explorative research design. Given the relative novelty of the sector, quantitative data to measure the performance of the innovation system is not readily available. Besides, due to the regulatory restrictions that currently hamper market development (see legislative framework), quantitative parameters such as market data or consumer acceptance would have reduced explanatory power and disregard the functional processes within the

innovation niche. While quantitative parameters could be useful to indicate the performance of an innovation at a later stage in its development, they are not suited to provide sufficient insight into the ‘take-off’ phase of a novelty, where breakthrough is dependent on qualitative processes such as interaction, cooperation and linkages among multiple actors and layers. Multiple on-going attempts to better understand the special characteristics of sustainable innovations and the conditions under which they emerge and diffuse, showed that applying a systems perspective on innovations can be a suitable tool to assess novelties in different contexts (Bergek et al., 2008; Hekkert et al., 2007). As the TIS perspective suggested by Bergek et al. (2008) offers a good basis to analyze the collective activities that generate and establish innovations, it is chosen as the starting point for this analysis. By combining a structural and functional approach, the TIS analysis considers the structural components as the actors, institutions, networks and technology that constitute a system, as well as the functional processes that induce the innovation process and indicate the performance of a technical innovation system (Wieczorek and Hekkert, 2012). Yet, the focus of the TIS approach is dedicated to a defined moment in time and closely tailored around the innovation system. While this perspective entails the benefit of an increased insight into the innovation systems’ performance, it is criticized for giving too little attention to the external developments and pressures that influence and direct the emergence of innovations (El Bilali, 2018; Weber and Rohracher, 2012). Especially in the light of the influence that factors like normative pressures and societal concerns have on innovation developments (e.g. sustainability deficiencies, animal welfare). An approach that considers the wider focus and scope on the emergence of innovation is the MPL perspective suggested by Geels (2005). With the idea that innovations evolve with developments and interlinked processes on macro-, meso- and micro- level (the landscape level, the regime level and the niche level), this perspective sets an adequate framework to analyze co-evolutionary processes that generate innovations and their relevance for strategic transformations of broader systems (entire production and consumption system).
To establish a convenient reference frame that suits the presented research objective of this work, consistent with Markard and Truffer (2008), it was chosen to combine the TIS approach and the MPL perspective into an appropriate analytical framework as illustrated in figure 4, ‘Analytical framework and implementation scheme'.

Figure 4: 'Analytical framework and implementation scheme'



(Source: Own representation)

On this basis, the implementation scheme of this master thesis comprises three consecutive steps:

The first part of this work (chapter 1-4) sets the theoretical framework for the analysis. It explores landscape developments and pressures in which the innovation evolved, depicts the theoretical foundations of sustainability innovation and systems theory and gives an overview on the current state of knowledge. For a better understanding of the socio-technical regime the niche is embedded in, chapter four introduces the corresponding legal framework.

The second part of this work focuses on analyzing the structural components (actors, institutions, networks, technology) and the functional processes (1. Entrepreneurial activities; 2. Knowledge development; 3. Knowledge diffusion; 4. Guidance of the search; 5. Market formation; 6. Resource mobilization; 7. Creation of legitimacy) of the innovation niche. This analysis gives insight into the systems behavior and performance (Alkemade et al., 2007) and demonstrates opportunities and obstacles the insect protein feed industry faces.

The third part of this work discusses how the identified obstacles could be transformed or coped with and how possible opportunities could be used in order to help the insect protein innovation to ‘break through’. With regard to the theoretical foundations, it will also be discussed what kind of structural effort will be needed to ultimately challenge the current protein provision sector while maintaining the concept of sustainability.

3.3 Materials and Data collection

The data foundation for this thesis was gained by a combination of an extensive literature review, the execution of expert interviews and by participatory observations during expert exchange events.

Desk research

The literature review forms the basis of the master thesis. It covers three thematic areas: (1) the theoretical foundations behind innovation processes and the special features of sustainability innovation; (2) the societal relevance of sustainability transformations in agriculture and protein feed as a defining issue; (3) an introduction to insect protein feed as the object of investigation (status quo) and exploration of the regulatory framework it is embedded in. Relevant literature includes academic and scientific articles as well as reports on research projects and relevant legal texts.

Expert Interviews

Potential interview partners were identified by an extensive desk research and by a screening of the FAO ‘Edible Insect Stakeholder Directory’. Interviewees were then selected with the aim to gain insight from the different perspectives of the private sector, the research sector, from farmer’s associations and the feed industry. Eventually, four semi-structured expert interviews with relevant stakeholders were conducted (see table 1: ‘Conducted interviews’). While it could be argued that this rather small number of interviews provides only a limited information base, it should be considered that due to the novelty of the endeavor, the field of experts suiting the selection criterion (animal feed, different background/perspective) is currently still very limited. To remedy shortcomings in information base and to keep an explorative and flexible approach, it was chosen to conduct semi-structured interviews. With the help of a related questioning scheme (Annex 2: ‘Interview questioning scheme’) and guiding questions (Annex 3: ‘Guiding questions for expert interviews’), the focus was kept on the specific research subjects. In order to keep up the narrative flow and to open possibilities for addressing new or additional information or personal contributions, the questioning scheme functioned as the common thread, while the guiding questions were used as fall-back in order to get a deeper insight into specific subject areas and to provide a comparable framework for subsequent analysis. The interview questions were designed to elicit responses regarding the current opportunities and obstacles the insect industry faces, a personal assessment of the sustainability of insect protein feed, a description of the structure and functioning of the German insect industry, as well as the perception of envisaged enabling conditions and a future outlook. The interviews lasted between 60 to 90 minutes and were all recorded to facilitate reworking the data. Subsequent to each meeting, the interviews were transcribed. Individual-related references and specific statements (especially regarding the functioning of the niche, the obstacles it faces and mentioned enabling conditions) were then used to identify stakeholders and to complement the guiding questions for subsequent interviews. This response-driven technique (Biernacki and Waldorf, 1981) allowed to detect consistencies, ambiguities and deviations among the experts and provided a framework to moderate the shortcomings of the small sample size. The collected data was then coded and analyzed with the help of the qualitative data analysis software 'MAXQDATA'. The coding process followed both a deductive approach with pre-specified codes, which reflected the analytical levels as presented in the analytical framework and an inductive approach that allowed including new aspects and peculiarities (see Annex 4: 'List of MAXQDA codes').

Participatory observations during workshops and conferences

In addition to the interviews, the research process also included the attendance of two topic related events: the final workshop of the doctoral program *'Sustainability transitions - alternative protein sources from a socio-technical perspective*', organized by Georg-August Universität Göttingen and the conference *'Food of tomorrow- Science and Fiction'*, organized by the German Agricultural Alliance (Deutsche Agrarforschungsallianz DAFA) (see Annex 5: 'Program of the doctoral program Sustainability Transitions' and Annex 6: 'Program of the DAFA Forum'). Participants were experts with different backgrounds from the research and industry domain. The participatory observation during these events provided a deeper insight into the current state of the research, the perceived research needs and the current opportunities and obstacles. Discussions and the interaction among relevant experts also provided empirical insights into the functionality of the insect protein niche. Memos were collected and transcribed according to the topic areas of the questioning scheme (Annex 2: ‘Interview questioning scheme’). They were analyzed in accordance with the procedure described for the evaluation of the interview data and served as a substantiation and complementation of the findings.

Table 1: ‘Conducted interviews’

Interview	*Domain*	*Occupation within the insect industry*
1	Research	Research field insects as food and feed
2	Private sector	Producer of insect protein
3	German Farmer's Association	Feedstuff advisor
4	Organic farmer’s federation	Feed expert

Systems boundaries and limitations

By analyzing the German insect protein feed sector, it was chosen to set the systems boundaries on a national and sectoral scale. On this basis, subsequent works can more distinctly identify national differences in the structure and functioning of the insect innovation niches and compare specific enabling conditions. In accordance with the perception that insect protein feed products stand a better chance at prevailing on European markets compared to the uptake of edible insect products in human consumption (PROteINSECT, 2015), the scope of this thesis was set on analyzing insect protein in animal feed. However, due to the fact that both application strategies are closely linked, it was not sensible to strictly focus the analysis on the feed application alone but to keep an open approach with regard to the developments in both fields. As dynamic entities, innovation systems are steadily changing and evolving. Against this background, the depicted state of the German insect protein feed innovation system is limited to the defined moment and contextual setting of the analysis.

4. FINDINGS

The following section presents the findings in accordance with the analytical framework conceptualized in Chapter 3 ‘Methodology’. First, following the structural- oriented analysis, an overview on the structural components of the German insect protein niche is provided. In a second step, following an analysis of the functional processes, the functional dynamics of the insect niche are presented. Both analyses were conducted in order to identify possible opportunities and obstacles for the performance of the German insect protein feed novelty.

4.1 Structural components of the German insect protein niche

4.1.1 Actors

The German insect sector engages various actors with different roles, stakes and power. As a ‘system in the making’ and with the holistic vision of insect production as the ‘missing link’ (van Huis et al., 2013) of a circular and sustainable protein feed production, the novelty not only aims at the introduction and acceptance of a new product (product innovation) but also touches innovations on process, technological and organizational level of the animal production system. This explains the wide range of actors involved with the topic. Based on the expert interviews and participatory observations, actors currently contributing to or impacting the ‘insect innovation niche’ can be attributed to three domains: (a) the private sector domain, (b) the academic and research domain and (c) the legal domain.

(a) Private sector domain

Actors of the private sector domain are the insect producing entrepreneurs who aim to open the market for livestock feed products as well as entrepreneurs aiming to start-up new businesses in this sector. In Germany, these actors are companies active in rearing beneficial insects (e.g. ‘Hermetia’), companies rearing insects as feed for zoo and pet animals (e.g. ‘Green petfood’; ‘tenetrio’; ‘Bugs International’) and companies aiming to broaden their portfolio or maintaining their market position (e.g. investments of ‘Wiesenhof’) (Interview 3). Due to shifting power constellations within the pig and poultry production value chains, large-scale processing companies (e.g. ‘Wiesenhof’, ‘Röthkötter’) as well as cooperatives and farmers associations (e.g. ‘Naturland’, ‘Bioland’, ‘Demeter’) were identified as actors with a special role in the niche development (Interview 3; Interview 4; Conference ‘Sustainability Transitions). As farmers produce for or under the label of these companies or farmers' associations, they are contractually tied to designated production specifications and guidelines. In these settings, the decision- making power for input factors like feedstuff is no longer inhibited by the farmers alone but moved to higher levels in the animal-production value chain (Interview 3; Conference 'Sustainability Transitions). Another group identified with great market power are actors of the compound feed industry (feed mills, feed companies, e.g. 'Agravis', 'Evonik'), since they are the ones to decide which feed ingredients to list and market (Interview 3; Interview 4; Conference 'Sustainability Transitions). As there is still ambiguity whether the practical implementation of insect production will establish in decentralized production units on farm level (Interview 3; DAFA) or in specialized large-scale insect production facilities with a centralized approach (Conference 'Sustainability Transitions'; Interview 3; Interview 4; DAFA), the role of farmers is still unclear. In both scenarios, insect farming is depending on actors involved in technical solutions and industrial applications (e.g. 'Bühler') as well as actors from the financial market (Interview 2; DAFA).

(b) Academic and research domain

Actors of the scientific community, involved in researching different aspects of the insect protein innovation can be found at universities (e.g. 'Universität Göttingen', 'Hochschule Bremerhaven', 'Universität Greifswald), research institutions (e.g. 'FiBL', 'ATB', 'Fraunhoferinstitut') and within international organizations (e.g. 'FAO'). Experts identified the involvement of actors of the research domain as a key component for the 'out of the niche' development of insect proteins (Interview 2; Conference 'Sustainability Transitions'; Workshop 'DAFA').

(c) Legal domain

Government bodies with an influence on the German insect sector exist on a national level, represented by the institutions of the German government (e.g. 'BMEL', 'BfR', 'BVL') as well as on EU level, represented by the institutions of the European Union ('European Commission', 'EFSA', 'DG Sante'). With the communal regulative setting of food legislation, authorization of insect feed ingredients is a competence of the EU. All experts agreed that due to the current legal restrictions of insect PAP in pig and poultry feedstuff, actors of the legal domain represent the key actors shaping the future of the emerging European insect protein sector and exhibiting decisive power.

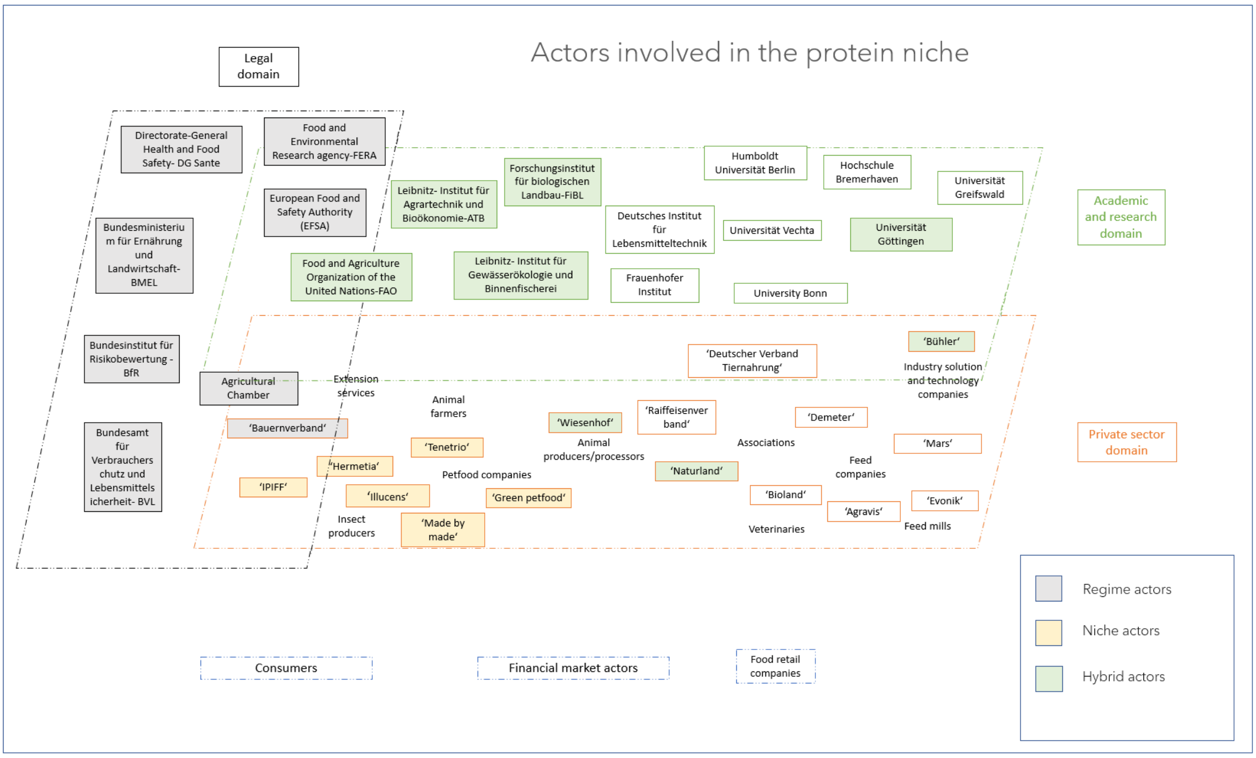
Based on the experts' statements related to the perceived role of the different types of actors, Figure 5 (Actors involved in the protein niche) gives an overview on the actors currently involved with the 'insect protein niche' and clusters them according to the domain they are imbedded in.

Actors that cannot be attributed to only one of the domains or actors that move between the scope of certain domains are depicted in the area of overlap. While the area of overlap illustrates the constant state of interlinkage and exchange between the domain types, actors of the overlap sphere are of particular interest for the niche development because, once invested in the topic, they could function as intermediaries and intercessors.

Depending on the level of involvement, stake and attitude towards the insect protein idea, actors display traits that assign them more towards the niche or more towards the regime level (see Figure 5). Actors with an active role in supporting the insect niche and with an interest in changing or restructuring the current status quo can be attributed to the niche level. In case of the insect niche, these actors are economically or ideationally invested and act as the prime movers and supporters of the niche (Conference 'Sustainability Transitions'; Interview 1; Interview 3).

Actors that apply prevailing cognitive, formal or normative rules towards the novelty and thus reproduce the current rule-system can be attributed to the regime level. Reproducing the status quo can be a result of inertia (actors are not concerned with the novelty or have a knowledge deficit of the context in which the novelty evolved) or rejection (actors disapprove of the novelty). Both regime actor types can be found in the insect protein innovation system and are mainly associated with the 'legal domain' but can also be found within the private sector and research domain (Interview 1); Conference 'Sustainability Transitions'). Regime actors within the insect protein innovation system are characterized as being guided by determinants like prevailing power constellations and by the 'market logic' (price, quality and quantity, economic rentability) (Conference 'Sustainability Transitions'). These behavioral patterns entail 'lock-in' and 'path dependency' effects. Organization and management processes along the existing animal production value chain are aligned to the application of traditional protein sources, particularly soy; any deviation from this path is associated with additional effort, cost and uncertainty. This 'lock-in' into established trajectories will challenge the out-of-niche development of insect protein feed. While the dichotomous distinction between niche and regime actors can help to evaluate the level of support and resistance within an innovation system, it does not mirror the reality due to the blurring lines between the levels. Niche and regime level are interdependent, actors '*interact within the constraints and opportunities of existing structures, while simultaneously acting upon and restructuring these systems'* (Geels, 2005: 11). This 'duality of structure' (Geels, 2005) implies that actors, due to momentum and interaction, cross the lines of the levels or move in a sphere that cannot be assigned to either one of the levels. These 'hybrid' actors (see Darnhofer, 2015) are knowledgeable of the novelty and display a general interest but compared to the innovators, they maintain a more cautious attitude. For the insect protein innovation system, this attitude applies mainly to actors of the 'academic and research domain' (Interview 1; Conference 'Sustainability Transitions') but they can also be found along the value chain (certain farmers associations and processing companies) and even within the legal domain (Interview 3; Interview 4).

Figure 5: 'Actors involved in the protein niche'



(Source: Own representation)

4.1.2 Networks

With the theoretical understanding of innovations as '*collective endeavors emerging from the interaction of multiple actors*' (Geels, 2005: 34), an overview on the existing network structures provides insight into the actor's openness to engage collectively and to cooperate as social groups.

Networks of the research domain

The research landscape evolving around the insect protein niche appears to be well connected. Actors of the research domain were able to establish a fair level of networking, resulting in overarching and interdisciplinary research activities. In the past few years, numerous topic related conferences were organized[8]. In 2015, the 1st national Symposium on insects in food and feed, 'INSECTA'[9], was held in Magdeburg. Now established as an annual event, the conference functions as a knowledge exchange and networking event with actors from various research disciplines, politicians and the industry (INSECTA, 2019; Interview 1). With regard to linkages and collaborations among German research institutions, one interviewee mentioned *'together we completely redesigned the research subject [and] managed to establish a new research infrastructure'* (Interview 1: 3).

Established networks between research and private sector domain

There are several established linkages between German research institutions and innovators of the insect protein niche. For the research sector this cooperation is essential to gather research data from production sites or to realize application trials. For actors of the insect niche, cooperation with the research and science sector is the key to close important research gaps and to bring more evidence in support of the feasibility and sustainability of insect protein production (Conference 'Sustainability Transitions'). Experts acknowledged that *'research and science are definitely important cooperation partners'* (Conference 'Sustainability Transitions': 174).

However, due to differing ambitions and expectations, cooperation and networking between research institutions and innovators are also charged with tension. Innovators expect researchers to clarify market- relevant uncertainties to bring the insect niche

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[8] e.g. 2016, Symposium on the topic 'insects as food and feed: nutrition of the future?' (BfR) or 2018 'Strategisches Forum- Lebensmittel von morgen: Science & Fiction'.

[9] Organized by Leibniz Institute for Agricultural Engineering and Bioeconomy and Pilot Pflanzenöltechnologie Magdeburg e. V. (PPM)

forward (DAFA; Conference 'Sustainability Transitions'; Interview 2). However, what innovators regard as urgent or relevant does not always correspond with the research interest of researchers. In order to maintain the standards of credible research, researchers keep their critical view and do not consider it their responsibility to promote insects without sound scientific evidence (Interview 1).

> *'…in my opinion, research needs to set a framework for companies to market sophisticated and not just trendy insect products' (DAFA:139)*

> *'It is not my task to promote insects, but to keep a critical view and to include different aspects' (Interview 1:28)*

Networks of the private sector domain

Linkages among German insect producers are comparatively weak (Interview 1; Interview 2). As private companies fear competition, they act rather secretive with regard to production and processing procedures. An insect producer described his unsuccessful attempt to build up contact with a fellow competitor '*I tried to get in contact…but there was no reaction'* (Interview 2: 15).

> *'We can notice a lack of collaboration due to a lack of trust.' (Conference 'Sustainability Transitions': 128)*

While some other European countries established national sector organizations to represent their specific interests (e.g. Venik- Dutch Association of Insect Producers; BIIF- Belgian Insect Industry Federation) there is no such association of German insect producers on a national level. When mentioning the lack of a German association during an interview, an expert considered the European association IPIFF to be *'the more obvious alternative since European regulation will subsequently be applicable at national level'* (Interview 1: 28). Still, the importance and need for closer collaborations among innovators was mentioned by several experts and stakeholders of the German insect sector. It was noted that a national industry organization would help to build trust among innovators and release some of the competitive tensions. It could also function as a platform for requested knowledge exchange (Conference 'Sustainability Transitions') and to create legitimacy by developing a common vision and strategy.

'On the national level there is certainly a need for organization' (Interview 1:28)

'We need cooperation with other businesses to increase knowledge exchange and shared learning experiences within the niche' (Conference 'Sustainability Transitions': 109)

'It is really important to pass information to existing networks and, by doing so, to create higher acceptance and higher capacity for action' (Conference 'Sustainability Transitions': 174)

However, on the European level, actors joined forces and established the 'International Platform of Insects for Food and Feed' (IPIFF). Founded in 2012, the organization is representing 42 members from all over Europe (including Germany). It was founded in order *'to network with and to raise awareness among the policy makers and steer them towards the 'right' direction'* (Conference 'Sustainability transitions': 17). The network is successful in its networking activities and in promoting the insect protein niche to the European institutions, thus, for example the inclusion of the Black Soldier Fly (BSF) on the positive list can be attributed to the efforts of the IPIFF (Conference 'Sustainability Transitions').

The focus is also set on establishing coalitions on a bigger scale, an IPIFF founding member explained *'we want to organize towards a global umbrella organization, there are associations in Asia, North-America and Australia…we want to bring them together, under one roof.'* (Interview 2: 16).

Networking along the value chain

Numerous experts also acknowledged the importance of intensified collaboration and communication along the value chain and assessed current linkages as insufficient (Conference 'Sustainability Transitions'). Especially when it comes to market development, it was noted that intensified communication and coordination within the animal- production value chain is seen as an essential component to bring the niche forward.

‘Opportunities within the entire range of the chain. Not only with the farmers.’ (Conference ‘Sustainability Transitions’: 170)

‘For market development it is crucial to closer engage with the agri-food and feed industry. Especially in the insect sector, to foster a collective development.’ (Conference ‘Sustainability Transitions’: 128)

‘…the communication within the value chain needs to be intensified.’ (Conference ‘Sustainability Transitions: 141)

However, networking along the value chain is slowly developing. While experts described initial difficulties to promote and sell insect protein to upstream actors of the pet feed industry (Interview 1; Interview 2), this attitude changed as some value chain actors now deliberately approach insect producers for pet feed innovations (Interview 2) or ‘*keep in touch*’ to remain up-to-date on price developments and possible production volumes (Interview 2, Conference ‘Sustainability Transitions’). During the conference ‘Sustainability transitions’, experts also identified the networking potential of and with farmers and emphasized their role as ‘hybrid actors’ or ‘change agents’ (Conference ‘Sustainability Transitions‘). As German farmers are often well connected and part of already established networks they could function as facilitators in transporting the insect niche onto the regime level and diffuse acceptance and legitimation by professional exchange (Conference ‘Sustainability Transitions). This perception is further supported when an expert described that ‘*There are in fact farmers, who call us and ask ‘what’s the deal with this insect protein? are we allowed to feed it?’’* (Interview 4: 22), which indicates that there are groups of farmers who display openness in adopting the insect protein novelty and who are well aware of innovative developments on the feed market. At the same time, current networking processes were deemed to not sufficiently include farmers, as it was stated that there is *‘still a lack of research and collaboration with fish breeders to demonstrate how insects can be used’* (Interview 1: 19).

4.1.3 Institutions

Institutions refer to formal (laws and regulations), as well as to the informal institutions (norms, values and routines), which structure and govern the social function of the innovation system. The analysis of the institutional arrangements provides information on the incumbent socio- technical regime and determines the niche actors’ scope for action.

Formal institution

While sustainability deficiencies in current production and consumption systems have been adequately proven and recognized (Conference Sustainability Transitions), experts constitute that the current institutional set- up fails to sufficiently address these deficiencies and set conditions to facilitate sustainable development. It is perceived that sustainability innovations face problems in competing with the stable 'business as usual' trajectory, if negative externalities are overlooked and not reflected by adequate pricing through political governance (DAFA).

> *'Despite the existing and adequately recognized sustainability problems of the agricultural sector, the institutional set-up is part of a stable regime and trajectory' (Conference 'Sustainability transitions': 145)*
>
> *'Addressing externalities, which play a big part in our food production system and can be influenced by consumers' food choices, is a task of politics.' (DAFA: 13)*
>
> *'At the moment we have this discrepancy, insects do not have the possibility to be established on the existing market because of a lack of economic viability, but the lack of economic viability is caused by an economy which does not set sufficient prices for sustainability aspects. If there were a nitrogen tax on soy or a …tax on fish meal, things would look different. This would need to happen in a regulatory context. Maybe less in the sense of punishing but by supporting more sustainable innovations to give them an impulse.' (DAFA: 54)*
>
> *'I think that in our country many things only change when there is a pressure from other sides (rise in soy price, economic incentives, reduced insect price).' (Interview 1: 40)*

All experts agreed that the current regulatory setting is a main factor hampering the 'out-of-the-niche' development of insect protein production. Two aspects are perceived as the main hurdles: (a) the TSE- Regulation which is not permitting insect PAP in livestock feeding of food- producing animals other than farmed fish and aquaculture animals and (b) the restrictions on feeding substrate applicable for farmed insects.

As the legal analysis (see Chapter 2.4) showed, food and feed legislation fall within the responsibilities of the European Union. While insects and insect derived products (e.g. protein and fat) are listed as feed materials, the applicable regulations of the 'TSE-Regulation' do not authorize insect protein in the form of insect PAP as a feed ingredient for food-producing livestock animals other than farmed fish and other aquaculture animals. However, when insect products emerged on the European market, the mismatch of then established food and feed regulation caused confusion and ambiguities on how these products should be regulated. Against the background that insects where never considered a potential food or feed ingredient when European food legislation was established, legal texts and legislative frameworks proved inappropriate to assess the novelty. In Germany, the lack of clear guidelines and standardized permission procedures led to uncertainty and confusion when handling registration requests and admission to trading (Conference 'Sustainability Transitions'). During the conference 'DAFA' an expert described the negotiation processes with local authorities and their taking different or inconsistent decisions *'Depending on who you talked to, you got different information, and sometimes you actually had to debate it. At one time, living insects were allowed, at another time they weren't. And then you've gone through it all and someone else suddenly says, 'living insects, yes, but not cooled.' There was a lot of uncertainty, you couldn't rely on anything.'* (DAFA: 71).
Inconsistencies in the interpretation of the legal texts became also apparent when the feed ban was partially lifted and PAP got authorized as feed ingredient for farmed fish and other aquaculture animals. Depending on the wording of the national translation, the regulation incorporated the term 'slaughterhouse' in several parts of the text and thus failed to include insect PAP, as insects per definition cannot be slaughtered. On that basis, German authorities detained permissions of insect meal for the feeding of farmed fish and aquatic animals.

> *'The legal situation was ambiguous. In the German translation, the term 'Schlachttiere' (slaughter animals) was used and because slaughter is defined as a bleeding process (Ausblutungsprozess), it was decided that insects are not allowed since insects can't be slaughtered according to the definition of a slaughter process.'* (Interview 1: 13)

'Well first, the whole thing happened like this, the BSE directive 56/ 2013 came; we were still rather naive then as association of the IPIFF, we had been to Brussels and active there; in 56/ 2013 it says that you are allowed to feed processed animal protein to fish in aquacultures if it stems from slaughterhouses in the EU. So we were happy, of course we can manage slaughterhouse criteria, but then the authorities came and said, 'wait, per definition insects cannot be slaughtered.' The definition of slaughter is blood removal for vertebrates...but insects are invertebrate. Secondly, a slaughterhouse has to be kept free of insects. So if you bring in insects, it's not free of insects.' (Interview 2: 42)

These ambiguities in the regulatory framework and the way they were handled were also identified as the reason why the German insect protein market developed at a slower pace than other European markets as for example the French or Dutch insect market (Interview 1; Interview 4). With the emergence of insect food and feed products on the European market, Germany pursued a zero-tolerance policy, while other countries, like the Netherlands, handled the same legal text more liberal and created structures and even guidelines to authorize certain insect products (Interview 1; Interview 4). On the Dutch market, insect food products were tolerated even before the amendment of the 'novel food regulation' and the insect fat fraction as well as living insects were permitted as feed ingredient for all livestock animals even before the European Commission explicitly mentioned them in the 'Catalogue of feed materials'. On that basis, insect companies in the Netherlands and France had the advantage of a sales market when other European countries still held back permissions. Experts determined that depending on the translation into the different national languages, wording of the legal text changed and gave room for different interpretations. Particular attention was given to the fact that missing or incomplete legal provisions during the initial market authorization stalled the development of insect protein novelties on the German market.

'The legislation is actually inconsistent, one could make a claim at the European Court of Justice. Originally it stated that it's forbidden to feed processed animal protein to ruminants. Which would have made sense. But then exactly what Person 2 just said happened: „ruminants" was replaced with „livestock" in general. And then people suddenly realized that they had no animal protein

anymore... especially for piglets and young animals, and then came the exemptions. But fish meal is the only exception and with that, politics has of course already deprived itself of alternative courses of action. The European Laws have numerous references and footnotes which still state „ruminants", so if you tried to challenge that, it might even be possible to succeed.' (Conference 'Sustainability transitions': 187)

'The great differences in Europe can be explained by specific approval processes in compliance with the dossier of the country.' (Conference 'Sustainability transitions': 29)

'There are transitional arrangements, which regulate, depending on the language you read them in, slightly differently, which products are allowed to be marketed' (DAFA: 69)

The slow pace in which the formal setting is evolving is met with incomprehension and caused frustration among insect niche actors. This frustration stems from a perceived lack of attention towards their interests and unnecessary bureaucratic burdens (Interview 2; DAFA). Despite its slow pace, legislation regarding the application is in a state of flux. With the authorization of insect PAP in farmed fish and aquaculture animals in 2017 and with the amendment of the 'Novel Food Regulation' in 2018, insect protein gained recognition in the legal domain. German industry experts generally expressed a positive outlook on the authorization of insect PAP as feed ingredient in pig and poultry feeding.

'At the moment, the topic is still tiptoed around. However, I consider an authorization a realistic outlook.' (Interview 1: 40)

'The commissioner of DG SANTE… promised us [IPIFF] an authorization as soon as all safety and health risks are sufficiently clarified…' (Interview 2: 36)

'Of course I would wish for it all to get started in 2021. But for now I see that only happening with fish. The EU regulation concerning additions (to feedstuffs)

> *will be revised in 2021, and then there will be a big renewal, and it should be included then.' (Interview 4: 67)*

Yet, restrictions on the feeding materials applicable for farmed insects are still an aspect of concern, as they have direct implications on the resource efficiency and thus sustainability potential of insect production. An expert expressed that *'under the current legal situation, the production of insect proteins as animal feed does not display any benefits and will not succeed in the long run'* (Interview 1: 35). This comment refers to the fact, that feed materials currently usable as substrate for insects are the same feed materials that can also directly be fed to livestock animals as pig and poultry. This is directly linked to the fact that insects are defined as 'farmed animals' and as such may only be fed with products of non-animal origin or category 3 material (see Chapter 2.4). The strict interpretation of the feed ban also hampers the use of organic waste and side streams that currently could be used as insect substrate (see Chapter 2.4). The double conversion, from increasingly scarce input feed materials, into insect protein feed material will eventually lead to the opposite and enhance resource- use competitions and sustainability deficiencies of the animal production sector. However, the great variety of insect species and their specified requirements offer opportunities to make better usage of biomass that is currently not included in the food production scheme, e.g. wood (Interview 1) or leaves and greenery (DAFA).

> *'To avoid competition for feed inputs, we would like to use waste materials and feed residues. But as soon as something is declared waste it is not allowed to go back into the food and feed chain.' (Interview 2: 39)*

> *'The detour via insects has to make sense, and that is only the case if residues can be used.' (Interview 1: 11)*

Informal institutions

The German animal production sector is subject of normative public debate. Topics as animal welfare, sustainability deficiencies and resource efficiencies have become part of public concern. Changing consumer attitudes and expectations have induced incentives to satisfy evolving demands. Yet, among regime-level actors a short-run productivity objective can still be considered the prevailing determinant for decision-making.

Regime actors of the animal production value chain are primarily contained by the dominant 'market logic' which is guided by the criteria: low price, high quality, consistent quantity (Conference Sustainability transitions). This especially applies to the compound feed industry. In the competitive global feed market, feed producers *'are aware and concerned with every space after the decimal point'* (Conference Sustainability transitions: 147).

But while the experts described the persistent nature of the animal production regime, they also acknowledged that regime actors do display a willingness to change.

> *'In principle, value chain actors are open for modifications towards more sustainable production modes and they also express responsibility towards animals and towards sustainability but, in the end the 'market-logic' dominates, it needs to be profitable.'* (Conference 'Sustainability transitions': 135)
>
> *'Market- logic dominates the sustainability strategy, while at the same time actors do display willingness to change.'* (Conference 'Sustainability transitions': 145)

Another institutional prerequisite, specific to the German feed market, is seen in certification, guidelines and labelling. Despite the authorization of insect protein feed for farmed fish and other aquaculture animals, market development is hampered by missing certifications and guidelines. This is specifically true for the organic sector where missing guidelines currently prevent the application of insect protein in fish feed (Interview 4). It was suggested that an alignment with countries like Canada, that already established these guidelines could drive the development on the German market forward (Interview 4).

In Germany, the safety of food and feed products is also subject to labelling. For German feed industry operations, a number of industry associations (DBV, DLG, Federation of Agricultural Chambers, drv) commonly established a 'positive list for straight feeding stuff'. In contrast to the EU 'Catalogue of feed materials', which is valid for all Member States, the 'positive list for straight feeding stuff', issued by the 'Central Committee of the German Agriculture', 'Standards Commission for Straight Feeding Stuffs', 'contains only feed materials, which have undergone a safety audit with regard to the raw materials, processing aids and manufacturing processes used and taking also in account their nutritional value and their suitability for livestock feeding'

(Postivliste für Einzelfuttermittel, 2019). The list is not legally binding as it is based on a voluntary agreement of the economic sectors and organizations concerned; however, feed industry operations that aim at being labelled by one of the leading associations under the Quality and Safety label (QS) may only market feedstuff from the list and animal producing farmers aiming at labelling their final product may only feed their animals with labelled feedstuff. For the application in the conventional animal production scheme, listing on the ‘positive list for straight feeding stuff’ is therefore regarded as an essential requirement to market insect feed components on the German market (Interview 3).

> *‘Naturland is the only organic association that certifies fish from aquacultures, but due to missing certification and guidelines, insect meal is currently not applicable in organic fish production.’ (Interview 4: 32)*
>
> *‘In order to put a new animal feed on the German market you have to be listed on the positive list of feed materials.’ (Interview 3: 14)*
>
> *‘On the European level we have a feedstuff registry…you can try to register your product there and by doing so put it on the European marketing channel. But Germany has QS. QS refers to the entire value chain from feed to meat production, food retailing and slaughterhouses. Every step has its own guidelines and criteria, for feedstuff the listing on the positive list of feed materials is the admission ticket for QS and the German market.’ (Interview 3: 14)*
>
> *‘With respect to conventional feeding, we still have to check some things, the Iso 9000 issue…We need to get onto the positive list of the German Agricultural Society and so on.’ (Interview 1: 20)*

4.1.4 Technology

Technology refers to the hardware (e.g. material objects: products, tools and machines), software (e.g. immaterial objects: procedures, processes,) and technical knowledge that can be used to solve problems (Bergek et al., 2008).

As a ‘system in the making’ the insect protein sector faces a number of technical challenges along the production chain.

Technical Knowledge

The history of German insect rearing is largely limited to the production of pollinators and biological control agents, but on a smaller scale also to the production of fish baitsand insect feed for exotic and zoo pets. While new insect farming businesses can utilize existing expertise to a certain extent, commercial insect protein production is a new endeavor and as such it is depending on new and specific technological solutions for different activities along the feed production value chain. As optimal facility design (ideal tray dimensions, thickness of substrate layer) and ideal management of the abiotic conditions has major impact on aspects as bioconversion, synchronized development, low mortality among the insects as well as resource efficiency of the production system – all, aspects influencing the profitability and sustainability of insect businesses,- developing technical knowledge in this field will be a crucial aspect. Due to the great variety of insect species, production facilities need to be modified to the specific demands of the target insect. In Germany, production of insect protein is primarily geared towards the production of *‘hermetia illucens’* also referred to as *‘black soldier fly’*. Despite the need for further up-scaling and automatization processes to increase the economic viability of insect protein production facilities, the technical knowledge of how and under which conditions to produce insect protein is generally established. During an interview the technical- readiness- level of product manufacturing was described as ‘back-end-of-line’, meaning that the insect products comply with the commercial standards and that the production processes are well aligned and functioning (Interview 2).

While lacking technical knowledge is not a constraint to insect production, it is still a main hurdle for the authorization of insect PAP.

Quick testing methods to unequivocally identify the taxonomic origin of insect PAP are not sufficiently established. While the Polymerase Chain Reaction (PCR)- method could be used on insects, observations by light microscopy illustrated a risk of confusion between the muscle fibres of insects and that of other livestock animals (DG SANTE, 2017). When authorized, insect PAP could thus bear a contamination risk by wrongfully including PAP of other animal species. Another difficulty is that established testing methods would need to be able to distinguish between different insect species, as currently only seven species are authorized as protein source. The lack of these testing methods is also the reason why, despite an authorization of insect PAP in farmed fish and other aquatic animals, authorities still refrain permission.

> *'…authorities still withhold permission because we are not yet able to unequivocally prove that the insect meal produced exclusively originates from the seven authorized species.' (Interview 2:35)*

> *'I am from the Federal Office of Consumer protection and Food Safety (BVL). We have an official collection of analysis methods for food and feed inspection but at the moment we are lacking an approach for insects. Which matrix should be applicable? A meat matrix? And on the basis of that we need to develop methods, which at the moment are not existing. Therefore, authorization of insect food and feed will remain difficult.' (DAFA: 74)*

Hardware

Due to the broad range of technological advancements in indoor farming and greenhouse technology (aquaponic, hydroponic, closed system cultivation), German insect production start-ups can resort to a well-developed field of corresponding technological hardware. Crucial technical equipment such as air circulation systems, temperature, light and humidity control are considered standards in modern animal breeding and plant cultivation. However, it is only recently that modern operational methods have been applied to large-scale insect farming and the agricultural equipment industry is not yet including comprehensive sector specific solutions (lack of established methods). Production and processing design to build a functioning insect-production facility is therefore mainly shaped by 'trial and error' approaches (van Huis & Tomberlin, 2017). While this process of customizing solutions is time- and cost-intensive, it is based on available and accessible technical hardware. Once established, it can easily be copied by competitors (van Huis & Tomberlin, 2017), which results in companies being rather secretive about their facilities and procedures. Due to this reticence of established insect producers and the novelty of large-scale insect production systems itself, the sector is lacking comprehensive application or 'best- practice' examples.

As the insect solution is scaled-up, greater focus will be set on technical innovation in automatization processes and technical solutions to work more energy efficient (e.g. make use of waste heat). A growing insect industry could shift production systems towards a new refinement of technologies and methods.

Software

The concept of a sustainable insect protein production evolves around the idea of using insects as a link between organic waste management and the production of high-quality protein. When used as animal feed, the use of organic waste streams is an essential component to avoid competition for feed materials and retain the sustainability aspect of the insect production (Interview 1; DAFA). Yet, the current infrastructure of the food production system is mainly arranged with a linear orientation. In order to recover and source organic waste streams suitable as insect substrate, it will need structural and organizational changes along the entire production chain to transform towards a circular approach. Current statutory requirements, with a zero tolerance for unprocessed former foodstuff containing meat or fish components, impedes the sourcing of suitable substrate. An insect producer explained '*in the greater Berlin region, 10 tons of bread are returned monthly, which currently goes into animal feeding – if it doesn't, it goes into biogas plants. I'm allowed to use that. Problem: every now and then, there's a bacon roll in between.' (Interview 2: 40).*

Changes in the processes and procedures of the businesses where waste streams occur, like the separation of bacon breads (and other bakery products containing meat or fish components) and baked goods well suited as insect substrate, entail additional efforts and costs. It will therefore be a question of creating incentive and fair distribution to realize functioning circular flows.

Moreover, varying quantities and compositions of waste streams could negatively impact the consistency of the nutritional value and quality of the insect protein (Interview 2, DAFA). During the conference 'Sustainability Transitions' it was stated that '*if it's not possible to produce large amounts in consistent quality, insect meals will definitely not achieve market access.'* (Conference 'Sustainability Transitions': 204)'. It will therefore need appropriate adjustment to source suitable waste streams, to monitor and guarantee their safety and to extend their durability and longevity. When using residues and waste- streams, a homogenous nutritional value of the substrate can only be realized by the mixture of different waste streams and by processing them into a compound insect feed. The logistics and processing of suitable waste streams could result in specialized business endeavors or a branch of industry for companies already involved in waste treatment (Interview 4).

> *'The question is availability, is it a seasonal product? Again that brings me to the area of homogenity and equability in feeding. They are partly very sensitive, those insects.' (DAFA: 37)*

> *'That will be the challenge, then, that you have the same consistent quality input substrate at a certain time, in order to reach process security. Fermentation will probably play a role there. Lactic acid bacteria, as used for pickling cabbage. So that's quite a challenge, yet, ensuring homogenous quality.' (Interview 2: 26)*

Although a look at the current market activities indicates that the current application of the insect protein solution is tending towards insect production at specialized production facilities, the option of designing the circular approach in a decentralized way (similar to the differentiated value chains of other animal- based products) in different value adding steps or to integrate the insect protein solution on farm- site and thus organizing the circular approach on farm level (where organic waste occurs and protein feed is needed) is still subject of discussion (Conference 'Sustainability Transitions'; DAFA; Interview 1). For this approach, production operations and processes would need crucial adjustments as well.

> *'If we're being honest, the number of farmers, who have enough space and say, I'll build myself a small shed or I already have an old shed where I'm going to start rearing insects now – I think that number is currently rather small. That's most likely going to happen on a larger, industrial scale. Or is already happening, if you look at France and Innovafeed, I think they already have 2 production sites.(Interview 4: 23)'*

'There is also the idea, that the insects could be reared in a decentralized way, directly on farm level and then used as feedstuff there. The eggs or young animals get delivered, and are then breed with the residual materials as a circular process, and then directly fed to the poultry on the farm.' (Interview 1: 27)

4.2 Functional processes within the German insect protein niche

In order to gain insight into the performance of the insect protein niche, the functional analysis focuses on discovering the dynamics and constellations of the entrepreneurial activities, the knowledge development, the knowledge diffusion, the resource mobilization, the market formation, the guidance of the search and the creation of legitimacy. This will help to identify and understand the factors hampering or facilitating the niche development and illustrate the current state of the insect protein niche.

4.2.1 Entrepreneurial activities

In Germany insect production only recently gained recognition as a possibly viable entrepreneurial endeavor. The revision of the Novel-Food-Regulation in 2018 (Regulation (EU) 2015/2283) provided a new regulatory framework to legally market insect products intended for human consumption. This gave boost to food product development activities. German food start-ups (see table 2 'German insect protein companies') launched products like insect burgers (Bug foundation, Bold Foods), insect pasta (Beneto) or insect cereal bars (Snack insect). Since the successful market introduction of these 'novel foods' is dependent on consumer acceptance, these food start-ups are mainly invested in marketing and sales activities. A desk research indicated that none of the German insect food start-ups is involved in insect production or processing activities and that all of them receive their insect ingredients from companies outside of Germany (mainly the Netherlands, Canada and France).

Due to the legal restrictions regarding insect feed ingredients in pig and poultry feed formula, entrepreneurial activities in the field of German insect protein feed production concentrate on product development for animals not regulated under the current 'TSE-Regulation'. Animal feed businesses (see table 2 'German insect protein companies') are involved in the production of cat and dog food ('Green Pet Food', 'Eat small', 'Tenetrio') and the production of feed insects for terrarium animals, as well as zoo and circus animals ('Bugs international'). While there are a number of small production sites or business endeavors, feed business operators actually specialized in insect protein production for animal feed and aiming at marketing their products for livestock animals are 'Hermetia', 'Made by made' and 'Illucens' (see table 2 'German insect protein companies'). All three companies are producing protein from the black soldier fly. As insect production also generates valuable by- products as fat, chitin and compost, entrepreneurial activities also include product development and marketing efforts for these products. While the fat fraction is currently also used as an animal feed ingredient (e.g. fat balls for bird food) and the digested substrate is marketed as compost material, the sales market for the chitin fraction is still developing. First attempts have been made to market chitin in the medical or beauty sector (Interview 2). With the aim to open the market for pig and poultry feeding, insect protein producers are invested in research activities and product developments (Interview 2, Conference 'Sustainability transitions'). However, the legal uncertainty regarding the potential sales market is withholding large investments in automatization and up-scaling processes and the companies are growing gradually with increasing demand of the pet- food sector (Conference 'Sustainability Transitions').

While the set up of insect production sites and their technical configurations is a knowledge intensive endeavor and still shaped by trial and error approaches, marketing this knowledge is discussed as a business branch. Reacting to the demand, an insect producer stated his willingness to sell his knowledge and technical equipment as soon as his system proves to be operational.

> *'I immediately have 14 people who would buy a turnkey factory from me. I stall them and say, we are now building the first factory in Brandenburg, that has to work, we have to be able to earn some money with it, and then we give you one of those as well.' (Interview 2: 51)*

In order to protect entrepreneurial activities and sensitive knowledge, German insect producers and start-ups producing or selling insect products do file patents (Conference 'Sustainability Transitions'; Interview 1).

Despite general interest from the farming sector (eg. DLG, 2016; Land&Forst, 2018) to this day there are no entrepreneurial activities involving insect breeding or processing on farm level. While the authorization of insect meal for the feeding of farmed fish and aquatic animals could suggest entrepreneurial activities in the segment of aquaponic farming or of specialized fish feed production, current insect production businesses are not involved in this field (Interview 1). Asked about the reserved attitude of German producers, an interviewee explained: *'In practice, this is not yet relevant, for two reasons: first, we are still too expensive and can't compete with the 1,40€ for fish meal, and the second issue is the implementation, the authorities don't approve it yet, because we can't definitely prove that, when there's this pile of meal, it actually is insect protein extracted from the seven approved kinds...So we are still working on implementing this verification process, as well as trying to make sure the whole process is economical.'* (Interview 2: 35).

'Naturland', the only organic farmers' association currently willing to certify fish produced in aquacultures, faces the problem that the vast majority of the traditional feed ingredients used in these systems proves not suitable for organic labelling (Interview 2). With the entrepreneurial attitude of *'sometimes you just have to go ahead and do it'* (Interview 4: 57), 'Naturland' is the first association that published guidelines on organic insect rearing (Naturland, 2019b).

Table 2: 'German insect protein companies'

German insect food companies	Insect pet food companies	Insect protein (meal) producers
Bug foundation **(bugfoundation.com),**	Green Pet Food Green Pet Food (www.green-petfood.de)	Hermetia Hermetia (www.hermetia.de)
Bold foods **https://www.bold-foods.de/**	Eat Small (www.eat-small.com)	Made by made (www.madebymade.eu)
Beneto foods **(www.benetofoods.com),**	Tenetrio (www.tenetrio.de)	Bugs international (https://www.bugs-international.com/index.html) Breeding insects for terraria animals
Brento **Brento (brento.de)**		Illucens https://illucens.com/
Instinct **Instinct (www.yourinstinct.de)**		
Isaac nutrition **Isaac nutrition (isaac-nutrition.de)** **Uses buffalo worms from Protifarm.**		
Imago **Imago insect products (www.imago-insects.com)**		
Plumento foods **(plumento-foods.com/)**		
Snack insects **(www.snackinsects.com)**		
Swarm Protein **(swarmprotein.com)**		
Sens foods **(www.wickedcricket.de)**		

(Source: Own representation based on a desk research)

4.2.2 Knowledge development

The insect niche is embedded in a well-established research landscape. International attention of the 2013 FAO & WUR (Wageningen University & Research) publication *'Edible insects: future prospects for food and feed security'*, which can be considered the starting point for serious global advances in insect protein research (see Vantomme, 2017), spurred global knowledge development activities. Compared to the uptake of knowledge development activities in other European countries (e.g. The Netherlands), the German research environment was more reluctant.

> *'In other countries the topic was handled more open-mindedly. In the Netherlands, the government provided one million Euros for research and financed five PhD positions at Wageningen University. This helped the Dutch research sector' (Interview 1: 14)*

The restrained approach towards the topic of insect protein became apparent during the initial efforts of knowledge development. According to Interview 1, the acquisition of research funding was hampered by a skeptical attitude and missing consent for the importance of the topic. It was also mentioned that while in countries like the Netherlands and in France the topic gained recognition and support via public funding, the German agricultural research regime was retaining a more rejecting manner.

> *'In Germany, the insect topic was handled with skepticism. I experienced it myself when applying for research projects. The subject was not taken seriously, there was no interest, either.' (Interview 1: 13).*

> *'In Germany, agriculture is sticking to a traditional image. I assume that especially for the agricultural sector, insects are considered a pest and this perspective might have caused a rejecting manner.' (Interview 1: 14)*

However, efforts of involved researchers succeeded in overcoming initial reluctance within the German research landscape, *'... together we completely redesigned the research subject*' and '*managed to establish a new research infrastructure'* (Interview 1: 3). Today, a number of German research institutes (e.g. 'ATB','FiBL','Fraunhofer Institute') is engaged with different aspects of the topic. Over the last decade various European and national research projects (e.g. 'PROteINSECT', 'Sustainability Transitions', 'InProSol', 'ProciNut' 'InVALUABLE') have been realized with the help of public funding.

Yet, among interviewed experts, the evaluation of the knowledge development function is subject to controversy. While some experts expressed contentment with the current knowledge base and constituted problems in the diffusion of knowledge, others criticized existing knowledge gaps and incongruences. Examples for different perceptions among stakeholders are illustrated by the following quotes:

> *'there is a good basis of research findings …it is the other way around, there is a lack of people trained in this field' (Interview 2: 19)*

> *'We definitely need more research in order to make scientifically founded statements.' (Interview 1: 11)*

> *'All these environmental and sustainability aspects can still only be dealt with theoretically, since there is no extensive data foundation yet, so there is a lot of room and need for research.' (DAFA: 56)*

> '*When looking at the life cycle assessment, of course insects occupy less room, consume less water and produce less CO2 emissions compared to conventional livestock. Especially compared to pigs and cattle. But the data basis for these conclusions is very thin, only from one study. (Interview 1: 11)*

Particularly the lack of context-specific environmental impact analysis was point of criticism (Interview 1, Interview 4, DAFA conference, Conference 'Sustainability Transitions'). In the current discourse, the use of insect protein in food and feed, especially regarding its sustainability, is often accompanied by a 'solution narrative' (Müller et al.,2016). However, sustainability impact assessments depend on context-specific production design and consideration of the actual practical integration into the food and feed sector. Many of the presented sustainability benefits lack practical integration into existing production modes. Due to regulatory restrictions regarding the substrate use for insects and an underdeveloped infrastructure regarding the sourcing and reprocessing of suitable waste streams, sustainability aspirations and current implementation of sustainability aspects into existing production modes differ. This applies particularly to the sustainability of insect ingredients in animal production.

> *'At this moment, with the current regulatory possibilities, it doesn't make a lot of sense with respect to sustainability. To study it because it provides research*

> *results is of course a temporary solution, but that is certainly something that would need to change in the future.' (DAFA: 144)*

So far, the knowledge development has mainly been focused on the basic feasibility of production and processing activities, as well risk and health assessments in different target species. When it comes to the attributed potential in resource efficiency and sustainability, numerous research gaps with regard to the actual environmental impact in different application scenarios, the safety and logistics surrounding a circular food model (substrate preparation) and the generation of in-depth knowledge regarding the optimal inclusion rates in different target species still need to be addressed. Knowledge of the genetics and specific requirements of different insect species will be key to develop efficient breeding and rearing techniques and will be essential to improve the desired characteristics as fertility, size and protein composition.

4.2.3 Knowledge diffusion

Knowledge diffusion is closely related to the networking activities within an innovation system. The knowledge flow from the research domain towards the private sector domain is facilitated by joint networking events like workshops and conferences, (e.g. 'Strategisches Forum 2018- Lebensmittel von morgen: Science & Fiction' and periodic events like the conference 'INSECTA'). As research actors and insect protein stakeholders are active in joint research projects (Interview 2; Conference 'Sustainability transitions'), knowledge transfer is opened in both directions.

Knowledge diffusion among insect industry stakeholders and towards the actors of the legal domain is facilitated by the European branch organization 'IPIFF'. Members of the branch organization are well-connected and maintain regular knowledge exchange on the latest developments (Interview 2). But while in some other European countries, educational services and workshops[10] facilitate knowledge diffusion towards people interested in the field, such learning opportunities are yet lacking on the German market.

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[10] E.g. in the Netherlands: seminars and workshops of the insect center http://www.insectcentre.com/en/edible-insect-seminar-workshop; summer school of Wageningen university https://www.wur.nl/en/activity/Summer-School-Insects-as-Food-and-Feed-from-producing-to-consuming-.htm
http://www.sun.ac.za/english/faculty/agri/conservation-ecology/ipm/workshops/insect-mass-rearing-workshop: Insect mass rearing workshop- IPM Initiative, Department of Conservation Ecology and Entomology, Stellenbosch University.

Despite the efforts of 'IPIFF', information exchange between the private sector and the legal domain seems tough. It took a while to bring the insect protein topic on the political agenda of EU legislators. From the niche actors' perspective, the insect protein solution is still attributed with marginal importance (Conference 'Sustainability Transitions'). When explaining the missing attention among European legislators during an interview with the magazine 'Pluimveeweb', Jan Huitema, a member of the European Parliament stated, 'unawareness causes ignorance' (Burgers, 2017: 12), which indicates that the benefits of the insect protein solution might not have sufficiently diffused among actors of the legal domain. The same applies to the knowledge diffusion activities along the value chain. With the perception of insufficient knowledge distribution being one of the reasons that fish breeders detain the application of insect protein feed (Interview 1), communication and information dissemination towards the production level can be regarded as an area with need for action. This is particularly true, as farmers were identified as possible 'change agents' (Conference 'Sustainability Transitions'), that could help spread acceptance of the insect feed novelty (see 6.1.2 Networks). Yet, it was also described that there are farmers already invested in the topic, who actively try to get information on the status of the novelty (Interview 4). This leads to the conclusion that the intended role as 'change agents' takes effect and that there are differences in the current level of knowledge and attitude among animal-producing farmers. To support the 'out of the niche' development of insect protein feed, questions as, '*who gets information from whom? who influences whom? And how is power distributed along the value chain?*' (Conference 'Sustainability Transitions: 110) will gain importance.

4.2.4 Resource mobilization

Human capital

The German academic system offers a number of technical and natural science programs that qualify graduates in knowledge areas relevant to the insect niche (entomology, biology, natural resource, agriculture, process engineering). However, when reflecting on enabling conditions for the developing insect sector, an interviewee stated *'Know-how. Too few universities have focused their studies on insects or insect production. There is a lack of qualified people'* (Interview 2). While aspects such as plant protection and pest control are integral parts of agricultural studies, the potential of insects as a bio-resource or as a link in a circular food system has been neglected. Only recently, the master program ‘Insect Biotechnology and Bioresources’ at Justus-Liebig Universität Giessen has been established. During an interview, current affiliation processes within the research area of ‘entomology’ were met with incomprehension:

> *‘Many of the academic chairs of entomology were transformed into chairs of microbiology…apart from a few junior professorships, there are only one or two remaining professorships in the field of entomology’ (Interview 2: 15)*
>
> *‘If you compare this to the eleven professorships for jazz-drums, you can see the lack of status of entomology in our society' (Interview 2: 15).*

While many insect food and feed start-ups are recruiting people with academic backgrounds (DAFA), it was stated that *‘it also needs more active people, for the practical field who are willing to engage with the subject’* (Interview 2: 47). The need for apprenticeships or practical training was mentioned by several stakeholders (DAFA; Interview 2). This indicates that the insect sector requires both people with expertise of the agricultural sector, insect biology and aspects of a circular food system, as well as people with a sound practical training in handling mini-livestock and in managing technical processes and devices. Limited or missing educational offers might pose a challenge for insect protein businesses to recruit qualified personnel, but private sector actors are willing to invest in resource mobilization themselves, *‘we now have to see what we can do on our own…so that an academic chair might get interested…*’ (Interview 2:19)

Financial capital

Data on investments in the insect protein niche is not readily available. Following an internal survey among members, ‘IPIFF’ determined that by October 2018, European insect producers have raised more than € 350 million through investments and were expected to raise more than € 2 billion by 2025 (IPIFF, 2018). However, mobilizing financial capital is a major difficulty for the German insect niche (Interview 2; ‘Conference Sustainability Transitions’). Due to the legal restrictions (limiting the market potential) and the remaining knowledge gaps, the risk of investment is perceived as high. As rearing facilities produce with different, often unique systems and regional settings, the sector lacks ‘best practice’ examples and established methods.

> *‘Availability of capital is an issue.’* (Interview 2: 46)

> *'IPIFF recently published the numbers of financial investments, but these investments did not result in any large-scale production facility, at least not in Germany.'* (Interview 2: 46)

With the understanding that with current production costs, insect protein will not be able to compete against current fish or soy-bean protein prices (Conference 'Sustainability Transitions'), cost reductions are depending on investments in up-scaling and automatization processes (Conference 'Sustainability Transitions; Interview 2; DAFA). However, as long as current market prospects are uncertain and high investment costs are reflected in relatively low return on investment (Conference 'Sustainability Transitions'), capital acquisition will be an obstacle for the emerging insect sector (Interview 2).

Yet, in 2018 one of the market leaders in poultry production, the 'PHW-group', invested in the Canadian insect feed company 'Enterra' (Interview 3; Schiermacher, 2018). While this investment is not for the benefit of a German insect producer, it indicates that the animal production regime is opening to the idea of including insect proteins and that the sector might put up more financial capital in the future.

> *'The capital expenses that we currently need to build the facility and to buy technical equipment swallows the investments and is too high compared to the revenues.'* (Interview 2: 46)

> *'One has to build the business plan on a relatively low-price level, in principle oriented on fish meal prices.' (Interview 2: 46)*

> *'Generally speaking, the product prices are too expensive. We have to see how to lower the production costs. When you have a viable business, you get access to capital.' (Interview 2: 46)*

The increasing number of project tenders, as from the Federal Ministry of Economics or the Federal Research Ministry and a perceived increase in the interest of research activities (Interview 2), indicates that the initial difficulties in the acquisition of research funds that hampered knowledge development (Interview 1) have been overcome. Still, with regard to the resource mobilization function it was also mentioned: *'It's a pity. There are enough people involved in the topic. But the topic is still kept small and lacks sufficient support.'* (Interview 4: 26).

'…there are a number of project tenders from the Federal Ministry of Economics and the Federal Research Ministry that explicitly mention insects as a field of interest. I get non-stop calls and requests for research cooperation, as a research partner or supplier for feeding trials.' (Interview 2: 19).

'I know this approach from another context, as well – with the development of new processes, everyone always says it will never work out. You don't receive funding and in the end in turns out that it does in fact work, and the new processes are established on the market. All these environmental and sustainability aspects can still only be dealt with theoretically, since there is no extensive data foundation yet, so there is a lot of room and need for research.' (DAFA: 55)

4.2.5 Market formation

While German insect producers experienced initial difficulties to market their products (Interview 1; Interview 2), the successful market launch of insect ingredients in dog food has led to a substantial increase in the demand of insect proteins (Interview 2). Due to the enormous German pet food market and the apparent success of insect feed products, a German insect producer described that demand soon surpassed his production capacities (Conference 'Sustainability transitions').

'We have a huge demand for insects in petfood. Our whole production goes into dog food.' (Interview 2: 30)

'So back then I approached the relevant pet food producers and they pretty much kicked me out. „We don't know any dogs who eat insects." And then, starting in 2011, the dogfood producers approached me. Works great. We now need 20.000 tons and so forth.' (Interview 2: 17)

'The big producers who are currently on the market in Europe, they have all sold all their products, in advance. The demand is that big. (DAFA: 142)

Market success of insect dog food can be attributed to the good tolerability and apparent positive palatability traits among all dog species. Due to emotional attachments, pet owners display an increased willingness to pay higher prices for products benefiting the health or well- being of their pets (Conference Sustainability transitions). Since, with regard to the production price, insect protein is not price competitive with other feed ingredients, marketing of the products is building on emotional aspects.

> *'In the dog- feed sector, we are currently at 5€ per kilo, that only works appealing to emotional aspects, a price competitiveness is just not possible, yet.' (Conference Sustainability Transitions: 158)*

Still, in 2018, IPIFF estimated that 1,9 thousand tonnes of insect protein were produced by European insect businesses (IPIFF, 2018). Their market segments range from the pet food market (e.g. cats and dogs, exotic pets), to the feed market for fur, zoo and circus animals (e.g. mink), as well as the feed market for farmed fish and aquatic animals (Interview 2). With an anticipated market opening for insect protein feeds in livestock animals like pig and poultry by the year 2020, 'IPIFF' predicts the production volume to increase up to 1,2 million tonnes by the year 2025 (IPIFF, 2018). However, with regard to the current price setting, insect proteins will not be able to compete against current prices of fish or soy meal (Conference Sustainability Transitions'). This is also the reason, why despite the market opening for insect ingredients in farmed fish and aquatic animals, insect protein has not yet carried through (Interview 2). As insect industry stakeholders seek to push insect protein on the livestock market, which in contrast to the pet food market is predominantly geared towards the market logic of price, quality and quantity, production volumes and price structure would need to shift immensely (Conference Sustainability Transitions). All experts identified the high cost price of insect protein products as a main hurdle for insect proteins to challenge traditional protein sources. At the same time, aspects that could have a significant impact on the production price (e.g. economies of scale, investments in automatization technology and energy efficiency, investments in logistics and treatment of waste streams) depend on the market opening.

> *'In practice, this is not yet relevant, for two reasons: first, we are still too expensive and can't compete with the 1,40€ for fish meal, and the second issue is the implementation, the authorities don't approve it yet, because we can't definitely prove that, when there's this pile of meal, it actually is insect protein extracted from the seven approved kinds...So we are still working on implementing this verification process, as well as trying to make sure the whole process is economical.'* (Interview 2: 35).

> *'Based on our first experiences on the market for fish feed, we see that they demand quantities we can't deliver and prices are still far from what we would need.'* (Interview 2: 20)

> *'The smallest fodder silo of Agravis contains 10.000 tonnes and is filled four times per year. I was told 'When you can fill it for 1,40€/t you can come back'. This will still take some time.'* (Interview 2: 22)

> *'And you have to consider, the economical framework for feed plants and farmers is such, that even price changes behind the point are carefully mentioned, there is simply no room for a feedstuff that is not economically competitive.' (Conference Sustainability Transitions: 184)*

> *'One can say that the final decision is usually based on the price and that also applies for the insect protein'(Interview 4: 64)*

In addition, international insect production companies that benefited from more market-oriented interpretations of the legal framework, like the Netherlands or France, could use their 'first mover advantages' and establish price settings and production volumes that German companies are not able to compete with. In that respect one expert *expressed 'While they [France and the Netherlands] managed to set up big production facilities, we [Germany] are still occupied with the question how to organize our sector?'* (Interview 4:26) and concluded that compared to the French market the German market is *'far behind'* (Interview 4: 26).

Another development that could be impacting the market formation of the insect protein feed novelty is the future of the 5% admixture quota of non- organic feed produce in poultry and pig production ((EU) 889/2008: Article 43). Initially intended as a transition period, shortcomings in the supply of organic protein feed have resulted in numerous extensions of the quota (initial phase out date was 31.12.2011). Yet, with the next amendment in 2021, it is expected that this extension period comes to an end. For the organic production of pig and poultry this could prove problematic.

> *' If this tolerance of admixture is dropped, a gap emerges.' (Interview 4: 30)'*

> *'So this 5% arrangement, that's not for nothing. And that it was extended wasn't for nothing, either. So if it is cancelled, that will be a problem.' (Interview 4: 33)*

> *'Only if the 5% regulation will be withdrawn and a gap will arise, [the industry] is willing to pay more and utilize it. (Interview 4: 64)*

With regard to the insect protein niche, an emergence of a protein feed gap in organic pig and poultry production could open new opportunities to position on the market (Interview 1; Interview 2; Interview 4). It is expected that with the withdraw of the 5% quota, pressure on the regime level could eventually lead to an increased willingness to use and pay for insect proteins (Interview 4). An expert concluded *'Organic turkey is a big issue. There are a few breeders I'm in contact with. They have the problem, that soon they aren't allowed to add the 5% non-organic feedstuff anymore. The EU has been planning to abolish this arrangement for a long time, but they can't seem to get it done, there's been a third extension now. But it's really a thorn in their side. If something is labelled 'organic', it's supposed to be 100% organic. This could be our market niche.'(Interview 2: 20)*

> *'And only with regard to this 5%, if it's still much more expensive than all the other components, probably nobody is going to use it. Only if this 5% arrangement is abolished and a gap emerges, actors are willing to pay more and actually use it. That's my assessment, that the feed mills that I am working with will think that way.' (Interview 4: 64)*

4.2.6 Guidance of the search

The fundamental feasibility of insect protein application in animal feed is sufficiently clarified (Interview 2; Conference Sustainability) and essential questions with regard to the production and processing of different insect species are resolved (Interview 1; Interview 2). Still, four essential research questions are currently guiding the search function of the insect niche, (1) How to unambiguously identify insect PAP from that of other species and from other insect species? (2) How to achieve an adjustment of the current legal framework? (3) How to reduce the cost price of insect protein? (4) How to realize the vision of a sustainable protein alternative?

While all experts agree that these questions need to be tackled in order to bring the insect niche forward, expectations and visions on how these aspects should be addressed vary and different foci can be attributed to the different domain types.

Niche actors of the private sector domain are clearly focused on an adjustment of the legal framework and the reduction of the cost price of the insect protein ingredient. Actors of the legal domain are primary concerned with consumer safety and compliance with the 'TSE- Regulation'. In order to consider authorization, their focus is set on the submission of unambiguous identification methods (DAFA). Actors of the research domain are concerned with filling current research gaps, whereby life cycle assessments of the sustainability performance of insect feed in different settings and scenarios can be considered a focus research area (Interview 1; DAFA). As actors were able to articulate their focus and orientation with regard to the insect niche and with the recognition that although spread among the different domain types, essential research questions are giving guidance for search.

4.2.7 Creation of legitimacy

With regard to the use of insect protein feed for livestock animals like poultry and pigs, institutional legitimacy is one of the sector's greatest challenges. EU authorities do not consider insect PAP a legitimate feed ingredient for pig and poultry production. Defined as a 'livestock animal', the current institutional setting equates insect PAP to the PAP obtained from any other livestock animal. Among insect niche actors this stance is met with incomprehension, especially since the use of insect protein, as the naturally preferred food of the envisioned target animals, is put on the same level with banned inter- and intra- species feeding practices among traditional livestock. An actor of the insect niche emphasized the natural behavior of chicken and builds legitimation on the fact that the insect niche is recreating already existing natural circles.

> *'It is forbidden by law, but what happens with free-range chickens? …the chicken finds a larva and eats it. This is considered natural and many consumers consider free-range chicken the best choice. But as soon as one tries to recreate this circle under controlled conditions, it is forbidden.' (Interview 2: 39)*

This view is shared by actors of the research domain, as well as actors of the animal-production sector (DAFA; Conference 'Sustainability Transitions'). When asked about possible adjustments of the current 'TSE- Regulations' in order to lift the feed ban on insect PAP, an expert stated *'I sincerely hope for it. But we still don't have the repeal for the intraspecies feeding of animal-sourced proteins, although this implies that one should be able to detect the origin of individual proteins even in the hydrolysate, I actually consider this a political formula'* (Interview 3: 31). Yet, it was also acknowledged that legislators will face difficulties in changing the feed ban rules due to the critical stance of the general public (Interview 3) and it was concluded that during the BSE-crises legislators established overly strict conditions (Conference ‘Sustainability Transitions’) that are now *‘tiptoed around’* (Interview 1: 40) to avoid a public outcry. Justifying an exception to the feed ban rules for insects will in this context depend on adequate methods to distinguish insect PAP from the PAP of other species and establishing adequate safety and monitoring measures.

> *‘It’s possible to change legal frameworks, after all. That is the good thing about them, it’s just a little slow sometimes. We are- legally- still in this Post- BSE-phase. Back then, people tended to overstep the mark because of the exceptional crisis situation.’ (Conference Sustainability transitions: 190)*

> *‘We also have to put monitoring and supervision offices in a position where they can make definitive identifications. There is still a lot to do.’ (Interview 2: 21)*

As the concept of feeding insects to pigs and poultry hardly faces any opposition within the animal- production sector, the current economic viability does (Interview 2; Interview 3; Interview 4). The ‘market logic’ that the incumbent animal production scheme displays towards feed ingredients is shaped by price, quantity and consistent quality (Conference ‘Sustainability Transitions). In this setting, legitimation of insect protein towards regime actors with market- power will eventually depend on the novelty’s alignment towards the prevailing criteria of the ‘market logic’. When discussing reactions of regime actors and possible legitimation strategies, experts stated the following:

> *‘I rather expect resistance from feed producers. Price, quantity and consistent quality need to be aligned. There are still great challenges to be faced.’ (Conference Sustainability transitions: 176)*

> *‘I am not sure if I can make a sweeping statement because even the feed mills I am responsible for are very different. There are some who are very open to new ideas (it is a bit more expensive but we can try it) and there are some who say, we have always done it this way and we should keep it that way.’ (Interview 4: 64)*

> *‘The German poultry sector is in the hands of five big companies… farmers producing for them merely provide the stables, the work and the management. They are contractually bound to use the feedstuff, the stable equipment and the fattening goals…with the software, delivery and collection of the*

slaughterhouse. They don't ask: What is the feed composition? They only say: fattening phase A, B or C, I need this input to produce the poultry in accordance to target mark 3 kilo in 40 days.' (Interview 3: 7)

'Money and time are the two factors which are important for them [the big companies]. So, in principle one would have to address one of these big companies and they have to open the way to the food retail trade, which plays a key role.' (Interview 3: 7)

While with regard to the increasing power- concentrations in the poultry sector, it was assumed that legitimation efforts along the value-chain could pass the production level and concentrate on establishing acceptance among the animal production companies (Interview 3), other experts emphasized the networking power of farmers and their potential role as 'change agents' (Conference 'Sustainability Transitions') (see 6.1.2 Networks). By giving positive feedback among colleagues, as well as into the value chain, farmers do exhibit substantial power in supporting niche developments. These considerations are validated by open- minded farmers that call their association in order to get information on the legal status of insect protein (Interview 4) and by farmers who discuss latest developments among their colleagues (Interview 2).

'When we started in 2006, we received positive feedback. Word soon got round among farmers. Every farmer knows that chickens like to eat insects and if you observe the wild boars, who dig up the golf course, they do this to find larvae. It is just natural.' (Interview 2: 17)

As labelling proves to be a consolidated prerequisite on the German food market (see also 6.1.3 Institutions), a current omission in the creation of legitimacy is the listing on the 'positive list for straight feeding stuff' (Interview 3). Yet, actors of the insect niche have recognized this problem as it was stated, '*We have to aim at being added onto the positive list of the German Agricultural Society and things like that'* (Interview 2: 20). While labelling would ease the market entry of products that were produced by using insect protein feed in retail markets, retailers emphasized their role as 'providers' for consumer demands and underlined a limited willingness to list products with market uncertainties (DAFA).

Looking at consumer acceptance and demand, it can be determined that in Germany, as in many countries of the global North, the use of insect protein is faced with ignorance and the perception as a novelty. The lack of a culturally grown familiarity is the reason that insect food products are approached with skepticism, whereas significantly more support can be attributed towards insects as a feed ingredient (PROteINSECT, 2015). Findings of consumer acceptance research demonstrated a more positive attitude towards insects as an animal feed ingredient (Verbeke et al., 2015). This aligns with the assessment of the experts, *'People are curious and start to see it more open-mindedly. I think with urbanization and globalization…vacation in other countries and cultures,…' (Interview 1: 16).*

With growing public concerns for topics as climate change and environmental degradation, products which transfer a positive environmental impact, or a sustainability message create higher legitimacy (Conference 'Sustainability Transitions').

> *'So it's much easier today than it was 10 years ago to get into retail with these products, if you are able to tell a plausible sustainability story about them and present a good sustainability balance.' (Conference Sustainability transitions: 176)*

Yet, despite the open-minded attitude towards insects as feed ingredient, experts regard legitimacy of the insect protein niche as an obstacle. While the envisioned sustainability advancements of the insect niche do serve evolving demands of German consumers, protein sourcing is primarily a sector intern topic and somewhat 'hidden' from the general public. More visible topics like animal welfare or deforestation are the subject of greater attention and thus exhibit greater pressure on the legal domain to take action.

> *'With animal feed, I'm generally skeptical. The public perception is currently dominated by the animal welfare debate, which leaves little room for other problems. Whether the feedstuff is slightly more sustainable or not is currently only a marginal issue. Like with the issue of GMO's, in my opinion the matter hasn't quite caught on as it was expected to with the introduction of the GMO-free label. I don't see any great shifts on the agricultural market because some can now claim the GMO-free label. To me that seems to show that in the end it's not that decisive on the level of feedstuff. Like the whole soy debate is a very academic, NGO-based debate, reaching only a few Berlin scene circles, while the mainstream doesn't care. That's why there is no real booster. The animal welfare debate stays dominant.' (Sustainability transitions: 184)*

In addition, despite the fact that sustainability advancements are used as the main argument of the insect protein niche to create legitimacy, this key message is not sufficiently clarified and current practical integration of insect feed production does not comply with this 'sustainability promise' (DAFA). Legitimation processes that are solely built around the sustainability massage could thus prove to become problematic.
Another aspect that might prove to be a hurdle when legitimating insect products is the fact that it is still not sufficiently clarified if and to what extent insects or certain insect species do experience pain and distress. Under the current legal framework insect production is not subject to any animal welfare rules and no standards are in place to regulate the mortification process.

> *'Of course a much higher number of creatures is being killed when rearing insects as compared to other types of animals, if you want to produce the same amount of protein. That is not to be neglected. It's highly debated whether insects can feel pain or not.'* (Interview 1: 11)

5. DISCUSSION

In the following section, findings from the structural- and functional- oriented analysis will be discussed in reference to the theoretical framework. The discussion focuses on the obstacles and arising opportunities identified as affecting the insect protein feed niche and aims at exploring the enabling conditions for a further 'out of the niche' development. The structural components are discussed according to the logic of the findings, whereby actors and networks are discussed as an entity. The functional aspects are discussed with regard to their contribution to fulfilling the criteria of a sustainable food system.

5.1 Discussion of the structural components

Actors and Networking

Findings of the structural analysis highlight the broad range of actors involved in or affected by the insect protein feed niche. In the current state of the niche's development a further 'out of the niche development' is mainly depend on an intensification of existing networking relationships and the creation of new networking structures, especially within the animal-production value chain and with actors of the legal domain.

As there are still a number of essential research gaps and aspects that need further clarification, networking between actors of the research domain and German insect producers should continue to focus on knowledge development and diffusion and make use of the well-developed research landscape in Germany. Frustrations of insect protein stakeholders due to differing research priorities between the research and private sector domain could be eliminated by intensified network activities among insect producers and by directing and clarifying more market-relevant aspects and uncertainties sector-internally. As linkages among German insect producers are rather weak, common research activities could create an incentive to collaborate and create trust among competitors. Based on the functioning of national branch organizations in the Netherlands or Belgium, the formation of a national branch organization could facilitate communication, knowledge diffusion and collaboration among German insect stakeholders and function as a solid structure to build trust.

As the basic feasibility of insect protein production and the application of insect protein feed ingredients in food-producing animals is clarified (Makkar et al., 2014; Velten and Liebert, 2018), a successful implementation depends on actors of the legal domain to consider insect protein feed a legitimate feed source and on a positive reception among actors of the animal-production chain. The foundation and successful work of the European insect sector branch organization 'IPIFF' facilitates networking activities towards European policy makers. Yet, EU legislators take a reluctant stance towards adjustments of the 'TSE-Regulation' and only slowly focus their attention on the topic of future protein supply. Increased pressure from actors of the animal production value chain could help to bring the topic to the attention of policy makers and underline the need for action. Creating this pressure is dependent on networking and creating acceptance and demand among actors of the value chain. While individual experts suggested to focus networking efforts on a specific group of actors within the value chain (e.g. the farmers, the big production companies or feed producers), it became apparent that for common learning experiences by knowledge exchange and diffusion, the success of the insect protein niche will rather depend on the intensification of network activities along the entire production value chain. Enabling these network activities will depend on successfully identifying 'hybrid actors' or 'change agents' that inhibit networking power to diffuse the insect novelty within the incumbent regime (e.g. farmers) or that have the decision-making power to actually implement the novelty (e.g. feed mills, big production companies and associations). This approach is supported by

Geels' (2005) concept of the 'duality of structure'. Due to ever changing landscape pressures and weaknesses of the incumbent socio- technical regime, actors' attitudes are not static and can be influenced by momentum. Although helpful when assessing the actors' attitudes towards a novelty, a dichotomous line between actors of the niche and the regime level should therefore be handled with reservations.

Institutions

Key result of the structural- and functional analysis is that the current institutional setting is the main hurdle for the insect protein solution. The restrictions in relation to the application of insect protein ingredient in the feed of food producing animals (with the exception of farmed fish and other aquatic animals) detains capital investments in insect producing companies or start-ups, inhibits the novelty entering a market with another order of magnitude (compared to the scale of the pet food market) and keeps the novelty from fulfilling its potential in closing the emerging 'protein gap'. The institutional setting therefore has considerable influence on functional dynamics like the resource mobilization and the market formation.

The restrictions in relation to the substrate use, that prohibit the use of numerous organic waste streams (e.g. catering and consumer waste or former foodstuff containing meat of fish components) or the use of biomass currently not included in the food production scheme (e.g. leaves, greenery or wood) have a negative impact on the sustainability aspirations of the insect protein feed solution. In current production settings, insects are fed with feed materials also directly applicable to livestock animals such as pigs and poultry. This double conversion negatively impacts the sustainability of insect protein feeds and even results in insects and livestock animals competing for protein feeds.

Adjustments of the current 'TSE- Regulation' will depend on the niche actors' efforts to create the necessary conditions for complying with future statutory and regulatory requirements. A main prerequisite for authorization is the introduction of an unequivocal detection method that can distinguish between insect PAP and the PAP of any other animal.

Authorization of additional waste streams could be facilitated by establishing transparent monitoring processes and the creation of guidelines on the basis of 'Hazard Analysis and Critical Control Point' (HACCP) management. Anticipating possible points of criticism especially with regard to safety considerations could enable legislators to legitimize adjustments of the 'TSE' provisions and create incentive to take action. For that, the insect protein niche can rely on a well-established branch organization that is communicating the sector's interests towards the legal domain. Networking activities of 'IPIFF' have already proven successful by leading legislators to include the BSF as one of the seven approved insect species. Existing contacts and communication channels could therefore be used to set further emphasis on the protein topic.

Although the insect protein solution touches multiple aims and strategies that the German government' has targeted on the national level (e.g. 'National policy strategy bio-economy' or 'Climate Plan 2050'), the strict and inconsistent interpretation of the EU regulatory framework among German authorities could be identified as a clear obstacle. Here, the already discussed option of a national branch organization could again help as a tool to improve networking structures. It could be an opportunity for the insect sector to better illustrate the benefits of the insect solution and to increase the sector's impact on a national scale.

Findings from the structural analysis indicate that legislators are trying to fit the insect protein novelty into existing legislation. Yet, when current European food and feed legislation was established, the idea of producing, processing and using insect ingredients in food and feed products was not an aspect to be considered. Fitting the insect protein feed novelty into an institutional framework that is geared towards traditional livestock animals such as pigs, poultry and cattle entails the risk of what Geels and Schot (2007) describe as a 'path dependency' or even a 'lock-in' effect. As the current 'TSE-Regulation' was established to eradicate the danger of infectious diseases and contamination risks among traditional livestock animals, provisions on what to consider a suitable feed material are tailored to the requirements of traditionally farmed animals. For the insect novelty, a 'lock-in' can be attributed to the fact that insects for feed production are defined as 'farmed animals' (Article 3 (6) of the ABP Regulation), as this status impedes any deviation from the provisions of current 'TSE-Regulation'. While biomass as greenery waste, wood or other underutilized bio-resources could be a species appropriate feed substrate for certain insect species, these materials are not suited to be fed to other food-producing animals and within the incumbent regime structures have limited prospects for authorization. To increase opportunities for insect proteins or other alternative protein innovations, it will be crucial to initiate a process that brings awareness to these manifested and possibly sub-optimal structures of the regime. In the same context, it should be emphasized that especially in the case of sustainability innovations in agriculture, it cannot be solely relied on market forces to bring about the desired changes in the environmental, social and economic performance of the current production modes.

Technology

Technological advances in the field of insect production are a main opportunity to enhance the profitability of insect protein business endeavors. Particularly important in this context are automatization technologies in order to replace labor- intensive and expensive manual work, waste-heat and solar-heat utilization to lower the energy cost (especially when rearing insect species in need of a tropical climate), as well as technological solutions to allow up-scaling processes. As a system in the making the insect protein sector lacks established production methods and readily available technical equipment. In order to depart from 'trial and error' approaches that each individual insect producer is currently occupied with and that lead to high investment costs, established methods and technical equipment could save time and costs. To identify the sectors' 'best practice' examples, it will need close cooperation and regular exchange of knowledge and experience. This would require a change of a the currently rather secretive attitude of German insect producers towards a more open attitude that is built on trust.

While current production modes suggest that insect production will primarily happen in more large-scale production facilities, a lift in the feed ban provisions could also entail entrepreneurial activities of animal producing farmers, aquaponic fish producers or waste management companies that aim at integrating the insect production into their existing production systems. In that scenario, it would need adapted technical solutions that fit the technical configurations on farm level. However, the necessary technological adaptions to induce automatization, energy-efficiency and up-scaling processes can resort to an already well-developed field of corresponding technological hardware and technical equipment (e.g. air circulation systems, temperature, light and humidity control) that can be considered standard in modern animal breeding and plant cultivation. This underlines that technological advancements in the insect niche are more a question of cooperation, sharing and building up common approaches and less a question of entirely new inventions or developments.

Regarding a successful market entrance of insect PAP in livestock feeding, the lack of an impeccable detection technique can be considered the sector's most pressing obstacle. In order to legitimize an authorization of insect PAP as a feed ingredient for pigs or poultry, while at the same time maintaining current feed ban rules for other food producing animals, the risk of confusion between the muscle fibres of insects and that of other livestock animals must be excluded. Supporting resource mobilization, knowledge development and research efforts in this field should thus become a priority of the insect niche. Depending on the statutory requirements, it may also become necessary to establish detection techniques that can also distinguish between the PAP of the seven approved insect species and the PAP of any other insect species.

As the concept of the insect protein niche evolves around the idea of 'closing the loop' or functioning as the 'missing link' between organic waste management and food production, the logistics and infrastructure of such a circular approach are of increasing interest. Yet, sourcing suitable waste streams, like bakery products is currently proving difficult. The strict handling of the feed ban (with a zero tolerance for the inclusion of meat or former foodstuffs containing meat or fish components, see Section 10 of Regulation (EU) No 142/2011) requires a clear separation of by-products and waste-streams well suitable as an insect substrate and those which fall under the feed ban. To facilitate the sourcing of insect substrates it would need adjustments in the waste management procedures and processes at the production sites where waste-streams occur. Here again, successful implementation of appropriate management processes depends on the insect niche's capacity to network within the food production value chain. As a conversion of the processes and the necessary knowledge diffusion (e.g. criteria of the feed ban, contamination risks) are linked to additional costs, it would need the creation of incentive. As the implementation of a circular food production, in line with the 'waste hierarchy', resonates with the German policy strategy of pursuing a 'bio-economy' (BMEL, 2018), it could be a strategy to apply or call for possible support funds and financial assistance. A possibility that could enable a comprehensive sourcing of suitable substrate on the long-run is the 'out-sourcing' of substrate aquisition, separation and treatment. While a new industry or business branch in this field could increase the price of the substrate, it would open the possibility to mix and process occurring waste streams into a safer and more durable substrate of a more homogenous quality. It would also move 'HACCP' management to the new industry and by establishing transparency of governance and monitoring processes give legislators a legitimation to allow additional waste streams.

5.2 Discussion of the functional aspects

With the understanding that innovations contributing to a sustainable food system should be assessed on the basis of their ability to harmonize environmental, economic and social criteria, while not compromising the food security and nutrition of future generations (FAO, 2018), opportunities, obstacles and enabling conditions that emerged from the findings of the functional analysis are discussed with regard to their ability in supporting the environmental, economic and social performance of the insect protein novelty.

Environmental performance of the insect protein novelty

By being independent from cropland use, having a significantly lower demand in water resources and by utilizing yet underutilized organic waste streams and bio-mass, the insect protein feed solution is centered around the idea of improving the resource efficiency and reducing the social and environmental cost of protein production.

The fact that soy is accounting for 62% of the German protein feed imports (BLE, 2018) and only 1-2% of soy used in animal feed is being certified as sustainable (Koeleman, 2019) illustrate a difficulty of sourcing sustainably grown proteins on the world market. In this context, the insect protein novelty has the potential to establish as an option to close the 'protein gap' and reduce dependencies on world market producers that are not bound to the same production, social and environmental standards as European producers. Yet, a key finding of the structural- and functional oriented analysis is that the current practical integration of the insect protein feed production does not comply with the sustainability aspirations that the initial concept of the insect protein solution suggested. Due to the legal restrictions regarding the application as a feed ingredient in pig and poultry feeding and regarding the use of multiple organic waste streams, the novelty's potential to improve the sustainability performance is substantially impaired. Particularly the restrictions regarding the feeding substrate suitable for insects are negatively affecting the current environmental performance of the novelty. As insects are fed with the same feed materials also suitable for the direct application in food-producing animals, the overall environmental performance of the novelty is undermined. This situation should nevertheless be regarded with consideration to the fact that in the early phases of their invention, novelties do display weaknesses or inconsistencies with respect to their ultimate use (Schot & Geels, 2008) and that these deficiencies in the current implementation should not be a criterion to generally dismiss the idea.

In order to improve the environmental performance of the German insect protein novelty, it needs an adjustment of the current 'TSE-Regulation'. However, due to the BSE-scandals of the 90's and the enormous public outrage on then common intra- and inter-species feeding practices, actors of the legal domain take a reluctant stance to the niche's calls for adjustments. Implementation of required changes will thus depend on the creation of legitimacy among policy makers, as well as on the sector's ability to put policy makers in the position to legitimize and justify amendments to the general public.

In its current setting, the environmental performance of insect production could be improved by increased networking and entrepreneurial activities. To better source already approved organic waste streams (e.g. former foodstuffs not containing meat or fish components as for example bakery goods) it would need the incentive of insect producers to approach businesses that have to handle these streams and engage to commonly develop processes that are feasible for both sides. It would also need the insect producers' willingness to experiment with different input substrates and possibly integrating substrate processing (e.g. heat treatment) into their business endeavors. Improvement of the energy efficiency (e.g. use of waste heat or solar panels) or the coupling of production systems (e.g. waste management businesses, indoor farming, aquaponic farming) also entail potentials to improve the environmental performance of insect production.

Due to the already discussed lack of 'best practice examples', environmental performances of current insect production sites might differ substantially. An authorization of additional waste streams can thus not automatically be equated with a better environmental performance. It needs further efforts in knowledge development with context specific life cycle assessments to ultimately identify the criteria for actual improvements and derive suitable guideline principles for the sector (e.g. Naturland).

Economic performance of the insect novelty

With the key finding that the incumbent animal-production regime is shaped by a 'market-logic', that considers a low price, a consistent quality and readily available quantity as the decisive factors when choosing and assessing protein feed components, the economic performance of the insect protein novelty will depend on an alignment towards these criteria. Due to the high production costs of insect protein, the novelty is not able to compete against significantly lower soy and fish meal prices. Yet, landscape developments such as climate change impacts, increasing overall feed demands and shifting market powers (due to an anticipated increase of animal production in China), might lead to an increased competition for protein feed sources and raise global price volatility (PROteINSECT, 2015). In the long-run, this might improve the market chances for alternative proteins but in the short run, profitability of the insect protein production will depend on enhanced entrepreneurial activities, the mobilization of resources and on activities to enhance the market formation.

The current animal-production regime with its differentiated value adding steps is aligned to the application of traditional protein sources, particularly soy. In order for the novelty to fit into these structures, entrepreneurial activities should converge towards meeting sector-intern production specifications. When marketing feed and food products in Germany, labelling is of great importance. Experts identified being listed on the 'positive list for straight feeding stuff' a condition to market feedstuff. Labelling would also increase trust and legitimation of the insect protein novelty. With increasing importance for the animal production sector to present evidence of a commitment to sustainability, entrepreneurial and market formation activities should also focus on emphasizing the sustainability benefits that could be marketed with the final product.

Mobilizing financial capital and human resources is a difficulty for the insect protein niche and a hurdle for the economic performance. Due to production methods and equipment that are based on 'trial and error' approaches (van Huis & Tomberlin, 2017) and due to high energy and labor cost, capital expenditures and production costs of insect production businesses are high. While investments in automatization, up-scaling and energy-efficiency could lower the overall production cost long-term, investments in these technologies are expensive. In order to mobilize financial capital, the niche should make use of its conformity with the political orientation towards a bioeconomy (BMEL, 2018a) and emphasize its potential in supporting the sector-specific target of the 'Climate Plan 2050'. By supporting political approaches the insect novelty might qualify for public funding.

The economic performance of the insect protein production could also be positively influenced by refinements in breeding and rearing techniques. Small adjustments in the production processes such as tray dimensions, temperature and light schedule and protein content as a selection criterion when rearing insects, could positively influence the protein content of the final product. Yet, the lack of educational offers in the field of insect production results in a shortage of people contributing to a further knowledge development. In this field it will need structural effort of the insect producing companies to diffuse knowledge of insect production as a viable business and enthuse people to get involved. The creation of learning opportunities like university courses, apprenticeships or workshops, would need sector-intern collaborations and networking activities with actors of the research domain. As the acquisition of financial capital as well as enthusing people for the industry also depend on the market potential of a new endeavor, efforts in market formation activities could also enable the mobilization of resources.

For years to come, global market prognoses predict significant increases in animal-based products (FAO, 2011). The German animal production sector already managed to establish as a net exporter of poultry and pork meat (Thünen Institute, 2019). To produce these quantities, the animal production sector is depending on the imports of high-protein feeds. Yet, supply conditions are not always in line with the criteria of the German or European market. The shortage in the production of protein feeds that meet the requirements of the organic label and the associated introduction of the 5% admixture quota for organic farming ((EU) 889/2008: Article 43) demonstrate the need for additional protein sources that are produced in line with established criteria. The anticipated elimination of the admixture quota for the organic pig and poultry production with the amendment of the EU regulation on organic farming in 2021 (Regulation (EU) 2018/848) could emerge as a market chance for insect protein feed. A strategy of insect producers could therefore aim at orienting their production towards the criteria of organic farming (e.g. following the ‘guidelines of organic insect rearing’ published by Naturland (2019b)).

Social performance of the insect novelty

In order for the insect protein feed solution to establish as a legitimate and trusted innovation, it needs to correspond with public concerns and interests. Landscape developments like the growing concern for the impacts of today’s production and consumption schemes allow sustainability innovations to attract widespread support. As consumer acceptance studies like Verbeke (2015) or PROteINSECT (2016) affirmed a positive attitude of European consumers towards the use of insect protein feed for food-producing animals, it can be assumed that the novelty is widely socially accepted. Current legitimation strategies of the insect sector build on the fact that insects count as a naturally preferred food choice of envisioned target animals as poultry or pigs and on the fact that insect protein feed application could improve the environmental performance of animal production. Enhancing public support for the novelty should continue to be pursued as it could help the sector legitimize their requests to change the current institutional arrangements among actors of the legal domain. The negative stance of German consumers towards GMO products and the fact that GMO-free soy is increasingly difficult to source on the world market (OVID, 2018b; BLE, 2019) could resonate with a credible protein alternative.

Yet, as a ‘hidden’ ingredient of the food supply chain (Forum for the Future), negative impacts and the complex interrelations of feed production are less transparent for the general public and concealed by more visible topics like animal welfare. The urgency to unfold new opportunities of protein sourcing is thus a primarily sector-intern focus topic. The limited public awareness of the ‘protein topic’ can be considered as an obstacle for the novelty. For one, the need for action is not recognized by the general public, the lack of social pressure can thus result in limited incentives for the regime level to alter their practices. In addition, it can limit consumers’ willingness to buy the - in all likelihood- more expensive food choice.

Due to the missing cultural history with insect food and feed products and the missing background knowledge of the protein complex, the seemingly positive attitude, still paired with caution or skepticism could quickly turn into a rejection of the novelty. Negative publicity targeting emotional aspects like the fact that insect farming is not bound to specific animal welfare rules and the lack of evidence with regard to insects’ ability to feel pain might turn the public opinion. It is therefore of particular interest for the niche to build legitimation and marketing strategies on sound scientific knowledge and to establish a common vision in order to avoid hasty action of individual producers that could harm the whole sector.

6. CONCLUSION

This work was intended to gain and collect knowledge of the structure and the functioning of the insect protein feed novelty in Germany, to identify the opportunities and obstacles the novelty faces and to explore specific determinants or enabling conditions to deliver a legitimate and trusted ‘insect protein solution’ with the prospect of challenging the incumbent protein provision scheme.

As the systems of innovation perspective provides an appropriate theoretical background to analyze and understand the processes underlying innovations, it was chosen as the reference frame. In line with the presented research objective, aspects of the two prevailing systems of innovations concepts, the Technical Innovation System approach (TIS) and the Multiple Layer Perspective (MPL), were combined into a convenient analytical framework. Based on expert interviews and participatory observations, the research followed an explorative research design. The first part of this work (chapter 1-4) set the theoretical framework for the analysis. It explored the landscape developments and pressures in which the innovation evolved, depicted the theoretical foundations of sustainability innovation and systems theory and gave an overview on the current state of knowledge. For a better understanding of the socio-technical regime the niche is embedded in, chapter four introduced the corresponding legal framework. The second part of this work focused on analyzing the structural components and the functional processes (1. Entrepreneurial activities; 2. Knowledge development; 3. Knowledge diffusion; 4. Guidance of the search; 5. Market formation; 6. Resource mobilization; 7. Creation of legitimacy) of the innovation niche. The structural- and functional-oriented analysis gave insight into the systems behavior and performance and demonstrated the opportunities and obstacles the insect protein feed industry currently faces. The third part of this work discussed how the identified obstacles could be transformed or coped with and how possible opportunities could be used in order to help the insect protein innovation to ‘break through’.

The key finding of the structural- and functional-oriented analysis is that in order to move forward and to develop its full potential, the current institutional setting is the main hurdle for the insect protein feed solution. Current provisions of the ‘TSE-Regulation’ that restrict the use of insect protein feed for food-producing animals, inhibit the market development of the insect niche, impede the resource mobilization and keep the novelty from closing the emerging ‘protein gap’. Restrictions with regard to the feeding substrate applicable for insects hamper the novelty’s potential to act as the ‘missing link’ in realizing a circular food production system and restrain the aspired resource efficiencies. The current practical implementation of insect protein production does thus not comply with the sustainability aspirations that the initial concept of an insect protein feed solution suggests. Yet, with the understanding that inconsistencies or weaknesses in the early stages of a niche’s performance can be a result of maladapted regulative, normative and cognitive rules of the prevailing regime-level, current shortcomings of the implementation should not be a criterion to generally dismiss the insect protein feed novelty. Instead, it should be concentrated on the structural efforts required to accomplish a further ‘out of the niche development’ and to legitimize it as an alternative. For the insect protein niche to comply with the environmental, economic and social criteria of a sustainable food system, necessary structural effort consists partly in aligning the niches activities towards the rules of the incumbent regime (e.g. the ‘market-logic’) and partly in using the ‘window of opportunity’ and adjusting the regime structures in a way to integrate the novelty (e.g. creating legitimacy by addressing public concerns and interests and pressuring the regime to adapt towards the novelty). To improve the overall functioning of the niche and to enable further development, existing networking activities should be intensified and new networking structures should be created. The formation of a German branch organization could facilitate the necessary networking efforts and increase the impact of the sector towards the German authorities. In addition, the sector should focus on creating the necessary conditions to make the insect protein feed solution eligible for authorization. Here, key enabling conditions are the creation of unequivocal detection methods and providing sufficient evidence for the safe use of additional organic waste streams and other underutilized biomass.

When analyzing the current structure and the functional dynamics within the insect protein sector it became apparent that the insect protein feed niche is in a state of flux. Being consistent with current aims and strategies pursued by the German government and with the potential to address persisting problems of the animal-production sector, the novelty caught the attention of multiple actors of the private sector, legal and research domain. It remains to be seen to which extent, the niche manages to align its efforts and increase the internal momentum.

Yet, with regard to the transformational process towards a sustainable food system as envisioned by the UN, it should be mentioned that managing the challenges of the 21.

Century and meeting the projected increase in global food and feed demand will depend on the plurality and combined effect of numerous sustainability innovations. To increase protein supply in a sustainable manner, it is therefore important to not solely focus on a single adjustment such as the application of insect protein but to simultaneously keep track of new technical solutions and other sustainability-driven feed innovations (e.g. essential amino acid supplements, algae, yeast, seaweed, bacteria), while also coordinating moderations and adjustments in todays' consumption patterns.

Due to the novelty of the insect protein sector in Germany, the main limitation of this work lies in the fact that findings are based on a small basis of data. The opinions and assessments of the experts are thus not necessarily representing the sector in detail but indicate possible perceptions of the different domain types.

As the presented research design proved as a suitable approach to analyze and understand the protein feed novelty, it can be suggested that in order to keep track with further developments of the niche's performance and behavior and to deliver a more accurate representation of the German insect protein feed sector the research could be revised with a larger scope of data.

To better carve out the reasons for country-specific differences in the performance of the insect protein niche within Europe and to establish opportunities to compare and learn from enabling conditions in different settings, it would be important to analyze the insect protein feed niche in other national settings. This would also clarify if and how a more tolerant interpretation of the same legal framework actually translated into a better performance of the insect protein novelty in other European countries and which conclusions could be drawn from that for the situation of German sustainability innovations.

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ANNEX

Annex 1: 'Summary of the legal requirements for insect proteins'

Regulation	Description	Relation to insect protein feed
General Food Law (GFL) **Regulation (EC) No 178/2002**	Foundation of food and feed legislation in the EU. GFL is laying down the main procedures and tools for the management of emergencies and crises as well as the Rapid Alert System for Food and Feed (RASFF).	The GFL defines feed business as *'any undertaking whether for profit or not and whether public or private, carrying out any operation of production, manufacture, processing, storage, transport or distribution of feed including any producer producing, processing or storing feed for feeding to animals on his own holding'* and feed business operators as *'the natural or legal persons responsible for ensuring that the requirements of food law are met within the feed business under their control.'*
Animal by-products Regulation (ABP) **Regulation (EC) No 1069/2009** **Regulation (EU) No 142/2011**	Laying down health rules as regards animal by-products and derived products not intended for human consumption. Regulation (EU) No 142/2011 implementing Regulation (EC) No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption.	According to the ABP Regulation, insects kept in the EU for the production of food, feed or other purposes fall into the category of 'farmed animals'. Therefore, insects are subject to the 'general EU feed rules' and can only be fed with feed materials authorized for 'farmed animals'. The ABP Regulation prohibits to feed 'farmed animals' with materials such as manure or catering waste and Regulation (EU) No 142/2011 prohibits the use of unprocessed former foodstuffs containing meat or fish. Article 10 of the ABP Regulation lists 'aquatic and terrestrial invertebrates other than species pathogenic to humans or animals' as category 3 material. As category 3 material, insects can be used as feed material for farmed and pet animals (This admission is restricted by the TSE regulation).

		The relevant Member State is responsible to enforce regulation for the approval of feed processing establishments or plants. According to chapter III of Annex IV to Regulation (EU) No 142/2011: When insects are rendered into PAP, operators currently producing insect meal with plant-based substrates must comply with processing methods 1-5 or processing method 7.
Feed Hygiene **Regulation 183/2005 EC**	Laying down the requirements for feed hygiene and animal health.	The Feed Hygiene Regulation applies to all 'feed business operators', including insect producers, to ensure that feed businesses operate in conformity with harmonized safety requirements. The Feed Hygiene Regulation includes *'the activities of feed business operators at all stages, from and including primary production of feed, up to and including, the placing of feed on the market.'*
Feed Marketing EC Regulation 767/2009	Laying down the rules for the marketing of feed materials and compound feed. Including: -Catalogue of feed materials -Revision of the tolerances for analytical constituents and provisions for the labelling of feed additives -Guidelines for the distinction between feed materials, feed additives, biocidal products and veterinary medicinal products -Guidelines for the feed use of food no longer intended for human consumption	According to the Feed Marketing Regulation feed may only be placed on the market if it is safe and does not have a direct adverse effect on the environment or on animal welfare. To ensure the safety of feedstuff, the regulation provides a list of materials whose placing on the market or use for animal nutritional purposes is restricted or prohibited. This list includes materials such as faeces and separated digestive tract content (Annex III).

Catalogue of feed materials **Regulation (EU) 2017/1017**	Listing EU feed materials.	The EU-Catalogue of feed materials lists insects in following categories: 1. Animal fat (entry 9.2.1) 2. Processed animal protein (entry 9.4.1) 3. Terrestrial invertebrates, live (entry 9.16.1) 4. Terrestrial invertebrates, dead (entry 9.16.2).
Feed additives **Regulation (EC) No 1831/2003**	Laying down the rules for the authorization, supervision and labelling of feed additives.	
Medicated feed **Directive 90/167/EEC**	Regulating the conditions for mixing veterinary medicine into feed, its marketing and use across the EU.	
Undesired substances **Directive 2002/32/EC**	Regulating the occurrence of undesired substances in animal nutrition.	The maximum levels of undesired substances in feed materials apply to the substrate used to fed insects as well as to insects used as feed material.
Maximum levels of pesticide residue **Regulation (EC) No 396/2005**	Laying down maximum residue levels of pesticides in or on food and feed of plant and animal origin.	Regulation (EC) No 396/2005 covers insects as_‘Terrestrial invertebrate animals’. The residue limits apply to the substrate used to fed insects as well as to insects used as feed material.
Genetically modified feed **Regulation (EC) 1829/2003** **Regulation (EC) No 1830/2003**	Laying down the rules on genetically modified food and feed. Laying down rules on traceability and labelling of genetically modified food and feed products.	
Regulation on transmissible	Laying down rules for the prevention, control	The EU ‘feed ban’ provisions contained in the TSE Regulation do

spongiform encephalo-pathies (TSE Regulation) **Regulation (EC) No. 999/2001**	and eradication of certain transmissible spongiform encephalopathies.	not allow the use of animal derived protein, including insect protein, to be used in feed for ‘farmed animals’ including fish (Article 7 and Annex IV). This ‘feed ban’ does not apply to fats and oil derived from insects and to the feeding of live insects, which may be fed to non-ruminant animals if authorized by the competent authority of the Member State. In 2017, with the introduction of Regulation (EU) No. 2017/839 the ‘feed ban’ is partially lifted and the use of processed Animal Protein (PAP) originating from insects is authorized for aquaculture animals. This authorization is limited to seven insect species: black soldier fly, house fly, yellow mealworm, lesser mealworm, house cricket, banded cricket and field cricket. The substrate used for the feeding of insects may only contain products of non- animal origin or the following products of animal origin of Category 3 material: fishmeal, blood products from non-ruminants, di and tricalcium phosphate of animal origin, hydrolysed proteins from non-ruminants, hydrolysed proteins from hides and skins of ruminants, gelatine and collagen from non-ruminants, eggs and egg products, milk, milk based-products, milk-derived products and colostrum, honey, rendered fats.
EFSA Risk profile related to the production and consumption of insects as	The European Food Safety Authority (EFSA) operates as an independent agency responsible for scientific advice and	In 2015, upon request of the European Commission, the EFSA published a risk profile assessment of the microbiological, chemical and environmental risks arising from the production and consumption of insects

food and feed	support.	as food and feed. EFSA concluded: '*When currently allowed feed materials are used as substrate to feed insects, the possible occurrence of microbiological hazards is expected to be comparable to their occurrence in other non-processed sources of protein of animal origin'.*
Animal Health Law **Regulation (EU) 2016/429**	Laying down the rules for the prevention and control of animal diseases which are transmissible to animals or to humans.	Article 10 of the Animal Health Law establishes the responsibilities of 'feed operators' concerning animal health and biosecurity measures for establishments keeping animals.
EU Reference Laboratory for Animal Proteins **Regulation (EC) No 152/2009**	Laying down the analytical methods of sampling and analysis for the official control of feed.	Methods of analysis for the determination of constituents of animal origin for the official control of feed. Annex VI to Regulation (EC) No 152/2009 (1) the PCR method can be used on insect PAP (no problems of interferences were detected); (2) certain particles can be identified by observations by light microscopy as being of insect origin, however, for certain muscle fibres, there is a risk of confusion with muscle fibres from other taxonomic PAP.
Directive 98/58/ EC	Concerning the protection of animals kept for farming purposes.	Under Article 1 (2) invertebrates are excluded from the Directive.

Annex 2: ‘Interview questioning scheme’

Personal background

Benefits of the insect protein solution

Sustainability of feed and insect protein feed

Structure and functions of the German Insect Industry

Opportunities **for the use of insect meal as livestock feed- (fish, poultry, pig), how to use them**?

Obstacles **for the use of insect meal as livestock feed- (fish, poultry, pig), how to cope with or transform them?**

Enabling conditions **to foster a legitimate and trusted ‘insect protein feed’ Industry?**

Outlook

Annex 3: 'Guiding questions for expert interviews'

Guiding questions for expert interviews

Personal background
-Fragen zur Person/Hintergrund/Position und Verbindung/Zugang zum Thema zum Thema
-Welche Aktivitäten im Bezug auf Insektenproduktion?

Benefits of the insect protein solution
-Wo liegen Ihrer Meinung die Vorteile der Nutzung von Insekten (Protein, Fett, Chitin)?
-Welche Erwartungen verknüpfen Sie mit der Nutzung von Insektenproteinen? und worauf begründen diese?

Sustainability of feed and insect protein feed
-Wie definieren Sie Nachhaltigkeit?
-Welche Kriterien sind Ihrer Meinung nach wichtig für eine nachhaltige Futtermittelproduktion?
-Welche Maßnahmen sind Ihrer Meinung nach nötig um die Erzeugung tierischer Produkte nachhaltig zu gestalten? (Auch andere alternative Proteinquellen oder Effizienzstrategien…)
-Welche Kriterien braucht es um die Produktion von Insektenfuttermitteln nachhaltig zu gestalten?

Structure and function of the German Insect Industry
-Beschreibung der heutigen Strukturen
- Wie schätzen Sie das Technik- und Innovation readiness level und Anpassungsvermögen an heutige Produktionsstrukturen und – Prozesse (regime level) ein? Komplexität? Kompatibel mit Praxisregeln?
Betriebsmodelle (Scope, Scale, automatization,complexity)
-Welche Akteure sind wichtig? Welche Netzwerke kennen Sie? Welche Institutionen sind wichtig?
- Wie vernetzt mit anderen Akteuren, Netzwerken, Institutionen (Forschung, Politik….
- Ist Insektenproduktion Landwirtschaft- (Definition Landwirtschaftliche Produktion) ?- Organisation? Technik, Aufzucht
-Austausch und Informationsquellen?

Opportunities for the use of insect meal as livestock feed- (fish, poultry, pig), how to use them?
-Welche Möglichkeiten sehen sie für die Nutzung von Insektenprotein in der Nutztierhaltung?

Obstacles for the use of insect meal as livestock feed- (fish, poultry, pig), how to cope with or transform them?
-Welche Hemmnisse gibt es? Wie kann der Sektor auf diese Hemmnisse einwirken oder auf diese reagieren?

Enabling conditions to foster a legitimate and trusted 'insect protein feed' Industry?
-Niche level- z.B collaboration, communication,…
-Regime level- z.B regulation, consumption patterns,

-Landscape level- z.B megatrends, international agreements, national strategies
-Legitimationsstrategien?- (regulatory, normative and cognitive legitimacy & organizational, intraindustry, interindustry and institutional strategies)

Outlook
-Einordung des Potentials? Realistische Einschätzung?
-Zukunft/Entwicklung-Wie sieht die Insektenproduktion in 5 und in 15 Jahren aus?

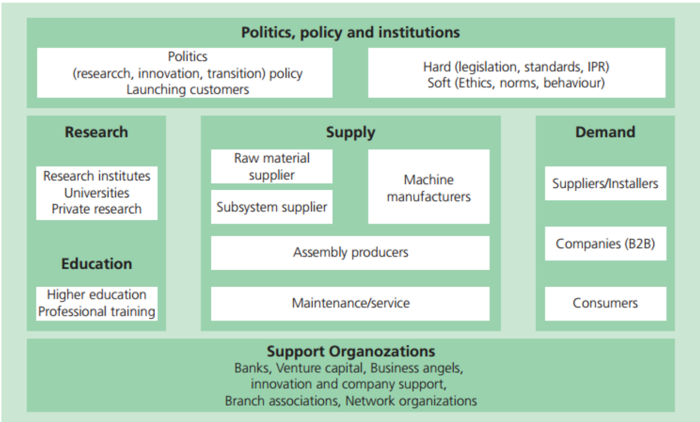

Figure 2 Structure of the innovation system (based on (Kuhlmann and Arnold, 2001)

(Source: Hekkert et al., 2011)

Functions and indicators	Diagnostic questions
F1 - Entrepreneurial Experimentation and production - Actors present in industry (from structural analysis)	- Are these the most relevant actors? - are there sufficient industrial actors in the innovation system? - do the industrial actors innovate sufficiently? - do the industrial actors focus sufficiently on large sale production? - Does the experimentation and production by entrepreneurs form a barrier for the Innovation System to move to the next phase?
F2 - Knowledge Development - Amount of patents and publications (from structural analysis)	- Is the amount of knowledge development sufficient for the development of the innovation system? - Is the quality of knowledge development sufficient for the development of the innovation system? - Does the type of knowledge developed fit with the knowledge needs within the innovation system - Does the quality and/or quantity of knowledge development form a barrier for the TIS to move to the next
F3 - Knowledge exchange - Type and amount of networks	- Is there enough knowledge exchange between science and industry? - Is there enough knowledge exchange between users and industry? - Is there sufficient knowledge exchange across geographical borders? - Are there problematic parts of the innovation system in terms of knowledge exchange? - Is knowledge exchange forming a barrier for the IS to move to the next phase?

F4 - Guidance of the Search - Regulations, Visions, Expectations of Government and key actors	- Is there a clear vision on how the industry and market should develop? - In terms of growth - In terms of technological design - What are the expectations regarding the technological field? - Are there clear policy goals regarding this technological field? - Are these goals regarded as reliable? - Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties? - Does this (lack of) shared vision block the development of the TIS?
F5 - Market Formation - Projects installed (e.g. wind parks planned, site allocation and constructed)	- Is the current and expected future market size sufficient? - Does market size form a barrier for the development of the innovation system?
F6 - Resource Mobilization - Physical resources (infrastructure, material etc) - Human resources (skilled labor) - Financial resources (investments, venture capital, subsidies etc)	- Are there sufficient human resources? If not, does that form a barrier? - Are there sufficient financial resources? If not, does that form a barrier? - Are there expected physical resource constraints that may hamper technology diffusion? - Is the physical infrastructure developed well enough to support the diffusion of technology?
F7 - Counteract resistance to change/legitimacy creation - Length of projects from application to installation to production	- What is the average length of a project? Is there a lot of resistance towards the new technology, the set up of projects/permit procedure? - If yes, does it form a barrier?

(Source: Hekkert et al., 2011)

Annex 4: 'List of MAXQDA codes'

Codesystem

1 Inconsistencies and contradictions	7
2 Other EU countries-different enabling conditions	6
3 Enabling conditions	0
3.1 Funding, subsidies, (financial) support	4
3.1.1 Economic sustainability-landscape developments	21
3.2 Involvement and participation actors-stakeholders	12
3.3 Eductaion and academic focus	6
3.4 Assessing and adressing risks	8
3.5 cooperation	14
3.6 Open-minded public-public acceptance	11
3.7 Perception-Legitimation	18
3.8 Need of adjustment existing legal framework-policy lobbying	23
4 Driver-Motivation	0
4.1 Negative effects soy and fishmeal sourcing	3
4.2 Compliance international agreements	1
4.3 Megatrends	2
4.3.1 Protein gap-crisis	6

4.3.2 Planetary boundaries-Climate change	0
4.3.2.1 Communication	13
4.3.3 Increasing meat demand	1
4.3.4 Population growth	0
4.4 Protein gap organic feedstuff	5
4.5 Benefits	1
4.5.1 converting efficiency	3
4.5.2 Increasing protein self-sufficency	4
4.5.2.1 Reliable source for GMO free protein	1
4.5.3 Animal health and welfare	6
4.5.4 Proteincomposition	6
4.5.5 Resource use: land use- feed conversation rate	5
4.5.6 Resource use: emissions	1
4.5.7 Resource use: water	1
4.5.8 Bioeconomy	12
4.5.9 Waste reduction	8
4.5.10 Circular economy	10
4.5.11 sustainability	43
5 System Problems	0
5.1 Competition other protein alternatives	2
5.2 Economic sustainability	49
5.2.1 Copetitive price level	12
5.2.2 entrepreneurial spirit	7
5.3 Technical-rediness level	15
5.4 Obstacles	0
5.4.1 Missing public understanding of protein gap	6
5.4.2 willingness to cooperate-collaborate-network	3
5.4.3 Education, training and academic focus	5
5.4.4 Research gap	7
5.4.4.1 Hygiene and safety-transparency	19
5.4.4.2 Organization and affiliation of the niche	21
5.4.4.3 Research gap: resource efficiency	4
5.4.5 Consistent quality and quantity	12
5.4.6 Regime level- Wait and see-skepticism	27

5.4.7 Ethical considerations and animal welfare	4
5.4.8 Double conversion	14
5.4.8.1 competition input substrat	4
5.4.9 Existing legal framework	38
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Annex 5: ‘Program of the doctoral program Sustainability Transitions’

Abschlussworkshop

Datum: 22. Juni 2018
Uhrzeit: 10:00 Uhr bis 17:00 Uhr
Ort: Kreishaus Osnabrück, Am Schölerberg 1, 49082 Osnabrück, Sitzungssaal 2091

Programm

- **10:00 Uhr: Begrüßung und Projektvorstellung** (Universität Göttingen): Prof. Dr. Ludwig Theuvsen

- **10:30 Uhr: Vortrag Rudolph Cordes** (NOVAgreen, Vechta): "Mikroalgen: Produktion, Ernte, Aufbereitung, Marktpotenzial"

- **11:00 Uhr: Vortrag Prof. Dr.-Ing. Stefan Töpfl** (Deutsches Institut für Lebensmitteltechnik, Quakenbrück): "Mikroalgen in der Lebensmittel-herstellung: Möglichkeiten und Grenzen der Technologie der Extrusion"

- **11:30 Uhr: Podiumsdiskussion** "Algenprodukte aus Verbrauchersicht"
Moderation: Eva Nitsch (Universität Vechta)
Teilnehmer: Rudolph Cordes (NOVAgreen, Vechta), Prof. Dr. Stefan Töpfl (Deutsches Institut für Lebensmitteltechnik, Quakenbrück), Prof. Dr. Martin K.W. Schweer (Universität Vechta), Stephanie Grahl (Universität Göttingen), Dr. Ramona Weinrich (Universität Göttingen)

- **12:00 Uhr: Mittagspause**

- **12:30 Uhr: Posterpräsentationen mit einzelnen Projektergebnissen**

- **14:00 Uhr: Vortrag Dr. Ludger Breloh** (REWE Group, Köln): "Insekten als innovatives Futtermittel aus Sicht des LEH"

- **14:30 Uhr: Vortrag Prof. Dr. Frank Liebert** (Universität Göttingen): "Insekten im Tierfutter aus Sicht der Monogastriden (Schwein / Broiler)"

- **15:00 Uhr: Vortrag Prof.'in Christine Tamásy & Prof. Dr. Daniel Schiller** (Universität Greifswald): "Wandel in der Lebensmittelproduktion: Akteure und Perspektiven"

- **15:30 Uhr: Kleine Pause**

- **15:45 Uhr: Podiumsdiskussion** "Reaktionen der Wertschöpfungskette auf innovative Futtermittel "
Moderation: Dr. Daniel Mörlein (Universität Göttingen)
Teilnehmer: Dr. Ludger Breloh (REWE Group), Prof. Dr. Frank Liebert (Universität Göttingen), André Woelk (Universität Greifswald), Arne Bünger (Universität Greifswald), Prof. Dr. Ludwig Theuvsen (Universität Göttingen)

Anschließend: Get-together

Annex 6: 'Program of the DAFA Forum'

09:00 Uhr	Ankommen
10:00 Uhr	**Produktion, Geschäftsfelder, Grenzen – zukünftiger Bedarf und neue Möglichkeiten** • Wie können neue Lebensmittel die Landwirtschaft verändern und welche Veränderungen bei Lebensmitteln und Landwirtschaft sind realistisch? • Was kann und sollte die landwirtschaftliche Produktion leisten? • Wie muss die Agrarforschung hierauf reagieren?
12:45 Uhr	Mittagspause

14:00 Uhr	**Was sind die zentralen Fragen für die Forschung?** Produktion, Forschung, Infrastrukturen, Kooperationen, Förderung – Ist Agrarforschung zukünftig nicht mehr erforderlich oder ändert sich die Agrarforschung? **Drei parallele Sessions: Rot, Gelb und Grün** • Rote Session: In-vitro-Fleisch und Fleischersatz • Gelbe Session: Insekten als Lebensmittel und Futter • Grüne Session: Vertical farming und Algenproduktion
16:00 Uhr	Kaffeepause
16:30 Uhr	Synthese und Ausblick Ergebnisse Rote, Gelbe und Grüne Session
18:15 Uhr	Get-Together mit Imbiss

Declaration on oath

I hereby declare that the present thesis has not been submitted as a part of any other examination procedure and has been independently written. All passages, including those from the internet, which were used directly or in modified form, especially those sources using text, graphs, charts or pictures, are indicated as such. I realize that an infringement of these principles which would amount to either an attempt of deception or deceit will lead to the institution of proceedings against myself.

Date Signature