WWF-UK and Tesco

Development of a roadmap to scale up insect protein production in the UK for use in animal feed

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1 INTRODUCTION

1.1 Background

Population growth is increasing the demand for food products

As the global population grows, the world's natural and finite resources are becoming increasingly strained. The United Nations estimate that world population is projected to reach 8.5 billion by 2030 and 9.7 billion by 2050 (United Nations, 2019). In order to provide enough food globally in line with a growing population, socio-economic changes, and measures to address the challenges of hunger, food insecurity and malnutrition; efficient and sustainable food production systems are required (FAO, 2018).

Humans require a range of essential nutrients in food that are necessary to support human life and good health. These include protein, carbs, fats, vitamins, minerals, and water. Of particular importance is protein, typically consisting of animal protein and to a lesser extent, plant-based protein. However, the average citizen typically consumes too much animal protein per capita in the UK and Europe, reaching levels that are unsustainable.

The World Wide Fund for Nature (WWF) recognise that animal protein will always remain an important part of human diets and the demand for meat and fish-based food products will remain strong as population increases. However, as demand for these products continues, so does the demand for feed ingredients that are high in protein. It is therefore important to ensure that animal protein produced is done so sustainably.

Farmed animals play an integral part of the food system

Farmed animals play a pivotal role in the food production system, enabling the creation of food products for humans, often utilising materials that are otherwise unsuitable for direct human consumption. For example, animal production can make use of marginal or unfavourable lands, utilising feed materials (e.g. grass) that can be turned into highly nutritious, protein-rich food.

The Food and Agriculture Organization (FAO) of the United Nations recognise that, globally, farmed animals primarily consume foods not fit for human consumption (e.g. forages, crop residues and by-products), with an estimated 86% of all animal feed being categorised as not edible for humans (Mottet *et al.,* 2017). However, this means that around 14% of feed ingredients consist of edible materials (e.g. grains).

The production of feed ingredients is competing with and utilising land that that could otherwise be used to produce other food crops for direct human consumption. Furthermore, land use change for producing crops is taking land away from natural habitats and ecosystems that provide a wide range of environmental benefits. The production of soy is one example, with large quantities produced each year to provide feed for farmed animals. The land used to produce this feed it often associated with recent or past land use change.

Food production is having a significant impact on the environment

The production of crops in some regions (for both food and feed) has come at a considerable cost to the environment. On land, for example, intensified agricultural production systems (e.g. soy and beef) in South America have led to the clearing of rainforests, the degradation of natural resources and contribution to climate change (FAO, 2018). In the seas, one-third of global marine fish stocks were fished at unsustainable levels in 2017, with the

Mediterranean and Black Sea considered to be the world's most overfished sea (FAO, 2020a). Producing feed ingredients to grow animal protein is exacerbating the issue.

Two key examples include the production of soy and fishmeal.

- Soy production in South America, for example, has been linked with extensive deforestation, where natural habitats are being destroyed and converted to farmland to create land for the production of soy and other agricultural products (e.g. beef).
- Fishmeal production for use in aquaculture feed has resulted in overfishing and has been associated with accelerated depletion of fish stocks and biodiversity loss.

An increasing demand for these products to meet the feed requirements of farmed animals is intensifying the impact that these production systems have on the natural environment.

Animal production in the UK continues to contribute to environmental degradation

The UK agricultural sector is making great strides in improving the sustainability of UK-based agriculture and home-produced foods. However, the sourcing of key commodities for animal feed, such as soybean meal and fishmeal, continues to have significant issues on the natural environment within the sourcing regions, which are typically abroad, out of sight and out of mind.

Whilst the soy industry is working to ensure that all soy produced is deforestation free; it was estimated in 2019 that only 27% of soy consumed in the UK was covered by a deforestation and conversion free soy (EFECA, 2019); the demand for soy cannot increase indefinitely. Similarly, the use of fishmeal in aquaculture feed must be balanced with the sustainable regeneration of global fish stocks to ensure the future availability of these products.

It is therefore important to find more sustainable ways of delivering the protein needs of farmed animals. This will require strategies that incorporate alternative feed ingredients, which are comparable or better than soy and fishmeal (in terms environmental impact, price, quality, and logistics etc.).

Alternative novel proteins for farmed animal feed are required

One way to address the protein needs of animals is to diversify the protein sources used within animal production systems and to reduce reliance on global supply chains. Within a UK context, for example, home-produced protein sources are becoming increasingly desirable as a viable alternative to importing feed ingredients from abroad.

Whilst there are a range of novel proteins emerging (e.g. algal, bacterial, and yeast-derived), insect protein is one alternative that has been acknowledged as having considerable potential for use in animal feed (for species such as e.g. chickens, pigs and salmon). Insect protein presents an opportunity to diversify, displace or replace some of the current protein needs of animals fulfilled by fishmeal and soybean meal. Not only can insects be farmed in relatively small spaces compared to other agricultural products, they offer the opportunity to utilise by-products that may otherwise be wasted, and farming can be conducted on non-agricultural land with fewer environmental consequences.

Can insect protein provide a viable solution?

The purpose of this study was to assess the environmental impact reduction potential of insect protein relative to soy and fishmeal, and to understand what might be required to see the scaling of production in the UK. This report provides WWF's evaluation and recommendations to the industry and policy makers on an alternative novel ingredient for animal feed in the form of insect protein.

1.2 Aim and Objectives

The overall aim of this project was to develop a roadmap indicating how the production of insect protein for animal feed can be scaled up, taking into consideration the environmental, legal, market and operational constraints.

The objectives of the project were:

- To evaluate and develop the evidence base around insect protein production.
- To develop a roadmap to rapidly scale insect protein.
- To draft recommendations to realise the roadmap.

1.3 Scope of project

The research outlined in this report was undertaken by ADAS and Michelmores on behalf of WWF and Tesco. The research provides an independent and neutral assessment of how the UK insect biomass value chain could be scaled up to provide processed insect protein meal for the use in farmed animal feed for poultry, pigs, and aquaculture.

Region: This research principally focusses on insect farming within a United Kingdom (UK) context.

Applications considered: We considered insect protein within the context of feed for poultry (i.e. chickens), pigs and aquaculture (i.e. salmon). These animals were chosen due to a combination of factors, including the fact that these species consume insects as part of their natural behaviour, the species have high protein requirements, and these species utilise large volumes of soybean meal and fishmeal (aquaculture only) in their diets. We do not consider any other applications for insect protein (e.g. direct human consumption, pet food etc.)

Insect products considered: The focus was on insect meal as a processed animal protein. We did not specifically consider other co-products (e.g. insect oil) or by-products (e.g. frass, or chitin) associated with insect production systems, although recognise how these high value products can contribute to viable insect farming businesses.

Insect species considered: Black Soldier Fly (BSF) was chosen as the primary focus of our assessment due to it being the most farmed insect globally. BSF is nutritionally comparable to fishmeal or soybean meal and is one of seven insect species that are authorised for use in aquaculture feed in the European Union.

Insect feedstocks considered: Insects are extremely versatile creatures, which can thrive on a huge range of substrates, such as former foodstuffs, animal by-products and even animal manures. We focus on viable substrate materials that are produced within the UK only. We do not consider substrates that might be imported as a suitable feedstock.

1.4 Approach

The approach taken to fulfil the project objectives included four core components:

1) Review of insects as a viable solution (Chapter 2)

A literature review of peer-reviewed publications and grey literature was conducted to examine and evaluate the evidence base for insects as an alternative novel protein for farmed animal feed.

2) Status of insect farming in the UK (Chapter 3)

Stakeholder perspectives were gathered from across the insect production value chain, from farm to retailer, to identify the barriers and opportunities for upscaling, and to inform the analysis, modelling and recommendations developed within this report.

3) Appraisal of current legislation and support schemes (Chapter 4)

A comprehensive review of the current legislative environment within the UK was undertaken. The review included current permitted use and prohibited use of insects in livestock feed (including poultry and pigs) and aquaculture feed, legislation concerning processed animal protein and animal by-products; and current permitted and prohibited substrates for use in insect production, including the use of by-products. A review of current legislation and environmental and land management schemes funding schemes was also undertaken, in addition to an analysis of current legislative

4) Future vision for insect farming (Chapter 5-7)

We assess and outline the future vision for insect farming in the UK, with a specific focus on the production of Black Soldier Fly (BSF), reared on a range of substrates, to produce insect meal for inclusion in fish (e.g. salmon) feed, as well as pig and poultry feed (when legislation allows). The assessment included three core parts:

a) **Assessment of suitable substrates (Chapter 5)**. An assessment of 22 substrates was made to identify those with most potential. This identified ten potential by-products for further analysis.
b) **Modelling options for upscaling insect biomass production (Chapter 6).** Using the ten substrates selected, we looked at three different scenarios for their use, based on estimations of substrate availability and what, if any, legislative changes would be required. Scenario 2 was selected as the basis for our calculations.
    - **Estimating the demand for insect protein in farmed animal feed.** Using the substrates identified, and using scenario 2 as the basis, modelling was conducted to identify the volume of insect meal the UK could produce, the facilities required (e.g. size and number), and the quantity of substrate required.
    - **Economic viability of insect farming in the UK.** A financial assessment was then conducted to understand what size of facility would be required, along with other factors, to demonstrate economic viability of the industry.
c) **Roadmap for upscaling UK insect protein (Chapter 7).** Outlines what the industry could look like in 2030, 2040 and 2050. Based on identified demand and the realistic upscaling (i.e. construction) of insect production facilities in the UK, we estimate the volume of insect meal that could be produced each year up to 2050.

5) Recommendations to achieve roadmap (Chapter 8).

Recommendations to achieve the volumes indicated possible by the modelling were then developed, providing actions required to achieve the roadmap for scaling up the insect biomass industry in the UK. Prioritised actions for key stakeholder groups were also identified.

2 INSECTS AS AN ALTERNATIVE NOVEL PROTEIN

There are a range of novel proteins that have the potential to displace conventional protein sources (e.g. fishmeal or soybean meal) for use in farmed animal feed. These include all sorts of innovative protein sources, from insect farming, seaweed and microalgae, plant proteins (e.g. pea protein) and single-cell protein or microbial proteins (e.g. yeast, bacteria, fungi, and algae). This research explores insect protein as a novel feed ingredient.

2.1 Insects as a feed ingredient

2.1.1 Typical species used for insect protein

More than 2,000 insect species are considered edible, with most of these originating in tropical countries (EFSA, 2015).

EFSA (2015) list the following species as those which are reported to have the 'biggest potential' to be used as food and feed in the EU, although it is unclear what factors contributed to making this assessment:

- *Musca domestica*: Common housefly
- *Hermetia illucens*: Black soldier fly
- *Tenebrio molitor*: Mealworm
- *Zophobas atratus*: Giant mealworm
- *Alphitobus diaperinus*: Lesser mealworm
- *Galleria mellonella*: Greater wax moth
- *Achroia grisella*: Lesser wax moth
- *Bombyx mori*: Silkworm
- *Acheta domesticus*: House cricket
- *Gryllodes sigillatus*: Banded cricket
- *Locusta migratora migratorioides*: African migratory locust
- *Schistocerca Americana*: American grasshopper

Species of particular interest for use in feed products include *Hermetia illucens* (black soldier fly), larvae of *Musca domestica* (common housefly), and *T. molitor* (yellow mealworm) (van der Spiegel *et al.*, 2013).

In 2020, there were seven insects authorised for the production of processed animal proteins for permitted uses (see section 4.2). These species and their characteristics are shown in Table 1.

Black Soldier Fly is currently the preferred species

Internationally, the preferred insect species for commercial scale production of insect protein for animal feed is black solider fly (BSF). In Europe, 95% of insect production is BSF and yellow meal worm (Fitches, 2019) and until 2018, around 80% of EU insect-producing companies based their business on BSF (Halloran *et al*., 2018; cited in Cadinu *et al*., 2020).

BSF was chosen as the primary focus of this study due to it being the preferred species, both in Europe and internationally.

Black Soldier Fly (BSF) larvae

- BSF is a common and widespread fly of the family Stratiomyidae.
- The protein from BSF larvae provides well-balanced, highly digestible amino acid profiles that can be used as a replacement to fishmeal and soybean meal.[a]
- BSF lifecycle includes eggs, larvae, pre-pupa, pupae and adult stages, taking around 40–45 days to complete.[b]
- Depending on the size of the larvae, type of the substrate available, and environmental conditions (e.g., moisture, temperature, and air supply), the larvae consume from 25 to 500 mg of organic matter per larva per day.[c]
- The food conversion ratio of BSF is estimated to be about 10-15 based on the wet weight diet as fed.[c,d]
- BSF produces a high-quality protein (37-47% dry weight) and can achieve more than 60% crude protein when de-fatted, which makes it superior to soybean meal.[e]
- BSF also maintains a consistent amino acid profile across different rearing substrates and is high in essential amino acids.[e]
- BSF meal is high in calcium and phosphorous and high in energy (25.7 MJ/kg compared to 13-17 MJ/ kg for soybean meal).[e]
- Extensive testing has shown that BSF is not an invasive species risk in northern climates and are not a vector of diseases for humans, animals or plants.[f]

Sources of information: a) IBCTFG, 2019; b) Cadinu et al., 2020; c) Surendra et al., 2016; d) Danieli et al., 2019; e) Fitches, 2019; and f) Zero Waste Scotland, n.d.

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- *Musca domestica*: Common housefly
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- *Acheta domesticus*: House cricket
- *Gryllodes sigillatus*: Banded cricket

- *Locusta migratora migratorioides*: African migratory locust
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There are seven insect species currently authorised for the production of processed animal proteins for use only in aquaculture (excluding fur animals) within the EU Regulation 2017/893 (section 4). These species and their characteristics are shown in Table 1.

Table 1. Characteristics of the seven insect species currently authorised to be produced for processed animal proteins intended as feed for aquaculture (data sourced from IPIFF, 2019b). Incubation period is the number of days from egg-laying to hatching; time to maturity is the number of days from hatch to maximum body weight. Protein content and fat content are both listed on a dry matter basis. Source: ADAS for WWF.

	Incubation period	Time to maturity	Size	Protein content	Fat content	Resistance to environmental conditions	Productivity
Banded cricket *(Gryllodes sigillatus)*	12 days	33-40 days	20-22mm	60-70%	20-25%	Extremely resistant	Very productive in mass culture and tolerates high population density
Jamaican field cricket (*Gryllus assimilis*)	12 days	42-49 days	25-28mm	50-65%	25-30%	Relatively resistant	Productive in mass culture but shows a tendency towards cannibalism under high population density
House cricket *(Acheta domestics)*	11 days	32-49 days	20-22mm	60-70%	20-25%	Resistant	Very productive in mass culture and tolerates high population density
Mealworm (*Tenebrio molitor)*	10-12 days	280-400 days	15-18mm (adult beetles) or 25mm (larvae at final stage)	50-65%	30-40%	Resistant	Very productive in mass culture and tolerates high population density
Lesser mealworm *(Alphitobius diaperinus)*	10-12 days	280-400 days	6mm (adult beetles) or 11mm (larvae at final stage)	50-65%	30-40%	Resistant	Very productive in mass culture
Black soldier fly *(Hermetia illucens)*	4 days	12-60 days	15-18mm (adult flies) or 25mm (larvae)	40-50%	35-45%	Extremely resistant	Very productive in mass culture and tolerate high population density. Able to complete their lifecycle within 3 weeks
House fly (*Musca domestica*)	1 day	2-30 days	10-12mm (adult flies) or 8mm (pupae)	40-65%	20-45%	Extremely resistant	Very productive in mass culture and tolerates high population density

2.1.2 Insect biology and nutritional profile

This section assesses the nutritional requirements for insect growth, and the nutritional benefits of insects for use in animal feed.

Insects, like other animals, require nutrients to grow

Studies performed on insects and vertebrates have established that diet balancing and protein:carbohydrate ratio (P:C ratio) is critical, influencing not only an insect's growth and development, but also body composition, reproduction, aging etc. (Bonelli et al., 2020). Insects need to be supplied with at least the ten essential amino acids (lysine, tryptophan, histidine, phenylalanine, leucine, isoleucine, threonine, methionine, valine, and arginine), whilst other amino acids are 'non-essential' and can be synthesised from other amino acids or similar chemical components (NC State University, 2015).

Insects have a high feed conversion ratio

Feed conversion ratio (FCR) is a way of measuring the efficiency with which an animal species converts feed into the desired output. The FCR is the mass of the input divided by the output (thus mass of feed per mass of product). For example, a FCR of 2.0 means that for every functional unit of mass output (e.g. kg of meat), the animal consumes twice that functional unit (e.g. 2 kg) in feed to produce the 1 kg of output. The lower the FCR, the greater the efficiency of the animal for turning feed into the desired output.

Insects have a good conversion efficiency as they do not need to maintain their body temperature. Recent studies cite feed conversion ratios of 1.4-2.6 for fly larvae (including BSF), 4.1-19.1 for mealworms, and 2.3-10.0 for crickets on a fresh matter basis. This compares to feed conversion ratios of 1.2 for salmon, 2.3 for poultry, 4.0 for pork, and 8.8 for beef (FAO 2017a; Fitches, 2019; Fowles and Nansen 2020).

Substrate material influences insect growth rates

The diet of an insect impacts on the efficiency of insect production, and the resulting protein content of the insect (Lundy and Parrella, 2015; Barbi *et al.,* 2020). The substrate that is used as feedstock for rearing insects therefore plays an integral part in the production process. Research has shown that carbohydrate and protein content in the rearing substrate significantly influences larval developmental time, larval and pupal weight, and the nutritional value of the insect (Bonelli et al., 2020).

The most widely farmed insect, black soldier fly, require substrates containing a minimum of 10% protein, 2% fat and 2% minerals for sufficient larval growth (Spranghers *et al.,* 2019). For optimal larval growth however, carbohydrates and total proteins should compose 50% of total dry matter in a 1:2 protein:carbohydrate ratio (Barragán-Fonseca *et al.,* 2018).

Insect diet impacts on the efficiency of insect production, and the resulting protein content of the insect (Lundy and Parrella, 2015; Barbi *et al.,* 2020). The feed conversion ratio achieved varies depending on the type of substrate used as a feedstock for the insect. Studies cited within Ites *et al.,* (2020) found that, in a modular system kept at 27°C and 60-70% humidity, the feed conversion ratio of BSF larvae for 1kg of dry larval biomass on environmental and economically efficient feed was 4.16 kg of dry feed, for brewery grains was 7.25 kg dry feed, potato peels were 6.28 kg, and expired food had a feed conversion ratio of 14.5 kg for 1 kg dry larvae.

Insects need to be supplied with at least the ten essential amino acids; lysine, tryptophan, histidine, phenylalanine, leucine, isoleucine, threonine, methionine, valine, and arginine.

Other amino acids are 'non-essential' and can be synthesised from other amino acids or similar chemical components (NC State University, 2015).

Insects provide a nutritional ingredient for animal feed

The main components of insects are fat, proteins, fatty acids, fibres, dietary minerals, and vitamins (FAO, 2014). Chitin is a primary component of insect exoskeletons and is made from a derivative of glucose (a simple sugar).

The crude protein content of insect meal depends on the insect's stage of development, the type of diet and the rearing conditions. Amino acid contents and digestibility will also vary accordingly (Nogales-Mérida *et al.,* 2019). Likewise, the lipid profile of the BSF mimics the lipid profile of the substrate (Liland e*t al.,* 2017).

For example, one study found that the protein content of BSF larvae was lowest on fruit surplus (307g/kg sample) and highest when fed organic materials from human food (522g-583g/kg sample). Brewery by-products (529.6 g/kg sample) and poultry droppings (480g/kg sample) also showed relatively high larval protein content (Nogales-Mérida *et al.,* 2019).

Protein from BSF larvae is proven to be of high quality and suitable for use as a partial replacement of both fishmeal in compound fish and pig feed and soymeal in poultry and pig feed (IBCTFG, 2019); whilst well-balanced highly digestible amino acid profiles of larvae are superior to soymeal and more comparable to fishmeal (IBCTFG, 2019).

The amino acid contents of insect meals can be comparable to those in fishmeal (Nogales-Mérida *et al.,* 2019), with essential amino acids higher than reported in other animal and plant meals. Insects are rich in omega-3 and also good sources of lipids and fatty acids, although the levels of these varies according to the insect species, development stage and type of feed.

When compared with soybean meal, insects tend to have a higher protein percentage as a dry meal (Pinotti *et al.,* 2019); with 86% of the composition of small mealworms and 63% of BSF larvae being protein. In comparison, soybean meal typically consists of 45% protein, high quality soybean meal extract is around 62% protein and fishmeal are around 65% protein.

2.1.3 Insect protein for farmed animal feed

The main form of insects used in feed is meal, which is produced following processing of the reared insects. Generally, the insects are crushed, and the oils are extracted, leaving a high protein material which can be added to animal feed rations, often as pellets or part of compound feeds.

The scientific literature indicates that insect protein is nutritionally comparable to fishmeal or soymeal (Shelomi, 2020). However, the protein content of insects can vary considerably depending on the species of insect farmed and the substrate that they are reared on. Some estimates put protein content of insects raised in natural conditions as 9.3-76%, with fat content ranging from 7.9% to 40% (Nogales-Merida *et al.,* 2019), with others quoting ranges of 30-68% protein on a dry matter basis (Gasco *et al.,* 2020), and 50-82% protein as a dry product (IPIFF, 2019a). This is compared to soybean meal which is comprised of 44-46% crude protein (Dei, 2011).

Insects have also been found to promote nutrient uptake and there is some evidence that they can promote animal growth performance, making them a good contender as a complementary material in animal feed for aquaculture and livestock (IPIFF, 2019a). Research exists which suggest that that antioxidant peptides, chitin, and antimicrobial peptides in the insect could stimulate the immune systems of the animals eating the insects as feed (Gasco *et al.,* 2020). Furthermore, chitin is known to have prebiotic qualities (IPIFF, 2019a).

Insect meals generally have higher essential amino acid contents than other meal types and are also a good source of lipids and fatty acids (Nogales-Merida *et al.,* 2019). Insect meals can be an important source of essential amino acids such as methionine, with contents ranging from 0.47-4.03 g/100g, which are higher than reported values for other animal and plant meals (Nogales-Merida *et al.,* 2019). Black soldier fly prepupal biomass levels of lysine, valine and arginine have all been shown to be in the range of 20-30 g/kg DM, with an overall incidence of essential amino acids of more than 55% (Spranghers *et al.,* 2017). In general, insect meal has a very similar essential amino acid profile to fishmeal and soybean meal (Pinotti *et al.,* 2019), meaning that the essential amino acids present in each are similar, although their quantities may vary. There can also be secondary benefits of insect meal, whereby insect peptides with activity against pathogenic micro flora may significantly improve animal health (Nogales-Merida *et al.,* 2019).

Insect-based feed products could have a similar market to fishmeal and soy, which are presently the major components used in feed formulae for aquaculture and livestock (FAO, 2013). Available evidence suggests that insect-based feeds are comparable with fishmeal and soy-based feed formulae (FAO, 2013).

Current applications of insect protein in Europe

Where it is legal to do so, insects can be specifically added to animal feed as an alternative protein to soybean meal or fishmeal. Globally, insect protein has a similar market to fishmeal; used as a feed ingredient in aquaculture and livestock feed and used in the pet industry (FAO, 2013).

Pet food

Pet food is a mainstream market for European insect producers. Mealworms and crickets are reared primarily as pet food in Europe, North America and parts of Asia (FAO, 2013).Several European pet food companies incorporate insects in their feed formula, notably as a means to diversify their products' range (e.g. in hypoallergenic products). This trend is expected to continue to grow (IPIFF, 2019a).

Aquaculture feed

Insects are high in protein and can also contain bioactive components that have immune-boosting properties (such as lauric acid, antimicrobial peptides and chitin), which have been shown to lead to improved immunity and lower mortality rates when used in aquaculture feed (IPIFF, 2019a). Chitin is primarily considered a fibre, but also contains amino acids and nitrogen (Nogales-Merida *et al.,* 2019).

Salmon require essential amino acids (arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) contained in protein for normal growth (FAO, n.d.). The crude protein dietary nutrient requirement for Atlantic salmon is estimated to be between 42-50% dependent on the growth stage of the fish (FAO, n.d.). This need is currently met with a combination of fish meal and plant meal, although there are limitations on how much of the salmon's diet can be composed of plant meals (such as soybean meal, corn gluten meal, canola meal or pea meal) while still ensuring essential amino acid requirements are met (FAO, 2020b).

Insect proteins, such as that produced from black soldier fly (BSF), could reduce the aquaculture industry's reliance on fishmeal as a protein source, providing an additional supplement to the existing use of plant-based meals (fishmeal currently represents around 20% of salmon diet composition). In the form of meal or pellets, insects can provide adequate protein to replace standard fishmeal in omnivorous fish feed for species such as carp and catfish, however, only some of the fishmeal can be replaced by insect products in carnivorous fish such as trout and salmon (Riddick 2014; cited in EFSA, 2015). Research has shown that insect/BSF meal can replace 50% or more of fishmeal in farmed fish diets (IBCTFG, 2019), thereby providing at least 10% of the dietary requirements of salmon.

Insect meal can also replace some of the plant-based meal. The amount of soybean meal and fishmeal that can be replaced with insect meal depends on the nutrient and amino acid profile, therefore the total replacement of major protein sources may not be possible in all instances (IPIFF, 2017). Insect meals are one of the best alternatives to either partially or completely replace fishmeal for salmon, because of their amino acid and fatty acid profiles, as well as insects already being a natural food source for fish (Nogales-Merida *et al.,* 2019).

PROteINSECT carried out fish feeding trials in 2015 in Belgium and the UK. Over an eight week period, 3,600 Atlantic salmon parr (juveniles) were involved in a feeding trial which found that common housefly larvae are able to provide a suitable meal which can be used to replace up to half of the fishmeal without affecting performance or the proximate compositions of the fish body, and that defatted insect meal has the potential to replace more than 50% of fishmeal in salmon parr diets (PROteINSECT, 2016).

Protein inclusion rate: Current inclusion rates of fishmeal and plant-based proteins (e.g. soybean meal) within salmon feed are highly variable depending on the region of production and life-stage of the fish; for example fingerling, juvenile, grower and adult (FAO, n.d.; Aas and Ytrestøyl, 2019; Feedback, 2019). The crude protein dietary nutrient requirement for Atlantic salmon is estimated to be between 42-50% dependent on the growth stage of the fish (FAO, n.d.). In the UK, average soybean meal (or equivalent) inclusion levels in 2018-19 were estimated to be 13.4% in fish feed (EFECA, 2020). The scientific literature suggest that the inclusion of marine protein provides benefits beyond that of just protein content (Egerton *et al.,* 2020); fishmeal comprises long chain omega-3 fatty acids, such as eicosapentaenoic acid and docosahexaenoic acid, and essential vitamins and minerals (Heuzé, 2015), whilst soybean meal provides a relatively cheap plant-based protein substitute alongside fishmeal. It is therefore unlikely that all fishmeal and soybean protein content would ever be completely displaced by insect meal.

Research underway to assess new applications of insect protein in Europe

There is huge potential for using insect protein as a source of animal feed for pigs, poultry and fish in the EU (ADAS, 2016). Insects are a high protein natural component of the diets of farmed animals including fish, poultry and pigs, and therefore offer a natural ingredient to be included within conventional feeds.

Chicken feed

Feeding insects to layer and broiler chickens was found to result in similar levels of productivity as traditional feed blends (Khusro *et al.,* 2012). A German study (Altmann et al., 2020) assessed the chicken meat quality derived when soymeal is substituted for partially de-fatted BSF larval meal. The research found that the meat reared on insect meal was of comparable eating quality; although other changes were noted, including the meat being slightly more yellow, having a slightly decreased pH, and less adhesive during chewing (meaning the texture required less mastication) compared to the soy-fed control. Furthermore, poultry fed on insect protein were found to have higher saturated fatty acids proportions in thigh meat (Altmann et al., 2020). Whilst the results showed that the BSF larval meal can be viably included in broiler chicken production, as investigated from a multi-faceted meat quality perspective, the meat also contained an increased proportion of saturated fatty acids. Whilst this is associated with increased quality parameters, such as shelf-life, it is not positively perceived from a health point of view (Altmann et al., 2020).

Calvert *et al.,* (1971; cited in Khusro *et al.,* 2012) found that insect meal led to a slight increase in chick growth rates compared to conventional protein supplements, with Johnson and Boyce (1990; cited in Khusro *et al.,* 2012) finding that an increase in the amount of insects in the diet led to an increase in survival and growth rate. EFSA (2015) states that studies of broiler chickens have found that fishmeal, soybean meal and groundnut cake could all be successfully replaced by insect protein.

PROteINSECT carried out poultry feeding trials in 2015 in Belgium and the UK. The poultry trial included 300 male chickens over a 39-day period and found that concentrations of 2% crude insect meal and 1.25% extracted insect proteins showed no significant difference in animal performance compared to birds fed on commercial diets (PROteINSECT, 2016).

Protein inclusion rate: Poultry have different nutritional requirements at different stages of growth. Broiler chicken diets are often formulated to contain 22% protein for the starter feed and 19% for the finisher feed (Poultry World, 2016). Layer feed rations typically contain no more than 16-17% crude protein. There are many protein sources that are commonly used in poultry diets. The majority of sources are from plant origin (e.g. soybean meal, cottonseed meal, alfalfa meal, and sunflower meal), whilst a minority may come from animal origin (e.g. fishmeal) (Poultry World, 2016). In the UK, average soybean meal (or equivalent) inclusion levels in 2018-19 were estimated to be 15.2% in chick rearing feed, 11.2% in layer feed and 21.8% in broiler chicken feed (EFECA, 2020). Scientists at the Food and Agriculture Organization suggest that insects contain the necessary nutrients, especially protein, to replace between 25% and 100% of soybean meal within chicken diets (The Guardian, 2020b). Fishmeal can be used in poultry diets at around 2-5% for broilers and layers (Poultry World, 2016), although in practice, we understand that very little is included within UK poultry diets at present.

Pig feed

PROteINSECT carried out pig feeding trials in 2015 in Belgium and the UK. Feeding insects to layer and broiler chickens was found to result in similar levels of productivity as traditional feed blends (Khusro *et al.,* 2012). A German study (Altmann et al., 2020) assessed the chicken meat quality derived when soymeal is substituted for partially de-fatted BSF larval meal. The research found that the meat reared on insect meal was of comparable eating quality; although other changes were noted, including the meat being slightly more yellow, having a slightly decreased pH, and less adhesive during chewing (meaning the texture required less mastication) compared to the soy-fed control. Furthermore, poultry fed on insect protein were found to have higher saturated fatty acids proportions in thigh meat (Altmann et al., 2020). Whilst the results showed that the BSF larval meal can be viably included in broiler chicken production, as investigated from a multi-faceted meat quality perspective, the meat also contained an increased proportion of saturated fatty acids. Whilst this is associated with increased quality parameters, such as shelf-life, it is not positively perceived from a health point of view (Altmann et al., 2020).

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The pig trial was conducted on 48 male castrated piglets over a four week period at concentrations of 2% crude insect meal and 1.25% extracted insect proteins and found that the levels of good micro-organisms (such as lactobacilli) were significantly higher in insect-fed piglets, there were no significant differences in body weight, daily gain, feed intake or feed conversion ratios compared to the piglets raised on commercial diets, and no differences in levels of negative micro-organisms (such as enterobacteriaceae and E.coli) compared to the piglets raised on commercial diets (PROteINSECT, 2016).

A recent study by Biasato et al (2019) found that partially defatted BSF larvae meal can be used in feed for weaned piglets without any negative impact on their growth, nutrient digestibility, gut and histological features. Chia et al. (2019) agreed, finding that BSF larvae meal is a ‘suitable and cost-effective alternative’ to fishmeal in pig diets. Some species also preferred the BSF larvae when prepared in different ways, e.g. chopped (Tran et al, 2015).

Protein inclusion rate: The diet composition for pigs typically requires a feed with 14.5-21% crude protein, depending on the stage of growth of the pig (AHDB, n.d.). Soy is an important ingredient in pig feed, due to a preferable nutrient profile with a high protein content and balanced amino acid composition, as well as year-round availability in predictable quantities (Pig World, 2019). Over the past decade the sector has halved the inclusion of soya in pig diets, from around 20%, to just under 10% (FarmingUK, 2020), due to the introduction of more rapeseed and sunflower meal, as well as distillers’ grains and use of synthetic amino acids (Pig World, 2019). In the UK, average soybean meal (or equivalent) inclusion levels in 2018-19 were estimated to be 15.8% in pig growing feed, 9.5% in pig breeding feed and 5% in pig finishing feed (EFECA, 2020).

2.1.4 Production process and technologies

Housing

Insect farms can range from a single small plastic enclosure to a large scale semi-automated factory farm (Yen, 2015). European insect farms are typically closed environments (such as boxes or mesh cages) where elements such as substrate and water can be controlled (EFSA, 2015). The insects are generally placed in a receptacle (e.g. a tray or tube) and piled on top of each other, similar to vertical farming. Alternative technologies being developed include insect bioreactors (rolling drums), which can be automated and accurately controlled (e.g. Entoprot).

Inputs to the production process

Substrate material forms the basis of the feedstock for insect production. In general, insect farming is typically classed as ‘low input’ with hormones, antibiotics and chemicals not typically used, except when disinfecting the production environment between batches of insects; however, antibiotics may be used to treat or prevent diseases in intensive production systems (EFSA, 2015).

Maturing of larvae

Eggs are introduced onto the growing substrate either manually, mechanically, or directly by adult insects. The larvae then stay on the substrate for 1-2 weeks (depending on species and temperature). The length of time required varies significantly by species, with BSF taking approximately 12 days to reach the size for harvest under conditions of 28-30^{o}C and 60%

relative humidity, whereas it would take 8-10 weeks for mealworms and lesser mealworms to reach the size for harvest under these conditions (EFSA, 2015).

The larvae are then separated from the substrate during harvesting. This can either be done manually by sieving in less industrialised systems, or an automated process in more developed systems (EFSA, 2015). Depending on the level of processing after harvest, the food substrates may be removed from the insects before harvest to allow the insects to empty their intestinal tract prior to harvesting (EFSA, 2015).

Some insects are produced to adult stage before harvesting; in these instances production is usually a two-step process, whereby there is one stage where the eggs are laid, hatched and grown to nymph size, and another stage where the nymphs are transferred to 'grow out' containers where they are raised to adult harvest size; this can take a longer time period of 3-4 months (EFSA, 2015).

The insects may, or may not, be killed (using freezing, hot water or vapour) after harvest before undergoing further processing, (EFSA, 2015). During the insect lifecycle, a metamorphosis occurs from egg, to larvae and pupa, to mature adults (van der Spiegel *et al.*, 2013).

Processing of insects into desired products

Depending on the end market, the insects can be used as whole insects, processed into powders or pastes; or protein isolate, fat/oil or chitin can also be extracted from the insect. Insects to be used as ingredients in food or feed are typically prepared into powders or pastes by milling either after drying, or when frozen (EFSA, 2015). Extraction technologies using water or steam can be used to separate large insoluble chitin particles from ground insects, with organic solvent extraction used to separate fats and oils from the protein (EFSA, 2015). Before distribution of whole insects (for food or feed), these are typically blanched, chilled or dried in order to extend shelf life and reduce the microbial load (EFSA, 2015).

Outputs from production

An efficient insect farm can utilise agricultural organic materials and by-products from the agri-food industries, converting these into high-value materials, such as protein meal, oil and chitin. A by-product of insect farming is insect excreta and the remains of substrates (known as frass) which can be marketed and used as fertiliser (EFSA, 2015).

Figure 1 shows an overview of the insect production chain, from farming to processing and utilisation, including some of the markets that the insects can be used for.

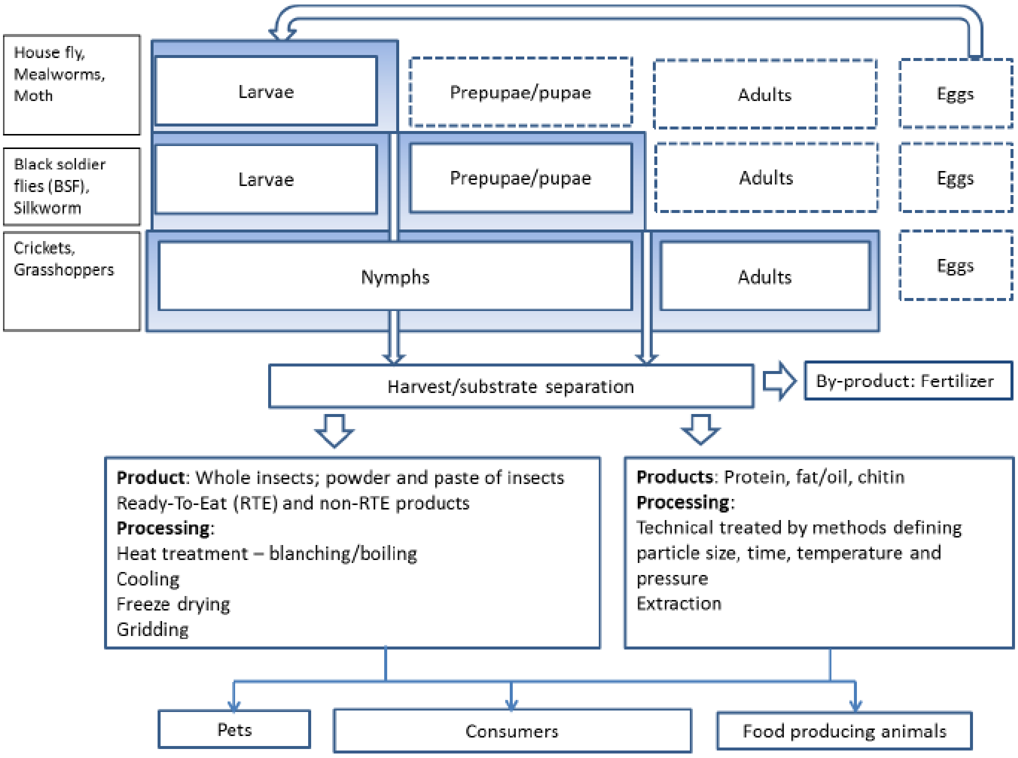

Figure 1. Overview of an insect farming operation from production to consumer. The shaded area in the lifecycle from larvae to adults indicates where exposures to feed substrates are carried over between early life-stages to the point of harvest, that is that that the original feed source is not replaced in that stage of the life cycle, e.g. BSF have the same food source at larvae and pupae stage but house flies do not. Source: EFSA, 2015.

Outputs from production

An efficient insect farm can utilise agricultural organic materials and by-products from the agri-food industries, converting these into high-value materials, such as protein meal, oil and chitin. A by-product of insect farming is insect excreta and the remains of substrates (known as frass) which can be marketed and used as fertiliser (EFSA, 2015).

2.2 Consideration of environmental, economic and social impacts

2.2.1 Environmental considerations

For this review, we consider state and pressure indicators within the Pressure State Response (PSR) framework. The framework presents indicators on environmental quality and the resulting impact of choices made, or to be made in the future. It thus provides a method of comparing outcomes of different decisions. The PSR framework was initially proposed for the purpose of analysing the interactions between environmental pressures, the state of the environment and environmental responses (OECD, n.d.). Human activities exert "pressures" on the environment and change its quality and quantity of natural resources ("state"). Society responds to these changes through environmental, general economic and sectoral responses ("societal responses"); such as through mitigating, adapting to or preventing human-induced negative effects on the environment, halting or reversing environmental damage already inflicted, and preserving and conserving nature and natural resources (OECD, n.d.). For the focus of this assessment, we focus on the environmental pressures and the state of the environment only. These terms are defined as (OECD, n.d.):

Environmental pressures – *Relate to pressures exerted on the environment and on natural resources as a result of human activity. In this context, pressures include indirect pressures (e.g. climate impact through greenhouse gas emissions) as well as direct pressures (i.e. the discharge of pollutants and waste materials). Indicators of environmental pressure often reflect emission or resource use intensities, for example measurements of water footprint.*

State of the environment – *relates to the quality of the environment or natural resource, and thus describes the impact of any pressure exerted. 'State' covers ecosystems, natural resources and environmental conditions as well as quality of life and human health aspects. As such they reflect the ultimate objective of environmental policies. Examples of indicators of environmental conditions are concentration of pollutants in environmental media, exceedance of critical loads, or degraded environmental quality, the status of wildlife and of natural resource stocks. In practice, measuring environmental conditions can be difficult or very costly. Therefore, environmental pressures are often measured instead as a substitute.*

State indicators used in this study

The state indicators used in this study included land use change, soil condition, climate impact, water usage, nitrogen, biodiversity, pollution and waste. A review of the evidence was conducted for each production system (soy, fishmeal and insect protein) to assess the impact that each has against the indicator.

Land use change

Definition: Land use change here related to conversion of natural habitat to intensive agricultural use.

Soy production: Demand for soy is vast and as a result much land is under soy production, often land converted from tropical forest or savannah. Over the past 50 years, this has placed intense pressure on ecosystems such as the Amazon, the Cerrado in Brazil, The Gran Chaco in Argentina and Paraguay and the Northern Great Plains in the USE. Demand for soy will continue to grow, with predictions that we will need to double our soy production by 2050. Whilst much of this expansion can take place on already converted land, or abandoned agricultural land, it will undoubtedly place additional pressure on these endangered landscapes (WWF, 2019; 2020)

Fishmeal production: Not applicable.

Insect production: Not applicable.

Soil condition

Definition: Soil condition can be defined as the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental health, and promote plant, animal, and human health.

Soy production: Soybean production is linked with soil erosion, associated with tilling practices and intensive crop cycles, along with high agrochemical use. High rates of soil erosion associated with soybean cultivation have been reduced in recent years, though the rate is still several times greater than is sustainable. New methods like conservation tillage minimize erosion, but lands classified as "highly erodible" are still in use for soybean production. Because soy cultivation is highly mechanized, soil compaction is also a problem on many large soybean farms. It is estimated that Brazil loses 55 million tonnes of topsoil to erosion processes every year (WWF, 2007).

Fishmeal production: Not applicable.

Insect production: Not applicable.

Climate impact

Definition: Climate impact refers to changes in the levels of atmospheric greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Soy production: LUC from primary forest or permanent grassland to cultivated arable land (e.g. for soybean production) has resulted in a significant loss of carbon to the atmosphere. In addition to the LUC emissions, shipping emissions from the import of soybean meal to the UK for livestock feed need to be considered. These all contribute to increased atmospheric greenhouse gas concentrations. Much of the soya that is produced in South America is produced using minimum tillage practices, and if well implemented there is the potential for these to allow for some sequestration and storage of carbon in the soil.

Fishmeal production: The emissions associated with the production of fishmeal come from two main sources; the fuel required to power the fishing vessel and processing facility, and the emissions associated with the refrigerant gasses that are used to maintain the cold storage facilities on the vessel and on land once the fish is brought to shore. The proportion of these emissions that are allocated to the fish meal depends upon the proportion of the catch that is used for fish meal production (whether the whole fish is used or the offcuts) and the overall value of the different parts of the catch as emissions are usually allocated on an economic basis.

Insect production: There are emissions associated with the heating requirements for the facilities and general temperature control, although these can be significantly reduced if renewable sources such as solar or wind are used. In addition, there are emissions associated with the transportation of the feed substrate to the facility. However, as the substrates are generally low value by-products the embedded emissions in the substrate is minimal as the majority of the emissions associated with their production are allocated to the primary product (e.g. ethanol, human food). A by-product of insect production is frass. The frass produced as a result of insect production contains nitrogen, therefore any application to land as a fertiliser will result in a nitrous oxide emission (both directly and indirectly through leaching and volatilisation of ammonia).

Water usage

Definition: The water footprint of a product is the combination of the rain water required (green water), the extracted water used (blue water) and the volume of water required to dilute any resultant pollutants in order to produce clean safe fresh water (grey water).

Soy production: Soy that is used within imported animal feed has a water footprint associated with the location it was grown. Soy can be produced either in rainfed systems using only green water and in irrigated systems where a combination of both green and blue water is used. The level of blue water required is dependent on the natural rainfall in the location where the crop is grown. The global water footprint for soybean production is about 2,145 litre/kg (Mekonnen & Hoekstra, 2011). Most Argentinian and Brazilian soybeans are rainfed.

Fishmeal production: The water use associated with fishmeal production is limited to the water required to produce the ice used to chill the fish on the vessel and then any water used to process the fish, which is small compared to the water requirements for crop production.

Insect production: Insect farming requires relatively little water usage, with some embedded water associated with the feed substrates, but again most of those embedded water footprint emissions will be allocated to the higher value part of the crop or raw material.

Nitrogen

Definition: Plants require nitrogen to grow and sources of nitrogen are typically applied to the land via fertilizers, other chemicals and animal manures to improve plant growth.

Soy production: Soybeans are leguminous crops and are therefore able to capture and fix much of their own nitrogen. However, where soybean yields are particularly high there are agronomic benefits in applying some additional artificial nitrogen (20-45 kg/ha) (Schmidt, n.d.). This rate of application is significantly lower than for other crops in the rotation such as cereals. Where nitrogen applications are not well managed this can have negative consequences in terms of run-off and pollution where the soybeans are grown. Moving from soybean meal to insect meal could reduce the demand for soybean meal production, thereby reducing the amount of nitrogen applied to plantations in these growing regions, although this depends on what new use the land is put to. It is unlikely that a replacement crop would reduce nitrogen as soya nitrogen use is relatively low.

Fishmeal production: Not applicable.

Insect production: The frass produced as a result of insect production has a value as a fertiliser in crop production systems. Gärttling *et al* (2020) found that the frass produced by black soldier fly had a typical nutrient content of 3.4% N, 2.9% P_2O_5 and 3.5% K_2O. It is possible to use this insect frass to displace some of the artificial nitrogen fertiliser that is applied to UK crops. However, wherever nitrogen is applied to the soil there will be associated direct and indirect emissions of nitrous oxide. Nitrogen vulnerable zones (NVZs) in the UK may prevent the ability to spread this frass in certain locations or at certain times of the year.

Biodiversity

Definition: Biodiversity relates to the variety of plant and animal life in a particular habitat, a high level of which is usually considered to be important and desirable.

Soybean production: Soybeans are typically produced on large arable fields, with low levels of crop rotation and high levels of weed, pest and disease control. This type of production system can produce high levels of soybeans, but the intensive management approach means that there is little biodiversity present within the crop and with large fields and a focus on production these farms have little in the way of uncropped areas available for biodiversity between the fields. In Argentina and Brazil, the main sources of soymeal consumed in the UK, a significant proportion of the soybeans that are grown are produced on land that has been converted from Cerrado, Pampa or primary forest in recent years. The loss of these natural habitats to create farmland results in significant negative impacts on biodiversity of plant, animal, fungi and microbial species.

Fishmeal production: The production of fishmeal has a negative impact on biodiversity due to the catching of fish which are then processed into fishmeal. There are concerns associated with exploitation of certain types of fisheries and the consequences on stocks of other wild fish as a result of over-reliance on the capture of fish products to produce fishmeal for aquaculture. Changing Markets Foundation (2019) found evidence that production of fishmeal and fish oil in India, Vietnam and the Gambia for use in global aquaculture supply chains is accelerating the collapse of fish stocks. Changing Markets Foundation (2019) found that Indian fishmeal plants have resulted in collapse of sardine fish stocks, with new species appearing in catches suggesting that other species collapse may follow. They noted that juvenile catch is also hauled in, making it more difficult for fish colonies to rebuild. Similarly, in Vietnam, widespread overfishing resulted in declining fish stocks (Changing Markets Foundation, 2019). It is important to note that even where non-commercial fish species are taken, they form key trophic levels for other species, and so their removal can have wider impacts across the marine ecosystem.

Insect production: The land requirements for insect production are low and therefore the impacts of insect production on direct land-use change and biodiversity loss are significantly lower than is experienced in soybean production in parts of South America. Using existing food surplus and non-food materials as feed substrates for the insects means that they should not require additional land areas to be utilised indirectly for the production of insect feed. However, consideration should be given as to whether utilisation of by-products by insects displaces other uses (e.g. use of distiller's grains in cattle feed, that might then result in additional feed from alternative sources being sought for cattle, resulting in indirect land use change). There could also be risks associated with the non-intentional introduction of invasive insect species, which should be considered when introducing insect species into different areas, although BSF is not considered to be an issue within a UK context.

Pollution

Definition: Pollution refers to characteristics that make an environment harmful or unpleasant for living organisms.

Soy production: The production of soy relies heavily on chemical inputs (e.g. herbicides, insecticides and to a lesser extent fertilisers) to protect crops from pest and diseases and to promote plant growth and higher yields; particularly in regions such as Brazil, Argentina and USA. Run-off from the fields can reach aquatic systems, resulting in bioaccumulation and eutrophication. When applied by aircraft, negative impacts can increase as the chemicals cover a wider than necessary area (Defra, 2006b). Furthermore, the processing of soybeans into meal most commonly uses a hexane solvent, an extremely flammable and non-bio-renewable product that poses health risks and is regulated as a hazardous air pollutant (Heuzé *et al.,* 2020).

Fishmeal production: The production of fishmeal can be associated with air pollution, through particulate matter, chemicals and greenhouse gases (covered under climate) released during the fishing process. In addition, diesel, oil and solvent spills can contribute to water pollution (Defra, 2006a). However, as fishmeal production is ever-more focused towards the use of fish surplus, cuttings and trimmings from fish processing, these pollutants are reducing. During the processing stage, there is a risk of effluent discharge with a high organic content, phosphate and nitrate; solid wastes may be a concern with certain technologies. When discharged without treatment, eutrophication and oxygen depletion can occur, resulting in pollution of nearby beaches and shores (Defra, 2006a).

Insect production: Other than the by-products produced from insect production (e.g. frass), there is minimal pollution as the production environment is contained and closely monitored. Where insect frass is used as a fertiliser there is the risk that the nitrogen in the fertiliser could be lost to the environment through leaching, volatilisation as ammonia or as nitrous oxide. The phosphate in the fertiliser is also a potential risk to water courses if it is washed of the treated land. For this reason, it is important that insect frass (as with all other organic amendments) is used according to best practice advice in order to minimise the impact on the environment.

Waste

Definition: Waste refers to solid, gaseous and liquid by-products that can create serious problems for humans, animals, and the environment if they are not treated, transported and managed safely.

Soy production: Soy production has little direct waste, with various products created from the bean, including soy oil and soybean meal. Crop residues can be used as low-quality animal feed, burnt or incorporated back into the soil. Soybean curd residue is the main surplus material of soybean products, and often regarded as waste.

Fishmeal production: The processing of fish for human consumption results in by-products in the form of heads, viscera, frames, skins and others such as tails, fins, scales, mince, blood, etc. The by-products generated are typically turned into fishmeal and fish oil. Fishmeal production therefore utilises fish processing by-products and creates very little waste material in the process.

Insect production: EFSA (2015) state that the environmental risk of insect farming is likely to be comparable to that of other animal systems; insect waste may contain some insects and insect material; however, existing waste management strategies should be applicable for managing this. The main by-product of insect farming is insect excrement (frass), which can be used as a fertiliser. In addition to insect frass, there may be amounts of uneaten substrate that would be a by-product of insect production. Whilst insect frass can be a highly valuable material, there can be instances where this material is considered a waste and is thus associated with a cost of disposal. There may also be restrictions around the amount of material that can be stored on site before it becomes a hazard. Some insect producers export their frass abroad as a means of disposal; they pelletise the material to reduce the volume and ship this to other countries as the EU fertiliser market is already saturated with livestock manure (Multibox, 2020, personal communication).

In 2020, French insect producer, Ynsect, secured certification and marketing approval for their insect fertiliser, YnFrass, which can be used in organic farming (Yates, 2020). This certification and market approval mean that the frass product can now be exported globally as a product (Yates, 2020).

Pressure indicators

Pressure indicators look at a snapshot of the production footprint, rather than looking at the cumulative impact over a period of time (i.e. state of the environment), focussing on the impact in terms of inputs/outputs such as resources required, carbon emitted or water required. The impacts of a pressure indicator will not be the same in every environment; for example, having a high water footprint may not be a problem in areas of high water availability, however, these landscape distinctions are generally not considered when looking at a footprint in isolation.

Land footprint

Definition: land footprint refers to the real amount of land, wherever it is in the world, that is needed to produce a product.

Soy production: The world's land footprint for soy is about 131 million ha or roughly one-third of the size of the European Union. The UK's imports account for about 1% of this land footprint. Between 2016 and 2018, the land required to produce the volume of soy imported was on average 1.7 Mha, or an area nearly the size of Wales (WWF, 2020). The GHG emissions from land-use change to produce the volume of soy imported to the UK were an estimated 18.8 Mt CO_2e per year between 2016 and 2018 – equal to around 35% of the emissions produced by the UK construction industry in 2016 (WWF, 2020).

Fishmeal production: Location of production (i.e. processing facility for fish by-products) is flexible and can be carried out on land that cannot be used for agricultural purposes, therefore minimising the land use burden.

Insect production: Location of production (i.e. insect farms) is highly flexible and can be carried out on land that cannot be used for agricultural purposes, therefore minimising the land use burden. Fitches (2019) found that using insect production at scale could result in more than a 120-fold reduction in land use compared to soybean meal as the amount of land required to grow crops is significantly lowered. However, Fitches (2019) notes that the impact on land use depends on the substrate used to rear the insects; for example, rearing insects on crop-based feedstocks would not result in the same extent of land use reduction.

Carbon footprint

Definition: Carbon footprint refers to the total greenhouse gas emissions caused by a product, expressed as carbon dioxide equivalent.

Soy production: Brazilian soy-related emissions stem from land-use change, domestic transport and industrial processing (Gil, 2020). The carbon footprint per unit of imported soy to the European Union is estimated at 0.77 $tCO_2e\ t^{-1}$ (Gil, 2020).

The average greenhouse gas impact of soybeans sold on the global market, according to ecoinvent 3.2, is 3.90 kg CO_2e/kg soybeans. However, the global number for soybeans is an average of soybean production in several regions and greenhouse gas emissions are highly affected by deforestation rates, resulting in a wide range from 0.39 kg CO_2e/kg soybean with no deforestation to 5.78 kg CO_2e/kg soybean with high deforestation (Beal et al., 2018).

Fishmeal production: There is limited literature on the carbon footprint of fishmeal production, which is highly variable depending on the source of rendered fish and/or fish trimmings used.

Insect production: Due to the requirement for insects to be produced in controlled environments, high amounts of energy can be required to heat the production environment and provide adequate lighting etc., particularly in cooler climates such as the UK. This high energy demand can be associated with increased levels of greenhouse gas emissions; however, the intensity of this emission depends upon the energy source. Given that the energy requirements for insect production are heat and power there are a range of options available to source these from renewable sources, such as waste heat or renewable energy.

Van Huis et al., (2020) highlights that there are only a few published studies on environmental impact of fly production and the available data for greenhouse gas emissions, energy use, and land use are extremely variable, which impairs a valid comparison regarding the environmental impact to other production systems. For example, the environmental impact recalculated to 1 kg of dried, defatted, insect powder by Smetana et al. (2016; cited in Van Huis et al., 2020) found that the global warming potential of BSF was between 1.2 and 15.1 kg CO_2 equivalent. A large part of this variation is due to differences in methodology, scale, and function of the studied systems, as well as the used substrate.

Water footprint

Definition: The water footprint refers to three contexts: green, blue and grey water. Green water is naturally available water (e.g. rainfall); blue water relates to any water taken from a surface or ground water resource (e.g. river, reservoir, borehole) and applied as irrigation; and grey water is the water required to dilute or neutralise any environmental pollutants, such as fertilisers, pesticides or cleaning products.

Soy production: The impact of water usage for soy production varies with location. For example, in areas where there are large green and blue water surpluses, the water footprint impact is less significant as there is more than enough supply to meet demand.

Fishmeal production: There is limited literature on the water footprint of fishmeal production, which is highly variable depending on the source of rendered fish and/or fish trimmings used.

Insect production: The water footprint of insect rearing can be highly variable, relating to the substrate used. Organic by-products and agricultural by-products do not have a water footprint associated with them, as it will have been accounted for in the product from which the material is derived (Tschirner and Kloas, 2017). PROteINSECT (2016) state that house fly and BSF production systems are favourable compared to fishmeal in terms of freshwater use and marine eutrophication and ecotoxicity. The processing of insects into meal also requires little water use. However, Tschirner and Kloas note that water footprint studies for insect production systems are currently lacking, and the only available assessment is for mealworms from Malcorps *et al.,* (2019).

Summary

Feed production for livestock generally makes up a large proportion of the overall environmental impact associated with livestock production; therefore, changes to the source of animal feed can significantly change the environmental impacts of livestock production. Insect farming and processing requires energy, water and land, and the extent of the environmental impact in terms of resource use and emissions will largely depend on the insect species, substrate used, the use of by-products from insect production, and the power and heat source for the insect rearing facility (e.g. whether this is a renewable source or making use of waste heat) (EFSA, 2015; Fitches, 2019).

Table 2 outlines the key environmental impacts of insect protein versus soybean meal and fishmeal.

Table 2. Indicative high-level comparison, based on expert interpretation of the literature, for the impact: high (red), moderate (orange) and low (green) of soybean meal, fishmeal and insect meal on the environment, considering both state indicators and pressure indicators. Source: ADAS for WWF.

Environmental Impact		Soybean meal	Fishmeal	Insect meal
State Indicators (i.e. changes to the state of nature)				
Land use change		High conversion risk	No impact	No LUC at scale
Soil condition		Intensive agriculture	No impact	No impact
Climate impact		Conversion	Low impact	Low impact
Water removed		Moderate volume	Low volume	Low volume
Nitrogen		N fertiliser applied	No impact	N available in frass
Biodiversity		Intensive agriculture	Reduced fish stocks	Low ecological impact
Pollution		Pesticide use	Effluent discharge	Limited Evidence
Waste		Limited evidence	Limited evidence	Frass as a fertiliser
Pressure Indicators (i.e. environmental footprint assessments)				
Land footprint		Large area required	Small area used	Small area used
Carbon footprint	**Direct**	Cultivation / shipping	Fishing vessels	Heating requirement
	Indirect	Land use change	Low indirect footprint	Substrate dependent
Water footprint		High water use	Limited evidence	Low water use

2.2.2 Economic considerations

Cost of insect-based products for animal feed

The price of producing insect protein is not yet competitive compared with conventional feed proteins (e.g. soybean meal), however, the economic viability is expected to improve as the industry transitions from a pilot to a commercial scale (Fitches, 2019), and in this study we calculate potential future costs of production (6.4).

Soyameal in 2020 (1st January to 15th October) cost an average of £304 per tonne (range of £295-361 per tonne) for Soyabean meal (Hi Pro); and an average of £318 per tonne (range of £301-376 per tonne) for Soyameal, Brazilian (48%) (AHDB, 2020).

In Table 3 the cost of different protein sources intended as animal feed is compared; when done on a per unit of protein basis, all current insect protein sources are more expensive than soybean meal (both standard and high protein) and fishmeal Pinotti *et al.,* (2019). The UK IBCTFG (2019) also acknowledge that to be commercially viable, insect product prices must be at least comparable to other protein sources. They believe that the rising price of fishmeal (to which they currently benchmark insect products) could help insect products to enter the UK market. Arru *et al.,* (2019; cited in Gasco *et al.,* 2020), estimate that the price of insect-derived processed animal proteins could be competitive with fishmeal by 2023.

Table 3. Estimate current trading price of protein sources intended for animal feed, expressed per unit of product and per unit of protein relative to soybean meal, 45% CP. CP = crude protein; BSF = black soldier fly (*Hermetia illucens*). Source: Adapted from Pinotti *et al.,* (2019).

Protein source	Protein % dry matter (defatted) meal	Trading price, relative to soybean meal (=1)	Trading price for 100g of protein, relative to soybean meal (=1)
Soybean meal	45%	1	1
Soybean meal hi-pro*	62%	7	5
Fishmeal	65%	3	2
Small mealworms	86%	12	6
BSF larvae	63%	12	9
Crickets	60%	285	213

**High-quality soybean meal extract*

Cost of insect farming infrastructure

FAO (2012) produced a manual and associated spreadsheet which aids users in designing and operating insect mass-rearing facilities. This generic spreadsheet was designed based on experience of mass-rearing Mediterranean fruit fly using genetic sexing strains (FAO, 2012). Whilst the tool is not suitable for providing an indicative figure for different types of rearing facilities (e.g. for BSF) in different countries (e.g. the UK), it provides an indication of the sort of scale of investment and operations required. For example, the manual suggests that the investment required to set up a facility (to process 2.5 billion male pupae) is in the region of $14.1 million (including purchase of land, construction, and the cost of equipment), and the rearing cost for the first year of production is estimated at $25.3 million (including the diet/substrate, electricity/heating and other factors such as equipment depreciation, building depreciation, loan paybacks, loan interest, and personnel) (FAO, 2012). This suggests that the setup costs and first year of operations would require investment in the tens of million, although this figure would be highly variable dependent on the site location, cost of land, technology used etc.

Value of using insects for bioconversion

A study conducted by Zero Waste Scotland (n.d.) found that (assuming identical gate fees – the charge per quantity of food surplus received at a waste processing facility), using pre-consumer food surplus for rearing BSF would generate 90% more economic value per tonne input than anaerobic digestion. This is largely because BSF can generate a protein value of £56 per tonne of input, as shown in Table 4.

Table 4. The value generated per tonne of wet food surplus input for black soldier fly (BSF) and anaerobic digestion (AD). Source: Zero Waste Scotland (n.d.)

	Gate fee	Fat/Oil	Protein	Frass	Total
BSF	£29	£26	£56	£1	**£113**
	Gate fee	**Electricity**	**Digestate**	**Liquor**	**Total**
AD	£29	£33	-£1	-£1	**£60**

The IBCTFG (2019) estimate that insect biomass conversion for the production of animal feed (as well as the associated by-products; valuable by-products, such as chitin, antimicrobials and oils, are generated during the processing of BSF larvae) could generate revenues of nearly £1 billion within five years as a new sustainable industry in the UK, as well as providing the opportunity for additional growth through the export of these new commodities.

2.2.3 Social, ethical and health and safety considerations

Insect production raises several important social and ethical considerations, including around food safety, animal welfare and performance, and consumer perceptions, in a similar way to those raised for other livestock systems.

Food safety

The safety of insects is deemed to be relatively good compared to other types of animal production. For example, BSF does not carry any human or livestock diseases (IBCTFG, 2019). It is thought that pathogenic bacteria (such as *Salmonella*, *Campylobacter* and *E.coli*) could be present in non-processed insects depending on the rearing conditions and the substrate use; however, these levels would be low compared to other non-processed sources of protein, and the transmission of these bacteria can be mitigated through processing (EFSA, 2015). Additionally, insect pathogen viruses that may be present in insects produced for feed are specific to insects and are not therefore regarded as a hazard for humans or vertebrate animals (EFSA, 2015).

Depending on the substrate that is used to rear the insects, there could be risk of contaminants, such as heavy metals, trace elements, mycotoxins, pesticide residues or packaging, accumulating in insects, with these then ingested by animals and humans (EFSA, 2015). However, there is limited data available regarding the influence that different substrates may have on the heavy metal contact of farmed insects (EFSA, 2015). Accumulation will vary based on the substrate, insect species, growth stage, and the metal in question (EFSA, 2015).

Animal welfare and performance

Key animal welfare laws in the EU[1] and the UK[2] apply to vertebrates only, meaning invertebrates are generally omitted. However, insects intended for animal feed remain captured within a wider 'farmed animal' definition under EU legislation, meaning insects

[1] Council Directive 98/58/EC concerning the protection of animals kept for farming purposes – Article 1(d).

[2] Animal Welfare Act 2006 – Article 1(1).

bred for animal feed are caught by animal by-product and feed legislation and must be reared and processed in compliance with that legislation.

Currently, insect production is generally carried out on a small scale and is very labour intensive, with cleaning between batches the most common method of controlling infection. However, as insect production scales up, there could be heightened risk of pests and diseases entering into the production system. Consideration will need to be given to how to avoid the risk of pests spreading within and between insect populations, whilst minimising the need for antibiotics and pesticides.

In terms of the welfare and performance of the animals consuming insects as feed, section 2.1.1 explains that insects are able to improve performance and animal health due to their immune-boosting properties and amino-acid profile. The scientific evidence suggests that there are little or no negative impacts on animal health and performance associated with consuming insect meal.

Consumer perception

From October 2013 to March 2014, PROteINSECT conducted a consumer perception survey to determine whether consumers would be accepting of insects in animal feed. There were 1,302 responses to the survey, from 71 different countries (Smith, 2016). Of the 1,302 respondents: 66% thought larvae of flies are a suitable source of protein for use in animal feed; 73% would be willing to eat fish, chicken or pork from animals fed on a diet containing insect protein; 57% thought it should be stated on the label if chicken, fish or pork on sale for humans was fed on protein from insects; 88% said more information should be made available on the use of insects as a food source for animals and humans; and 39% had eaten insects directly themselves.

PROteINSECT conducted a second consumer perception study between March and October 2015 to gather insight into the consumer perception of using insects in animal feed (including fish feed) versus other existing and potential sources of protein (Smith, 2016). Of 1,150 respondents, 80% of whom had no special dietary requirements, from more than 50 countries: 70% said that it is totally acceptable/ acceptable to feed insect protein to farmed animals, including fish; 66% said they would be very comfortable/ comfortable eating meat from a farmed animal (including fish) fed on insect meal; and 64% said there is no risk or low risk to human health in eating farmed animals (including fish) fed on insect meal.

The survey also found that there was a 30% ‘knowledge gap’ between how knowledgeable consumers were, and how knowledgeable they felt they should be on this topic.

Sogari *et al.,* (2019) conducted a multi-perspective review of the potential role of insects as feed, which included a systematic literature review of consumers’ acceptance and awareness of insects as feed. In addition to the PROteINSECT study (Smith, 2016), seven surveys were found. Of a survey of 341 students, university employees and consumers unrelated to academia in Italy, 53% reported that they would consume animals reared on diets using insects as a “supplement” (Laureati *et al.,* 2016, in Sogari *et al.,* 2019). In Poland, 58% of a study sample said they would consume birds (poultry) and 57% would consume fish fed insects as feed, whilst 42% would consume cattle fed insects as feed, and 47% would consume pigs fed insects as feed. The potential reasoning is associated with insects already being a part of poultry and fish diets, both in the natural environment and in free-range poultry systems (Kostecka *et al.,* 2017, in Sogari *et al.,* 2019). Similarly, in Belgium citizens’ attitudes towards the use of insects in animal feed were generally favourable (Verbeke *et al.,* 2015; cited in Sogari *et al.,* 2019), with use in fish and poultry gaining more acceptance than pigs. Rationale for acceptance of insects as feed was the perception that insect-based feed was more sustainable and of higher nutritional value, but lower microbiological safety. Similarly, animals fed insect-based feed were also perceived to produce food products that are more sustainable, of a higher nutritional value and healthier, despite concerns over off-flavours and the presence of allergens.

An Italian study by Mancuso *et al.,* (2016; cited in Sogari *et al.,* 2019) of fish consumers showed a relationship with price; as long as hygiene requirements were met and there was no increase in price, they were willing to consume fish fed with insects. The main basis for rejecting the idea of eating fish fed with insects was possible "distaste" and a lack of trust in production processes. For trout production in Germany, 77% of consumers showed positive preferences towards insects as feed; again, lower prices could increase consumer acceptance (Ankamah-Yeboah *et al.,* 2018; cited in Sogari *et al.,* 2019). In France, consumer choice was influenced by information on the environmental impact of aquaculture feeding methods (Bazoche and Poiret, 2016; cited in Sogari *et al.,* 2019). When considering the incorporation of cultured insect larvae into commercially formulated feed for Scottish salmon, only 10% of UK consumers opposed the idea (Popoff *et al.,* 2017; cited in Sogari *et al.,* 2019).

In 2018, French retailer Auchan launched an insect-fed trout range into supermarkets in the north of France. Auchan are now looking to expand the range of insect-fed fish into further species such as shrimp, salmon, bream and bass (Byrne, 2020). This expansion into additional species implies that the consumer reaction to the insect-fed trout has been positive. To accompany the release of the insect-fed trout, a designated website[3] was set up to explain the benefits of using insects as feed to consumers.

Consumers are increasingly interested in how their food is produced and, following recent episodes of food fraud, want to be sure that their food is what it claims to be. Transparency is key in overcoming the challenge of consumer acceptance (Smith, 2016).

2.3 Extent of the insect protein sector in Europe

2.3.1 Extent and capacity of the European insect market in 2020

In Europe, around 95% of insect farms use BSF and yellow meal worm as the preferred insect species (Fitches, 2019), with over 6,000 tonnes of insect protein produced in 2018 (IPIFF, 2019a). Gasco *et al*. (2020) estimate that by 2025, insect protein used in both animal and human feed will surpass 1.2 million tonnes and equate to roughly 10% of the EU share of total protein supply, whilst IPIFF (2019a) estimate that this will increase to around 3 million tonnes by 2030, resulting in a reduction in the need for imports of high protein feed materials.

Since authorisation of seven insect species for aquaculture feed in 2017, approximately 5,000 tonnes of European produced insect meal have been consumed by the aquaculture feed market; however, none of this was produced in the UK (IBCTFG, 2019; IPIFF, 2019a). In 2019, the aquaculture feed market consumed over 50% of European animal feed made from insects, with the demand for insect protein in fish feed expected to increase over the coming years (IPIFF, 2019a).

[3] http://nourrialinsecte.com/

There has been a significant increase in global investment in animal protein. By September 2019, European insect products alone had raised more than €600 million through investments, with over €2.5 billion expected to be raised by the mid-2020s (IPIFF, 2019a).

According to Meticulous Research data cited in a Barclays report in 2019, the insect protein market could be worth $8 billion globally by 2030, up from less than $1 billion in 2019 (Barclays, 2019).

In the UK, the insect biomass industry for animal feed is far less developed than that of mainland Europe, USA, Canada and South Africa (IBCTFG, 2019). Despite contributing and leading a significant amount of research into insect biomass, alternative proteins and waste valorisation, the UK is currently lacking a central strategic government policy to support generation of a national insect biomass conversion industry.

2.3.2 Scope to scale insect production in the UK and Europe

Theoretically, the insect industry can easily be scaled up due to the short life cycle of insects and their exponential reproduction rate (IPIFF, 2019a).

The minimum viable throughput for a standalone BSF plant is 50 tonnes a day (Zero Waste Scotland, n.d.). Based on the principle that the UK produces over 9 million tonnes of food waste per year (WRAP, 2017), at a 20% conversion rate, this would provide an estimated 1.8 million tonnes of insect meal per year from food surplus alone (IBCTFG, 2019).

The IBCTFG (2019) estimate that implementing insect biomass conversion at scale in the UK has the potential to achieve revenues of up to £1 billion within five years. This is based on an annual UK demand for 70,000 tonnes of protein for aquaculture feed, 200,000 tonnes of dried meal for poultry (5% inclusion rate), and over 100,000 tonnes for pig feed (5% inclusion rate), in addition to a further 20,000 tonnes for pet food (based on 5% of the current pet food market) (IBCTFG, 2019).

The IBCTFG (2019) estimate that a single commercial insect farm has a potential (and further scalable) annual output of 5,600 tonnes of meal, 2.8 million litres of oils and fats and 21,000 tonnes of soil conditioner. Using food surplus as a substrate could make use of 1.8 million tonnes of food surplus currently wasted per year (based on the 20% conversion rate cited by IBCTFG, 2019). This would be using 20% of the total UK food surplus, indicating capacity for further expansion also. The IBCTFG (2019) suggest that in the UK in the short term (3-5 years), 12 commercial insect farms could be established, with a total of 24 commercial insect farms in the medium term (5-10 years).

IPIFF (2019a) recognise that the insect industry needs to scale up to reach its full potential and meet the demand for protein, but state that the short life cycle and exponential reproduction rate of insects should make this easily achievable. The ability to automate and control insect production reduces labour requirements for insect production, although optimal conditions within systems still need to be found to achieve a reliable and stable quality of supply at increased production capacity (IPIFF, 2019a). This includes optimisation of the materials fed to the insects to ensure the greatest possible efficiency (Barbi *et al.,* 2020).

Currently, the legislative framework is insufficient to support development of the insect sector in Europe. Figure 2 shows the expected growth potential in the European insect protein sector to 2030 if legislative opportunities were unlocked, compared to expected growth if they remain locked. In these scenarios, IPIFF (2019a) suggest:

- Over 6,000 tonnes of insect protein are produced in Europe annually.

- By 2030, IPIFF expects around 3 million tonnes to be produced annually.
- With the right legislative framework, the sector can grow to around 5 million tonnes a year (Scenario 1). This would require diversifying the substrates authorised for insect farming and opening the poultry and pig feed markets for insect-derived protein earlier than anticipated.
- If these legislative changes are not made, the sector's growth would decelerate to around 2 million tonnes of protein per year by 2030 (Scenario 2).

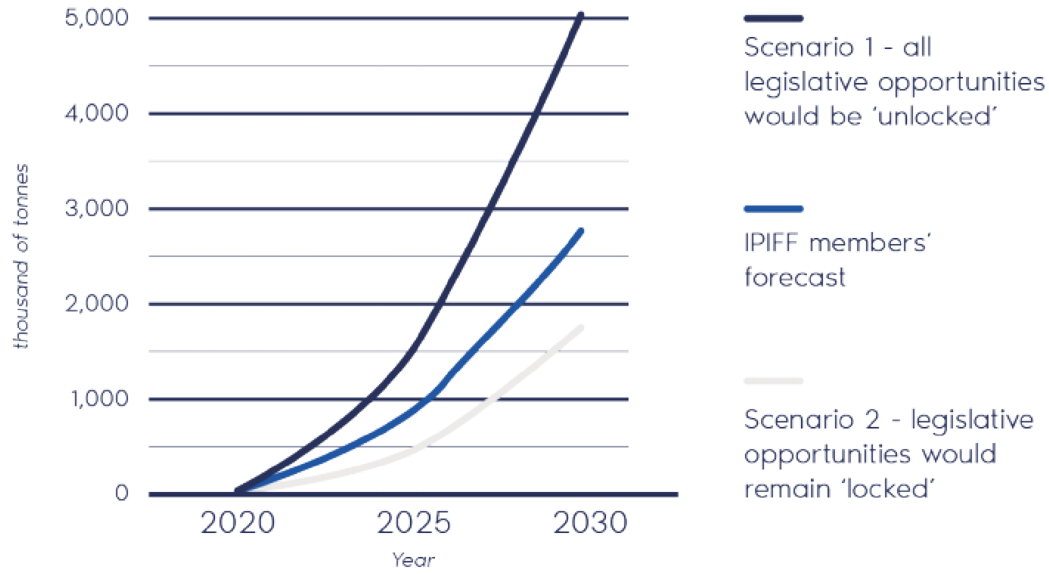

Figure 2. The estimated volumes of production of insect protein until 2030 in Europe with and without unlocking of legislative opportunities. Source: IPIFF, 2019a.

2.3.3 Inclusion of insects within industry standards

A range of standards were reviewed to determine whether insects are specified within these in relation to their inclusion/exclusion in feed. The standards reviewed included Red Tractor, GLOBAL G.A.P., Aquaculture Stewardship Council (ASC), the Feed Materials Assurance Scheme (FEMAS) and Tesco's salmon and feed standards.

For each standard a key word search was conducted ("insect") to ascertain if there was any mention of insects within the standards. The specific documents and results of the search are shown in Table 5.

Table 5. Inclusion of insects within aquaculture and livestock industry standards. Green ticks (✓) indicate standards that include insects within the context of 'insects as feed'; red dots (●) refer to standards that do not; and asterisk (*) refers to standards where insects are mentioned, but within a non-feed context. Source: ADAS for WWF.

Standard	Documents reviewed
Red Tractor	● Pigs Standards Version 4.4* ● Chicken Standards: Breeder Layers Version 4.1* ● Chicken Standards: Broilers and Poussin Version 4.2* ● Chicken Standards: Indoor Enhanced Welfare Version 1* ● Duck Standards Version 4.1* ● Turkey Standards Version 4.2*

Standard	Documents reviewed
GLOBALG.A.P.	• Integrated Farm Assurance; All Farm Base – Aquaculture Module; Control Points and Compliance Criteria Version 5.2* • GLOBALG.A.P. General Regulations; Aquaculture Rules Version 5.2 • GLOBALG.A.P. General Regulations; Livestock Rules Version 5.2 • GLOBALG.A.P. Compound Feed Manufacturing General Rules Addendum to GLOBALG.A.P. General Regulations Version 2.2 • Integrated Farm Assurance; All Farm Base – Livestock Base – Pigs; Control Points and Compliance Criteria Version 5.2* • Integrated Farm Assurance; All Farm Base – Livestock Base – Poultry; Control Points and Compliance Criteria Version 5.2* • GLOBALG.A.P. Compound Feed Manufacturing Control Points and Compliance Criteria Version 2.2* • GLOBALG.A.P. General Regulations Part 1 – General Requirements Version 5.4-GFS • GLOBALG.A.P. General Regulations Part 2 – Quality Management System Rules Version 5.4-GFS • GLOBALG.A.P. General Regulations Part 3 – Certification Body and Accreditation Rules Version 5.4-GFS
ASC	• ASC Salmon Standard Version 1.3*
Tesco Standards	• Tesco Salmonid Farm Standard ✓ Tesco Salmonid Farm Requirements[4,5] ✓ Tesco All Species Feed Standard[6,7]
FEMAS	• Feed Materials Assurance Scheme*

Whilst the word “insect” is sometimes mentioned in livestock and aquaculture standards, this is generally in relation to the use of plant protection products, or in terms of vermin control and preventing contamination and food safety risk by ensuring responsible control of birds, rodents, insects and other animals; rather than in relation to insects as feed.

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[4] Tesco Salmonid Farm Requirements - Feed exclusions for salmon and trout include “Processed Animal Proteins (PAP – excluding insect meals), Salmonid Derived Meal or Oil, Avian or Mammalian Meal or Oil, Protein from Diseased Animals or those with Potential to Cross-Contaminate GM Ingredients in Organic Feed” (page 7)

[5] Tesco Salmonid Farm Requirements - Feed inclusions allowed for salmon and trout include “GM, Soya or Other Crops, Non-Salmonid Fish Meal or Oil, Insect meals, Algal oil or meal” (page 7)

[6] Tesco All Species Feed Standard - CS38 Insect protein is recognised as a potential sustainable source of protein. Tesco permits the use of insect protein meal in aqua feeds subject to compliance with Regulation (EU) No 2017/893 amending Annexes I and IV to Regulation (EC) No 999/2001, Regulation (EU) No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species. and Regulation (EU) No 142/2011 implementing Regulation (EC) No 1069/2009. (annex IV, chapter III)

[7] Tesco All Species Feed Standard - Suppliers of insect protein meal must be members of The International Platform of Insects for Food and Feed (IPIFF) and subject to FEMAS or equivalent certification. Substrates must be of vegetal origin only.

Out of the standards reviewed, Tesco’s standards were the only documents to specifically mention the use of “insect” within the context of insects as feed. Note that no other retailer standards were reviewed in this assessment.

3 CURRENT STATUS OF INSECT FARMING IN THE UK

Stakeholder perspectives were gathered from across the insect production value chain, from farm to retailer, to identify the perceived barriers and opportunities for upscaling, and to inform the analysis, modelling and recommendations developed within this report.

3.1 Approach to stakeholder engagement

Stakeholder engagement was undertaken through phone interviews and an online survey.

Phone interviews

Telephone interviews were conducted with 14 stakeholders within the insect production value chain, including: insect producers (Better Origin, Entocycle, InnovaFeed, Inspro, Monkfield Nutrition and Multibox), feed mixers and suppliers (Cargill, Davidsons Feeds and Green Grub Solutions), trade associations (Agricultural Industries Confederation and FabraUK) and researchers and consultants (Poseidon, Unconventional Connections Ltd/ Woven Network and Zero Waste Scotland).

Online survey

An online survey was developed and shared with a range of stakeholders to capture perspectives from across the value chain.

Stakeholders were approached and made aware of the survey through several mechanisms, including direct email invites, social media platforms (e.g. Twitter and LinkedIn), and distribution through relevant networks such as ADAS News[8], the Woven Network newsletter[9], the Food Climate Research Network (FCRN) newsletter "Fodder"[10], the Insect Biomass Conversion Task & Finish Group (IBCTFG)[11] and the Royal Entomological Society "Insects as Food and Feed conference" network[12].

It is acknowledged that whilst responses (both positive and negative) were welcomed from any stakeholder that wished to participate, the networks and forums used to circulate surveys typically favoured stakeholders who may already have vested interest in the insect value chain. Whilst this enabled a comprehensive insight into the current barriers and opportunities facing the sector, it creates a bias towards stakeholders that are in favour of the industry developing.

In total, 73 responses were submitted, shown in Figure 3. It was not mandatory for all questions to be answered within the survey, so the responses had varying levels of completeness.

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[8] https://www.adas.uk/News

[9] https://woven-network.co.uk/

[10] https://www.fcrn.org.uk/fodder

[11] https://www.fera.co.uk/media/wysiwyg/our-science/FAQs_on_Insect_Biomass_Conversion.pdf

[12] https://www.royensoc.co.uk/special-interest-groups/food-feed

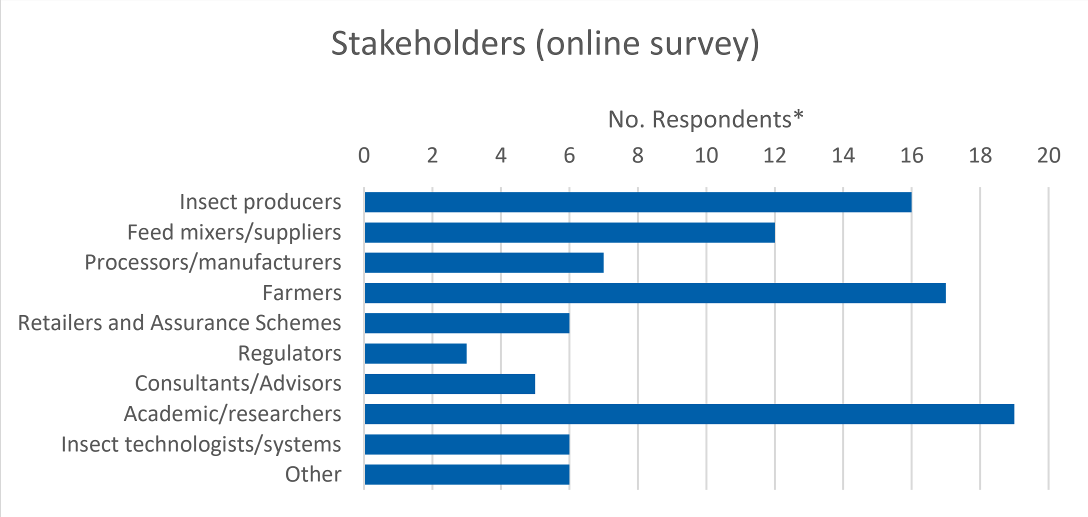

Figure 3. Type of organisation that the 73 survey respondents categorised themselves as (*Some respondents ticked more than one category). Source: ADAS for WWF.

3.2 Extent of insect farming in the UK in 2020

Stakeholders indicated that the insect farming industry in the UK is relatively new and unestablished, consisting of just a few micro and small-scale facilities (e.g. AgriGrub, Beta Bugs, Better Origin, Entocycle, Inspro, and Monkfield Nutrition). These facilities have a range of functions, including applied research, developing new technology and producing insects for a range of end uses, such as feed for birds, reptiles and hedgehogs, aquaculture feed and live feed for livestock (e.g. poultry).

Whilst there are some small-scale examples of insect biomass production in the UK, the scale of the industry is lagging behind other regions, such as mainland Europe and North America where large industrial-scale facilities are already operational. However, the UK is starting to make positive progression, with the first industrial-sized facility in the UK set to be constructed in the near future following the award of government grant funding in 2020. The new facility will enable the breeding and rearing of insects on substrates consisting of former foodstuffs and food surplus (e.g. fruit and vegetables) to create insect meal (processed animal protein) for animal feed for the aquaculture and pet food markets.

3.3 Impacts of insect production

Stakeholders were asked to indicate (on a five-point scale from very negative to very positive) the perceived impacts of increasing the proportion of insects used in UK animal feed. Six key areas were focussed on: the cost of feed, insect health and welfare, animal health and welfare, human health and welfare, the environmental impact (e.g. land use, greenhouse gases, water quality etc.), and the reputational risk to the industry or organisations within the insect production value chain.

We found that overall, increasing the proportion of insects in UK animal feed was perceived to have a positive impact, or little or no change, shown in Figure 4.

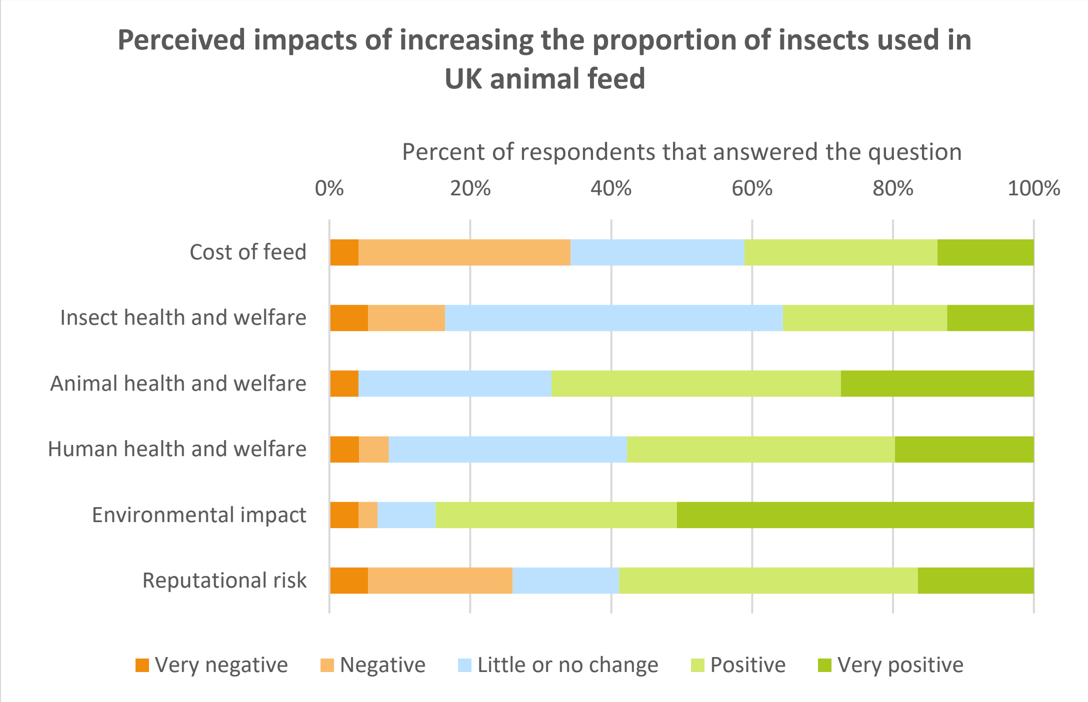

Figure 4. Stakeholders perceived impacts associated with increasing the proportion of insects used in UK animal feed. Source: ADAS for WWF.

With regards to the specific impact on each topic area:

Stakeholders were also asked to outline the advantages and disadvantages of insect production on key environmental considerations, summarised in Table 6.

Table 6. Perceived risks and opportunities of insect production compared to soybean meal and fishmeal, as outlined by stakeholders for each environmental consideration. Source: ADAS for WWF.

Environment consideration	Opportunities	Risks
Land use	✓ Can use less land and lower quality land compared with livestock production or soybean production. ✓ Reduced demand for soybean that could prevent deforestation and reduce pressure on key sourcing regions (e.g. Amazon). ✓ Higher efficiency, density output and increased protein production per land unit.	X It is dependent on the substrate being fed to insects, e.g. if crops are grown for the substrate, this may be detrimental. X Construction of enclosed buildings or containers and industrialised systems required. X Insect production similar or more land intensive when compared to fishmeal.
Carbon	✓ Reduced carbon footprint associated with land use and deforestation in soybean growing regions (e.g. South America). ✓ Reduced miles and transport footprint from production in the UK rather than feed imported.	X If insect meal is traded globally and/or crops are grown specifically to feed to insects. X Depends on production methods and logistics of substrate. X Construction of insect facilities.

Environment consideration	Opportunities	Risks
	✓ Use of former foodstuffs, by-products or non-food materials will reduce reliance on primary resources / production. ✓ Energy requirements (e.g. electricity / heat) for insect production could utilise green sources or waste heat.	X Temperate climate requires much energy to provide heat, light and humidity for insects in buildings. X Temptation to grow the insects in low cost countries and imported to UK markets. X Insect farms would need to consider Net Zero targets. X Higher emissions compared to soybean or fishmeal if insect rearing is done poorly.
Water	✓ Insect production has relatively low water use compared to soybean, especially where irrigation is required. ✓ Water can be obtained through substrates (e.g. vegetables). ✓ Insects have much greater water use efficiency.	X Higher water usage potentially compared to fishmeal production. X Water needs to be piped, purified and filtered from a microbiological point. X Efficiency of system and cleaning of boxes, equipment etc. will require a supply of water.
Nitrogen	✓ Little or no nitrogen required for insect production depending on the substrate. ✓ A reduction in nitrogen applications to land will reduce eutrophication and leachates. ✓ Nitrogen waste (e.g. from manure) can be processed by insects.	X If crops are grown specifically for insect feed, then nitrogen impacts may be similar or worse than soybean.
Pollution/ waste	✓ Opportunity to create a valuable product from materials currently ‘wasted’ otherwise. ✓ Promotes a bicircular economy as some materials could have a new purpose. ✓ Less waste produced through insect production process. ✓ By-products from insect production (e.g. frass) could be used as fertiliser and offset emissions from chemical fertilisers. ✓ Opportunity for conversion of organic materials to a protein. ✓ Black solider fly systems can be zero waste if designed properly.	X Frass is a by-product of insect production and will need disposing of (i.e. if not used as a fertiliser). X Perceived risk that by-products from insect production may be toxic and cause new issues (e.g. ammonia production). X Risks competition for pre-consumer food surplus that diverts away from current end uses. X Potential disease risk to humans and animals through contaminants. X Poor management of high intensity farms risk polluting the local environment.
Other	✓ Less fishing could lead to a reduction in fishing equipment (e.g. nets) lost at sea and reduce microplastics.	X Production of insects abroad may mitigate benefits of current impacts associated with fishmeal or soybean.

Environment consideration	Opportunities	Risks
	✓ Reduced biodiversity loss on land and sea, lower food miles and shorter supply chains. ✓ Opportunity to process contaminants, subject to the health and welfare of insects. ✓ Allows advances in sustainable packaging (e.g. plastic digesting species could help degrade microplastics). ✓ A reduced reliance on imports could increase supply chain resilience and traceability. ✓ Greater efficiency and conversion of resources to proteins will use less resources overall. ✓ Improved food security as there would be less reliance on soybean imports.	X Insects that consume microplastics in the substrate risk passing these up the food chain to animals and then humans. X If microplastics feed through to the frass, this may then enter the environment again if used as fertiliser. X Depending on how insect meal is packaged, there could be more plastic used than fishmeal or soybean. X Requires strict control to prevent non-native insects escaping and impacting local habitats. X Consumer education is required to promote benefits and risks around the sustainability benefits and challenges of insect production. X Demand for food surplus and non-food materials could outstrip supply.

3.4 Perceived barriers

There are a wide range of perceived barriers identified by stakeholders that currently prevent the scaling up insect production in the UK, and more widely in Europe. This section outlines the key barriers that existed in the UK in 2020, informed through stakeholder engagement.

Current regulatory environment

The majority of stakeholders felt that regulatory barriers were the biggest challenge at present and the most important to be overcome. The current regulatory framework in the UK (see Chapter 4) has prevented the establishment of large-scale producers of insects within the UK. Without changes to legislation and local regulations, the insect sector is constrained from adequately developing and upscaling. However, some stakeholders did recognise that regulation was not a limiting factor in all instances, as being able to feed insect protein to fish has enabled the industry to get started, albeit not growing at the speed and scale that it could if more by-products were allowed and greater end uses (beyond fish feed and pet food) were enabled.

The key perceived barriers associated with the regulatory environment are outlined in Table 7.

Table 7. Perceived regulatory barriers. Source: Stakeholder Feedback.

Perceived Barriers	Description
Current laws preventing insects in animal feed	Insect protein is authorised in aquaculture feed but is currently not permitted in other livestock feed. Draft EU regulations allow insects to be used as animal feed, but there is uncertainty as to what the UK regulations will be following exit from the EU. The current situation prevents European or global insect producers looking at the UK, as the regulation is prohibitive to growth. It also prevents investment in insect production as too many legal hurdles to overcome at present.
Lack of a strategic policy framework	There is currently no central government strategic policy framework to support the insect industry.
Restriction on substrates that can be used	Current legislation around using mixed food surplus and post-consumer surplus restricts the opportunity for insect farmers to utilise this material.
Planning permission	As with many industries, there can be difficulty when trying to obtain planning permission. This can include objections from neighbours regarding pollution, noise and odour from insect farming.
Classification of insects as a farmed animal	Confusion over the current classification of insects. Insects being classed as an animal means that veterinary controls are required for the slaughter of insects. This classification also prevents substrates such as manures being fed to insects.
No classification of 'organic'	There are no guidelines to show what an organic insect farm would look like which makes it challenging to state whether insects are organically produced. This presents a barrier to where insect protein can be used as it would not be permitted in organic fish.
Regulation of insect frass	No clear regulation around how to treat insect frass which prevents this being sold or used by farmers as a fertiliser. This can be sold to the home market at present, for gardeners to use, but it is considered a 'grey' market.
Lack of a 'protein strategy' in the UK	The UK does not have a 'protein strategy'. This compares to many other EU member states that have and which has enabled these states towards faster advancement in looking for and investing in alternative protein sources. Stakeholders estimate that the UK is 10 years and €1.5 billion behind European leaders in this space.
Lack of an industry standard	The food and feed industries have been encouraged to be self-regulating and that's fine to manage 'business as usual' however this environment isn't conducive to encourage emerging technologies and applications.

Financial viability, subsidies, investment etc.

The perceived financial barriers to scaling up insect production are shown in Table 8. For many stakeholders, these barriers were considered very important, second only to regulatory challenges. Stakeholders noted that, whilst there has been some investment in insect production in the UK, a collaborative approach is needed to decrease entry barriers into the market, with investment, subsidies and grants all options that could provide mechanisms for scaling up the industry. Without these mechanisms, it was felt that the growth of the industry would inevitably be slower than if comprehensive financial support were available. It was also raised that the scaling up of the industry would help to make insect meal production more competitive with soybean meal and fishmeal and allow for profitable production of insect meal.

Table 8. Perceived financial barriers. Source: Stakeholder Feedback.

Perceived Barriers	Description
Lack of investment	It can be challenging to raise capital as investors do not understand the insect industry so do not have confidence in investing. Investors want to see insect production being carried out at a commercial scale in the UK before investing. The EU law limits the marketplace for insect production, thereby reducing investment. Insects being classed as farmed animals also makes them difficult to fund. Insect protein is a risky investment choice given an unpredictable regulatory environment.
Funding for primary agriculture	It is not possible to get certain funding for primary agriculture as the industry is covered by subsidies.
Subsidies for by-product end uses	Currently, subsides are available for some end uses of by-products, for example AD or heat generation, meaning insect producers would have to compete with these end uses to access the by-products.
Restrictions around grant funding	Grant funding can be available, but this does not generally allow for investing in purchasing equipment, technology or building infrastructure. Grants tend to be focussed on research rather than commercialisation. Many insect producers are start-up companies who find it difficult to leverage funding.
Price of insect meal vs. soybean meal and fishmeal	Insect meal is not currently competitive in the market which is a significant barrier. For example, the price of imported soya (at ~£200/t) is far lower than the cost of home-produced protein, especially compared with the high start-up costs for insect production, limiting the feasibility to compete on a cost per gram of protein basis. One stakeholder reported that the big producers of animal feed hold all the cards in terms of supplying into the bigger markets. They want costs to be significantly below what they already pay (e.g. would not buy insect meal to replace fishmeal for more than £800/t, despite the fact that fishmeal trades at £1,200/t).
Cost on the environment and social values	Insect production needs to be socially responsible and contribute to a circular economy and protection of the environment. For example, through using surplus materials rather than competing for products (e.g. brewers' grains) that could go directly to livestock feed and have a high cost of access.
Cost of access to substrates	As demand for substrates increases, the cost of these would also increase. Logistics of transporting by-products will also have financial implications.
Energy requirements	Insect production in the UK requires a lot of energy, including electricity and heating compared with other insect producing regions (e.g. Africa) where the climate is more favourable.

Covid-19	It was noted that Covid-19 has resulted in a reduction in GDP, so it is even more challenging to access funding for high innovation projects at the current time.

Technological requirements

The technological barriers associated with scaling up insect production are shown in Table 9. The technology involved in insect production was generally considered to be straightforward with few barriers to overcome. Of the few barrier identified, purchasing technology, fully integrated systems and volume of production were raised as potential challenges. It was noted that there are a lot of players in the insect industry, and there is likely to be consolidation in the future, so there is benefit in being the fastest to scale up and lead the industry.

Table 9. Perceived technology barriers. Source: Stakeholder Feedback.

Perceived Barriers	Description
Optimum production practice	Due to the infancy of the sector, there is still limited knowledge on insect physiology and nutritional requirements, which combination of substrate materials work best in each situation, what size of production unit is most efficient, etc.
Limited scientific literature	Academia is felt to be lagging behind the industry which is preventing advancements in the design of new experiments and ways to mitigate risks etc. The research budgets for start-ups in this space is minimal, with many relying on academics to produce outputs they can utilise.
Availability of technology	It is not possible to buy an insect bioreactor or protein processing equipment off the shelf. There is limited equipment built specifically for rearing insects.
Automation	Insect production is labour intensive in terms of monitoring welfare and spotting issues within the system.
Transferring substrate materials to insect pens	There can be challenges in transferring substrate materials to the insect pens within the production system, with this often being a labour-intensive process. If the substrate is liquid, this can be pumped, however it will drown the insect. If the substrate is dry, it can be blown, but would need to be made wetter for the insects to consume this.
Volume produced	Animal feed producers and users want a minimum quantity before they will enter into purchasing discussions. This can require a high amount of substrate to produce the volumes of protein required.

The availability of suitable by-products

The availability of permitted by-products that can be used as insect substrates is a limiting factor, outlined in Table 10. The majority of stakeholders stated that competition with other markets would continue to be a challenge and as insect farming scales, the availability of suitable by-products would likely become more restrictive due to demand from the insect sector. Additionally, as businesses become more efficient, there could be a reduction in the amount of surplus materials produced, which could present challenges for the economics of producing feed for insects. Any product relying on a by-product from another process is at the mercy of that process.

Table 10: Perceived barriers around permitted by-products and substrates. Source: Stakeholder Feedback.

Perceived Barriers	Description
Permitted substrate materials	Current legislation only permits a small range of materials that can be used as substrates by insect farmers.
Geographic spread of substrate material	The geographic spread of permitted substrate materials creates challenges for achieving required volumes to meet demand.
Consistency and seasonality	It can be challenging to find a permitted substrate material that has a consistent supply that is available every week of the year to meet demand.
Competition	AD and incineration are heavily subsidised and already well established which can create competition for materials. Re-routing these materials may have unintentional impact on other sectors.
Contamination	Perceived concerns over the contamination levels in the substrate material.

Health and safety and risk of contamination

Providing that adequate measures are taken to reduce the risk of contamination of by-products used as substrates, there are not envisaged to be any more health and safety issues than that of other farming systems and insect farming is not considered to be any more dangerous than other livestock production (Table 11).

A potential concern raised was the risk of insects escaping from the production unit into the wild if it were an invasive or problem species. The possibility of increasing microbes and contaminants due to the moisture of the insect production environment was raised as another issue. One insect producer noted there is also a risk to insect production unit workers from occupational asthma, with regulation required to ensure insect producers are compliant. There could also be a risk of human allergens being derived or transferred in insects. However, one insect producer raised that the risk of disease transmission from insects to humans is low due to insects being genetically further removed from mammals than other animal species.

Whilst risk of substrate contamination is a potential barrier to the scaling up of insect production, it is possible to overcome these risks with adequate research and quality control measures put in place. Insect producers have to comply with the necessary EU hygiene and safety standards. EFSA (2015) concludes that '*the specific production methods, the substrate used, the stage of harvest, the insects' species and developmental stage, as well as the methods for further processing will have an impact on the occurrence and levels of biological and chemical contaminants in food and feed products derived from insects*'.

Table 11. Perceived health and safety barriers. Source: Stakeholder Feedback.

Perceived Barriers	Description
Risk of contamination of feedstocks	There could be risk of contamination of feedstocks. This will vary depending on the substrate used and the general level of hygiene on the production line. Risk of contaminants will be particularly high in post-consumer materials. The risk with feed grade substrates (as per the current situation) is low. The risk could also be lower where production line equipment is typically used for production of vegan/ vegetarian products, or where feedstocks are vegan/vegetarian.
Risk of contamination of insect meal	Insects can bioaccumulate some compounds.
Risk of disease transmission	There is nervousness about feeding animals back to animals that harks back to BSE. The situation is of course different in so far that mammalian animal tissue isn't being fed back to mammals, but the concerns remain.
Risk of insects escaping into the environment	There is concern that escaping insects could have negative consequences for the local ecosystem. Invasive species threaten both natural systems and production systems which could worsen the biodiversity impacts of insect meal.

Retailer requirements, assurance and land management schemes etc.

Where insects are not fed on commercial animal feed, the environmental impact of replacing fishmeal and soybean meal could be seen as a benefit for buyers of animal protein. Retailers are also starting to reduce the amount of fishmeal used in production, with soya and other plant-based proteins taking its place, therefore substituting with insects may be seen as a more natural choice. A summary of the barriers under this theme are shown in Table 12.

Table 12. Perceived barriers associated with retailer requirements, assurance schemes, land management scheme etc. Source: Stakeholder feedback.

Perceived Barriers	Description
Rules around processed animal protein (PAP)	Can be strict rules for having no PAPs being fed to animals that are being sold through retail.
Retail/consumer perception	Some retailers are hesitant to use insect protein in animal feed due to consumer acceptability.
Lack of standardisation	There is currently a lack of standardisation in insect meal production.
The need for additional assurance schemes etc.	There is a need to ensure that insect protein can be included within suggested schemes and requirements.

Perceived Barriers	Description
Red Tractor requirements	Red Tractor standards require feed to be assured, and only certain animal proteins are permitted.
Risk of competition from overseas production	As the use of insects in animal feed increases, there may be increased pressure from overseas production that can be produced more cheaply due to lesser quality production/ lower wages/ fewer health and safety costs etc.
Positioning products to reflect benefits	The positioning of products that use insect meal need to carefully consider the environmental and ethical benefits to demonstrate to consumers that this alternative source of protein in feed is sustainable. If the benefits are based purely on price, insect meal will struggle to upscale.

Social factors (e.g. perspectives of consumers, retailers, feed mixers etc.)

Consumer attitudes towards the use of insect meal in animal feed was identified as a big concern for industry representatives. It was felt that the risk of negative publicity would have detrimental impacts on reputation and acceptability of the industry. The main barriers associated with social factors, and how to overcome these are shown in Table 13.

With good, upfront, and transparent marketing however, several stakeholders felt that consumer acceptability can be greatly increased. For example, one insect producer introduced insect fed trout in 2018. They had a specific label and website explaining what they were doing and why they were doing it to the customer. The producer was also looking to introduce an insect fed chicken to the market. Their plan was to follow the same well received approach of explaining what they were doing and why. It was felt that transparency is key, with messaging that is not seen to be 'greenwashing'. Furthermore, specific statements that use targeted language such as 'better for deforestation' rather than 'better for the environment' was also thought to get a better reaction from the consumer.

Some stakeholders noted that consumer acceptance had increased substantially in recent years, whilst others disagreed and were unsure how consumers might react to insect protein being used more widely in animal feed. As consumers themselves were not interviewed as part of this study, it was not possible to determine what the actual consumer position was.

Table 13. Barriers associated with social factors, including the perspectives of consumers, retailers, feed mixers etc. Source: Stakeholder feedback.

Perceived Barriers	Description
Consumer perception of consuming insects	The consumption of insects in the Western world is in its infancy and consumers are not familiar with the potential opportunities at this early stage in the development of the market. Consequently, the 'yuck' factor is a key barrier.
Lack of research on consumer acceptance	There is currently limited research to really understand if UK citizens would be accepting of insect protein being used for livestock feed (e.g. poultry and pigs).
Ethical perception of insect production	Public perception of insect welfare in insect meal production can be negative. The people likely to be concerned about this will also likely be concerned about animal welfare. It may be that some consumers are against animal production more generally so may be difficult to reach.

Perceived Barriers	Description
Perception of feed mixers (ultimately driven by consumer acceptance)	Compound feed manufacturers (who produce feeds for pigs and poultry) produce products that are considered to be acceptable to consumers and reduce the risk of any negative reputation on their products or industry. This can prevent new and innovative mechanisms from materialising.
Social acceptance of production sites	There may be objections to the location of insect production facilities.

Relative importance of barriers for scaling up insect production

Stakeholders were asked to identify the current barriers that needed to be overcome and then rate how critical they perceived each type of barrier to be in order to allow the scaling up the insect production value chain.

The most important barrier identified was legislation and regulation, with 90% of respondents identifying this as being very important or critical, shown in Figure 5. This was followed by the financial viability of insect farming, with incentives and investment being very important or critical for three quarters of respondents: and social factors (e.g. consumer acceptance) with two thirds of respondents identifying this as very important or critical. Other barriers, including the availability of suitable substrates, risk of contamination, technological, health and safety, and retailer requirements were considered to be very important or critical by more than half of the respondents.

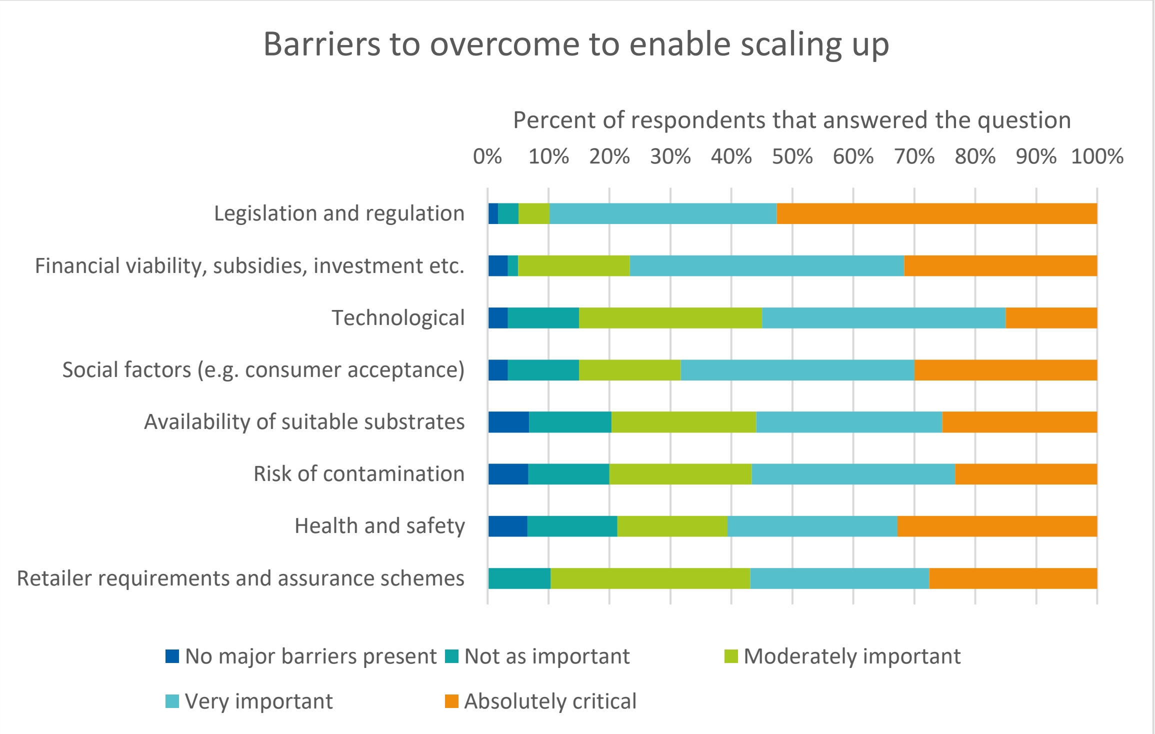

Figure 5. Stakeholders perceived importance of key barriers that needed to be overcome to enable the scaling up of the insect production value chain. Source: ADAS for WWF.

It was noted by stakeholders that, before insect protein becomes mainstream, it must have strong scientific based regulation from government to give retailers and consumers confidence. Retailer requirements and assurance schemes can also help to drive consumer acceptance. It is expected that technology will continue to improve the process and decrease costs, bringing the cost of technology down and create a product that is more competitive on price with fishmeal and potentially soybean further down the line once scaled up. If the economics work, it is safe and effective and good for animals that consume the feed, and the environmental impacts are shown to be improved over current protein sources, then the potential for upscaling will be much more appealing.

Demand for insect meal

Stakeholders were asked about their perception of the current demand for insect meal, and whether this is something that could prevent the scaling up of the insects as feed industry. Demand was considered independently of the previous barriers as it was felt that current demand was not a limiting factor and would naturally change over time as alternative proteins became more available, at more competitive prices, and more accepted by consumers.

It was considered that the volume of insect meal available due to low production levels could be limiting demand at present, along with the higher associated cost of insect meal compared to existing alternatives. If insects were able to be sold at a comparable or favourable price compared to soybean meal and fishmeal, and the product became more widely available, it was anticipated that the demand for this would increase. It was thought that feed manufacturers would buy thousands of tonnes of insect meal if it were available in the volumes needed and at the right price point. Demand is potentially in a negative loop cycle at the moment as insects are more expensive than the alternatives, thereby reducing demand; however, low demand then means small scale production which is more expensive and further exacerbates the challenge.

Beyond these cost and availability barriers, demand was not considered to be a challenge in scaling up the insects as feed industry, so long as the nutrition/welfare and quality of the product stand up. Demand was thought to be present due to the preference for natural entomophagy associated with insects as feed. With retailers placing additional scrutiny on the environmental impacts of soybean meal and fishmeal, and consumer awareness around this increasing, there is likely to be increased demand for a more sustainable alternative. As well as sustainability more generally, demand for insect meal could be increased by framing this as deforestation free, or as a way of managing risk within the supply chain.

Insect producers currently in operation noted that they are unable to meet the current level of demand, implying that the interest and market for insect meal is present. Demand is also considered to be strong for speciality applications such as novel proteins for pets with allergies, or to improve gut health during the early stages of fish growth. The growth of the aquafeed industry, to be able to feed the continuing growth of the aquaculture industry, will also mean there is a constant requirement for more volume of feed ingredients. As mainstream insect meal products enter into the market, traction and consumer acceptance will increase. As exposure to the insect meal products increases, demand is expected to further increase.

Increasing awareness of the multiple benefits that using insects as feed can bring was thought to be a mechanism which could be used to help grow demand for insect meal. Using insect meal as a supplement to existing feed sources was also seen as a way of increasing demand; as the producer becomes more familiar with the feed, if it is an adequate replacement, they will gravitate to it over time, particularly as supply increases and price falls. Going to agricultural shows, raising awareness of nutritional content, and having influencers highlight the potential of insects were considered as ways to increase demand

and acceptability. Once producers and retailers are on board it is expected that insect protein will be a viable competitor, if not a leader. Having the whole supply chain committed to insect protein will greatly assist in increasing demand. Investment in the insect sector will also help to increase confidence, and subsequently demand.

To ensure that the supply of insect meal would meet the demand that is created, it is recommended that the insect producers work together with the feed industries to ensure the product is what the industry wants in terms of nutritional content, assurance and price.

3.5 Opportunities that can be unlocked

The challenges outlined above create a significant obstacle to the upscaling of insect biomass production in the UK, which is preventing a number of opportunities being unlocked and capitalised on. If some, or all, of the barriers were addressed, the following opportunities could be unlocked:

Improved environmental sustainability

UK-produced insect protein would provide an alternative protein source for use in animal feed that could displace a proportion of protein sources currently used in livestock and aquaculture feed, which are associated with negative environmental impacts. For example, soybean meal imported from South America is often associated with deforestation, whilst fishmeal production has been linked with biodiversity loss and reduced fish stocks.

The stakeholder consultation found that over 90% of respondents considered insect production to have a better environmental impact on land use compared with soybean production.

Enhanced circular economy

Insects can feed on certain materials that may otherwise be unused and sent to landfill, or for incineration. This includes former foodstuffs, food surplus, animal by-products and other materials that may end up being categorised as a 'waste' product otherwise. Insect biomass production therefore presents an opportunity to enhance the circular economy through utilising materials that are otherwise wasted, to create a new product that has value as a feed ingredient. If changes were made to legislation to allow more by-products to be authorised for use as substrates, the scale of this opportunity would increase considerably.

The stakeholder consultation found that vegetable and bakery by-products and mixed food by-products were perceived to have the greatest potential for use as insect substrates, whilst sewage biosolids were considered to have the least potential.

Improved food security

In 2019, the UK imported 3.5 million tonnes of soybean equivalent, with a further 0.7 million tonnes of embedded soya imported. The total consumption amounts to around 4.2 million tonnes soybean equivalent, of which approximately 75% is used within animal feed, meat, dairy and eggs.[13] The UK's reliance on soybean as a feed and food ingredient creates a level of risk in terms of security of supply and susceptibility to price fluctuations on the global market. UK-produced insect protein would displace some of this risk and increase food security within the UK.

[13] EFECA (2020) UK Roundtable on Sustainable Soya: Annual progress report, 2020. Available at: https://www.efeca.com/wp-content/uploads/2020/10/UK-RT-on-Sustainable-Soya-APR-19_20-final.pdf [Accessed 14 January 2021]

Development of new markets

If changes to legislation were made to permit the use of processed animal proteins as a feed ingredient in pig and poultry diets, in addition to aquaculture, the market opportunity would increase substantially, providing greater confidence to investors that there will be adequate demand and multiple buyers for insect protein.

The stakeholder consultation found that overall, the majority of stakeholder considered the impact (e.g. cost of feed, animal health and welfare, environmental impacts, reputational risk etc.) of increasing the proportion of insects in UK animal feed to have a positive impact or have little or no change, indicating a real opportunity for insect protein to be a viable alternative.

4 REVIEW OF CURRENT LEGISLATION

This section provides a legislative review by Michelmores for the application of insect processed animal products for use in animal feed.

4.1 Introduction to the legislative environment

Legislation plays a central role in shaping the commercialisation of food production. Historically, agricultural practices and European feed law have not reflected the role insects play in the food chain as converters of waste to protein. European legislation governing the composition of feed for farmed animals (including fish) intended for human consumption, prohibits the utilisation of insects as a source of protein (see in particular the 2001 European feed ban rules, outlined in section 4.2.1). As the market for insects has developed there has been pressure on the legislature to develop new legislation to take account of the emerging role of insects in the feed market.

A summary of the relevant legislation is set out below and focuses on a consideration of:

- the **current permitted and prohibited use of insects in feed for farmed animals** including those intended for human consumption.
- the **current permitted and prohibited use of substrates** in insect rearing.
- the **history and rationale behind current feed restrictions**.
- the **implications of the UK's departure from the European Union; and**
- **Funding for insect producers under existing subsidy scheme.**

This chapter also summarises recommendations from industry on regulatory change required to support the insect protein industry.

See the Animal Feed Glossary (section 4.6) for definition of key terms. Key terms are also signposted throughout this review.

4.1.1 Brexit

Legislation that currently regulates the use of insects in animal feed in the UK predominantly derives from EU Regulations and Directives, supported by implementing domestic regulations. Despite the UK's withdrawal from the EU, pursuant to the European Union (Withdrawal) Act 2018 and supplementary UK legislation, all EU legislation applicable in the UK immediately before 11.00 pm on 31 December 2020[14] (including that regulating insects in animal feed), form part of UK 'retained' EU law[15].

A consequence of this is that EU Regulations and Directive are heavily referred to in this Legislative Review unless the UK has adopted separate domestic (non-EU) legislation (see below and section 4.5 below).

[14] The 'IP completion day', is defined in the European Union (Withdrawal Agreement) Act 2020, s39(1)-(5) as 11.00pm on 31 December 2020.

[15] European Union (Withdrawal) Act 2018, s3(1).

Any future legislative changes at EU-level (including to EU Regulations and Directives detailed in this Legislative Review) will not automatically apply to the UK but will instead be at the discretion of the UK (and any devolved powers). Equally, the UK has the power to implement and adopt domestic legislation applicable to insects in animal feed, at its own discretion, independent of the EU position.

Notwithstanding EU withdrawal, continued compliance with EU animal feed legislation is also essential for any business wishing to export animal feed (including insect substrates, livestock feed and pet food) into the European Community[16]

4.1.2 Protection of Health and the General Food Law

The rules regulating the use of insects in animal feed are predominantly contained in EU Regulations and Directives supported by implementing domestic regulations.

The "overriding principle" informing European food and feed law is the **protection of human life and health, animal health and welfare, the environment and consumers' interests**. This is reflected in **EU Regulation 178/2002** (known as the **"General Food Law"**), and in particular in the "general objectives"[17] and "precautionary principle"[18] set out therein.

The General Food Law lays down the general principles governing food and food safety, and more significantly **feed[19]** and **feed safety**. It applies to all those producing insects for feed across various stages of the production and supply chain and must be adhered to.

KEY TERM

'**feed**' (or '**feeding stuff**') is defined in **EU Regulation 178/2002** as "***any substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals***"

[16] Article 11 of Regulation (EC) No 178/2002 - Feed imported into the Community must comply with Community law.

[17] Article 5(1), EU Regulation 178/2002: "*Food law shall pursue one or more of the general objectives of a high level of protection of human life and health and the protection of consumers' interests, including fair practices in food trade, taking account of, where appropriate, the protection of animal health and welfare, plant health and the environment.*"

[18] Article 7(1), EU Regulation 178/2002: "*In specific circumstances where, following an assessment of available information, the possibility of harmful effects on health is identified but scientific uncertainty persists, provisional risk management measures necessary to ensure the high level of health protection chosen in the Community may be adopted, pending further scientific information for a more comprehensive risk assessment.*"

[19] Article 4(4), EU Regulation 178/2002 defines feed (or feeding stuff) as "*any substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals*".

Article 15 provides that *"feed shall not be placed on the market or fed to any food-producing animal if it is unsafe*[20]*"*. This requirement that feed (including feed that comprises insects and insect protein) shall only be placed on the market if it is safe is a theme which runs through all of the key legislation in this area.

4.1.3 Animal Feed Legislation- Insects as "Farmed Animals"

Whilst the General Food Law has overall application, there is extensive legislation governing animal feed including feed composition, feed hygiene and animal by-products legislation. This review concentrates on addressing the permitted and prohibited use of insects in animal feed, the permitted and prohibited substrates for use in rearing insects and the legislation that addresses that.

With the exception of legislation introduced in 2017 (referred to below), European regulations and directives concerning animal feed have developed without anticipating the use of insects as a source of protein in feed. Insects do, however, fall within the category of "farmed animals" for the purposes of feed legislation governing food and feed.

KEY TERM

'Farmed animals' are defined in Article 3(6) of **EC Regulation 1069/2009** as: ***"(a) any animal that is kept, fattened or bred by humans and used for the production of food, wool, fur, feathers, hides and skins or any other product obtained from animals or for other farming purposes; and (b) equidae"***

The wide definition of farmed animals captures insects bred for animal feed without a corresponding anticipation of the use of insects in that market[21]. As a consequence, insects bred for feed are caught by animal by-products and feed legislation applicable to "farmed animals" which restricts not only the substrates which may be used for rearing insects but also restricts the use of insects in animal feed.

[20] Feed will be considered "unsafe" if it is considered to "*have an adverse effect on human or animal health*" or "*make the food derived from food-producing animals unsafe for human consumption*" – See EU Regulation 178/2002, Article 15(2).

[21] Recital 6, EC Regulation 2017/893 confirmed that insects bred for the production of processed animal protein fall under the definition of "farmed animals" as laid down in article 3(6) EC Regulation 1069/2009.

4.2 Current Permitted and Prohibited use of Insects in animal Feed

The use of animal by-products ("**ABPs"**) in animal feed is highly regulated with legislation restricting and prohibiting the use of protein derived from animals. The categorisation of insects as "farmed animals" has the consequence of bringing insects produced for use in animal feed within the scope of legislation which governs the use of ABPs and Processed Animal Protein ("**PAPs**") more generally and corresponding feed rules.

KEY ACRONYMS

ABPs = animal by-products

PAPs = processed animal proteins

EFSA = European Food Safety Authority

4.2.1 The Feed Ban Rules / TSE Regulations

The European feed ban rules, also known as the TSE Regulations, are set out in EC **Regulation 999/2001** (the "**Feed Ban Rules/TSE Regulations**") and prohibit:

FEED BAN RULES PROHIBITIONS

1. the feeding of protein derived from animals to ruminants[22] (e.g. cows, sheep, deer); and

2. the feeding of the following material to non-ruminants (with the exception of fur animals)[23]:

   a. processed animal protein;
   b. collagen and gelatine of ruminant origin;
   c. blood products;
   d. hydrolysed protein of animal origin;
   e. dicalcium phosphate and tricalcium phosphate of animal origin; and
   f. feed containing the products listed in (a) to (e).

There are prescribed methods for processing insects intended for use in animal feed which are set out in **EC Regulation 142/2011**[24].

[22] Article 7(1), EC Regulation 999/2001

[23] Article 7(2) and Annexe IV, Chapter 1 EC Regulation 999/2001

[24] Methods 1-5 of method 7 of Annexe IV of Regulation (EC) 142/2011

The Feed Ban Rules provide certain derogations from the prohibitions and permit non-ruminant farmed animals to be fed on the following materials and compound feed:

FEED BAN RULES DEROGATIONS FOR NON-RUMINANT FARMED ANIMALS

1 Hydrolysed proteins from parts of non-ruminants or from ruminant hides and skins;

2 Fishmeal;

3 Dicalcium Phosphate and Tricalcium Phosphate of animal origin; and

4 Blood products derived from non-ruminants.

Until recently, the effect of the Feed Ban Rules was a total prohibition on the feeding of PAP from insects to all ruminants and non-ruminants. Hydrolysed proteins from insects, however, were and are permitted to be fed to farmed animals.

4.2.2 Aquaculture feed

EU Regulation 56/2013 introduced an exception to the prohibition of feeding PAP to ruminants contained in the TSE Regulations. That exception authorised the use of PAP from non-ruminant animals for feeding aquaculture animals.

Whilst insects fall into the category of "non-ruminant animals", EU Regulation 56/2013 required that the ABPs intended to be used for the production of the PAP were to be derived from certified slaughterhouses[25]. As a result of this condition, therefore, PAP derived from insects fell outside of the exception introduced by EU Regulation 56/2013.

Nonetheless, interest in production of insects for feed in the EU was growing. In 2013, the Food and Agricultural Organization of the United Nations ("**FAO**") published a paper summarising the opportunities for the use of insects as animal feed[26]. The EC proceeded to co-finance a feasibility research project on insect proteins[27] and asked the European Food Safety Authority ("**EFSA**") to produce a scientific opinion (published in October 2015)[28] (“**EFSA Opinion**”). The EFSA Opinion preceded the EU legislation amendment to permit the use of insect PAP in aquaculture feed. The amendments were introduced by **EU Regulation 2017/893** (the **"2017 Regulations"**) which makes changes to EC Regulation 999/2001 and EU Regulation 142/2011. Such amendments were effective from 1 July 2017.

The key changes made by the 2017 Regulations are as follows:

[25] See Chapter IV, Section D, paragraph a of the Annex to EU Regulation 56/2013

[26] Edible Insects: Future prospects for food and feed security (FAO, 2013).

[27] PROteINSECT Consensus Business Case Report: 'Determining the contribution that insects can make to addressing the protein deficit in Europe' (2015).

[28] EFSA Scientific Committee, 'Risk profile related to production and consumption of insects as food and feed', (5 October 2015)

2017 REGULATION CHANGES (SUMMARY)

1 PAP derived from insects is authorised for feeding to aquaculture animals limited to **7 Species**:

- Black Soldier Fly;
- Common Housefly;
- Yellow Mealworm;
- Lesser Mealworm;
- House Cricket;
- Banded Cricket; and
- Field Cricket.

2 A new definition of "farmed insects" was added to EC Regulation 999/2001

3 Specific conditions have been introduced to regulate the production of insect protein including (but not limited to)[29]:

- PAP derived from farmed insects must be produced in approved processing plants;
- Those processing plants must be dedicated exclusively to the production of products derived from farmed insects;
- PAP must be produced in accordance with certain regulatory requirements; and
- Additional conditions are imposed relating to, for example, storage, labelling, documentation and contamination.

The 7 species (the "**7 Species**") were identified in the 2017 Regulations as those reared in the European Union which were known, at the time the legislation was drafted, to fulfil the relevant safety conditions for insect production for feed use[30]. They reflect the main insect species reared in the European Union at an "industrial scale" at that time[31];

Around the same time the 2017 Regulations were implemented, **EU Regulation 2017/1017**, was adopted which amends EU Regulation 68/2013 on the catalogue of feed materials. EU Regulation 2017/1017 sets out (amongst other matters e.g. labelling requirements) a list of different feed materials being used in the EU and revises the descriptions given for "Processed animal protein"[32] and "Animal fat"[33] to include insects - by including specific

[29] See, for example, new Section F to Annex IV of Regulation (EC) 999/2001 and EU Regulation 2017/893.

[30] See recital 12 to EU Regulation 2017/893

[31] IPIFF, 'IPIFF position paper on the use of insect proteins as animal feed', (26 July 2017), p2

[32] Part C, paragraph 9.4.1 of Annex to EU Regulation 2017/1017

[33] Part C, paragraph 9.2.1 of Annex to EU Regulation 2017/1017

reference to "invertebrates". This is consistent with the changes brought about by the 2017 Regulations.

The amendments made by the 2017 Regulations and Regulation (EU) 2017/1017 are the first pieces of legislation that specifically cater for the use of insect protein as feed. The legislation represented a recognition at EU level that farmed insects could represent an "*alternative and sustainable solution to conventional sources of animal proteins destined for feed for non-ruminant farmed animals*"[34].

4.2.3 Animal By-Product Regulations

There is a series of further regulations to be complied with in order to rely on the derogations provided for in the Feed Ban Rules.

APBs are also categorised depending on the risk they pose to human and animal health under Regulation (EC) No 1069/2009:

CATEGORY ONE	includes entire bodies and all body parts of certain- high risk farmed animals (e.g. suspected TSE[35] or contaminated)[36]
CATEGORY TWO	includes products of animal origin declared unfit for human consumption due to presence of foreign bodies in those products and animal by-products other than those falling within Category One and Three
CATEGORY THREE	includes carcases and parts of animals slaughtered or killed which are fit for human consumption but are not intended for human consumption for commercial reasons

Provided insects and insect by-products fall into Category 3 they can be processed and authorised for use as animal feed (subject always to the Feed Ban Rules on PAPs[37], which currently only permits insect PAP from seven approved species in animal feed. There is a further requirement that ABPs and derived products which are destined for feeding may only be placed on the market if they have been processed in accordance with the conditions for pressure sterilisation and the other conditions that are set out in the regulations[38] and they come from registered establishments/ plants[39].

Live Insects

Live insects are referred to in the Catalogue of Feed Materials in EU Regulation 2017/2017 ("Catalogue") at 9.16.1 and described as "live terrestrial invertebrates, in all their life stages, other than species having adverse effects on plant animals and human health". Their inclusion in the Catalogue is subject to a requirement that when used as a feed material they

[34] See recital 4 to EU Regulation 2017/893

[35] See section on the consideration of TSE

[36] Article 8 of EC Regulation 1069/2009

[37] Article 14 of EC Regulation 1069/2009

[38] Article 31(1)(b) of EC Regulation 1069/2009

[39] Article 31(1)(c) of EC Regulation 1069/2009

comply with EU Regulations 1069/2009 and 142/2011 concerning animal- by products and their derived products, as well as EC Regulation 999/2001.

It is considered that live insects are permitted to be used in animal feed[40] and that practice is already taking place with Protix producing live insects which are fed to chickens producing eggs under the Oerie brand. As indicated above, engrained in animal feed law is the overarching requirement that animal feed must not be marketed or fed to animals if it is unsafe[41]. There must also be compliance with relevant feed legislation[42]."

Pet Feed

Provided the insects and their derived products fall within "Category 3" materials under Regulation (EC) 1069/2009, they are accordingly authorised for use as feed in pet food[43]. There must be compliance with the overarching requirement that the feed is safe[44].

Insect-derived Lipids (fats) and hydrolysed proteins

Insect derived fats hydrolysed proteins (from non-ruminants) are permitted in feed for farmed animals and pet food animals, and the permitted species are not limited to the 7 Species[45]. Certain ABP material that can be used to produce fats/oils and hydrolysed proteins (from non-ruminants) is categorised as 'Category 3' material under the regulations[46]. Such Category 3 material may be processed and used for the manufacturing of feed for farmed animals other than fur animals[47]. Such fats and oils[48]. Animal fat including invertebrates is referred to in the Catalogue[49]. Similarly, hydrolysed protein must comply with the specific processing requirements applicable to hydrolysed proteins[50] (there are currently no plants approved to make hydrolysed protein in Great Britain[51]).[52,53]

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[40]Page 43, IPIFF Guide on Good Hygiene Practices, December 2019

[41] Article 15 of Regulation (EC) No 178/2002 and Article 4 of Regulation (EC) No 767/2009, which expands the principle of feed safety to all animals and not just food-producing animals.

[42] Predominantly set out in Regulation (EC) No 767/2009

[43] Article 14(d)(iii), Regulation (EC) 1069/2009 and Article 35, Regulation (EC) 1069/2009

[44] Article 15, Regulation (EC) 178/2002

[45] DEFRA and APHA Guidance "Supplying and using Animal by Products as animal feed or in animal feed and how to get your site authorised" 14 Jan 2019

[46] See Article 10 of Regulation (EC) No 1069/2009.

[47] Article 14(d)(i) of Regulation (EC) No 1069/2009

[48] See Annex X, Chapter II, Section 3 of Regulation (EU) No 142/2011

[49] Part C, 9.2.1, Annex to Regulation (EU) No 2017/1017

[50] See Annex X, Chapter II, Section 5 of Regulation (EU) No 142/2011.

[51]DEFRA and APHA Guidance "Supplying and using Animal by Products as farm" 14 Jan 2019.

[52] Article 15 of Regulation (EC) No 178/2002 and Article 4 of Regulation (EC) No 767/2009, which expands the principle of feed safety to all animals and not just food-producing animals.

[53] Predominantly set out in Regulation (EC) No 767/2009

Invasive Alien Species

Again, to the extent that insects can be used in feed, the use of insect species which are defined as "invasive alien species"[54] in accordance with **Regulation (EU) 1143/2014** (the **"IAS Regulation"**) is prohibited. The list of invasive alien species of the Union (referred to in the IAS Regulation as the "**Union list**") is currently found in **Commission Implementing Regulation (EU) 2016/1141**. This set of regulations is particularly geared towards protecting biodiversity and related ecosystems.

To date, the only insect species on the Union list (and thus prohibited from use in feed) is the vespa velutina nigrithorax (more commonly known as the Asian predatory wasp or Asian hornet). The Union list is, however, continually updated. Further species of insects might be added over time and therefore the Union list should be closely monitored.

Cattle, Poultry and Pig Feed

The only permitted use for insect PAP (which is subject to additional restrictions, under the Feed Ban Rules, than other category 3 ABPs) in farmed animals is aquaculture. As it stands, insect PAP is not permitted to be used in feed for any other farmed animal intended for human consumption including, cattle, poultry and pig (Table 14). A change in European legislation permitted the use of insect PAP in poultry and swine feed is anticipated.

Table 14. Summary table for permitted and prohibited use of insects in animal feed. Source: Michelmores for WWF.

	Insect PAP – All species	Insect PAP – from the 7 Species	Insect Lipids and Hydrolysed Protein	Live Insects
Ruminants	✗	✗	✓	N/A
Poultry	✗	✗	✓	✓
Pigs	✗	✗	✓	✓
Fish	✗	✓	✓	✓
Pet Food	✓	✓	✓	✓
Fur Animals	✓	✓	✓	✓

*"***Insect PAP-All Species***" = except "invasive alien species".

[54] "[I]nvasive alien species" is defined in Article 3(3) of the IAS Regulation as "*an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services*". "[A]lien species' is defined in Article 3(2) of the IAS Regulation as "*any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or micro-organisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce*".

4.3 Current Permitted and Prohibited Insect Substrates

The inclusion of invertebrates in the definition of "farmed animals" not only prescribes what animals the insects may be fed to but also the permitted substrates which insects may be reared on. Insects kept or bred for use in animal feed must currently be treated as farmed animals and consequently fed in accordance with general animal feed law.

KEY NOTE

Insects kept or bred for use in animal feed must currently be treated as farmed animals and consequently fed in accordance with general animal feed law.

Whilst this Section makes reference to the impact the relevant legislation has on the materials that can and cannot be used as insect substrate, the legislation is not directed at insect substrate in particular but rather at materials prohibited/restricted from inclusion in feeds given to farmed animals (or animals in general).

As per the permitted and prohibited uses of insects in livestock feed (set out above) the law surrounding insect substrates is predominantly controlled by EU Regulations and Directives. The applicable domestic law (in its current form) most notably implements powers of enforcement of the EU legislation.

4.3.1 Feed Safety

As indicated above, engrained in animal feed law is the overarching requirement that animal feed must not be marketed or fed to animals if it is unsafe[55]; with a fundamental objective of food law (incorporating all aspects of the food chain, including feed[56] and primary production[57]) being a high level of protection of human life and health.

Another fundamental principal of feed law is traceability. Article 18 of the General Food Law mandates that traceability must be established at all stages of feed production, processing and distribution.

[55] Article 15 of Regulation (EC) No 178/2002 and Article 4 of Regulation (EC) No 767/2009, which expands the principle of feed safety to all animals and not just food-producing animals.

[56] Regulation (EC) No 178/2002, Recital 12.

[57] Commission Notice – Guidance document on the implementation of certain provisions of Regulation (EC) No 183/2005. Section 4 (Primary Production)

4.3.2 Feed Business Operators

KEY ACRONYM

FBO = Feed Business operator

Only registered and/or approved animal feed business operators ("**FBO**s") may make, market or use animal feed[58] (including insect feed). It is the primary responsibility of each FBO to ensure that feed satisfies the requirements of food law (relevant to their activities)[59]. See outline FBO checklist (Figure 6), together with a non-comprehensive list of activities requiring FBO registration and approval, which are set out in Table 15.

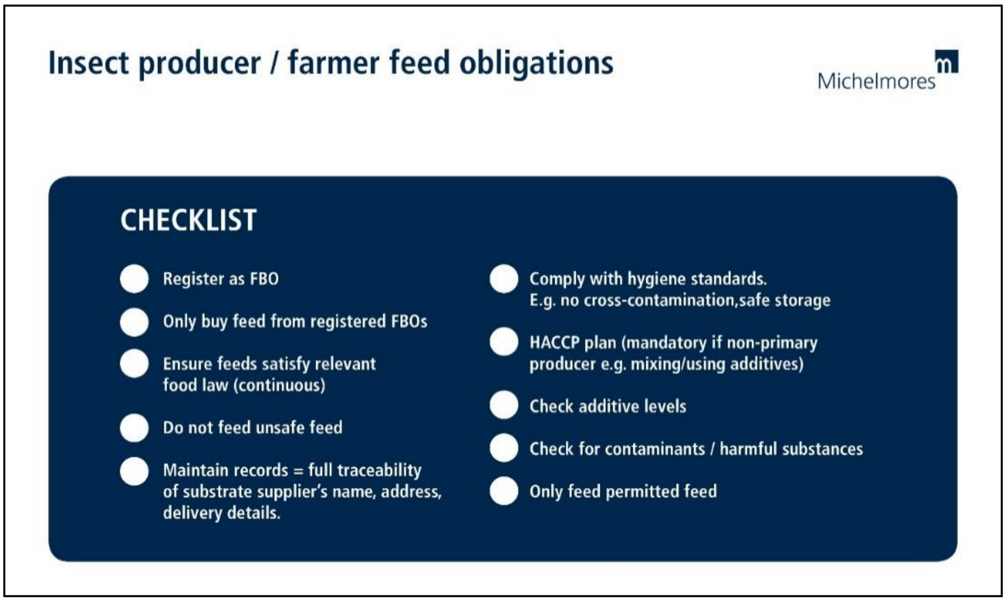

Figure 6. Checklist for insect producer / farmer feed obligations. Source: Michelmores for WWF.

Table 15. Feed business activities requiring registration and approval. Source: Michelmores for WWF.

Feed business activity	Registration	Approval	None / other
Manufacturing feed materials	X		
Manufacturing feed additives	X		

[58] Article 5.6 of Regulation (EC) No 183/2005 requires that "*feed business operators and farmers shall only source and use feed from establishments which are registered and/or approved in accordance with this Regulation*".

[59] See Article 17 of Regulation (EC) No 178/2002.

Manufacturing pet foods	X		
Transporting / storing feed	X		
Food / non-feed business selling products destined as feed materials (e.g. brewers, distillers)	X		
Farms mixing additives	X		
Livestock farms	X		
Farms selling crops for feed	X		
Manufacturing / placing on the market nutritional additives		X	
Manufacturing (for feed use) products derived from vegetable oils and blended fats		X	
Feeding animals intended for own consumption			X
Feeding animals not kept for food production			X
Pet food retailer			X

4.3.3 Permitted Substrates and Prohibited Substrates

Animal feed legislation permits feedstuffs that satisfy the overarching feed safety requirements and that do not contain any prohibited substrates or restricted material in excess of the permitted levels.

Permitted substrates

EC Regulation 767/2009 requires the creation of a 'Community Catalogue of feed materials'[60] (the "**Catalogue"**). The Catalogue[61] contains a comprehensive list of permitted feed materials (including products derived from those materials). Table 16 lists the Catalogue categories.

KEY TERM

Catalogue = Community catalogue of feed materials set out in Part C of the Annex to Regulation 2017/1017.

[60] Article 24(1) of Regulation (EC) No 767/2009

[61] Set out in Part C of the Annex to Regulation (EU) No 2017/1017. This replaces the original list set out in Regulation (EU) No 68/2013.

Table 16. The categories of permitted feed materials (and including products derived from those materials) in the Catalogue. Source: Michelmores for WWF.

Vegetable Substrates	
(i)	Cereal grains (*e.g. malt, maize, oats, wheat, brewers' grains, distillers' grains*)
(ii)	Oil seeds and oil fruits (*e.g. cocoa husks, cotton seed, linseed, olive pulp, rape seed, soya beans*)
(iii)	Legume seeds *(e.g. carob seeds, chickpeas, horse beans, lentils, peas)*
(iv)	Tubers and roots *(e.g. sugar beet, carrots, onion pulp, potatoes, dried garlic, beetroot juice)*
(v)	Other seeds and fruits *(e.g. almond, apple molasses, buckwheat, coffee skins, fruit pulp, tomato pulp)*
(vi)	Forages and roughage *(e.g. beet leaves, hay, maize silage, clover meal, cereal plants, pea straw)*
(vii)	Other plants and algae *(e.g. algae, barks, sugar cane molasses, mint, dried leaves, chemically untreated wood)*
Non-Vegetable Substrates	
(viii)	Milk products* (e.g. butter, buttermilk powder, cheese, lactose, whey powder)
(ix)	Land animal products* (e.g. animal by-products, processed animal proteins, blood meal, gelatine, eggs)
(x)	Fish and other aquatic animals* (e.g. fish, fish meal, krill oil, squid meal)
(xi)	Minerals* (e.g. calcium carbonate, magnesium carbonate, magnesium phosphate, bone ash, sodium chloride, potassium sulphate)
(xii)	Products and by-products obtained by fermentation using microorganisms, inactivated resulting in absence of live microorganisms** (e.g. brewers' yeast, yeasts from biodiesel process, yeast products)
Former Foodstuffs (examples)	
(xiii)	Miscellaneous* (*e.g. bakery and pasta products, products from the pastry, ice cream and confectionary industries, products of the breakfast cereal manufacture, products and by-products from processing fresh fruit, vegetables, plants, spices and seasoning, fruit syrups*).

TO NOTE

* Feed materials containing animal products must fulfil requirements in Regulations (EC) No 1069/2009, (EU) No 142/2011 and (EC) No 999/2001 regulating the use of ABPs. See below

** Feed materials produced from genetically modified (GM) organisms, or that result from fermentation process involving GM micro-organisms must also comply with Regulation (EC) No 1829/2003 on GM food and feed

Many former foodstuffs / by-products can become animal feed and the Catalogue of permitted feed materials refers to a number of by-products and surplus / former foodstuffs. However, the following rules must also be applied:

- The usual feed law (e.g. hygiene, traceability, additive levels etc.) requirements must be satisfied (see Figure 9 above).
- Materials not consisting of, containing or contaminated with products of animal origin (e.g. vegetal matter) can become feed if they are by-products arising from the food manufacturing process.[62]
- Materials must not have been contaminated with any prohibited or restricted (beyond accepted maximums) materials (see 'Prohibited Substrates' below). Further, if consisting of or contaminated with products of animal origin, the material is an animal by-product and must be treated accordingly (see 4.3.4 below).
- Materials must not inadvertently become waste within the definition and scope of the Waste Framework Directive[63], as that is likely to exclude them from the further feed chain.

Foods that have passed their best before dates, use by dates, or that have fallen on the establishment floor may still be used as feed if:

- they have not been identified by the relevant food business operator or FBO as no longer being intended as feed use (see above regarding materials becoming waste);
- the food business operator (and subsequent FBO) considers on a case-by-case basis that the general feed hygiene requirements regarding safety for consumption are met; and
- (in the case of material fallen on the floor) the FBO has in place appropriate protocol for keeping the floor hygienic, uncontaminated and for collecting such material.

The simplest means of ensuring an insect substrate is permitted is to refer to the Catalogue and use feed materials in accordance with the feed specifications stipulated in the Catalogue. Whilst use of the Catalogue is voluntary,[64] it sets out mandatory requirements and declarations for the relevant listed feed material, which must be adhered to if any listed feed material is used by an FBO. The Catalogue also names specific processes (e.g. dehulling, milling, pressing, roasting) which must be adhered to and labelled (as a compulsory declaration) if the relevant material and process are combined in the Catalogue.[65]

Deviating from Catalogue introduces additional obligations as any person placing on the market (for the first time) a feed material that is not listed in the Catalogue must immediately notify its use to the relevant authority[66].

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[62] Chapter 1.3(a)(i) of the Commission Guidelines for the feed use of food no longer intended for human consumption (2018/C 133/02).

[63] Directive 2008/98/EC (see also Section 4.3.5 below).

[64] Article 24(5) of Regulation (EC) No 767/2009.

[65] Annex, Part A, paragraph (8), Regulation (EU) No 2017/1017.

[66] Article 24(6) of Regulation (EC) No 767/2009

Prohibited substrates

Annex III to EC Regulation 767/2009 sets out a list of materials prohibited from being placed on the market or used for animal nutritional purposes (the "**Unauthorised List**"). There is no exception for use in insect feed and as insects also fall within the 'farmed animal' definition, the following prohibitions will also apply to insects reared other than as feed (such as for biofuels and bioplastics).

UNAUTHORISED LIST

1 Faeces, urine and separated digestive tract content resulting from the emptying or removal of digestive tract;

NOTE: This is expressly irrespective of any form of treatment and will include livestock manure / slurry and human excrement

2 Animal hide treated with tanning substances (including waste);

3 Seeds which, after harvest, have undergone specific treatment with plant protection products for their intended use (propagation);

4 Wood and materials derived from wood (e.g. sawdust) which has treated with preservatives[67];

5 Waste obtained from various phases of the urban, domestic and industrial wastewater[68] (irrespective of further processing or origin);

6 Solid urban waste (e.g. household waste);

7 Packaging from the use of products from the agri-food industry;

8 Feed materials which chemical impurities that result from their manufacturing process (unless a specific 'maximum' content is fixed in the Catalogue); and

9 Material with a botanical impurity of less than 95% (unless a different level is set out in the Catalogue).

This is a blacklist of prohibited substrates.

Non-blacklist prohibitions / restrictions: Materials not on the blacklist may nonetheless be subject to restrictions and prohibitions set out in EU and domestic legislation. For example, those relating to additive and chemical quantities - FBOs of particular materials (palm kernel expeller, fish/marine processing, seaweed meals or complete feeds for fish or fur-producing

[67] Relevant preservatives are defined in Annex V of Directive 98/8/EC

[68] Defined in Article 2 of Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment.

animals) must produce an analysis showing that inorganic arsenic levels are below a certain level[69].

'Undesirable substrates'[70] must not exceed the maximum quantities set out in Annex 1 of Directive 2002/32/EC.

4.3.4 Animal By-Products as a Substrate

As set out above, the handling and use of ABPs is highly regulated at an EU level, including in respect of the use of APBs in animal feed. Consequently, a number of legislative instruments prohibit and restrict the use of APBs as insect substrate.

The TSE Regulations[71] are the key regulations which prohibits feeding certain materials to insects (as non-ruminant farmed animals)[72] (the **"Prohibited Materials"**). The Prohibited Materials are listed in the first column of Table 17. There are, however, a number of exceptions to this. The feed materials and compound feed that it is not prohibited to feed to insects (as non-ruminant farmed animals)[73] (the **"Permitted Materials"**) are separately listed in the second column of Table 17.

Table 17. The prohibited and permitted materials as stated in the TSE Regulations. Source: Michelmores for WWF.

PROHIBITED MATERIALS	PERMITTED MATERIALS
• processed animal protein • collagen and gelatine of ruminant origin • blood products • hydrolysed protein of animal origin • dicalcium phosphate and tricalcium phosphate of animal origin • feed containing any of the products listed	• hydrolysed proteins derived from parts of non-ruminants or from ruminant hides and skins • fishmeal and compound feed containing fishmeal* • dicalcium phosphate and tricalcium phosphate of animal origin and compound feed containing such phosphates* • blood products derived from non-ruminants and compound feed containing such blood products* • feed materials of plant origin (and compound feed containing such feed materials) contaminated with insignificant amounts of bone spicules derived from unauthorised animal species[74].

[69] See Articles 14 & 15 of the Animal Feed (Composition, Marketing and Use) (England) Regulations 2015.

[70] Defined in the Animal Feed (Composition, Marketing and Use) (England) Regulations 2015.

[71] Enforced in England by the Transmissible Spongiform Encephalopathies (England) Regulations 2018 (and parallel legislation in Scotland, Wales, and Northern Ireland).

[72] Annex IV, Chapter I of Regulation (EC) No 999/2001

[73] Annexe IV, Chapter II, paragraph (b) of Regulation (EC) No 999/2001

[74] Annex IV, Chapter II, paragraph (e) of Regulation (EC) No 999/2001

	• Protein of animal origin (e.g. dairy, rather than protein derived from animals)

* Which are produced, placed on the market and used in accordance with certain conditions laid down in the regulations.

The broad effect of the TSE Regulation is that meat products and similar proteins derived from (i.e. the bodies of) animals (other than the Permitted Materials) cannot be used as an insect substrate.

ABPs that are not 'protein derived from animals' but rather 'protein of animal origin' – for example dairy products – are not restricted by this legislation and therefore can be used to feed insects (as non-ruminant farmed animals) unless otherwise restricted under other legislation which the TSE Regulation should always be read in conjunction with.

In terms of that "other legislation", it is then necessary to consider Regulation 1069/2009 which is the primary legislation under which ABPs and derived products which are not intended for human consumption are regulated.

Significantly, Article 14 provides that Category 3 material[75] can be processed and then used for the manufacturing of feed for farmed animals (which includes insects) in accordance with Article 31. Accordingly, provided it is not, or is not mixed with, a Prohibited Material (see above), **Category 3 material can be used for insect substrate**. Indeed, Regulation (EU) No 142/2011 (see below) provides that only Category 3 material can be used for insect substrate. It must not contain any "Category 1" or "Category 2" materials. Regulation (EU) No 142/2011 is also the legislation which limits processed animal protein derived from insects, intended for the production of feed for farmed animals (other than fur animals), to 7 insect species (see Section 4.2.2).

KEY NOTES

1. See Section 4.2.3 of this Report for ABP Categories.
2. **EU Regulation 142/2011** provides that any former foodstuffs containing ABPs to be used as feed for farmed animals (including insects) cannot be composed of or have been in contact with material of animal origin which has not undergone processing in accordance with the regulations – this potentially limits streams of material available for use as insect substrate further

The effect of Regulation 1069/2009 is also that insect substrates cannot include ABPs of insects of the same species[76]. Given the lack of specific law aimed at insect substrates, it is not clear if this restriction would prevent cross-insect species use in feed or whether the definition of 'species' would cover the fuller invertebrate umbrella.

[75] Other than the materials referred to in Article 10(n) (hides and hooves etc), Article 10(o) (adipose tissue) and Article 10(p) (catering waste).

[76] See Article 11(1)(a) of Regulation (EC) No 1069/2009

The feeding of farmed animals (which includes insects) with catering waste or feed material containing or derived from catering waste[77] is also prohibited outright.

The regulations also set out a number of procedural and other requirements which must be complied with but those are beyond the scope of this review.

Regulation 1069/2009 should be read in conjunction with its implementing legislation, EU Regulation 142/2011, which sets out further details and requirements for all ABPs intended to be used as insect substrate (including regarding processing, storage and handling). Those must be strictly adhered to.

Table 18 provides a summary table of ABPs as insect substrate, combining all regulations.

[77] Article 11(1)(b) of Regulation (EC) No 1069/2009

Table 18. Summary table of ABPs as insect substrate – combining all regulations. Source: Michelmores for WWF.

Animal by-products PROHIBITED as or in insect substrate	Animal by-products PERMITTED as or in insect substrate
• processed animal protein • collagen and gelatine of ruminant origin • blood products • hydrolysed protein of animal origin • dicalcium phosphate and tricalcium phosphate of animal origin • feed containing any of the products listed • animal by-products of insects of the same species • catering waste or feed material containing or derived from catering waste • former foodstuffs containing ABPs which contains or has been in contact with material of animal origin which has not undergone processing in accordance Regulation (EU) 142/2011. • Material categorised as "category 1" or "category 2" material under Regulation 1069/2009	• hydrolysed proteins derived from parts of non-ruminants or from ruminant hides and skins • fishmeal and compound feed containing fishmeal* • dicalcium phosphate and tricalcium phosphate of animal origin and compound feed containing such phosphates* • blood products derived from non-ruminants and compound feed containing such blood products* • protein of animal origin (rather than protein derived from animals). • feed materials of plant origin (and compound feed containing such feed materials) contaminated with insignificant amounts of bone spicules derived from unauthorised animal species. • Material categorised as "category 3" material under Regulation 1069/2009 unless otherwise prohibited.
* Which are produced, placed on the market and used in accordance with certain conditions laid down in the regulations.	

4.3.5 Waste as a Substrate

As set out in Section 4.3.3 there is a mandatory **'unauthorised'** list of materials prohibited from being placed on the market as animal feed. This list includes certain waste materials (e.g. animal and human waste (excrement), wastewater, solid urban (household) waste and food packaging). Under current law[78], under no circumstances (e.g. even if treated), can these unauthorised materials be used in, or contaminate, feed substrates.

Addressing waste specifically, Directive 2008/98/EC (the "**Waste Framework Directive**") is the key piece of legislation although, notably, ABPs are excluded from the scope of the

[78] Regulation (EC) 767/2009

Waste Framework Directive[79] and are instead addressed in separate legislation (set out above).

KEY TERM

"Waste" = Article 3(1) of **Directive 2008/98/EC** defines "waste" as *"any substance or object which the holder discards or intends or is required to discard."*

Within the scope of the Waste Framework Directive, "waste" is "*any substance or object which the holder discards or intends or is required to discard*"[80].

Once material is discarded as waste, it cannot be used as food or feed.

To not fall into the 'waste' classification, Article 5 of the Waste Framework Directive sets out four criteria which must be met by the relevant by-product:

- Production (of the by-product) must be an integral part of a production process;
- It must be possible for the by-product to be used directly without any further processing (other than normal industrial practice);
- Further use as animal feed (in compliance with animal feed law) must be certain;
- The further use must be lawful (e.g. the by-product must satisfy feed safety law / must not contain prohibited levels of undesirable substrates).

The above allow certain non-animal by-products (e.g. sugars, crops, etc.) to be utilised in the feed chain, rather than entering the waste hierarchy.

ABPs are excluded from the scope of the Waste Framework Directive (except those which are destined for incineration, landfilling or use in a biogas or composting plant). Accordingly, to the extent that material comprising ABPs is intended to be used in a way set out in Section 4.3.4, the legislative framework set out therein will apply.

Another useful legislative tool is Article 6(1) of the Waste Framework Directive. Which permits certain 'waste' materials to cease being waste if strict criteria are met. These include the substance being commonly used for the specific (intended) purpose, with appropriate market demand (e.g. insect / livestock feed) and the substance must fulfil all relevant technical and (for the purpose of animal feed) feed safety requirements. This is important, as it provides scope for currently prohibited 'waste' materials, if deregulated under other feed law (e.g. animal waste (manure) and / or catering waste not containing ABPs) to be used as insect substrate.

Further, the prohibitions in Regulation (EC) No 767/2009 outline material types that will ordinarily be considered in the category 'waste' also (e.g. faeces, household waste and food packaging). These prohibitions are important in the context of insect substrate as they rule out the use of a number of sources of potentially nutritional value for use as insect substrate. In particular, the prohibition on packaging (or any parts of packaging) being present in feed

[79] Article 2 of Directive 2008/98/EC

[80] Article 3(1) of Directive 2008/98/EC.

materials is likely to have a practical effect of limiting the potential input streams for insect substrate, unless the relevant material has been subject to rigorous processing and quality assurance.

It is also useful to note here that certain triggers that would render food automatically 'unsafe' under food safety law (e.g. foodstuffs that have fallen onto a factory floor or that are past their use-by / best-before dates), are less rigid under animal feed law. Such materials may still enter the feed chain if the relevant FBO determines that the feed material still meets the overarching safety requirements.

Figure 7 provides a decision tree for insect substrates.

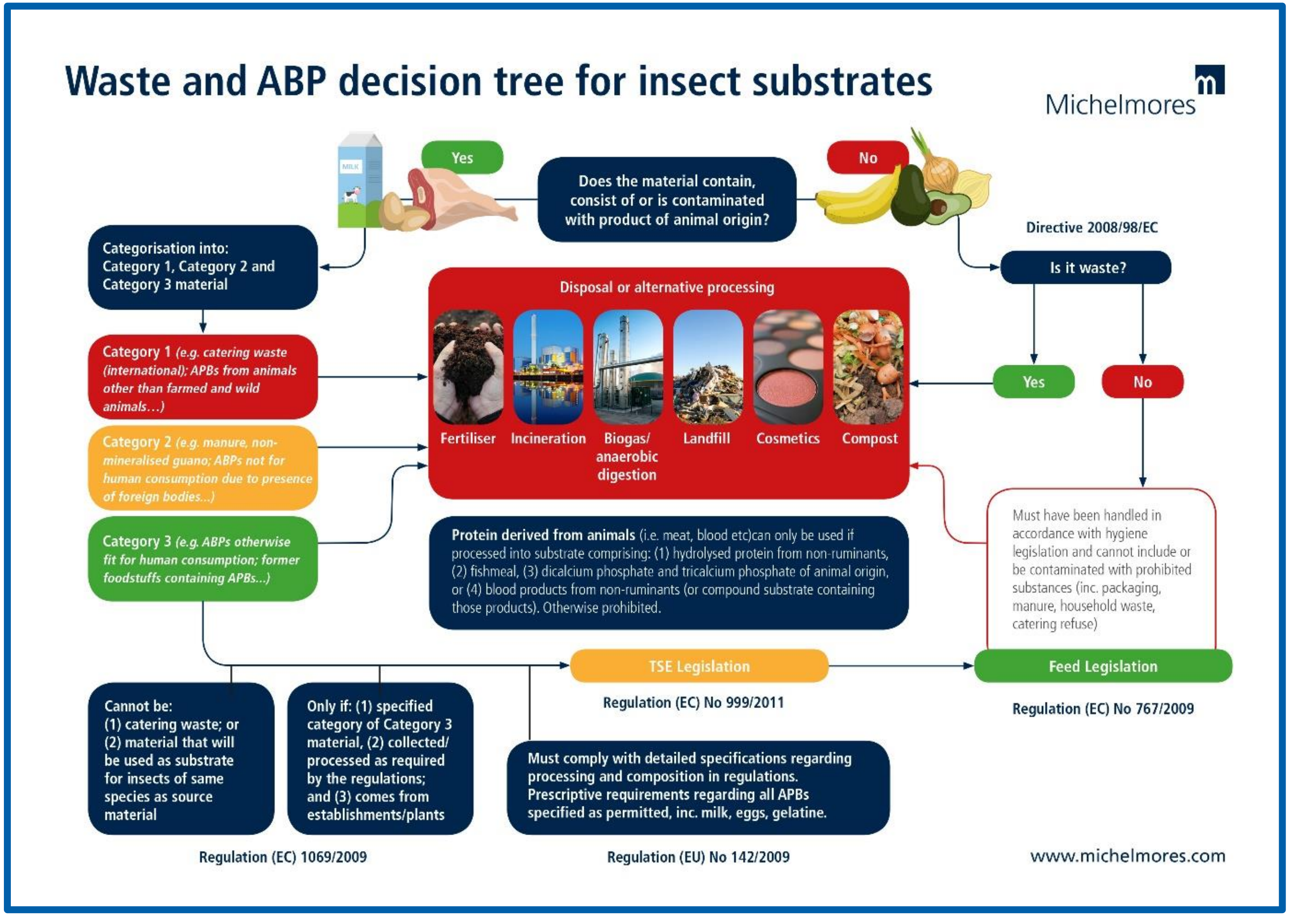

Figure 7. Decision tree for insect substrates. Source: Michelmores for WWF.

4.3.6 New EU waste directive

The new EU Waste Directive[81] came into force on 4 July 2018. This new EU Waste Directive has not been implemented by the UK. However, the 'gaps' between the 'older' 2008 Waste Framework Directive[82] (in force in the UK) and the new EU Waste Directive are bridged under UK law in new Waste (Circular Economy) (Amendment) Regulations 2020[83]. These came into force on 1 October 2020.

UK LAW UPDATE

UK Waste (Circular Economy) (Amendment) Regulations 2020 came into force on 1 October 2020.

On 30 July 2020, DEFRA, the Welsh Government, the Scottish Government, and DAERA jointly also issued a policy statement[84] which confirms that the UK nations will transpose the new EU Waste Directive to assist in the transition to a circular economy.

The policy statement reiterates that leaving the EU has not changed the UK governments' world-leading ambitions on the environment, and there is no intention of weakening current environmental protections after the end of the transition period. The statement specifically notes that the transition to a circular economy requires changes throughout value chains and novel ways of turning waste into a resource.

The EU Waste Directive is an important indicator of the EU position on waste, circular economy and waste 'exemptions'. Set out below are the most pertinent components:

- Animal by-products destined to be used as feed materials in accordance with Regulation (EC) No 767/2009 of the European Parliament and of the Council 7 are excluded from the scope of Directive 2008/98/EC to the extent that they are covered by other Union legislation.[85]
- "In order to promote sustainable use of resources and industrial symbiosis, Member States should take appropriate measures to facilitate the recognition as a by-product of a substance or an object…The Commission should be empowered to adopt implementing acts in order to establish detailed criteria on the application of the by-product status, prioritising replicable practices of industrial symbiosis."[86]
- Member States must "take measures to promote prevention and reduction of food waste…in particular…halving per capita global food waste at the retail and consumer

[81] Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste.

[82] Directive (EU) 2008/98/EC)

[83] (SI 2020/904)

[84] https://www.gov.uk/government/publications/circular-economy-package-policy-statement/circular-economy-package-policy-statement

[85] Directive (EU) 2018/851, Recital (8).

[86] Ibid, Recital 16.

levels and reduce food losses along production and supply chains, including post-harvest losses". [87]

- Substances that are destined for use as feed materials (as defined in point (g) of Article 3(2) of Regulation (EC) No 767/2009), that do not consist of or contain animal by-products, are to be added to the list of exclusions from the scope of Directive 2008/98/EC. [88]
- Further, Article 1 of the EU Waste Directive amends Article 29 of Directive 2008/98/EC to insert the following paragraph: "2a. Member States shall adopt specific food waste prevention programmes within their waste prevention programmes." NOTE: This amendment is copied into the Circular Economy Regulations.[89]

Figure 8 provides a summary table of permitted and prohibited insect substrates.

[87] Ibid Recital 31.

[88] Ibid, Article 1.

[89] Ibid, Article 1.

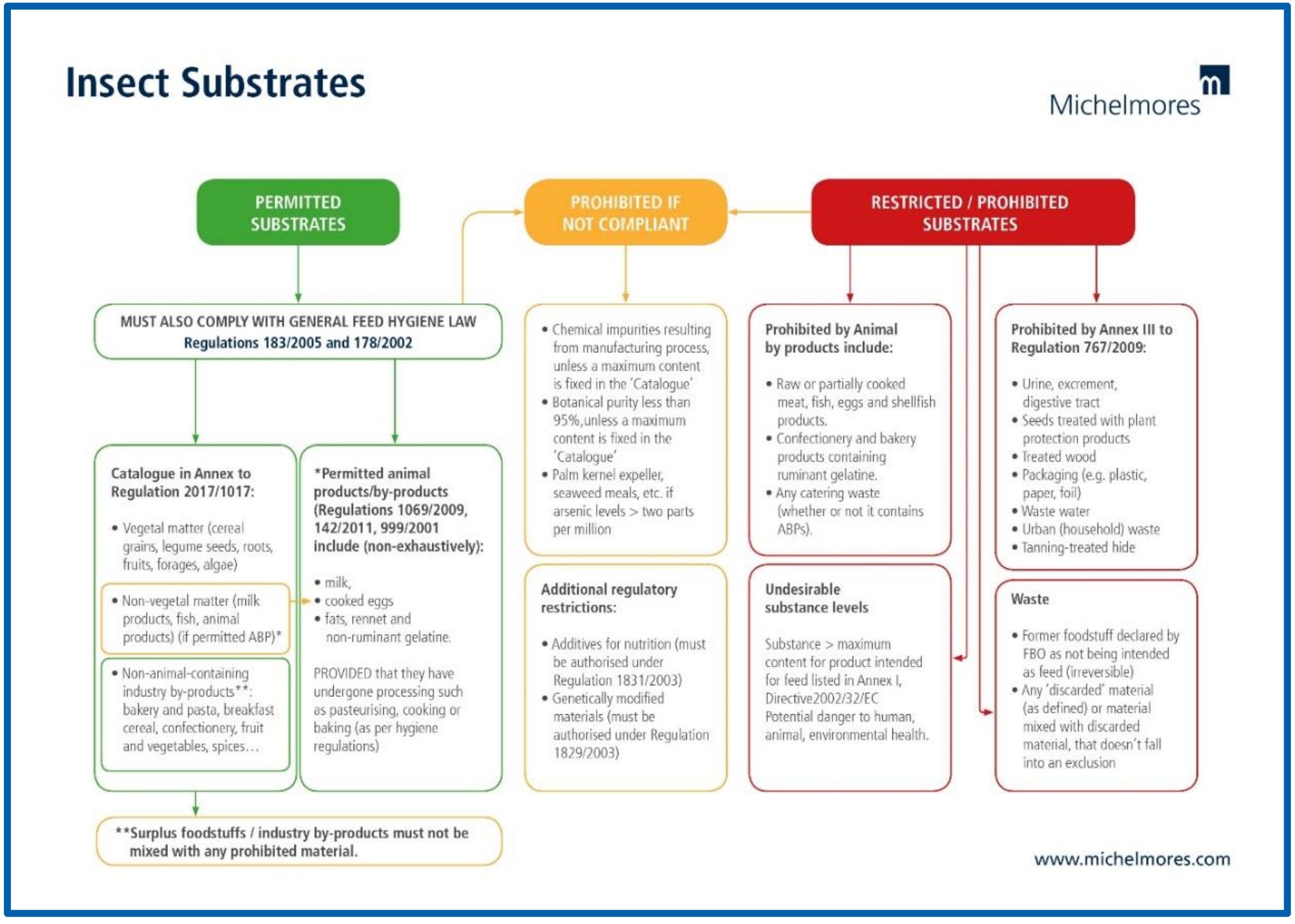

Figure 8. Summary table of permitted and prohibited insect substrates. Source: Michelmores for WWF.

4.3.7 Sewage for agricultural use

Sewage falls within the definition of waste and is therefore regulated under the EU Waste Framework Directive, requiring it to be managed in compliance with the waste hierarchy set out in that framework.

Directive 91/271/EEC requires that member states provide certain collecting systems and treatment plants for wastewater. In the UK, the directive is implemented by the Urban Waste Water Treatment (England and Wales) Regulations 1994. Amongst other things, this puts an obligation on regulated wastewater treatment entities to treat sewage and only discharge it following treatment. The residue of such treatment is what is known as 'sludge'.

It is prohibited to use or spread sewage sludge on agricultural land unless it complies with regulation 3 of the Sludge (Use in Agriculture) Regulations 1989/1263. There is a Government-published code of practice for use of sewage sludge in agriculture, which is used to demonstrate compliance with the regulations.[90]

4.3.8 Analysis of legality of materials as substrate

Table 19 provides a legal analysis of substrate materials and their permitted or prohibited uses in 2020.

[90] See here: https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland

Table 19. Analysis of legality of materials as substrate. Source: Michelmores for WWF.

Legislation Key Terms:

The **'Catalogue'** of permitted materials is set out in Part C of the Annex to EU Regulation 2017/1017. All materials listed in the Catalogue must also, if sold / marketed / used for animal feed, meet any relevant process for that material (where relevant and listed in the catalogue next to the material)

'**Category 2'** and '**Category 1**' animal by-products (ABPs) are set out in EC Regulation 1069/2009 - Category 1 and 2 materials cannot be processed / used as animal feed.

The '**Unauthorised List**' of prohibited feed materials is set out in Annex III, Chapter 1 of EC Regulation 767/2009.

Material type	Currently permitted as insect substrate?	Legal Analysis
Vegetable surplus	Yes	The following categories of materials are listed in the Catalogue and accordingly usable as feed: • Cereal grains (e.g. malt, maize, oats, wheat) • Oil seeds and oil fruits (e.g. cocoa husks, cotton seed, linseed, olive pulp, rape seed, soya beans) • Legume seeds (e.g. carob seeds, chickpeas, horse beans, lentils, peas) • Tubers and roots (e.g. sugar beet, carrots, onion pulp, potatoes, dried garlic, beetroot juice) • Other seeds and fruits (e.g. almond, apple molasses, buckwheat, coffee skins, fruit pulp, tomato pulp) • Forages and roughage (e.g. beet leaves, hay, maize silage, clover meal, cereal plants, pea straw) • Other plants and algae (e.g. algae, barks, sugar cane molasses, mint, dried leaves, chemically untreated wood)
Bakery surplus	Yes	Products from the bakery and pasta industry are listed in the Catalogue, as: "*Products obtained during and from the production of bread, biscuits, wafers or pasta. They may be dried*". This material may therefore be used as feed, provided it does not include ABPs (Animal by Products).

Bakery surplus mixed with ABP	No/Partially	Foodstuffs containing products of animal origin which are no longer intended for human consumption (for commercial reasons or due to problems of manufacturing or packaging defects or other defects from which no risk to public or animal health arise) are categorised as 'Category 3' material under the Regulations[91]. That material *may* be processed and used for the manufacturing of feed for farmed animals other than fur animals[92]. It must, however, comply with certain specific requirements to be placed on the market[93]. However, that is subject always to the TSE Regulations[94] and the prohibition on feeding protein derived from animals to ruminants[95] and feeding PAP (Processed Animal Protein) (amongst other things) to non-ruminants[96]. Any baker products containing meat or fish, for example, will therefore not be permitted as a substrate.
Abattoir surplus	No/ Partially, as a raw material	**Abattoir by-product / surplus**: Material from slaughterhouses may be processed and used for the manufacturing of feed for farmed animals other than fur animals[97] provided that: • It is derived from the range of materials originating from slaughterhouses which are categorised only as 'Category 3' material under the regulations[98] (which includes carcasses of animals and parts of animals, hides and skins, pig bristles and feathers); **AND** • The material is used to produce the following products: hydrolysed protein (from non-ruminants or ruminant hides and skin)[99], dicalcium phosphate[100], tricalcium phosphate[101] and/or blood products from non-ruminants[102], being the only permitted products that may be fed to farmed animals[103]. The resultant product must comply with the specific requirements for each such product to be placed on the market.

[91] Article 10 of Regulation (EC) No 1069/2009
[92] Article 14(d)(i) of Regulation (EC) No 1069/2009
[93] See Annex X, Chapter II, Section 10 of Regulation (EU) No 142/2011
[94] EC Regulations 999/2001.

[95] Article 7(1) Chapter 1 EC Regulation 999/2001.

[96] Article 7(2) and Annex IV, Chapter 1 EC Regulation 999/2001.

[97] Article 14(d)(i) of Regulation (EC) No 1069/2009
[98] See Article 10(a) to 10(c) of Regulation (EC) No 1069/2009
[99] See Annex X, Chapter II, Section 5 of Regulation (EU) No 142/2011
[100] See Annex X, Chapter II, Section 6 of Regulation (EU) No 142/2011
[101] See Annex X, Chapter II, Section 7 of Regulation (EU) No 142/2011
[102] See Annex X, Chapter II, Section 2 of Regulation (EU) No 142/2011
[103] Article 7(1) and Annex IV, Chapter II of Regulation (EC) No 999/2001

		Note ABPs collected during the treatment of wastewater from slaughterhouses is categorised as either 'Category 2'[104] or 'Category 1'[105] material and is not permitted to be placed on the market. If any Category 3 material is mixed with Category 1 or Category 2 material, it automatically adopts the more stringent classification.
Abattoir Blood	Partially, as a raw material	**Blood**: Blood products from non-ruminants[106] may be processed and used for the manufacturing of feed for non-ruminant farmed animals other than fur animals[107] provided that: • the material comes from: ➢ carcases and parts of animals slaughtered (or, in the case of game, bodies or parts of animals killed) and which are fit for human consumption in accordance with Community legislation, but are not intended for human consumption for commercial reasons; or ➢ carcases and the following parts originating either from animals that have been slaughtered in a slaughterhouse and were considered fit for slaughter for human consumption following an ante-mortem inspection or bodies and the following parts of animals from game killed for human consumption in accordance with Community legislation: (i) carcases or bodies and parts of animals which are rejected as unfit for human consumption in accordance with Community legislation, but which did not show any signs of disease communicable to humans or animals[108]. Accordingly, blood from live animals is excluded from production of insect substrate; and The material must also comply with certain specific requirements applicable to blood products to be placed on the market[109]. KEY POINT: Abattoir blood should be treated with caution as the legislation is not overly clear and may be contradictory – the permitted 'blood products' section of Regulation 142/2011 only refers to article 10(a) (I.e. carcasses) material and not the specific blood products material (article 10(e) or article 10(h).
Abattoir Rendered Meat & Bone Meal (MBM)	No	**Rendered MBM**: Rendered MBM is processed animal protein. Non-ruminants (i.e. insects) may not be fed processed animal protein[110].

[104] Article 9(b)(ii) of Regulation (EC) No 1069/2009
[105] Article 8(e) of Regulation (EC) No 1069/2009
[106] Article 7(1) and Annex IV, Chapter II of Regulation (EC) No 999/2001
[107] Article 14(d)(i) of Regulation (EC) No 1069/2009
[108] See Annex X, Chapter II, Section 2(A) of Regulation (EU) No 142/2011
[109] See Annex X, Chapter II, Section 2 of Regulation (EU) No 142/2011
[110] Annex IV, Chapter II, (b)(i) of Regulation (EC) No 999/2001

Fats and oils (cooking oil)	Yes	**Fats and oils (derived from/ including ABPs):** Certain ABP material that can be used to produce fats and oils is categorised as 'Category 3' material under the regulations[111]. Such Category 3 material (excluding hides/skins/hooves etc., adipose tissue and catering waste[112]) may be processed and used for the manufacturing of feed for farmed animals other than fur animals[113]. It must, however, comply with certain specific requirements applicable to fats and oils to be placed on the market[114]. Those specific requirements address fish oil separately.
	Yes	**Fats and oils (derived from vegetables):** The Catalogue contains a number of vegetable oils that could be used as insect substrates in the first instance, depending on the particular material.
	No	**Cooking oil:** Used cooking oil comprises 'catering waste'[115] and is prohibited for use in animal feed. It is an offence to bring catering waste onto a premises at which farmed animals may have access[116].
Surplus whey	Yes	The following ABPs are described as 'Category 3' material under the regulations: ABPs arising from the production of products intended for human consumption, including degreased bones, greaves (tallow rendering residue) and centrifuge or separator sludge from milk processing[117]; products of animal origin, or foodstuffs containing products of animal origin, which are no longer intended for human consumption for commercial reasons or due to problems of manufacturing or packaging defects or other defects from which no risk to public or animal health arise; and blood, placenta, wool, feathers, hair, horns, hoof cuts and raw milk originating from live animals that did not show any signs of disease communicable through that product to humans or animals. Milk, milk-based products and milk-derived products based on the above raw material (other than centrifuge or separator sludge) may be processed (except in the case of Category 3 material which has changed through decomposition or spoilage so as to present an

[111] See Article 10 of Regulation (EC) No 1069/2009.
[112] That is, materials referred to in Article 10(n), (o) and (p) of Regulation (EC) No 1069/2009
[113] Article 14(d)(i) of Regulation (EC) No 1069/2009
[114] See Annex X, Chapter II, Section 3 of Regulation (EU) No 142/2011
[115] Annex I of Regulation (EU) No 142/2011
[116] Section 4 of The Animal By-Products (Enforcement) (England) Regulations 2013
[117] Article 10(e) of Regulation (EC) No 1069/2009

		unacceptable risk to public or animal health through that product) and used for the manufacturing of feed for farmed animals other than fur animals[118]. It must, however, comply with certain specific requirements applicable to milk products to be placed on the market[119].
AD digestate fibre	No	Digestate is considered a type of biowaste (and therefore waste) under applicable regulations. Whilst AD digestate fibre, if handled correctly, could be excluded from the applicable waste framework on the basis that it no longer comprises waste, use as feed (and accordingly substrate) is not listed as a potential end use in the relevant framework[120].
AD food-based*	No	As above.
AD non-source segregated (compost like origin, CLO)	No	As above.
Animal manures	No	The regulations provide that feed (and therefore substrate) shall not contain or consist of materials whose placing on the market or use for animal nutritional purposes is restricted or prohibited[121]. All faeces, urine and separated digestive tract content resulting from the emptying or removal of digestive tract, irrespective of any form of treatment or admixture is on the 'Unauthorised List' and prohibited for use for animal nutritional purposes[122].
Poultry manures	No	As above, general prohibition applies.
Cattle manures	No	As above, general prohibition applies.
Swine manures	No	As above, general prohibition applies.

[118] Article 14(d)(i) of Regulation (EC) No 1069/2009
[119] See Annex X, Chapter II, Section 4 of Regulation (EU) No 142/2011
[120] See the Anaerobic Digestate Quality Protocol, published here: https://www.gov.uk/government/publications/quality-protocol-anaerobic-digestate
[121] Article 6 of Regulation (EC) No 767/2009
[122] Annex III, Chapter 1, point 1 of Regulation (EC) No 767/2009

Sewage biosolid	No	As above, general prohibition applies. Furthermore, all waste obtained from the various phases of the treatment of urban, domestic and industrial waste water irrespective of any further processing of that waste and irrespective of the origin of the waste waters is on the 'Unauthorised List' and prohibited for animal nutritional purposes[123].
Paper sludges	No	Paper sludge is likely to be considered waste under relevant legislation. It would accordingly be subject to the Waste Framework Directive[124] and would need to be disposed of in accordance with applicable regulations. In addition, all wood, including sawdust or other materials derived from wood, which has been treated with wood preservatives[125], is on the 'Unauthorised List' and prohibited for animal nutritional purposes[126].
Drinking water treatment cake	No	All waste obtained from the various phases of the treatment of urban, domestic and industrial wastewater irrespective of any further processing of that waste and irrespective of the origin of the waste waters is on the 'Unauthorised List' and prohibited for animal nutritional purposes[127].
Beverage industry residues **Brewers/ distillers grains**	Yes	**Beverage industry residues:** A number of materials are listed in the Catalogue and accordingly usable as feed: • Plants by-products from spirits production: "Products from the soft drink industry obtained from the production of sweet flavoured soft drinks or from unpacked, non-marketable sweet-flavoured soft drinks. They may be concentrated or dried." • Feed beer: "*Product of the brewing process which is unsaleable as a human beverage.*" • Sweet flavoured drink: "*Products from the soft drink industry obtained from the production of sweet flavoured soft drinks or from unpacked, non-marketable sweet-flavoured soft drinks. They may be concentrated or dried.*" **Brewers/ distillers grains:** The following materials are listed in the Catalogue and accordingly usable as feed: • Distillers' dark grains: "*Product of alcohol distillation obtained by drying solid residues of fermented grains to which pot ale syrup or evaporated spent wash has been added. It may be rumen protected.*"

[123] Annex III, Chapter 1, point 5 of Regulation (EC) No 767/2009
[124] Directive 2008/98/EC
[125] 'Wood preservatives' are as defined in Annex V to Directive 98/8/EC
[126] Annex III, Chapter 1, point 4 of Regulation (EC) No 767/2009
[127] Annex III, Chapter 1, point 5 of Regulation (EC) No 767/2009

		• Brewers' grains: "*Product of brewing composed of residues from malted and un-malted cereals and other starchy products, which may contain hop materials. Typically marketed in a moist condition but may also be sold in a dried form. May contain up to 0,3 % dimethyl polysiloxane, may contain up to 1,5 % enzymes, may contain up to 1,8 % bentonite.*"
Fin fish surplus	Partially	Aquatic animals, and parts of such animals, except sea mammals, which did not show any signs of disease communicable to humans or animals is categorised as 'Category 3' material under the relevant regulations[128]. Such material may be processed and used for the manufacturing of feed for farmed animals other than fur animals[129], provided the material is used to produce: • Hydrolysed protein (from non-ruminants or ruminant hides and skin)[130], dicalcium phosphate[131], tricalcium phosphate[132] and/or blood products from non-ruminants[133], being permitted ABPs that may be fed to farmed animals[134]. • Fishmeal. Fishmeal is considered a processed animal protein under the applicable regulations. Non-ruminants (i.e. insects) may not be fed processed animal protein[135]. However, the regulations go on to state that the prohibition shall not apply to the feeding of non-ruminant farmed animals' fishmeal and compound feed containing fishmeal[136]. It must, however, comply with certain specific requirements to be placed on the market as processed animal protein[137].
Shellfish surplus	Partially	Shells from shellfish with soft tissue or flesh is considered 'Category 3' material under the relevant regulations[138]. (NOTE: shells from shellfish with the soft tissue and flesh removed fall outside of the ABP regulations). Such material may be processed and used for the manufacturing of feed for farmed animals other than fur animals[139], provided that it is used to produce:

[128] Article 10(j) of Regulation (EC) No 1069/2009
[129] Article 14(d)(i) of Regulation (EC) No 1069/2009
[130] See Annex X, Chapter II, Section 5 of Regulation (EU) No 142/2011
[131] See Annex X, Chapter II, Section 6 of Regulation (EU) No 142/2011
[132] See Annex X, Chapter II, Section 7 of Regulation (EU) No 142/2011
[133] See Annex X, Chapter II, Section 2 of Regulation (EU) No 142/2011
[134] Article 7(1) and Annex IV, Chapter II of Regulation (EC) No 999/2001
[135] Annex IV, Chapter II, (b)(i) of Regulation (EC) No 999/2001
[136] Annex IV, Chapter II of Regulation 999/2001
[137] See Annex X, Chapter II, Section 1 of Regulation (EU) No 142/2011
[138] Article 10(k) of Regulation (EC) No 1069/2009
[139] Article 14(d)(i) of Regulation (EC) No 1069/2009

		• Fish oil[140]. See above in respect of the use of that oil for substrate. • Fishmeal. Fishmeal is considered processed animal protein. It is in the first instance prohibited to feed non-ruminants farmed animals processed animal protein[141]. However, the regulations go on to state that the prohibition shall not apply to the feeding of non-ruminant farmed animals' fishmeal and compound feed containing fishmeal[142]. It must comply with certain specific requirements to be placed on the market as processed animal protein[143]. • Hydrolysed protein (from non-ruminants or ruminant hides and skin),[144] dicalcium phosphate,[145] tricalcium phosphate[146] and/or blood products from non-ruminants,[147] being permitted ABPs that may be fed to farmed animals.[148]

[140] Annex X, Chapter II of Regulation (EU) No 142/2011
[141] Article 7(1) and Annex IV, Chapter I of Regulation 999/2001
[142] Annex IV, Chapter II of Regulation 999/2001
[143] See Annex X, Chapter II, Section 1 of Regulation (EU) No 142/2011
[144] See Annex X, Chapter II, Section 5 of Regulation (EU) No 142/2011
[145] See Annex X, Chapter II, Section 6 of Regulation (EU) No 142/2011
[146] See Annex X, Chapter II, Section 7 of Regulation (EU) No 142/2011
[147] See Annex X, Chapter II, Section 2 of Regulation (EU) No 142/2011
[148] Article 7(1) and Annex IV, Chapter II of Regulation (EC) No 999/2001

4.4 Rationale for the Current Feed Legislation and Prohibitions

4.4.1 Why was Current Legislation Enacted?

The TSE and Foot-and-Mouth Outbreaks

The principal reason for strict controls on what is fed to livestock is the prevention of the spread of Transmissible Spongiform Encephalopathies (TSE). TSE is a family of diseases occurring in man and animals which are characterised by a degeneration of brain tissue giving a sponge-like appearance leading to death.

TSE includes Bovine Spongiform Encephalopathy (BSE) which is a disease of cattle, first diagnosed in the UK in 1986 and following which BSE reached epidemic proportions. Findings by the scientific committees linked the spread of BSE to the consumption of feed contaminated by the infected ruminant protein in the form of PAP (Processed Animal Protein). In other words, PAP produced from ruminant carcasses, some of which were infected, was considered to be the transmission route of BSE.

The common symptoms of BSE include behavioural changes, lack of coordination, difficulty in walking or standing up, decreased milk production and weight loss. However, the disease has also been detected in animals showing no symptoms or atypical signs of the disease. The average incubation period of BSE in cattle is 4-6 years, but it can be much longer. BSE is considered to be transmissible to humans where it causes Variant Creutzfeldt-Jacob Disease.

Outbreaks of foot-and-mouth disease was also linked to the improper use of animal by-products.

The Feed Ban

The feed ban is the basic preventive measure laid down against TSE and consists of a ban on the use of PAP in feed for farmed animals.

The Commission introduced the first EU legislation on BSE in July 1989 but today, the TSE Regulations forms the legal basis for almost all legislative actions on TSEs. It gathers together all BSE measures adopted over the years into a single, comprehensive framework consolidating and updating them in line with scientific evidence and international standards. It has been amended many times in response to the evolution of the BSE situation, new or updated scientific advice and/or technological developments.

The purpose of the TSE legislation is again to protect the health of consumers and animals and to control and eradicate TSEs. In addition, according to the EU hygiene legislation (EC Regulation 854/2004), all animals presented for slaughter must undergo a veterinary inspection (ante mortem) to ensure that suspected cases do not enter the food and feed chain.

The concerns relate to Specified Risk Materials (SRM) which are the tissues of bovine, ovine and caprine animals where BSE infectivity is most likely to occur. SRM must be removed from the food and feed chain and destroyed. For bovine animals, the list of SRM depends on the BSE status of the country of origin of the animal slaughter. The list of SRM currently in force, in accordance with Annex V to the TSE Regulation, is summarised below[149].

[149] Regulation (EC) No 999/2001, Annex V,.

The following tissues shall be designated as an SRM if they come from animals whose origin is in a country with a 'controlled' or 'undetermined' risk status:

a) Bovine animals:

(i) The skull excluding the mandible and including the brain and eyes and the spinal cord of animals ages over 12 months;

(ii) The verbal column excluding the vertebrae of the tail, the spinour and transverse processes of the cervical, thoracic and lumbar vertebrae and the median sacral crest and wings of the sacrum, but including the dorsal root ganglia, of animals aged over 30 months; and

(iii) The tonsils, the last our meters of the small intestine, the caecum and the mesentery of animals of all ages.

a) Ovine and caprine animals: the skull, including the brain and eyes, and the spinal cord of animals ages over 12 months or which have a permanent incisor erupted through the gum, or aged over 12 months as estimated by a method approved by the competent authority of the Member State of slaughter.

Tissues listed in (a)(i) and (b) above, which are derived from animals whose origin is in Member States with a negligible BSE risk, shall be considered as SRM.

According to the World Organisation for Animal Health (OIE), in terms of the United Kingdom and Ireland the BSE status is as follows:

i. Northern Ireland – Negligible BSE risk
ii. Jersey – Negligible BSE Risk
iii. Ireland – Controlled BSE risk
iv. England & Wales – Controlled BSE risk
v. Scotland - Controlled BSE risk

Animal By-Products

EC Regulation 1069/2009 and its corresponding implementing regulation EC Regulation142/2011 set out the framework for such controls which are enforced in England by the Animal By-Products (Enforcement) (England) Regulations 2011. The devolved administrations have their own legislation. The regulations are wide reaching and cover a number of diverse sectors.

The regulations continue to prevent the feeding of catering waste to livestock. This practice was the cause of the Foot & Mouth Disease outbreak in 2001. Pigs were fed with contaminated meat which had not been properly heat sterilized– under cooked swill.

4.4.2 The Application of TSE and ABP Regulations to Insect Protein

The main obstacle to the use of insects as feed is the TSE risk. The feed-ban provisions of the TSE Regulation do not allow insect PAP to be fed to farmed animals (other than in aquaculture) due to the lack of a safety profile.

The prion related insect risks are 3-fold:

i. Insect specific prions;
ii. Insects as mechanical vectors of animal/human prions; and
iii. Insects as biological vectors of animal/human prions.

The first of these can be discounted because specific prion diseases cannot develop in insects. This reasoning also rules out the biological vector route as mammalian prions cannot replicate in insects.

The mechanical vector route is a possibility where substrate is used where infectious prions are present. Again, the importance of substrate being of non-human and/or non-ruminant origin is clear.

This would suggest the continued exclusion of SRM and Category 1 ABP but Categories 2 and 3 should be evaluated. This would include slaughterhouse by-products and sewage sludge with the latter perhaps being regarded as too risky because of possible transmission of human prion diseases (VCJD) to cattle. This represents the current grey area between the binary choice of TSE risk material on the one hand and existing food and feed grade substrates on the other.

Those food and feed grade substrates should be considered in the light of:

i. the species from which they are derived – namely are they or ruminant or non-ruminant origin?
ii. the tissue of those species used in the substrate; and
iii. the species which the feed is destined to be fed to as the risks are higher when the substrate source and end consumer are the same species.

The EFSA findings[150] state that insects fed on substrates of non-human and non-ruminant origin should not pose any additional risk compared to the use of other food or feed. Further scientific evaluation is required of the risk of using substrate of human or ruminant origin.

Based on the EFSA findings, it would appear to be no TSE based reason why pigs, poultry and indeed other farmed livestock should not be fed insect PAP which has been produced on substrate not derived from human or ruminant origin.

Also, if the mechanical vector risk is removed (either by thermal treatment or because there is a continued blanket ban on the use of SRM/ABP) the potential for bioconversion of that material into insect PAP could be investigated. However, this has to be seen in context and the joint WHO/FAO/OIE Technical Consultation on BSE confirmed that animal products that could be a source of the BSE agent should not be used for feeding directly to, or for feed manufacturing for, ruminants. That would include human waste such as sewage sludge given the risk of Variant Creutzfeldt-Jacob Disease transmission to ruminant animals.

4.5 Domestic enforcement and implementation

4.5.1 The Animal Feed (amendment) (EU Exit) Regulation 2019

The Animal Feed (Amendment) (EU Exit) Regulations 2019 (the "**Feed Exit Regulations**") came into effect on 'exit day'[151](31 December 2020[152]), following the UK's exit from the EU The purpose of the Feed Exit Regulations is to retain the EU legislative position in relation to

[150] EFSA Scientific Committee, '*Risk profile related to production and consumption of insects as food and feed'*, (5 October 2015)

[151] Part 1(1) of the Animal Feed (Amendment) (EU Exit) Regulation 2019

[152] The 'IP completion day', is defined in the European Union (Withdrawal Agreement) Act 2020, s39(1)-(5) as 11.00pm on 31 December 2020.

animal feed, whilst ensuring all enforcement and management of such EU feed law can be dealt with domestically.

The Feed Exit Regulations address amendments to a number of feed-specific EU regulations set out in this report, including Regulations 183/2005, 767/2009, 68/2013 and 152/2009[153]. Notably EU and domestic regulation references to:

i. the "Commission", are amended to the Food Standards Agency ("**FSA**");
ii. "third countries" are amended to include third countries to the EU, other than the UK;
iii. "Community" are amended to the "UK"; and
iv. "Member States" are amended to the "appropriate authority".

The Feed Exit Regulations do not just cover England. For example, Article 36 (which amends Regulation (EC) 183/2005), defines the "appropriate authority" as meaning:

i. for England, the Secretary of State;
ii. for Wales, the Welsh Ministers;
iii. for Scotland, the Scottish ministers; and
iv. for Northern Ireland, the Northern Ireland devolved authority[154].

The relevant food standards authority is also distinguished between the FSA for England, Wales and Northern Ireland and Food Standards Scotland, for Scotland.

Powers are also conferred on the appropriate authorities within the UK to prescribe future amends and (for example) maintain the feed catalogue[155].

Further withdrawal legislation may be implemented over time. However, the Feed Exit Regulations are a helpful steer as to how the UK will continue to implement the principles entrenched into EU animal feed law. However, adoption of any future changes at EU level will be at the discretion of the UK (and any devolved powers).

4.5.2 Key implementing domestic regulations

The following are additional key implementing domestic regulations relevant to this Section of the Report:

The Animal Feed (Hygiene, Sampling etc. and Enforcement) (England) Regulation 2015 enforces the relevant obligations under Regulation (EC) No 183/2005 under domestic law, together with the Animal Feed (Amendment) (EU Exit) Regulations 2019, which address the UK's withdrawal from the EU and continued application of EU animal feed law at a domestic level.

The Animal Feed (Composition, Marketing and Use) (England) Regulations 2015 enforces the relevant obligations under Regulation (EC) No 178/2002 under domestic law and, again, the Animal Feed (Amendment) (EU Exit) Regulations 2019, addresses the UK's withdrawal from the EU and continued application of EU animal feed law at a domestic level, by substituting 'Community-specific' references in Regulation 183/2005.

The Animal Feed (Composition, Marketing and Use) (England) Regulations 2015 enforces the relevant obligations under Regulation (EC) No 767/2009 (including Catalogue requirements)

[153] Part 1(2) of the Animal Feed (Amendment) (EU Exit) Regulation 2019

[154] Article 26(h) of the Animal Feed (Amendment) (EU Exit) Regulation 2019

[155] Article 110 of the Animal Feed (Amendment) (EU Exit) Regulation 2019

under domestic law. The Animal Feed (Amendment) (EU Exit) Regulations 2019, address the UK's withdrawal from the EU and continued application (and substitution where necessary) of EU animal feed law (including Regulation 767/2009 and the Catalogue of Feed Materials) at a domestic level.

The Animal Feed (Composition, Marketing and Use) (England) Regulations 2015 enforces the relevant obligations under Regulation (EC) No 767/2009 and Directive 2002/32/EC.

The English regulations enforcing the TSE Regulations is the Transmissible Spongiform Encephalopathies (England) Regulations 2018. There is separate parallel legislation in Scotland, Wales and Northern Ireland.

4.6 Animal Feed Law Glossary

Animal feed law glossary to define key terms in this chapter.

Term used	Definition	Legislation
'alien species'	any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or micro-organisms introduced outside its natural range; it includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce	Article 3(2) of Regulation (EU) No 1143/2014
'animal'	any invertebrate or vertebrate animal.	Article 3(5) of Regulation (EC) No 1069/2009
'animal by-products'	entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption, including oocytes, embryos and semen.	Article 3(1) of Regulation (EC) No 1069/2009
'derived products'	products obtained from one or more treatments, transformations or steps of processing of animal by-products.	Article 3(2) of Regulation (EC) No 1069/2009
'establishment' or 'plant'	means any place where any operation involving the handling of animal by-products or derived products is carried out, other than a fishing vessel; NOTE: alternative meaning of 'any unit of a feed business' for the purpose of feed hygiene legislation	Article 3(13) of Regulation (EC) No 1069/2009 Article 3(d) of Regulation (EC) No 183/2005
'farmed animal'	(a) any animal that is kept, fattened or bred by humans and used for the production of food, wool, fur, feathers, hides and skins or any other product obtained from animals or for other farming purposes; (b) equidae;	Article 3(6) of Regulation (EC) No 1069/2009

Term used	Definition	Legislation
'feed' or 'feeding stuff'	any substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals.	Article 3(4) of Regulation (EC) No 178/2002
'feed business'	any undertaking carrying out operation of production, manufacture, processing, storage, transport or distribution of feed including any producer processing or storing feed for feeding to animals on his own holding	Article 3(5) of Regulation (EC) No 178/2002
'feed business operator'	natural or legal person responsible for ensuring that the requirements of the present Regulation are met within the feed business under their control'	Article 3(b) of Regulation (EC) No 183/2005
'feed materials'	products of vegetable or animal origin, whose principle purpose is to meet animals' nutritional needs, in their natural state, fresh or reserved, and products derived from the industrial processing thereof, and organic or inorganic substances, whether or not containing feed additives, which are intended for use in oral animal feeding either directly as such, or after processing, or in the preparation of compound feed, or as carrier or premixtures	Article 3(g) of Regulation (EC) No 767/2009
'food' (or 'foodstuffs')	Any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. 'Food' includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance as defined in Article 6 of Directive 98/83/EC and without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC. 'Food' shall not include: a) feed; b) live animals unless they are prepared for placing on the market for human consumption; c) plants prior to harvesting; d) medicinal products within the meaning of Council Directives 65/65/EEC (1) and 92/73/EEC; e) cosmetics within the meaning of Council Directive 76/768/EEC; f) tobacco and tobacco products within the meaning of Council Directive 89/622/EEC; g) narcotic or psychotropic substances within the meaning of the United Nations Single Convention	Article 2 of Regulation (EC) No 178/2002

Term used	Definition	Legislation
	on Narcotic Drugs, 1961, and the United Nations Convention on Psychotropic Substances, 1971; h) residues and contaminants.	
'food business operator'	the natural or legal business persons responsible for ensuring that the requirements of food law are met within the food business under their control.	Article 3(3) of Regulation (EC) No 178/2002
'food no longer intended for human consumption'	food which was manufactured for human consumption in full compliance with Union food law, but which is no longer intended for human consumption	Chapter 1.2 of the Guidelines for the feed use of food no longer intended for human consumption
'former foodstuff'	any substance or product, whether processed, partially processed or unprocessed intended to be, or reasonably expected to be ingested by humans	Regulation (EC) 767/2009 and Regulation (EU) No 68/2013
'invasive alien species'	an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services".	Regulation (EU) No 1143/2014
'manure'	any excrement and/or urine of farmed animals other than farmed fish, with or without litter.	Regulation (EC) No 1069/2009
'operator'	the natural or legal persons having an animal by-product or derived product under their actual control, including carriers, traders and users. NOTE: feed and food business operator are defined separately.	Article 3(11) of Regulation (EC) No 1069/2009
'placing on the market'	any operation the purpose of which is to sell animal by-products or derived products to a third party in the Community or any other form of supply against payment or free of charge to such a third party or storage with a view to supply to such a third party. NOTE: alternative meaning of 'the holding of food or feed for the purpose of sale, including offering for sale or any other form of transfer, whether free of charge or not, and the sale, distribution and other forms of transfer themselves' under General Food Law	Article 3(2) of Regulation (EC) No 1069/2009 In relation to ABP / derived products. Article 3(8) of Regulation (EC) No 178/202
'primary production of feed'	The production of agricultural products, including in particular growing, harvesting, milking, rearing of animals (prior to their slaughter) or fishing resulting exclusively in products which do not undergo any other operation following their harvest, collection of capture, apart from simple physical treatment.	Article 3(f) of Regulation (EC) No 183/2005

Term used	Definition	Legislation
'pressure sterilisation'	the processing of animal by-products, after reduction in particle size to not more than 50 mm, to a core temperature of more than 133 °C for at least 20 minutes without interruption at an absolute pressure of at least 3 bar	Article 3(6) of Regulation (EC) No 1069/2009
'products of animal origin'	— food of animal origin, including honey and blood; — live bivalve molluscs, live echinoderms, live tunicates and live marine gastropods intended for human consumption; — and — other animals destined to be prepared with a view to being supplied live to the final consumer.	Annex X, point 8.1 of Regulation (EC) No 853/2004
'undesirable substrate'	any substance or product, not being a pathogenic agent, which is present in or on a feed and (i) constitutes a potential danger to human or animal health or to the environment, or (ii) could adversely affect livestock production	Animal Feed (Composition, Marketing and Use) (England) Regulations 2015
'waste'	waste as defined in point 1 of Article 3 of Directive 2008/98/EC.	Article 3(27) of Regulation (EC) No 1069/2009

4.7 Infographics and summary information

4.7.1 Funding under the Common Agricultural Policy

Current agricultural subsidies and grants that are available under the Common Agricultural Policy (CAP) are shown in Figure 9.

4.7.2 Industry proposals for regulatory change

Comments from industry representatives were collected to understand their proposals for regulatory change on the classification of invertebrates (Figure 10), the risk of prion infectivity (Figure 11), the use of insect protein in pig and poultry feed (Figure 12),financial support (Figure 13) and for regulatory change on authorising materials for insect substrates (Figure 14).

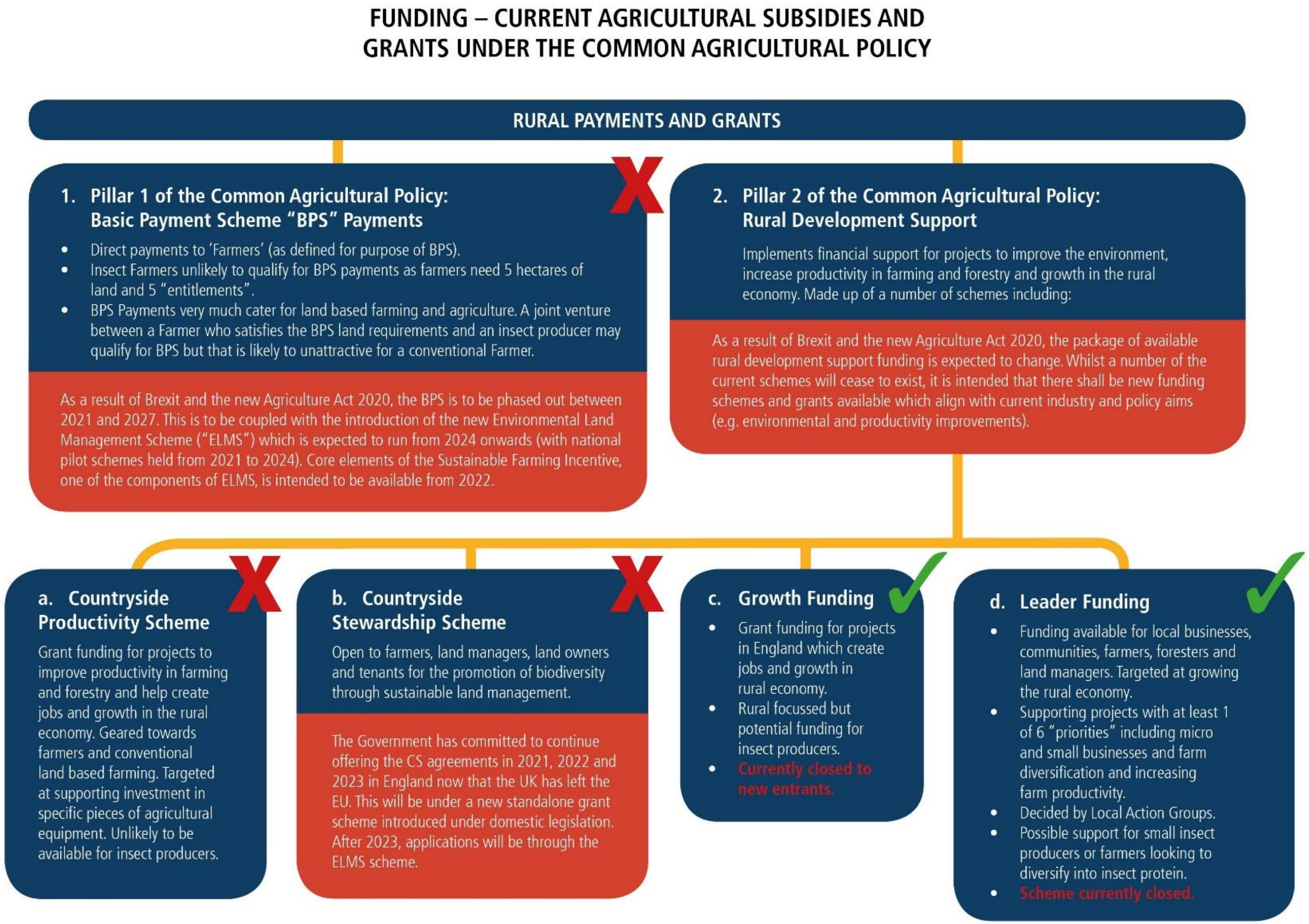

Figure 9. Funding – Current agricultural subsidies and grants under the Common Agricultural Policy (CAP). Source: Michelmores for WWF.

Industry Proposals for Regulatory Change

CLASSIFICATION OF INVERTEBRATES

'IPIFF, The insect sector milestones towards sustainable food supply chains, (27 May 2020), p12
'IPIFF, The insect sector milestones towards sustainable food supply chains, (27 May 2020), p12
'IPIFF, The insect sector milestones towards sustainable food supply chains, (27 May 2020), p.14
PROteINSECT, 'Insect Protein – Feed for the Future. Addressing the need for feeds of the future today' (2016), p.17

Figure 10. Industry proposals for regulatory change on the classification of invertebrates. Source: Michelmores for WWF.

Figure 11. Industry proposals for regulatory change on the risk of prion infectivity. Source: Michelmores for WWF.

USE OF INSECT PROTEIN IN PIG AND POULTRY FEED

IPIFF, The insect sector milestones towards sustainable food supply chains, (27 May 2020), p.9-10.
Fera Science and Minerva Communications UK Ltd on behalf of the Insect Biomass Task and Finish Group, 'The Insect Biomass Industry for Animal Feed – the Case for UK based and Global Business' (April 2019), p 3
PROteINSECT, 'Insect Protein – Feed for the Future Addressing the need for feeds of the future today' (2016), p 15

Figure 12. Industry proposals for regulatory change on the use of insect protein in pig and poultry feed. Source: Michelmores for WWF.

Figure 13. Industry proposals for regulatory change on financial support. Source: Michelmores for WWF.

Figure 14. Industry proposals for authorising materials for insect substrates. Source: Michelmores for WWF.

5 ASSESSMENT OF INSECT SUBSTRATE MATERIALS

This section provides an assessment of food surplus and non-food materials that could be used as substrate materials in insect farming in the UK.

Some low value materials could be suitable as a substrate for insect farming

Food surplus, non-food materials and by-products are an incidental or secondary product made in the manufacture or synthesis of something else. Example materials include: the trimmings and bones from fish or livestock; processing residues derived from agricultural crops, including fruits, vegetables and seeds; the straw remains from grain harvesting; or the faeces of animals. The materials are typically an output from the production process that has low value relative to the product or co-products that were intended.

Where a material has no end-use, it may subsequently be processed as a waste material. Waste relates to something which is discarded, is intended to be discarded or is required to be discarded. Waste streams are flows of specific waste, from its source through to recovery, recycling or disposal.

Insects require substrates for feed

For insect production, the insects are fed on substrates; this is the surface or material on which the insect lives and obtains its nourishment. Insects are very adaptable and can gain the nutritional requirements for growth from a variety of materials.

The type of substrate that insects are reared on is an important consideration, as the quality of the feedstock will impact on the nutritional qualities of the insect, and thus the quality and quantity of protein in the final product (Gasco *et al.,* 2020). Insects are much more efficient in converting feed to body weight than conventional livestock and are particularly valuable because they can be reared on organic materials (FAO, 2013). Using substrates which naturally contain polyunsaturated fatty acids or those which are rich in minerals, result in insect-derived materials which are more suited for animal feed (Gasco *et al.,* 2020).

Example materials that have been used as insect substrates globally, specifically for the rearing of BSF, include coffee pulp, catering surplus, vegetable surplus, straw, dried distillers grain, almonds, sweet potato roots, seafood surplus, olive cake, pulp and paper sludge, coconut endosperm, mushroom root and soybean curd residue, as well as manures and faecal sludge (EFSA, 2015). However, the use of certain materials for insect production is subject to legislation and in-country regulations, as well as the availability and adequate supply of the intended substrate.

Suitability of substrates for insect farming in the EU

The suitability of by-products as substrates for insect production is influenced by a number of key factors, including: regulations; the health and safety of substrates; the availability of substrate materials and the cost of access (driven by other competing demands for the material); how the substrate will be distributed to the insects; and the efficiency of the material for insect rearing.

Substrates available for use in the UK and Europe

Permitted substrates for use in the EU are outlined in section 4.

A survey of IPIFF members in Europe in March 2018 highlighted the main substrates currently being utilised to feed insects were fruits and vegetables (75% of IPIFF members);

cereal raw materials (71%); co-products for agri-food industries such as bran, distillers grains and vegetable peelings (54%); former foodstuffs including vegetable origin, dairy and eggs (37.5%); and commercial feed (29%) (Arsiwalla, 2018). Insect producers may use more than one feed during the year, or combine feeds, therefore these numbers do not add up to 100%.

Health and safety

There are several risks with regards to health and safety. These are as follows:

- Feed safety - ensuring that the feed provided to the livestock is not going to cause them any harm;
- Insect safety - ensuring that the substrate that is used to produce the insects is not going to cause any harm; and
- Food safety - ensuring that the final human food product is safe to eat.

In terms of feed safety, the use of food and feed-grade substrates of non-ruminant origin, non-ruminant animal manure and intestinal content, and organic surplus of vegetable nature should not pose any additional risk to livestock being fed insects as feed compared to other feed (EFSA, 2015). Risks of using unsuitable substrates can include bioaccumulation of heavy metals and hormones in insect fat, as well as bioaccumulation of pesticides or herbicides.

In terms of insect safety, it is important to ensure that material from pre-processing vegetal origin does not have any insecticide on it as this may kill the insect population when the feed is delivered to the insects. This can also be a consideration in terms of location of the insect farm, as an insect farm located near an active field being sprayed with pesticides may draw in outside air that is contaminated with pesticide residues which could cause risk to the insect population.

Regarding the food safety of using materials to rear insect protein, an assessment in Nicholson *et al.,* (2016) indicated that there could be microbiological and chemical risks associated with some materials, although the risks from antimicrobial resistance (AMR) were evaluated to be low, and therefore AMR should not be a constraint at selection but may be subject to research in respect to the selected list.

IPIFF (2019c) state that including former foodstuffs and catering surplus that contains meat and fish in insect feed is expected to have minimum chemical risks for insect production. This is because those products were initially intended for human consumption. However, IPIFF (2019c) raise that there may be inedible elements, such as packaging, labels, paper tissues or plastic cutlery that might also be present in these materials. Some insects, such as the yellow mealworm, can degrade (consume) these plastics, however other insects, such as BSF, would avoid these impurities (IPIFF, 2019c).

Availability of substrate materials and competing markets

It is important to consider the competing markets for substrate materials, as some materials will be destined for other purposes; for example, generating electricity or heat through anaerobic digestion, or as a direct feedstock for livestock. If feedstock for insects displaces existing uses, which results in alternative materials being generated, it could result in unintended consequences (e.g. increased demand for cereals for livestock feed). For insect production to be truly reducing 'waste' it needs to be identifying materials that are either surplus (current market uses are unable to utilise the full volume produced) or currently have no alternative use.

There can also be challenges around the continuity of supply associated with some materials as a substrate. For example, there is a parallel drive in industry to reduce surplus materials entering waste streams, so focus on the bioeconomy and improved efficiencies may reduce absolute volumes of surplus material over time. In addition to this, if there becomes increased demand for large quantities of material, this becomes a commodity for which the provider may start to charge a fee.

Distribution of feed

The transportation and logistics of transferring different materials (e.g. bulky, wet, dry, heavy etc.) has a big impact on the feasibility of using it as an insect substrate. There are maximum gross weights for road traffic which must be followed. For example, an articulated lorry carrying packaged waste may carry up to about 16 tonnes net, whilst a tanker might carry around 23 tonnes net.

Given transport costs increase with distance, the closer the insect farm is to the source of the substrate(s), the greater the feasibility of utilising such substrate. Moisture content is another challenge; ideal moisture content for insect feed is not synonymous with the ideal moisture content for distribution of the material. This can present a technological or capital cost barrier. Pre-processing of the materials may be required to balance water content or integrate additives, which can add to the machinery and capital costs.

Ideally, the development of insect farms would be located close to a reliable long-term source of substrate, which would minimise the logistic costs and optimise the economies of production at the insect farm.

Efficiency and feed conversion ratio of substrate (FCR)

Feed conversion ratio is the ratio of measuring the efficiency with which the bodies of animals convert feed into the desired output. The feed conversion ratio is calculated by dividing the mass of input by the mass of output.

The diet of the insect influences the efficiency of the insect production system and the FCR, and the resulting protein content of the insect.

5.2 Evaluation of substrate materials

Here we evaluate some of the key sources of food surplus and non-food materials, identified by WWF, ADAS and others; as having potential for use as substrates for insect feedstocks in the UK. These are considered based on their potential as an insect substrate and exclude any current legislative or regulatory barriers to its use, which is discussed in section 4.

Please note that some food surplus items, and non-food materials are not suitable for insect rearing due to the risks they pose to the farmed animals and/or humans through direct or indirect consumption. For example, materials containing high tannin levels can result in the poisoning of animals.

5.2.1 Mixed food surplus and former foodstuffs by-products

Millions of tonnes of post-farm food, which are surplus to requirements, are produced every year. This includes food surplus from households, hospitality and food service (HaFS), food manufacture, retail and wholesale sectors. This can be made up of a wide range of organic materials, including animal by-products (meat and fish), vegetables, fruit, grains etc. For the purposes of this research, we consider this material within the four main sources of origin:

household mixed food surplus, hospitality and food service surplus, retail food surplus (e.g. supermarkets), and manufacturing and processing food surplus.

Availability and affordability

In the UK it is estimated that around 10 million tonnes of food are wasted post-farm-gate (WRAP, 2017). In the UK, this includes approximately 6.6 million tonnes attributed to household food waste, 1.5 million tonnes of manufacturing waste, 1.1 million tonnes from the hospitality and food service sector and 0.3 million tonnes associated with retail and wholesale waste (WRAP, 2020). These are food waste figures and do not include volumes redistributed or used in and animal feed (which are classified as food surplus). It is estimated that there is a further 0.3 million tonnes of surplus from households, 1,000 tonnes from hospitality and food service, 0.04 million tonnes from retail, and 0.65 million tonnes from manufacturing (WRAP, 2020). A further 0.6 million tonnes of animal by-products is created by the manufacturing industry which is currently rendered (considered surplus), and 2.2 million tonnes of other food by-products which may include spent grain from brewing (WRAP, 2020).

Gate fees (charges levied upon waste disposal at a waste processing facility) for wet material are estimated to be £10-30/tonne for household food waste, £0-30/tonne for manufacturing waste, £20-40/tonne for waste from the hospitality and food service sector, and £30-50/tonne for food waste from retail and wholesale. WRAP produce an annual gate fee report that survey these fees across the waste industry (e.g. Dick and Scholes, 2019). It should be noted that there is wide variation across the UK.

Current application, disposal, or recycling of surplus

In the UK, mixed-food surplus from industry, retail, food service and household sources are typically associated with poor waste collection, separation and segregation infrastructure. For example, vegetable surplus may not be separated from say animal by-products, but instead incorporated together.

Where food surplus is still considered fit for human consumption (e.g. retail surplus at the end of its use by dates) it may redistributed via charitable and commercial routes. Where food surplus is not deemed fit for human consumption but is separated and segregated (e.g. potato peels are not mixed in with other materials) it's component parts may be destined for other end-uses, such as animal feed or rendering.

Where food surplus is mixed and therefore not suitable for other uses, due to a lack of traceability and a high risk of contamination, this material will instead be sent to landfill sites, incinerated, or processed through Anaerobic Digestion (AD) technology.

Risk of contamination, health and safety

The level of contamination and traceability varies between the different sources of food surplus. Food surplus from manufacturing and processing is considered to have low contamination risk and good traceability, as products are being prepared in line with standards required for human consumption and are sourced from known suppliers. However, material containing animal by products (e.g. bakery surplus with milk and eggs) come with higher risk of contamination. Retail and wholesale surplus have a medium risk of contamination, with traceability more difficult for some by-products, as well as issues with packaging that will include plastic, card, paper and other materials. Household and hospitality and food service food surplus are considered to have a high contamination risk, with material likely to be mixed with other products and traceability virtually impossible.

Feasibility of mixed food surplus as an insect substrate

Industrial insect rearing can efficiently turn many tonnes of food surplus into valuable products (Fowles and Nansen, 2020). Lundy and Parrella (2015) suggest that BSF could be better suited to converting low-quality materials into protein than many other insects (e.g. crickets). Similarly, kitchen and restaurant surplus food containing meat are too wet for mealworms, but well suited for BSF and housefly larvae (Fowles and Nansen, 2020). In BSF, protein content of larvae was shown to be high when fed organic materials from human food, estimated at 522g-583g/kg sample (Nogales-Mérida *et al.,* 2019). A pilot bioconversion facility feeding BSF with food surplus reported that for every 10 tonnes of food surplus input, 0.3 tonne of dried larvae (insect meal) were produced; this aligns with reports from full-scale operations, such as Agriprotein and Nextalim (Fowles and Nansen, 2020).

5.2.2 Fruit and vegetable surplus

Fruit and vegetable by-products can include whole products, for example items that don't meet specification or are left on-farm, and solid residue of peels, seeds, stones, stem and pulp from manufacturing.

Availability and affordability

Approximately 1.6 million tonnes of agricultural materials (e.g. vegetables and grains) remain on-farm (pre-farm gate) and 2 million tonnes of vegetable and fruit are wasted post-farm gate (i.e. not consumed) in the UK each year (WRAP, 2020).

Whilst vegetable surplus can be used for animal feed (e.g. pigs), mixed vegetable materials will typically go to AD with a gate fee of £10-20 for its disposal. In certain production systems, where it becomes un-economic to harvest, this surplus is simply left in the field or ploughed in. As a result, it is not always clear what quantities of fruit and vegetable surplus is available.

Current application, disposal, or recycling of surplus

Vegetable and fruit surplus can be used as animal feed, put into AD (often as part of mixed food surplus), or incinerated. Due to the material being plant-based, the by-product can be suitable for farm animal feed, provided it also complies with feed legislation as set out in section 4.

Risk of contamination, health and safety and stakeholder perception

Vegetable by-products can currently be used for animal feed and have a relatively low risk of contamination. Feasibility of by-product as an insect substrate

Both BSF and mealworm larvae can be fed vegetative food surplus. Vegetable by-products are one of the most popular choices for rearing BSF due to legislation allowing this material to be used as an insect substrate.

In trials with BSF, insect growth and final nutritional composition of the BSF was best using a mixture of vegetable leftovers, including legume (25% by weight), cereal (20% by weight) and vegetable (25% by weight) surplus (Barbi, 2020). BSF prepupal biomass levels of lysine, valine and arginine have all been shown to be in the range of 20-30 g/kg dry matter, with an overall incidence of essential amino acids of more than 55% when using a vegetable substrate (Spranghers *et al.,* 2017).

5.2.3 Bakery surplus

Surplus bakery items comprise a range of products including bread, cakes, pastry and biscuits, pasta, chocolate, sweets and similar products (e.g. breakfast cereals) which are not suitable for entry into the food chain. Reasons for quality failure include over baking, poor appearance, damaged or subject to the exceedance of 'use by' date (FERA, 2012).

Availability and affordability

Approximately 635,000 tonnes of bakery surplus are produced in the UK each year (WRAP, 2020). Of this, 500,000 tonnes are estimated to be bakery surplus mixed with ABP, leaving only 135,000 tonnes of uncontaminated bakery surplus.

Bakery surplus is in demand as it can be used in farmed animal feed and consequently has a cost associated with the material, estimated at £10-50/tonne, based on the feed value. The cost of access is higher for dry food (e.g. bread), whilst wet feed has a lower cost of access.

Current application, disposal, or recycling of surplus

Bakery surplus may contain a range of ingredients including rennet, melted fat, milk, milk products, flavourings, egg, honey and gelatine of non-ruminant origin. If bakery surplus does not contain and has not been in contact with raw eggs, meat, fish, and products or preparations derived from or incorporating meat or fish; the products are potentially suitable for feeding to livestock (FERA, 2012).

Where bakery surplus contains animal by-products (e.g. pies, meatloaf, sausage rolls etc.), the material is considered category 3 animal by-products and is therefore not currently permitted for animal feed. This material is instead typically sent for composting or AD.

Risk of contamination

Bakery surplus can already be used for animal feed as long as it meets the permitted requirements outlined in section 4.

Feasibility of by-product as an insect substrate

Bakery by-products are good sources of energy due to their high carbohydrate content, and often fat content too. However, they are generally poor sources of protein (Pinotti *et al.,* 2019).

5.2.4 Animal by-products (abattoir by-products, blood and rendered MBM)

Animal by-products (ABPs) typically come from abattoirs and include animal carcasses, parts of animals, blood, or other materials which come from animals, but which aren't intended or suitable for human consumption. Inedible animal tissues (organs, integument, ligaments, tendons, blood vessels, feathers, bone) can comprise up to 45% or more of the slaughtered animal (Franke-Whittle and Insam, 2013).

Typically, animal by-products are rendered in order to separate out the impurities. Rendering is a cooking or drying process that destroys pathogens and stabilises animal by-products, removing the moisture and separating the fat and protein meal components into a range of marketable products. Rendering refers to any process which separates out the fat from the protein content of mixed meat/animal by-products. Meat and bone meal (MBM) are a product of the rendering industry where bone is added to the meat meal.

Availability and affordability

FABRA UK is the UK's leading authority on the use, value and biosecurity of animal by-products and edible co-products generated by the animal-based food industry. FABRA UK (n.d.) estimate that over two million tonnes of animal by-products are processed by the UK meat industry each year. Rendered products are used in the manufacture of animal feed, pet food, pharmaceuticals, organic fertilisers, biofuels, cosmetics and oleochemicals.

WRAP (2017) estimate that around 600,000 tonnes of animal by-products are sent primarily to rendering derived from the slaughter of animals/fish (WRAP, 2017).

Current application, disposal, or recycling of by-products

Different methods for the disposal of abattoir by-products include composting, anaerobic digestion (AD), alkaline hydrolysis (AH), rendering and incineration (Franke-Whittle and Insam, 2013). In the UK, abattoir by-products are disposed of in a variety of ways depending on its category of use (see section 4).

Risk of contamination

No animal by-products can be fed to ruminant livestock (ruminants are animals that have specialised stomachs that ferment forage prior to digestion, e.g. cattle and sheep), due to concerns linked to transmissible spongiform encephalopathies (TSEs) and the fact that these species are true herbivores. However, for other species, such as pigs, poultry and farmed fish, there is the possibility to feed certain ABPs where the material meets permitted uses.

Abattoir by-products are a potential reservoir of bacterial, viral, prion and parasitic pathogens, capable of infecting both animals and humans (Franke-Whittle and Insam, 2013). Abattoir by-products consist of several pollutants such as animal faeces, blood, bone, fat, animal trimmings, paunch content and urine from operations or areas like lairage, stunning or bleeding, carcass processing and by-product processing (Bandaw and Herago, 2017). These materials can have a detrimental effect on the environment and public and animal health. Good management and hygienic practices are critical to minimise these harmful impacts. Traceability issues and contamination risk makes this a moderate risk by-product.

Feasibility of by-product as an insect substrate

The high fat and protein content of slaughterhouse by-products makes the material an excellent substrate for AD processes (Franke-Whittle and Insam, 2013). The high nutritional value could therefore be desirable for use in other contexts, such as insect feed. In one study, abattoir-based substrates showed the highest conversion ratio in BSF larvae, and the highest crude protein content on a dry matter basis, when compared to a range of other substrates including general food surplus, vegetable surplus and sewage sludge (Lalander, 2019).

5.2.5 Animal by-products (finfish and shellfish)

Finfish refers to bony fish (salmon) and cartilaginous fish (e.g. shark), whilst shellfish refers to exoskeleton-bearing aquatic invertebrates used as food, including various species of molluscs, crustaceans, and echinoderms. Finfish by-products typically include trimmings, skins, heads, frames (bones with attached flesh), viscera (guts) and blood. Shellfish by-products includes discarded shellfish (e.g. defect mussels) and parts of the shellfish not intended for human consumption (e.g. shell, viscera, head, legs etc.).

Availability and affordability

Estimates of the amount of finfish and shellfish by-products available in the UK vary between 353,000 tonnes (Seafish authority) and 450,000 tonnes (Olsen et al., 2014) a year.

The affordability to access this surplus is dependent on the transport cost to value markets and/or treatment cost for recycling. There is a cost for the disposal of animal by-products, with costs varying dependent upon the availability of facilities and the disposal approach taken. Gate fees for in-vessel composting, a method of composting which confines the composting materials to a building, container or other vessel, are up to £68/tonne. Render or incineration facilities are likely to be considerably more.

Current application, disposal, or recycling of by-products

Finfish is more easily processed into fishmeal than shellfish by-products. The largest volumes of finfish surplus are in Humberside (177,000 tonnes) and North East Scotland (60,000 tonnes) with 99% being processed to fishmeal in two main production facilities in Aberdeen and Grimsby. All other regions produce smaller amounts of finfish surplus with 40-60% going to fishmeal. Other outlets for fish by-products include composting and maggot farming for angling bait (Seafish Authority, 2004).

With regards to shellfish, England and Scotland generate around 43,400 tonnes of shellfish surplus annually (Seafish Authority, 2004). Shellfish by-products are generally unsuitable for conversion to fishmeal, because of low protein content and/or high shell content (ADAS, 2014).

Feasibility of by-product as an insect substrate

Some finfish by-products that are contaminated with other material is not able to be used for fishmeal. Also, some finfish by-products are not used as fishmeal because of uneconomic transport distance to the processors. These two sources of finfish materials could potentially be suitable as a substrate for insects as the material is nutritionally rich. Fish by-products containing meat such as heads, frames and belly flaps, and parts of the viscera like liver and roe contain high quality proteins and lipids with long-chain omega-3 fatty acids (Olsen et al., 2014).

5.2.6 Animal by-products (manure and digestive tract content)

Animal manure is often a mixture of animal faeces and bedding, with the disposal or recycling of manure a key aspect for many environmental policies relating to water and air quality.

Availability and affordability

The EU generates as much as 1.4 billion tonnes of manure annually (PROteINSECT, 2016). In the UK, an estimated 25 million tonnes of cattle manure and 3.1 million tonnes of pig manure are produced annually (DEFRA, 2019). Cattle (and to some extent pig) manure is abundantly available, with farmers generally having too much for their land due to nitrate vulnerable zone (NVZ) regulations, limiting the total amount of nitrogen that can be applied in any one season. The cost of accessing manure as a substrate is typically associated with only the transport required to move the material from source to the desired location. Cattle and pig manure have an estimated value of £8/tonne and £11/tonne respectively.

In terms of poultry, an estimated 3.6 million tonnes of litter (a mixture of faeces and wood shavings or chopped straw with dry matter up to 60%), are produced in the UK each year, of which around 2.5 million tonnes is from the broiler (meat bird) sector and 1.1 million tonnes from layers (egg producing birds) (DEFRA, 2019). Egg laying hen litter has a low cost of access, typically relating only to the cost of transporting the material and then spreading it on land. Broiler litter has more value than layer litter, with broiler litter often destined for renewable energy plants where it can achieve a cash revenue to the producer, as opposed to being applied to land as a fertiliser.

Many intensive poultry farms have limited land available for spreading and usually export to neighbouring farms. Broiler and layer litter has a nutrient value of £20-40/tonne (DEFRA Manner – NPK, 2019). Some laying hen manure is sufficiently dry to be used for renewable energy combustion and the normal 30% dry matter product can go to anaerobic digestion although it's use is limited by high ammonia and the amount of grit (a feed additive to eggshell growth) accumulation in the digester.

Current application, disposal, or recycling of by-products

The primary end use for manure is as a fertiliser applied to agricultural land to improve soil structure and provide nutrients to the crop. It is also an important feedstock in anaerobic digestion.

Poultry (including broiler and layer) manure is the faeces (by-product) of poultry, such as chickens. Of all animal manures, it has the highest amount of nitrogen, phosphorus, and potassium and is often used as an organic fertiliser. The dry composition of broiler litter lends itself to being used as a fuel source in power plants.

Pig and cattle faeces take the form of either relatively solid farmyard manure or liquid slurry, depending on the type of housing system.

Risk of contamination

In the UK, manure and digestive tract content is classed as a Category 2 high risk animal by-product which has a high risk of contamination.

Feasibility of by-product as an insect substrate

Animal manures have been cited in the scientific literature as a material that could be used as a viable substrate for insect farming due to its nutritional composition. Although not permitted in the UK and EU, recycled animal by-products, such as processed chicken manure and litter, is used as an insect feedstock where animal feed is scarce or expensive (Nicholson *et al.,* 2016).

BSF can convert manure from cattle, chickens or pigs into a product containing approximately 40% protein and 35% dry matter fat, with the volume of manure reduced by more than 50% to leave a material containing 60%-70% phosphorous and 30-50% nitrogen (Moula *et al.,* 2018). It is estimated that one kilogram of manure can be converted into 155g of pupal mass by BSF (van Huis *et al.,* 2020).

5.2.7 Anaerobic digestate / sludge

Anaerobic digestion (AD) is the breakdown of organic matter in the absence of oxygen by micro-organisms called methanogens. Suitable biodegradable materials for use in AD include left-over food, livestock slurries or crops such as maize and grass silage (WRAP, 2012). The process of anaerobic digestion provides a source of renewable energy; through the production of biogas (a mixture of methane and carbon dioxide). A by-product of this process is sludge known as 'digestate', which is left over following digestion

Availability and affordability

Anaerobic digestate is becoming increasingly available due to the rapid expansion of these facilities in the last decade. The main route for the material is recovery to land for use as fertiliser, although this can be limited both geographically and seasonally. It is therefore possible that large volumes of digestate can become available at certain times of the year.

AD plants have a cost of disposing of the digestate; for example, spreading it to land of £5-6 per tonne including transport.

Current application, disposal, or recycling of material

Anaerobic digestion (AD) is an effective means of treating organic materials from households and municipal authorities, organic solid materials from industry, and agricultural residues (WRAP, 2009). The end products of anaerobic digestion are biogas and digestate, which typically comes in three forms: whole (similar in its appearance to a livestock slurry, with typically less than 5% dry matter); liquor (this is whole digestate which has had most, or all, of the solid material separated); and fibre (similar to compost, this is the solid material separated out of the whole digestate) (WRAP, 2012).

Anaerobic digestates are not all the same, as dry matter and nutrient contents will vary depending on the input materials used and the nature of the AD process. Digestates are typically used as a biofertiliser and are a good source of readily available nitrogen (RAN) (i.e. ammonium-nitrate), which is potentially available for immediate crop uptake when applied as a biofertiliser. Food-based digestate typically contains around 80% of its total N content as RAN, compared with around 70% for pig slurry and 45% for cattle slurry (WRAP, 2016).

This high level of nutrient availability means that digestate can be used as a direct replacement for 'bagged' nitrogen fertiliser (WRAP, 2012). In addition, digestate contains useful amounts of phosphate and potash, together with small quantities of other nutrients and trace elements to help maintain soil fertility (WRAP, 2012). However, where land falls under Nitrate Vulnerable Zones (NVZs); to limit the risk of nitrate pollution of watercourses, land spreading may not be suitable and alternative uses of the digestate would be needed.

Other uses of digestate, identified by WRAP (2011) as having the most potential for commercialisation, include the extraction of nutrients and production of solid fuel; use of composted fibre as a bedding material for home gardens/landscaping/publicly owned flower beds and urban forestry; use of separated liquor for turf fertiliser in home gardens/turf on publicly owned sports grounds; algal growth for use as animal feed/fertiliser or feedstock for biofuels production; use as a construction material; and cellulosic ethanol production. Insect production was not explored as part of the research.

Risk of contamination

Some digestates include animal by-products such as dairy by-products, meat, and fish. The production and use of these digestates is governed by the Animal By-Products Regulations (see section 4).

Feasibility of by-product as an insect substrate

To the best of the authors' knowledge, there has been no research into the use of anaerobic digestate as a substrate for insect production. However, there has been limited research on anaerobic digestion as a new method for valorisation of insect post-production by-products (frass), as an alternative to being applied as plant fertiliser, to produce methane (Bulak et al., 2020).

5.2.8 Sewage biosolids

Sewage sludge is a semi-solid residual, or by-product, arising from the treatment of municipal wastewater (Ofwat, 2015).

Availability and affordability

Around 4.6 million tonnes of treated sewage biosolids are produced in the UK each year (Biosolids Assurance Scheme, n.d.). Water companies sell biosolids to farmers for around £7-8/tonne to be applied on land as a fertiliser. Around 3.6 million tonnes per of biosolids are recycled to agricultural land in the UK, which is applied to about 150,000 hectares per annum, or 1.3% of the UK's agricultural land (Biosolids Assurance Scheme, n.d.).

The financial value of nutrients in biosolids to UK agriculture is around £25 million per annum – mainly as phosphate and nitrogen as well as sulphur, potash, and magnesium. There is a strong demand from farmers for this material as it is worth about £170 per hectare in terms of nutrient value when applied to the land (Biosolids Assurance Scheme, n.d.).

Current application, disposal, or recycling of material

The sludge/biosolid residue that accumulates in sewage treatment plants is passed through a dewatering step where the dried solids are disposed of, and the water is sent back to secondary treatment. Currently around 78% (3.6 million tonnes) of biosolids are recycled to agricultural land, 12% are incinerated, 5% goes for industrial use (e.g. as a fuel for cement production or for soil manufacturing) and 5% are used for land reclamation or restoration.

Risk of contamination

Raw sewage is high in contaminants, with excrement the major source of harmful micro-organisms, including bacteria, viruses and parasites (HSE, n.d.). The main objective of sludge treatment is to create a product that is safe and acceptable to recycle to agriculture. This process includes reducing or eliminating potentially harmful micro-organisms (e.g. *E. coli* and *Salmonella* spp.) in biosolids and reducing the fermentability of the final product to acceptable levels. With an appropriate heat treatment such as composting, all harmful pathogens in human excreta can be eliminated to produce fertilisers safe to use in agriculture (Piceno et al., 2017; cited in Moya et al., 2019).

Farmers that utilise sewage biosolids follow strict regulations and codes of practice to prevent materials polluting the environment. Farmers and sludge producers have a responsibility to make sure liquid sludge does not run off into roads, adjacent land, rivers or waterways. Sewage sludge can contain potentially toxic elements (PTEs) which are a risk to human, plant and animal health. PTEs include elements such as zinc, cadmium, mercury, chromium, selenium and arsenic. Sludge may also contain virus and disease-causing pathogens including salmonellae, beef tapeworm eggs and potato cysts nematodes.

Sewage biosolids are regarded as a dirty material that is not fit for consumption by animals or humans. The potential of rearing insects on sewage biosolids was considered to be a non-starter and unacceptable to retailers, consumers and most other parts of the value chain.

Feasibility of by-product as an insect substrate

There have been some examples globally of insects being reared on faecal material. In Kenya, the firm Sanergy build affordable sanitation products designed specifically for urban slums, they professionally collect sanitation materials from the community by handcarts and truck, and then convert the material at a centralized facility into valuable end-products such as organic fertilizer and insect-based animal feed.[156]

A study in Kenya explored the effect of four locally available organic materials (faecal sludge, banana peelings, brewer's by-products and restaurant food surplus) as feedstocks for production of BSF larvae. It assessed BSF larvae growth rate, larvae weight, total prepupal yield in grams, crude protein and lipid (ether extract) content analysed, and found that despite larvae having a lower individual weight, the crude protein levels for harvested BSF larvae fed on faecal sludge was significantly higher than banana peelings and restaurant food surplus, with protein levels of 45.4±0.1% (Nyakeri *et al.,* 2017). In another study, no significant difference was seen between crude protein content on a dry matter basis when BSF larvae reared on human faeces were compared to those reared on general food surplus, although it was found that a vegetative substrate produced a higher crude protein content in the BSF larvae than the human faeces substrate (Lalander *et al.,* 2019).

5.2.9 Other food surplus and non-food materials

There are a wide range of food surplus and non-food materials that are produced in the UK, which could potentially be used as a substrate material for insect production. However, the availability, affordability, feasibility, and nutritional profile is highly variable. We briefly outline some of these that were identified as having potential for insect rearing, based on evidence in the scientific literature.

Brewers' grains

Brewers' grains are a co-product from the brewing industry; a solid residue left after the processing of germinated and dried cereal grains (malt) for the production of beer and other malt products (malt extracts and malt vinegar). Brewers' grains are a very palatable moist feed with useful protein content and comprise an excellent feed for ruminants due to the source of digestible fibre and heat-treated protein. In addition, brewers' grains are used as a forage extender to provide valuable nutrients, which can also replace concentrate feeds.

Along with other by-products from beer production, such as brewers' yeast and cane molasses, brewers' grains are suitable substrates for BSF (Chia *et al.,* 2018). In one study, the time needed for BSF larvae to reach the prepupae stage decreased to just 8 days with beer agro-industrial by-products, compared to 20-22 days on fruit surplus, wine by-products and vegetable surplus (Menguez *et al.,* 2018), despite the high moisture and fibre content of these substrates (Pinotti *et al.,* 2019). Crude protein content of BSF larvae was also shown to be significantly higher on brewers' grains than restaurant food surplus, despite a lower larval weight (Nyakeri *et al.,* 2017).

Dairy by-products

Dairy by-products include milk products (e.g. butter, buttermilk powder, cheese, lactose, whey powder) and land animal products (e.g. animal by-products, processed animal proteins, blood meal, gelatine, eggs). The high protein, fat, and sugar content of milk give the material a substantial organic load (Ryder et al., 2017).

Milk and milk products fit for, but no longer intended for, human consumption, and by-products of the milk processing industry such as whey, centrifuge or separator sludge from a processor, can be processed for use in feed products for general sale, or sent to farms

[156] Sanergy – The Urban Sanitation Challenge. Available at: http://www.sanergy.com/ [Accessed 28 Aug. 2020]

unprocessed,[157] subject to being handled in accordance with and may be restricted by ancillary legislation (e.g. hygiene legislation, processing legislation, safety regulations etc.). See section 4 for permitted uses and regulatory requirements that must be met.

An estimated 870,000 tonnes of surplus whey are produced in the UK each year (Farmers Weekly, 2019). In addition, salty whey is also produced during the cheesemaking process, following the salting and shaping stages. This material is hard to dispose of (e.g. through AD) due to its high salt content. Estimates suggest that around 95,000 tonnes of high protein salty whey are disposed from cheese production sites across the UK, which could instead be a valuable food ingredient used for pig feed or to grow algae or insects to make aquaculture feed (WRAP, 2019). However, salty whey would require mixing with another substrate to reduce the salt content, which would otherwise result in high insect mortality.

Fats and oils

Surplus fats and oils include yellow grease (e.g. used or recycled cooking oil and vegetable oil), tallow (a hard fatty substance made from rendered cattle or sheep fat), lard (a semi-solid white fat product obtained by rendering the fatty tissue of pig) and chicken fat (a fat obtained from chicken rendering and processing). Whilst fats and oils could potentially be combined with other by-products to provide an insect substrate (fats and oils on their own would be too wet and lack the protein content required), the by-products are often destined as feedstock for biodiesel and combustion, so used cooking oil is collected at no charge to the producer (Ecofys, 2014). See section 4 for permitted uses.

Drinking water treatment cake / residuals

Water treatment residues are sludge cake materials generated from the latter stages of the treatment of water destined for drinking, conducted in purification plants (water treatment works). Annual production in the UK is estimated at 131,000 tonnes of dry matter (Mineral Industry Research Organisation, 2007). The by-product typically goes to landfill, is spread on agricultural land, or is incinerated, although research has been conducted into its use in brick manufacture. Treatment works typically pay around £6/tonne for the disposal of drinking water treatment cake, therefore alternative uses and markets are highly desirable.

Whilst drinking water treatment cake can have low levels of contamination, there is the risk of unknown chemicals (e.g. pesticides) being present in the substrate. Additionally, aluminium sulphate is added to water to improve clarity, which results in the treatment cake also containing aluminium. If levels of aluminium were above the thresholds deemed safe, this could pose a risk of harm to the animals that consumed it.

Paper sludges

Paper sludge or crumble is a by-product of the paper recycling and manufacturing process and consists mostly of short wood fibres (cellulose) and clay fillers. Paper crumble is applied to agricultural land primarily for its liming properties and organic matter content to improve the physical structure and biological nature of the soil (ADAS, 2016). It is estimated that around 160,000 tonnes of paper sludge are produced in the UK each year (ADAS, 2016).

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[157] GOV.UK - Using leftover milk and milk products as farm animal feed. Available at: https://www.gov.uk/guidance/using-leftover-milk-and-milk-products-as-farm-animal-feed [Accessed 1 Sep. 2020]

Paper sludge has low nutritional value and can contain potentially toxic elements, although the content depends on the treatment process with higher concentrations in secondary biologically treated materials; however, concentrations are lower than biosolids and similar to livestock manures (EA, 2005; cited in ADAS, 2016). See section 4 for permitted uses.

Alternative by-products suggested by stakeholders

Other types of substrate, which are not assessed further in this report, but identified by stakeholders as having potential, include seaweed, sawdust, tofu surplus, maize, palm oil surplus (i.e. kernel), pumpkin seed surplus, fallen stock and other organic surplus materials.

5.2.10 Summary overview of table by-products

A range of by-products were considered within this study as potential substrates for rearing insects (i.e. BSF). Table 20 provides an indication of the key attributes for each by-product, including the availability and affordability, protein content, and the key pros and cons associated with each.

Table 20. Summary of possible substrates (food surplus, animal by-products and non-food materials) for UK insect farming. Legislation Key Terms: the 'Catalogue' of permitted materials is set out in Part C of the Annex to EU Regulation 2017/1017; 'Category 3' animal by-products (ABPs) are set out in EC Regulation 1069/2009 - if meeting certain conditions, Category 3 materials can be processed / used as animal feed; and the 'Unauthorised List' of prohibited feed materials is set out in Annex III, Chapter 1 of EC Regulation 767/2009. Source: ADAS and Michelmores for WWF.

By-product category	By-product option	Current use	Nutritional value to insects*	Availability (versus demand)	Volume produced (tonnes)	Current cost of access	Permitted for use in Legislation governing insect rearing	Advantages as substrate for insect feed	Disadvantages as substrate for insect feed
Mixed Food	Food surplus (Household)	Compost/A.D. where source selected. Landfill/ incineration where non-source selected	Medium	High	6,900,000	None; gate fee of £10-30 per tonne for disposal	No; solid urban waste (including household) is on the 'Unauthorised List'.	UK wide distribution.	Contamination and traceability issues.
	Food surplus (Hospitality and Food Service)	Mainly Landfill/ incineration	Medium	Medium	1,100,000	None; gate fee of £20-40 per tonne for disposal	No; catering waste (ABP and non-ABP) is prohibited.		Contamination and traceability issues; and expensive to collect source segregated.
	Food surplus (Retail)	Re-distribution/ A.D./ composting/ incineration	Medium	Low	340,000	None; gate fee of £30-50 per tonne for disposal	No; if catering waste, but some 'surplus' food products may be permitted if not discarded as waste.	Food that was fit for human consumption and good nutritional profile.	Material will start packaged. Contamination issues with microplastics.
	Food surplus (Manufacturing)	Redistributed/recovery to land/ composting/ A.D.	Varied (depending on source)	High	2,150,000 (this includes vegetable and bakery by-products)	None; gate fee of £0-30 per tonne for disposal	Maybe; depending on type. No; if already entered waste stream. Yes; if Catalogue-permitted.	Less contamination, locally abundant, consistent	Geographically variable.
Vegetable	Vegetable by-products	Animal feed, AD, incineration, applied to land	Low (plant based)	High	600,000	None; gate fee of £10-20 per tonne for disposal	Yes; see Catalogue of permitted materials.	Plentiful supply Low contamination	Potential animal feed. Unknown nutrient value

By-product category	By-product option	Current use	Nutritional value to insects*	Availability (versus demand)	Volume produced (tonnes)	Current cost of access	Permitted for use in Legislation governing insect rearing	Advantages as substrate for insect feed	Disadvantages as substrate for insect feed
Bakery	Bakery by-products	Animal feed, AD, incineration	Low (plant based)	Medium	135,000	£10-50 per tonne	Yes; see Catalogue of permitted materials.	Low contamination	Bread etc. used directly for animal feed. Light, dry material would need wetting; and low protein.
	Bakery mixed with ABP (e.g. pies, pasties)	Composting, AD,	High (mixture with animal origin)	Medium	500,000	None; gate fee of £10-30 per tonne for disposal	No, unless permitted as a Category 3 material.	Difficult to recycle due to ABP; Category 3 ABP clean; better protein content than straight bakery surplus; and low contamination.	Packaging could be an issue.
ABP – animal parts	Abattoir by-products; blood (incl. ruminant); MBM	Cat 1 will be incinerated. Cat 2 will be rendered. Cat 3 can go to AD or render. Blood from healthy animals can be spread to land	High (animal origin)	High	2,000,000 (total ABP) 600,000 (rendered)	None; gate fee of £70 per tonne for disposal	Abattoir Waste – No; except in limited circumstances. Blood – Yes; if non-ruminant blood and meets additional criteria.	Requires treatment to be spread to land Render processes Low contamination	Odorous; AMR concerns; and structure.
	Finfish trimmings (high quality material)	Fishmeal	High (meat origin)	Low	267,000 tonnes to fishmeal	None; gate fee of £20-38 per tonne for disposal	No; unless as a permitted Category 3 material for limited uses.	High protein	Already going to fishmeal market at a high price (£1,200/t delivered to farm; Nix 2020)
	Finfish trimmings (low quality material)	AD, compost, land spreading	High (meat origin)	Low	31,900 tonnes available for other use in the UK		No; unless as a permitted Category 3 material for limited uses.	High protein; too low quality for direct fishmeal use.	Proximity to fishmeal processor and transport cost is a factor

By-product category	By-product option	Current use	Nutritional value to insects*	Availability (versus demand)	Volume produced (tonnes)	Current cost of access	Permitted for use in Legislation governing insect rearing	Advantages as substrate for insect feed	Disadvantages as substrate for insect feed
	Shellfish by-products	AD, compost, land spreading	High (meat origin)	Low	53,575	None; gate fee of £10-100 per tonne for disposal	No; unless as a permitted Category 3 material for limited uses.	High protein	A lot of other materials, including shell
ABP - manure	Poultry manure (broiler)	Energy recovery, land spreading, incineration, AD	High (manure is high in protein as poultry are fed a high protein feed)	High	2,500,000	None; farmers generally have too much for their land	No; faeces are on the **'Unauthorised List'**	Concentration on large units. Land area requirement Laying hen manure difficult to manage	~£3/t cost of land spreading on farm but has fertiliser value. Broiler manure used for energy AMR concerns
	Poultry manure (layers)	Land spreading, incineration, AD	High (manure is high in protein as poultry are fed a high protein feed)	High	1,100,000	None; farmers generally have too much for their land	No; faeces are on the **'Unauthorised List'**	Concentration on large units. Land area requirement	~£3/t cost of land spreading on farm but has fertiliser value. Laying hen manure difficult to manage AMR concerns
	Cattle manure	Land spreading, incineration, energy recovery, AD	Low (low protein feed/grazing)	High	25,000,000	None; farmers generally have too much for their land	No; faeces are on the **'Unauthorised List'**	Recycled to land on site	~£3/t cost of land spreading on farm but has fertiliser value.
	Pig manure	Land spreading, incineration, energy recovery, AD	Medium (mono-gastric; receive a high protein feed)	High	3,100,000	None; farmers generally have too much for their land	No; faeces are on the **'Unauthorised List'**		~£3/t cost of land spreading on farm but has fertiliser value. Pig manures contain Zn and Cu AMR concerns

By-product category	By-product option	Current use	Nutritional value to insects*	Availability (versus demand)	Volume produced (tonnes)	Current cost of access	Permitted for use in Legislation governing insect rearing	Advantages as substrate for insect feed	Disadvantages as substrate for insect feed
Anaerobic Digestate	AD digestate fibre	Spread to land	Low (mainly vegetable or energy crops)	Medium	Low volumes	None; typically spread to land	No; considered a biowaste.	Concentrated at sites	Volatiles removed
	AD food-based digestate (incl. manure and crops)	Spread to land	Medium/High (may contain meats)	Low	5,000,000 (presumes current level of manufacturing and retail surplus going to AD)	None; typically spread to land	No; considered a biowaste.	Low contamination	Efficiency of material.
	AD non-source segregated	Landfill or incineration or spread to non-agricultural land (e.g. restored land for recreation)	Medium (will be made up of many components)	Low	Low volumes	None; gate fee of £40-90 per tonne for disposal	No; considered a biowaste.	Difficult to recycle in UK due to regulation EC 1069	PTEs / PCDD/F
Sewage	Sewage biosolids / sludge	Spread to land, incinerated if high levels of contamination	Medium (mixed origin)	High	5,000,000	£0-8 per tonne; region dependent	No; faeces and wastewater are both on the **'Unauthorised List'**	Good records HACCP systems	PTEs; High PCDD/F; human pathogen risks; perceptions; structure poor; AMR concerns.
Other by-products and co-products	Brewers' grains	Animal feed	Medium (brewers' grains: 250g/kg crude protein)	Medium	2,200,000	£40-220 per tonne Brewers grains (wet product): £40/t and Distillers wheat grains (dry product): £220/t	Yes; see Catalogue of permitted materials.	Plant based Crop residues have good structure Concentrated at individual sites	Sold as animal feed. Poor structure for sludges/ liquids requires a mix.

By-product category	By-product option	Current use	Nutritional value to insects*	Availability (versus demand)	Volume produced (tonnes)	Current cost of access	Permitted for use in Legislation governing insect rearing	Advantages as substrate for insect feed	Disadvantages as substrate for insect feed
	Dairy by-products (e.g. surplus whey)	Pig feed, spread to land	High (animal origin)	Medium	870,000	None; gate fee of £0-20 per tonne for disposal	Yes; as Category 3 material, unless entered waste stream.	Easily handled Low contamination	Poor structure
	Fats and oils (cooking oil)	Biodiesel, direct combustion	Low (fat rather than protein)	Medium	Between 128,000 and 270,000	£50-100 per tonne	No if used cooking oil, which is 'catering waste' on the 'Unauthorised List'	Low contamination	Biodiesel opportunities cooking oils Poor structure anaerobic
	Drinking water treatment cake	Spread to land, landfill, incinerated	Low (mainly vegetable material)	Medium	130,000 dry matter	None; gate fee of £6 per tonne for disposal	No; subject to composition, not permitted. Wastewater (no matter treatment) is on the **'Unauthorised List'**	Low Contaminations	Unknown concentration of insecticides; aluminium comes into solution at low pH (5)
	Paper sludges	Land spreading to add organic matter	Low (cellulose material)	High	160,000	None; gate fee of £0-10 per tonne for disposal	No; likely considered waste (prohibited) and wastewater and treated wood are both on the **'Unauthorised List'**	Low nutrients	Low nutrients; Metals content; PCDD/F

5.3 Prioritised list of potential by-products

5.3.1 Approach for identifying by-products of focus

Insects are very adaptable and can be reared on a variety of by-products, including former foodstuffs, food surplus and non-food materials. However, the applicability of using certain by-products for insect production is subject to relevant legislation and regulations, health and safety issues, the nutritional qualities of the feed (which can affect the quality and quantity of protein), as well as the availability and adequate supply of the intended substrate, cost of access and competing demands for the material (e.g. anaerobic digestion).

This study evaluated 24 materials, identified by WWF-UK, ADAS, Michelmores and other stakeholders, which were deemed to have potential for use as a feed substrate for insects, with a focus on substrates for black soldier fly (BSF) production.

A semi-quantitative assessment of both food- and non-food-based materials was conducted through a RAG analysis.

Definitions used for substrate materials and by-products

To ensure consistency within the assessment, between both the project team and external stakeholders, descriptions for each material were defined from the outset, outlined in Table 21.

Table 21. Definition of materials and by-products assessed

Category	Material	Definition
Mixed Food	Food surplus (Household)	Non-segregated mixed food surplus from households that includes animal by-products and is highly likely to be contaminated with other materials.
	Food surplus (Hospitality and Food Service)	Non-segregated mixed food surplus from hospitality and food service that includes animal by-products and is likely to be contaminated with other materials.
	Food surplus (Retail)	Non-segregated mixed food surplus from retail that has been de-packaged and includes animal by-products.
	Food surplus (Manufacturing)	Non-segregated mixed food surplus from manufacturing that includes animal by-products.
Vegetable	Vegetable by-products	Segregated vegetable and fruit surplus from manufacturing and processing units.
Bakery	Bakery by-products	Segregated bakery surplus from manufacturing (e.g. bread, cakes, pastry and biscuits, pasta, chocolate, sweets and similar products such as breakfast cereals).
	Bakery mixed with ABP (e.g. pies, pasties)	Non-segregated bakery surplus from manufacturing that contains animal by-products (e.g. raw eggs, meat, fish, and products or preparations derived from or incorporating meat or fish).

Category	Material	Definition
ABP – animal parts	Abattoir by-products; blood (incl. ruminant); MBM	Slaughterhouse animal by-products, including blood, meat and bone meal etc.
	Finfish trimmings (high quality material)	Fish trimmings or other fish processing by-products (e.g. trimmings, skins, heads, frames, bones with attached flesh, viscera and blood) of good quality that are typically used in the production of fishmeal.
	Finfish trimmings (low quality material)	Fish trimmings or other fish processing by-products (e.g. trimmings, skins, heads, frames, bones with attached flesh, viscera and blood) of poor quality that are not suitable for the production of fishmeal.
	Shellfish by-products	Shellfish by-products including discarded shellfish (e.g. defect mussels) and parts of the shellfish not intended for human consumption (e.g. shell, viscera, head, legs etc.).
ABP - manure	Poultry manure (broiler)	Poultry litter from floor-raised birds (broilers, turkeys, broiler breeder pullets) consisting primarily of droppings and bedding (usually wood shavings or sawdust). Feathers and waste feed make up the remaining litter components.
	Poultry manure (layers)	Poultry manure consisting of only faecal droppings associated with caged layers and broiler breeders.
	Cattle manure	Manure from cattle in the form of slurry or farmyard manure (FYM); primarily made from cow dung, cow urine, waste grass, and other dairy waste.
	Pig manure	Manure from pigs in the form of slurry or; typically made up of a mix of urine, faeces and waste water, and pig muck from straw based sheds.
Anaerobic Digestate	AD digestate fibre	Fibre fractions that have been separated from whole digestate produced by anaerobic digestion.
	AD food-based digestate (incl. manure and crops)	Digestate produced by anaerobic digestion that contains source segregated biodegradable materials such as left-over food, livestock slurries or crops such as maize and grass silage.
	AD non-source segregated	Digestate produced by anaerobic digestion that contains non-source segregated materials.
Sewage	Sewage biosolids / sludge	A residual, semi-solid material that is produced as a by-product during sewage treatment of industrial or municipal wastewater.
	Brewers' grains	A solid residue left after the processing of germinated and dried cereal grains (malt) for the production of

Category	Material	Definition
Other by-products and materials		beer and other malt products (malt extracts and malt vinegar).
	Dairy by-products (e.g. surplus whey)	Surplus material from the processing and manufacturing of milk products (e.g. butter, buttermilk powder, cheese, lactose, whey powder).
	Fats and oils (cooking oil)	Used cooking oils and fats that have been used for cooking or frying in the food processing industry, restaurants, fast foods etc.
	Drinking water treatment cake	Dewatered sludge cake produced from drinking water treatment plants.
	Paper sludges	Paper sludge consisting of fibres that are discarded in the pulping process.

Criteria for RAG analysis

Ten core criteria, agreed between the project team and WWF, were identified and scored used RAG (Red Amber Green) analysis. The criteria assessed against were:

- The risk of contamination and/or traceability issues (scoring = high risk (R), medium risk (A) and low risk (G));
- The reputational risk to retailers associated with perceived acceptability to consumers (scoring = high risk (R), medium risk (A) and low risk (G));
- The perspectives from feed mixers on how acceptable the by-product would be for use in aquaculture feed (scoring = not acceptable (R), possibly acceptable (A) and acceptable (G));
- The perspectives from feed mixers on how acceptable the by-product would be for use in livestock feed (scoring = not acceptable (R), possibly acceptable (A) and acceptable (G));
- The volume of total material produced each year (scoring = low volume (R), medium volume (A) and high volume (G));
- The volume of surplus material available (i.e. left over after alternative end uses that currently utilise the by-product, such as for animal feed, renewable energy generation, or fertiliser) (scoring = low volume (R), medium volume (A) and high volume (G));
- The security of supply for the by-product (i.e. consistently available, seasonal, periodic etc.) (scoring = inconsistent (R), variable/seasonal (A) and consistent (G));
- The affordability / cost of access of the by-product as an untreated substrate (scoring = poor / high (R), moderate / moderate (A) and good / low (G));
- The nutritional profile of the by-product, considering general aspects such as protein content, fatty acids etc. (scoring = poor (R), moderate (A) and good (G)); and
- The effectiveness of the by-product as a substrate for insect (i.e. BSF) production, considering the quality and nutritional profile, the logistics of utilising or transporting the by-product, the risk of insect mortality (e.g. due to disease) and the suitability as a sole substrate or requirement to mix with other substrates due to the

by-product being too wet/dry, for example (scoring = poor (R), moderate (A) and good (G)).

RAG scores for each criterion and each substrate were assigned and agreed in a workshop between experts in the project team, informed by the available evidence-base collected as part of the study, and supplemented by feedback from the stakeholder consultation. The semi-quantitative approach used information from the literature, stakeholder engagement and expert opinion from within the project team. This RAG assessment did not consider any current legislative or regulatory barriers to its use, as we wanted to consider each substrate outside of the current restrictions.

Results from the RAG analysis are outlined in Table 22.

5.3.2 RAG analysis scoring

Table 22. RAG analysis scoring for each by-product identified as a potential substrate for insect rearing of BSF (■ low potential; ■ moderate potential; and ■ high potential). Assessment based on information from the literature, stakeholder engagement and expert opinion from within the project team. Source: ADAS for WWF.

Category	Substrate	Contamination risk and traceability issues	Reputational risk and consumer acceptability	Feed manufacturer perspective (for aquaculture feed)	Feed manufacturer perspective (for livestock feed)	Estimated volume of by-product produced	Estimated volume of surplus (available)	Security of supply (consistent / inconsistent)	Affordability / cost of by-product (untreated)	Nutritional profile of by-product as insect feed	Effectiveness as an insect substrate (i.e. BSF)	Current legislation regarding insect feed
Mixed Food	Food surplus (Household)	Red	Amber	Red	Red	Green	Green	Green	Green	Amber	Green	X
	Food surplus (Hospitality and Food Service)	Red	Amber	Red	Red	Red	Red	Red	Green	Amber	Green	X
	Food surplus (Retail, non-packaged)	Amber	Green	Amber	Amber	Red	Red	Green	Green	Amber	Green	X / !
	Food surplus (Manufacturing)	Green	Green	Green	Green	Amber	Red	Green	Green	Amber	Green	X / !
Vegetable	Vegetable by-products	Amber	Green	Green	Green	Green	Amber	Green	Green	Red	Amber	✓
Bakery	Bakery by-products	Green	Green	Green	Green	Amber	Red	Green	Red	Red	Amber	✓
	Bakery mixed with ABP (e.g. pies, pasties)	Amber	Amber	Amber	Red	Red	Red	Green	Green	Green	Green	X / !
ABP – animal parts	Abattoir surplus; blood (incl. ruminant); MBM	Amber	Red	Amber	Red	Green	Green	Green	Amber	Green	Green	X / !
	Finfish trimmings (high quality material)	Amber	Amber	Green	Amber	Amber	Red	Green	Red	Green	Green	X / !
	Finfish trimmings (low quality material)	Amber	Amber	Green	Amber	Amber	Amber	Green	Amber	Green	Green	X / !
	Shellfish by-products	Amber	Amber	Green	Amber	Red	Amber	Green	Green	Amber	Amber	X / !
	Poultry manure (broiler)	Amber	Red	Red	Red	Green	Red	Green	Red	Green	Amber	X

Category	Substrate	Contamination risk and traceability issues	Reputational risk and consumer acceptability	Feed manufacturer perspective (for aquaculture feed)	Feed manufacturer perspective (for livestock feed)	Estimated volume of by-product produced	Estimated volume of surplus (available)	Security of supply (consistent / inconsistent)	Affordability / cost of by-product (untreated)	Nutritional profile of by-product as insect feed	Effectiveness as an insect substrate (i.e. BSF)	Current legislation regarding insect feed
ABP - manure	Poultry manure (layers)											X
	Cattle manure											X
	Pig manure											X
Anaerobic Digestate	AD digestate fibre											X
	AD food-based digestate											X
	AD non-source segregated											X
Sewage	Sewage biosolids / sludge											X
Other by-products and co-products	Brewers' grains											✓
	Dairy by-products (e.g. surplus whey)											✓
	Fats and oils (cooking oil)											X / !
	Drinking water treatment cake											X
	Paper sludges											X

Key to legislation:

✓ Authorised (e.g. within catalogue of permitted materials and, if an ABP, as a Category 3 material)

X Unauthorised (e.g. on the unauthorised list, or defined as a prohibited material)

X / ! Generally unauthorised, except in limited instances (e.g. subject to composition or if classed as a category 3 material, for example)

5.3.3 Rationale for inclusion / exclusion

The qualitative rationale used for the inclusion/exclusion of by-products of focus within the modelling is outlined in Table 23. This used a combination of evidence from the literature review, findings from the RAG analysis, and insight from the technical experts on the project team. The list was then agreed with WWF.

Table 23. Assessment for inclusion / exclusion in the modelling based on results from the RAG analysis. Source: ADAS for WWF.

By-product	Overall potential	Comments	Included
Food surplus (Household)	Low	High risk of contamination, traceability virtually impossible and therefore something that would not be considered by feed mixers.	No
Food surplus (Hospitality and Food Service)	Low	High risk of contamination, traceability virtually impossible and something that would not be considered by feed mixers.	No
Food surplus (Retail)	Medium	Food was previously fit for human consumption, traceable, with good nutritional content. Issues around packaging contamination and microplastics.	Yes
Food surplus (Manufacturing)	High	Good potential to use certain materials that have a good nutritional profile, are traceable back to farm, and have a low risk of contamination.	Yes
Vegetable by-products	High	Whilst not a highly effective substrate in terms of nutritional profile, it is legal and is currently be used by insect producers globally.	Yes
Bakery surplus	High	Whilst not a highly effective substrate in terms of nutritional profile, it is legal and is currently be used by insect producers globally.	Yes
Bakery mixed with ABP	Medium	Substrate with relatively good nutritional value due to inclusion of meat, but risk of contamination and same animal-to-animal feeding if insect meal used for livestock.	Yes
Abattoir surplus; blood (incl. ruminant); MBM	Medium	Whilst an effective substrate with high protein content, poor consumer perception, risk to reputation of retailers (i.e. feeding on dead animal parts), and concern from feed mixers about its use makes it a controversial option.	No
Finfish trimmings (high quality material)	Low	This is a high-quality by-product that is used directly in fishmeal already. A combination of adding extra steps in the feed chain, as well as the high cost of access makes this highly unlikely.	No

By-product	Overall potential	Comments	Included
Finfish trimmings (low quality material)	Medium	Low quality fish trimmings are not suitable for direct use in fishmeal, but contain good nutritional profile to insects, so present an effective option to use this material. Raw materials would require processing.	Yes
Shellfish by-products	Low	Shellfish by-products that would provide nutritional value to insects are heavily incorporated with undesired material (e.g. shell, viscera, head, legs) resulting in poor usability and applicability to insect farming.	No
Poultry manure (broiler)	Low	Manures are currently considered a non-starter due to being faeces, on the 'unauthorised list' legally and not fitting well with consumer acceptance. Broiler manure is often used for energy generation and is therefore in demand.	No
Poultry manure (layers)	Medium	Manures are currently considered a non-starter due to being faeces, on the 'unauthorised list' legally and not fitting well with consumer acceptance. However, poultry manure does have reasonable nutritional value, and is a natural feed for some insect species, so could offer an option in the future.	Yes
Cattle manure	Low	Manures are currently considered a non-starter due to being faeces, on the 'unauthorised list' legally and not fitting well with consumer acceptance. Cattle manure is of low nutritional value and a non-desirable material to work with for insect production.	No
Pig manure	Low	Manures are currently considered a non-starter due to being faeces, on the 'unauthorised list' legally and not fitting well with consumer acceptance. Pig manure is of low nutritional value and a non-desirable material to work with for insect production.	No
AD digestate fibre	Low	Moderate risk of contamination, traceability issues and poor nutritional value. Relatively low volumes of digestate fibre produced.	No
AD food-based digestate	Medium	Moderate risk of contamination, traceability issues and poor nutritional value. However, relatively large volumes of food-based digestate produced, which is typically spread to land and could therefore be made available, if legislation permitted it in the future.	Yes

By-product	Overall potential	Comments	Included
AD non-source segregated	Low	Moderate risk of contamination, traceability issues and poor nutritional value. Relatively low volumes of non-source segregated digestate produced.	No
Sewage biosolids / sludge	Low	A non-starter in the UK, with high risk of contamination, low stakeholder/consumer acceptance, high risk to retailer reputation, and a poor substrate for insect production due to limited nutritional value.	No
Brewers' grains	Medium	High nutritional value to insects, with low risk of contamination, high acceptability to stakeholders and relatively large volume produced. However, grains are also used directly in animal feed and therefore have a high cost of access.	Yes
Dairy by-products (e.g. surplus whey)	Medium	Relatively high nutritional value which is authorised under legislation with low risk of contamination. Currently not considered to be very acceptable to feed mixers, low volumes produced and animal-to-animal issues if it were to be used as cattle feed.	Yes
Fats and oils (cooking oil)	Medium	Low nutritional value and not an effective substrate on its own. Alternative uses of oils for bioenergy make this a desired by-product with a high cost of access for insect producers and used cooking oil will be prohibited catering waste on the 'unauthorised list'.	No
Drinking water treatment cake	Low	Low nutritional value with moderate risk of contamination and relatively low volumes produced. Current ends use is typically application to land as a fertiliser.	No
Paper sludges	Low	Low nutritional value with a high risk of contamination. Not considered to be an effective insect substrate.	No

5.3.4 List of by-products short-listed for modelling

The scores from the RAG analysis were then considered to determine whether the substrate would be taken forward for further consideration. A shortlist of ten by-products were selected based on a balanced overview of the foreseen potential as a substrate, informed by the RAG scores assigned. Whilst the top seven were taken forward based on score alone, a balanced approach, rather than a definitive score was used for the final three. This is because we wanted to capture substrates that offer the potential for large-scale upscaling, through large volumes of material being available.

The priority list of ten included some which are currently authorised for use, and others that could one day be made available if changes were made to legislation.

By-products currently allowed under current UK legislation included:

1. **Vegetable by-products**
2. **Bakery by-products**
3. **Beverage industry brewers' grains**
4. **Surplus whey**

By-products which are not currently authorised for use, but which have high potential included:

5. **Food surplus (manufacturing)**
6. **Bakery mixed with ABP**
7. **Food surplus (retail) - assume packaging removed**

Non-food by-products that are not currently authorised for use, and which are unlikely to be authorised in the near-term, but which have relatively high volumes available and which offer great potential for upscaling in the future included:

8. **Finfish by-products (very low-quality material)**
9. **AD food-based digestate**
10. **Poultry manure (layers)**

Whilst this was done with BSF in mind, the materials will offer similar opportunity with other farmed insect species, however there may be some differences present in terms of feasibility due to food conversion ratios, nutritional profile etc.

It is recognised that the list of substrates reviewed and chosen was not considered exhaustive and other more suitable options may be available.

6 MODELLING OPTIONS FOR UPSCALING

This section models a range of options for upscaling the production of insect protein within a UK context. We consider 'upscaling' in this study to be the action of increasing the size of production facilities or improving the volume of UK insect biomass produced. This could be, for example, small-scale insect facilities increasing their production capacity to a scale that is much greater than it first started out; an increase in the absolute number of insect biomass production facilities; or through new insect production facilities entering the market, which operate at a scale that is considered to be bigger than small-scale.

Examples of upscaling in the UK, Europe and Globally

In the EU there are several examples of industrial-scale insect facilities including Hexafly in the Republic of Ireland; Agronutris, Ynsect, and Innovafeed in France; Buhler in Switzerland; Protix, Amusca, and Agroloop in the Netherlands; BioflyTech in Spain; and Hermetia in Germany. More widely, other examples of upscaling include Enterra Feed in Canada, and Symton and Enviroflight in the US. Agriprotein is another example, which spans across different countries including the US, South Africa, Singapore, Hong Kong and the UK.

Barclays estimate that the insect protein market could be worth as much as $8 billion by 2030, linked with population growth and a need for protein sources with a smaller environmental footprint (Barclays, 2019; Financial Times, 2020).

Whilst progress has been relatively slow in the UK (compared to other nations), the UK's first industrial-scale insect facility is set for construction. Table 24 provides a case study on the new facility.

Table 24. Case study outlining the UK's first industrial scale insect production facility. Sources: Financial Times, 2020; The Guardian, 2020a.

Case study: Entocycle to build UK's first industrial-scale insect production facility
Overview A consortium, led by Entocycle with ten other partners, have been awarded government grant funding of £10 million to develop the first industrial-sized facility in the UK for breeding insects for animal feed and pet food. The project consortium involves a range of organisations including UK insect companies Better Origin and Beta Bugs, and Tesco, which has provided it with seed funding. **Current operations** Entocycle was set up in 2017. It is currently (October 2020) a small-scale facility, based under the railway arches at London Bridge. The facility feeds local food surplus (typically surplus fruit and vegetables, discarded brewer's grains and coffee grounds) to insects, which is then converted into protein to feed pets and farmed animals such as fish and livestock. **Proposed upscaling to an industrial-scale facility** The new industrial-scale facility, due to be built on a site outside of London, plans to breed up to 5 million black soldier fly larvae per year to convert into protein for animal feed, with the purpose of producing more sustainable animal feed for big livestock suppliers. Tesco is backing the project through encouraging its fish suppliers to buy insect-based feed from Entocycle.

It is estimated that the new facility will be able to process 33,000 tonnes of food surplus a year, including materials such as overripe fruit and vegetables and stale bakery goods.

A key by-product from the production facility, the insects' excrement (frass), will be sold to the horticultural industry as fertiliser. Frass is an important by-product from insect biomass production that can provide an additional income stream to increase the commercial viability of insect farming businesses.

Support, funding and investment

The UK government is investing £10 million in the project through funding from the government's Industrial Strategy Challenge Fund (ISCF). The start-up has also secured $8 million (approx. £6.2M) in funding from private sources and seed funding from Tesco. The consortium seeks to secure a further $20 million (£15.5M) by the end of 2020.

Sources: Financial Times, 2020; The Guardian, 2020a

6.1 Method

There are several steps required to determine how feasible upscaling BSF protein production for animal feed products in the UK would be, including understanding supply and composition of substrate materials, demand for insect protein and the competitive price required for BSF end products. Figure 15 and Figure 16 illustrate the steps undertaken to model the supply, demand and financial feasibility of upscaling BSF production in the UK.

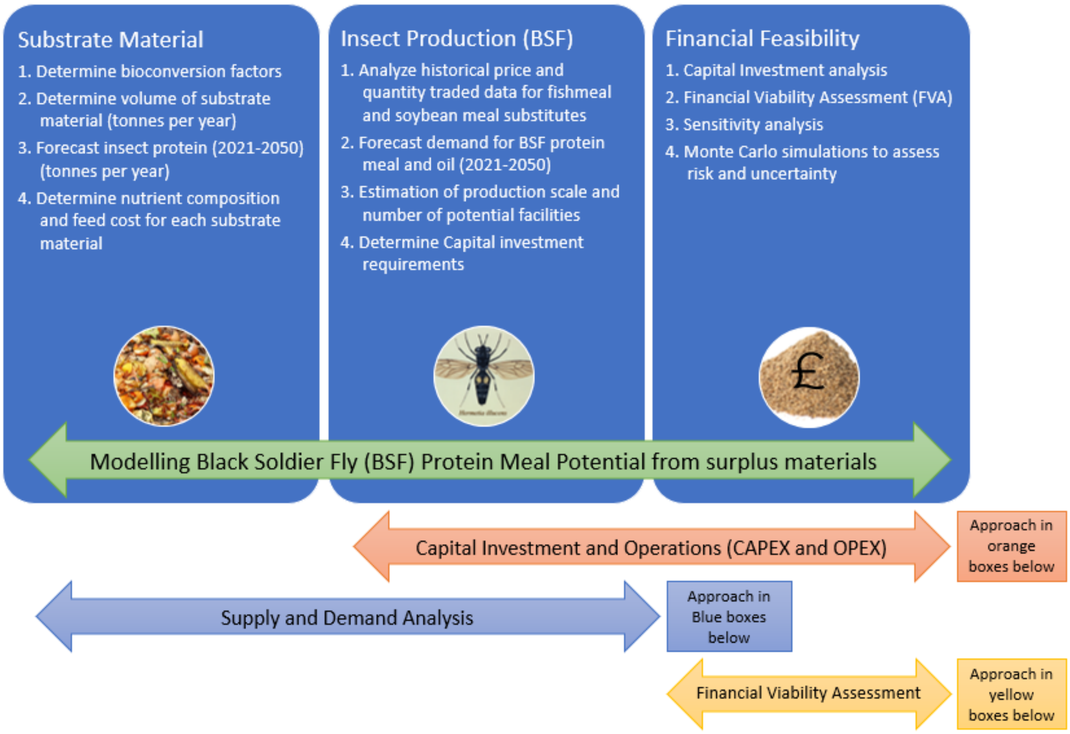

Figure 15. Modelling framework for assessing upscaling potential for BSF production in the UK showing key steps followed for Black Soldier Fly (BSF) production and financial feasibility sub models. Source: ADAS for WWF.

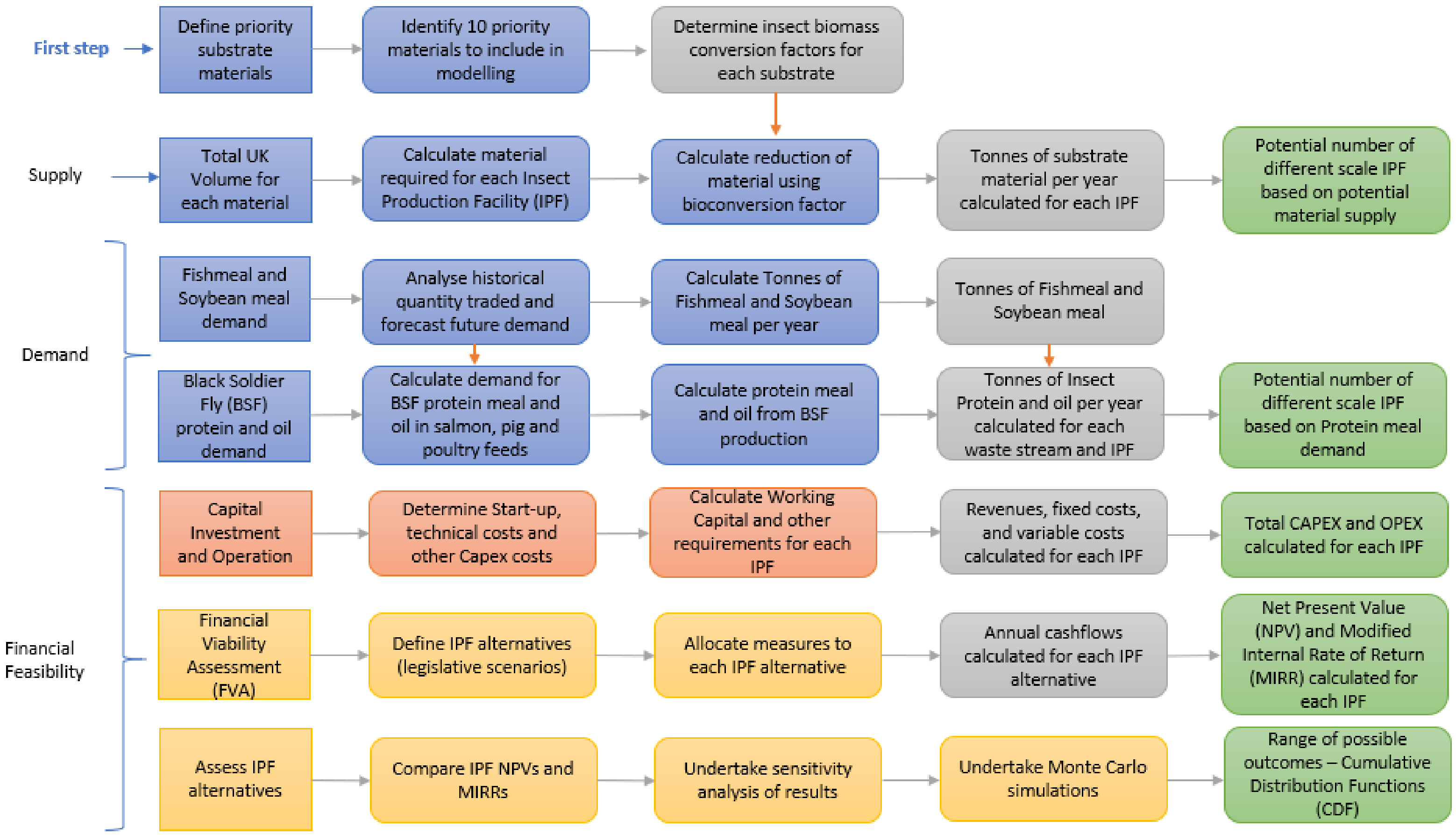

Figure 16. Steps (grey arrows) and links (orange arrows) in modelling process for assessing viability of upscaling Black Soldier Fly (BSF) production in the UK. Blue shaded boxes relate to steps undertaken to determine the potential supply of substrate materials available as a source of feed for BSF and the potential demand for BSF protein meal and oil as a substitute for fishmeal and soybean meal in salmon, pig and poultry feed. Orange boxes relate to steps undertaken to determine capital investment, start-up and working capital requirements. Yellow boxes show steps in financial feasibility analysis. Grey boxes are sub model outputs and green boxes are reported outputs. Source: ADAS for WWF.

Black Soldier Fly used as basis for model

Black Soldier Fly (BSF) larvae have an insatiable appetite and polyphagous nature that enables them to consume large amounts of organic material from both plants and animals (Mutafela, 2015). This ability, coupled with BSF feed conversion efficiency and biomass statistics (see Table 29) that compare favourably to fish meal and soybean meal, has led to an increased global interest in the development and adoption of BSF farming and BSF bioconversion technology. To date though, few studies have looked closely at the economics of BSF bioconversion and the suitability and impact of different materials on the diets of BSF in confinement or upscaled commercial production systems (Surendra et al., 2020). The highly heterogenous nature of organic materials in terms of nutrient content and moisture also makes it difficult to generalise findings and assess the economic costs and benefits of utilising different substrates in BSF diets across different geographical regions (Gold et al., 2019; Holmes et al., 2012).

Type of insect farming facility

The economic and production challenges involved in operating a large scale BSF facility capable of processing enough tonnes of substrate material (under optimal conditions) to enable viable production of BSF larvae, are complex. Firstly, the natural lifecycle of the BSF must be utilised in the most efficient way to enable optimal substrate reduction and biomass conversion by BSF larvae (Joly and Nikiema, 2019). Secondly, the price and demand for insect meal must be competitive enough to encourage animal feed manufacturers to incorporate insect meal into their feed products as a suitable substitute for other ingredients such as fish meal or soybean meal (as discussed in section 2). These complexities, along with other key factors such as surplus protein and volatile solid content, time required to convert material, availability and cost to access a continual stream of suitable material, breeding conditions (temperature, humidity, light, survivability etc.) and facility specifications (energy efficiency, size of larvae processing areas, technology and refining capabilities etc.) will ultimately influence the financial profitability of the BSF production system.

Substrate material

The quantity, quality and composition of the different materials that are incorporated into a feed ration for BSF is critical in optimising larval growth and nutrient accretion (Gold et al., 2019). As discussed in section 3, the type of substrate material that insects are reared on is an important consideration, with the composition and quality of different substrates influencing development, growth rate and biomass production of different insects in different ways.

Economic feasibility of insect farming

To understand the economic feasibility of upscaling BSF protein production for animal feed products in the UK it is important to first understand how each of the different substrates identified in section 5.3 influence BSF performance. This can be done using bioconversion rates, material reduction rates, larval biomass composition, larval development days and survivability, to inform the best blend of substrates needed to achieve optimal BSF performance and cost effectiveness. It should be noted however, that there are significant variations in the literature for these measures and limited data related specifically to each of the identified materials. As such, the modelling has been based on a number of assumptions which are detailed in the sections below.

To supplement this, a financial feasibility model and analysis was also carried out to look at start-up costs, operating costs, cash flow and profit potential for insect farming and processing businesses. The modelling also considered scale of production, cost, and value of by-products.

6.2 Model Parameters

Modelled scenarios

To assess the potential scale and feasibility of upscaling BSF production in the UK an Excel-based model was produced to simulate insect protein production potential from 4 different sized Insect Production Facilities (IPF) over the timescale 2021 to 2050 for use in salmon, chicken and pig feed.

Whilst these feeds were the focus, it is recognised that there are other applications for insect protein and oil (see section 7.3) and this list is therefore not exhaustive.

The model is based on production of black soldier fly (BSF) larvae and quantifies potential insect protein meal and oil production from the ten priority substrate materials chosen in this study: food surplus (retail), food surplus (manufacturing), vegetable surplus, bakery surplus, bakery surplus mixed with ABP, surplus whey, AD food-based digestate, poultry manure, brewers' grains, and finfish by-products (outlined in section 3.3.2).

For the modelling exercise, we considered these ten materials under three alternative legislative related scenarios:

Scenario 1: **Business as usual (BAU)**

- No legislative change.
- Processed insect protein only permitted in aquaculture feed.
- Only four food surplus substrate materials included: vegetable surplus, bakery surplus, surplus whey, and brewers' grains; based on what is currently permitted to be used as substrates for insect farming.

Scenario 2: **Optimistic with legislative changes**.

- Legislative change required within ~5-10 years.
- Processed insect protein permitted (hypothetically) in aquaculture, chicken, and pig feed.
- In addition to the four food surplus materials in Scenario 1, three additional materials: food surplus (retail), food surplus (manufacturing), and bakery surplus mixed with ABP; are permitted (hypothetically) to be used as substrates for insect farming.

Scenario 3: **Future prospect with legislative changes.**

- Legislative change required in the future.
- Processed insect protein permitted (hypothetically) in aquaculture, chicken, and pig feed.
- In addition to the seven food surplus materials in Scenario 2, three additional materials: AD food-based digestate, poultry manure, and finfish by-products; are permitted (hypothetically) to be used as substrates for insect farming.

Modelled insect production facilities

For the assessment, four sizes of facility (insect farms) were modelled, based on their substrate processing capacity potential:

Table 25. Insect Production Facilities assessed in the modelling. Source: ADAS for WWF.

Insect Production Facility	Model Reference	Processing capacity	Facility management	Production system
Micro-scale	IPF1	75 tonnes of material per day	Decentralised facility	BSF farm with substrate material bought in
Small-scale	IPF2	100 tonnes of material per day	Localised facility	BSF facility with substrate material bought in
Medium scale	IPF3	250 tonnes of material per day	Centralised commercial facility	Material treatment and BSF facility
Large-scale	IPF4	1300 tonnes of material per day	Centralised commercial facility	Material treatment and BSF facility

Other modelled parameters

Key parameters within the model and units applied are outlined in Table 26.

Table 26. Model parameters and key values applied. Source: ADAS for WWF.

Model parameter/variable	Units	value currently set at
Financial Viability Assessment		
Discount Rate	*%*	3.50%
Construction cost	*£/m2*	Individual value for each facility size: • Micro-scale facility (IPF1) = £970 • Small-scale facility (IPF2) = £970 • Medium-scale facility (IPF3) = £970 • Large-scale facility (IPF4) = £1,020
Administration, Licences and Legal	*£/tonne Protein/year*	£50
IT and Communications	*£/tonne Protein/year*	£30
Marketing, Research & Development	*£/tonne Protein/year*	£20
Maintenance and repairs	*£/tonne Protein/year*	£40
Substrate Materials		
Substrate processing capacity of facility	*tonnes per day (wet)*	Individual value for each facility size: • Micro-scale facility (IPF1) = 75 • Small-scale facility (IPF2) = 100 • Medium-scale facility (IPF3) = 250 • Large-scale facility (IPF4) = 1,300
UK volume of material	*tonnes per year*	Individual amount for each material (see section 6.3.1).

Material Access Costs	Cost to access (wet weight) - Gate fee/tonne	Average of range sourced by ADAS from literature: • Bakery surplus = £30 • Brewers' grains = £40 • All other materials = £0
Material Access Costs	Cost to access (dry weight) - per tonne	Average of range sourced by ADAS from literature: • Bakery surplus = £33 • Brewers' grains = £154 • All other materials = £0
Substrate reduction	%	Individual value for each material (see Table 29)
Bioconversion factor *The conversion of organic materials, such as plant or animal by-products, into usable products or energy sources by biological processes or agents.*	%	Individual value for each material (see Table 29)
Substrate Feed Mix *The mix of substrate materials used to make up the insect feedstock*	%	Scenario 2 was based on: • 10% for each of vegetable surplus, bakery surplus, brewers' grains, and surplus whey. • 20% for each of food surplus (retail) food surplus (manufacturing) and bakery mixed with ABP.
Courtald target - waste reduction	%/year	3%
BSF Production		
Proportion of total material used for BSF production	%	50%
Larvae conversion factor (for protein meal)	ratio	0.60
Larvae conversion factor (for oil)	ratio	0.20
Feed Conversion ratio *Ratio measuring the efficiency with which insects convert substrate material into the desired output*	Ratio	Individual value for each material (see Table 29)
Fishmeal and soybean meal inclusion rates		
Share of UK fishmeal consumption	% of total fishmeal consumed in UK	90% in salmon feed 0% in chicken and pig feed
Share of UK soybean meal consumption	% of total soybean meal consumed in UK	2% in salmon feed 62% in chicken feed 15% in pig feed
Estimated current fishmeal inclusion rate in species diet	% of total diet	20.0% in salmon diets 0% in chicken and pig diets
Estimated current soybean meal inclusion rate in species diet	% of total diet	13.4% in salmon diets 20.3% in chicken diets 17.0% in pig diets
Fishmeal replacement	%	25% in salmon feed 0% in chicken and pig feed
Soybean meal replacement	%	50% in salmon feed 30% in chicken and pig feed

6.3 Modelling of insect protein production in the UK

This section outlines the modelling that was undertaken to assess the feasibility of upscaling BSF protein production in the UK.

6.3.1 Substrate material supply

Substrate materials assessed under each scenario

Scenario 1: Business as usual (BAU)

Only four food surplus substrate materials included: vegetable surplus, bakery surplus, surplus whey, and brewers' grains; based on what is currently permitted to be used as substrates for insect farming.

Scenario 2: Optimistic with legislative changes.

In addition to the four food surplus materials in Scenario 1, three additional materials: food surplus (retail), food surplus (manufacturing), and bakery surplus mixed with ABP; are permitted (hypothetically) to be used as substrates for insect farming.

Scenario 3: Future prospect with legislative changes.

In addition to the seven food surplus materials in Scenario 2, three additional materials: AD food-based digestate, poultry manure, and finfish by-products; are permitted (hypothetically) to be used as substrates for insect farming.

Determining annual volumes of supply

To determine potential annual volume of material available for each of the short-listed potential substrate materials over the period 2021-2050, the following four steps were undertaken in the modelling process:

- Identification and sourcing of data related to UK food surplus and non-food material volumes (as outlined in section 3) and Courtauld waste reduction targets (from literature and WRAP reports). This data was used as the basis for modelled predictions of likely annual supply for each of the 10 short listed substrate materials, considering waste reduction targets for food surplus and non-food material (excluding household waste).
- Identification and sourcing of data related to UK population forecasts, milk production, poultry production, malted grain and fish production (AHDB, ONS, and OECD commodity statistics). The data sourced was used to predict likely changes in available materials. For example, food surplus will change depending on changes in population, while surplus whey will be dependent on changes in milk production.
- Estimation of annual tonnes of UK material based on forecast method as shown in Table 27. Material (tonnes/unit/year) is simply the tonnes of material available divided by the baseline unit in 2020. Forecasted changes in the baseline unit over the period 2021-2050 are then multiplied by the material (tonnes/unit/year) to determine annual tonnes of available material from 2021-2050.
- Exponential smoothing of AHDB historical data for UK Barley used as straight grain for brewing/distilling (Kt) to determine forecasted tonnes/year for brewers' grains.

Table 27. Substrate material supply parameters and forecast method. Food surplus and non-food materials (tonnes per unit per year) is the total UK tonnes of material available

(in 2020) divided by the baseline unit (population or production unit) in 2020. Source: ADAS for WWF.

Food surplus and non-food materials assessed	UK Volume of available material (tonnes)	Baseline (population or production)	Forecast Method (Units)	Material (tonnes/ unit/year)
Food surplus (retail)	340,000	67	UK Population (millions)	5,052
Food surplus (manufacturing)	915,000	67	UK Population (millions)	13,596
Vegetable surplus	600,000	67	UK Population (millions)	8,915
Bakery surplus	135,000	67	UK Population (millions)	2,006
Bakery surplus mixed with ABP	500,000	67	UK Population (millions)	7,429
Surplus Whey	870,000	15,727	UK Milk Production (Kt)	55
AD food-based digestate	2,510,000	67	UK Population (millions)	37,296
Poultry Manure	1,100,000	1,764	UK Poultry Production[158]	623
Brewers' grains	2,200,000	56	UK Barley (brewing/distilling) (Kt)	39,510
Finfish by-products	32,000	903	UK Fish Production (Kt)	35
Total	**9,202,000**			

Forecasted supply of substrate materials

Table 28 shows the forecasted volumes of the ten short-listed substrate materials available in each specified year under the 3 alternative legislative scenarios. For the purposes of the modelling it was assumed that the additional materials under scenario 2 would be available for use from 2025 onwards. The purpose of scenario 3 was to assess potential volumes and production if all ten materials were available in the UK with no legislative restrictions, as such the modelling assumed these would be available from 2021 onwards.

Figure 17 shows the total forecasted volume of food surplus and non-food material available in the UK under each legislative scenario. It should be noted that the calculations include an average allowance of 3% reduction per year in food retail and food manufacturing related surplus to meet Courtauld targets[159] to 2025.

Table 28. Forecasted volumes of materials that could be available to insect producers in the UK between 2020 – 2050 under the modelled scenarios. Source: ADAS for WWF.

Material	Available Volume of materials (000 tonnes/year)				
	2020	2025	2030	2040	2050
Scenario 1 (Business as usual – only permitted materials under current UK legislation)					
Vegetable surplus	600	614	628	648	667
Bakery surplus (no ABP)	135	138	141	146	150
Brewers' grains	2,200	2,300	2,456	2,551	3,079

[158] Annual UK Poultry meat production. Source: FSA, E&W Poultry Slaughterhouse Survey, DAERA and RESAS. Poultry production forecasts were based on Defra data for UK commercial Layers (millions of chicks/annum).

[159] Wrap report: https://wrap.org.uk/sites/files/wrap/Food_%20surplus_and_waste_in_the_UK_key_facts_Jan_2020.pdf

Surplus Whey	870	891	919	974	1,030
Total	**3,805**	**3,943**	**4,143**	**4,319**	**4,926**
Scenario 2 (Same as scenario 1, with the addition of 3 materials subject to legislative change)					
Vegetable surplus	600	614	628	648	667
Bakery surplus (no ABP)	135	138	141	146	150
Brewers' grains	2,200	2,300	2,456	2,551	3,079
Surplus Whey	870	891	919	974	1,030
Food surplus (retail)	0	338	345	356	367
Food surplus (manufacturing)	0	909	928	959	986
Bakery surplus mixed with ABP	0	512	523	540	556
Total	**3,805**	**5,701**	**5,940**	**6,175**	**6,835**
Scenario 3 (Same as scenario 2, with the addition of 3 materials subject to legislative change)					
Vegetable surplus	600	614	628	648	667
Bakery surplus (no ABP)	135	138	141	146	150
Brewers' grains	2,200	2,300	2,456	2,551	3,079
Surplus Whey	870	891	919	974	1,030
Food surplus (retail)	0	299	305	315	325
Food surplus (manufacturing)	0	804	822	849	873
Bakery surplus mixed with ABP	0	512	523	540	556
Finfish by-products	0	33	34	34	35
AD food-based digestate	0	2,570	2,626	2,711	2,790
Poultry Manure	0	1,135	1,183	1,267	1,466
Total	**3,805**	**9,296**	**9,636**	**10,036**	**10,970**

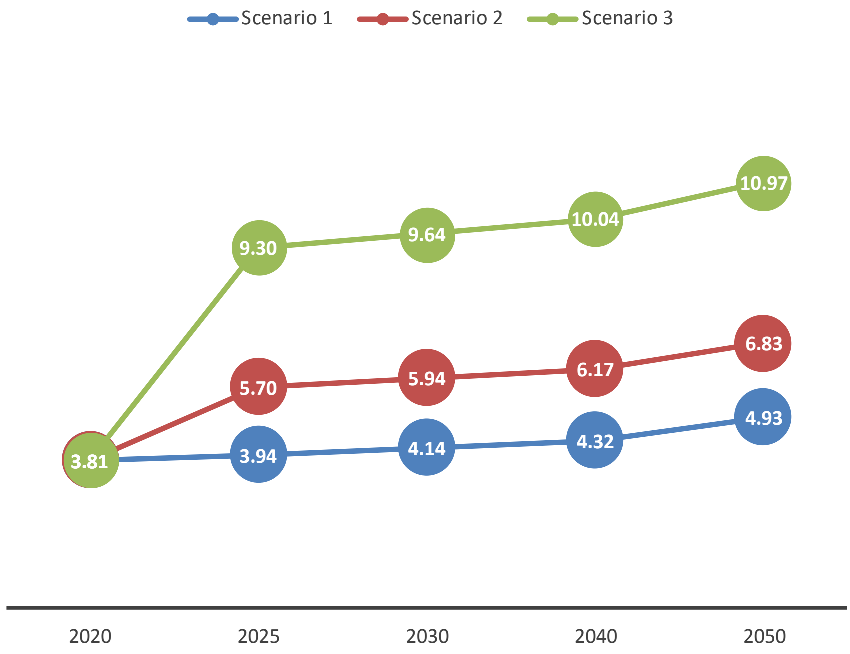

Figure 17. Total forecasted volume (million tonnes) of potential substrate materials under alternative legislative scenarios. Source: ADAS for WWF.

6.3.2 BSF performance across substrate materials

The short lifecycle and frequent reproduction of the BSF means there is a steady supply of larvae available to convert materials. Therefore, to optimise BSF production, there also needs to be a continuous supply of substrate materials. To understand how the different priority materials (shown in

Table 28) influence the level of BSF protein and oil that could be produced from the larvae that feed on the substrate materials, the modelling process involved the following steps:

- Identification and sourcing of data related to food surplus and non-food material reduction percentages, bioconversion rates, BSF feed conversion rates and larvae development days (from literature).
- Forecasting the optimal proportion of each food surplus and non-food material to include in the BSF feed mix. This was determined using a feed optimisation calculation (Figure 18), based on nutrient composition (expressed on a dry matter basis) for each of the 10 materials.
- Calculating substrate material feed requirements (tonnes/year) by multiplying feed mix proportion by available food surplus and non-food material volume (tonnes/unit/year).
- Forecasting of larval biomass (tonnes mature larvae/year) by multiplying biomass conversion rate (%) by the volume of material (tonne/year) for each food surplus and non-food material (as determined in 6.2.3), shown in Table 29.
- Forecasting tonnes of mature larvae to protein meal tonnes per year and oil tonnes per year using larvae conversion factors.
- Calculating potential number of different sized BSF facilities based on protein meal production potential from forecasted volumes of UK food surplus and non-food

material (across all priority streams). This was determined by dividing the UK wide protein meal potential (tonnes/year) by the forecasted protein meal production (tonnes/year) for each IPF.

Insect Feed Optimisation Tool

Optimises the mix of waste streams available to minimise the cost per unit of weight gain in BSF larvae

Does not include the costs of handling waste streams during processing

Feeds	% of blend (Wet)	£/tonne (Dry)	Nutrient cost: Unit cost of energy (p/MJ ME)	Nutrient cost: Unit cost of Crude Protein (p/100g CP)
VbP	10%	£0.00	0.0	0.00
BbP	10%	£33.33	0.2	3.03
BDG	10%	£153.85	1.3	6.15
WW	0%	£0.00	0.0	0.00
FWr	20%	£0.00	0.0	0.00
FWm	13%	£0.00	0.0	0.00
BMabp	17%	£0.00	0.0	0.00
FF	0%	£0.00	0.0	0.00
ADfbd	20%	£0.00		
PM	0%	£0.00	0.0	0.00
Blend results	100%			

Blend Composition	Dry basis	Wet basis
Bioconversion Rate %	23%	12%
Dry matter %	50%	50%
MJ ME/kg Dry Matter	6	3
Crude protein %	6%	3%
Starch %	13%	6%

Ration cost (tonne Dry)	£14.03
Ration cost (tonne Wet)	£7.00
Cost/% Bioconversion	0.60

Use solver to minimise the cost per % point in Bioconversion Rate.

Represents the lowest cost mix of waste streams for weight gain in BSF larvae

Figure 18. Optimal feed-mix for BSF based on nutrient content; megajoules (MJ) of metabolizable energy (ME) of each available food surplus and non-food material. Screenshot of tool for calculating the optimal feed mix. Source: ADAS for WWF.

Table 29. Black Soldier Fly feed conversion parameters for material reduction, feed conversion ratio (a measure of the kilograms of feed required to produce one kilogram of BSF larvae) and bioconversion, for substrate materials. Data sourced from Surendra (2020), Joly & Nikiema (2019), Ingvarsson (2018), Xiao et al. (2018), Nyakeri et al. (2017), Cammack (2017), Oonincx et al. (2015), Lalander (2015) and Diener et.al. (2011). Source: ADAS for WWF.

Material	Material Reduction (Dry Matter %) **	Feed Conversion Ratio	Bioconversion (% Dry Matter) ***
Vegetable surplus	82%	1.4-2.6	15%
Bakery surplus (no ABP)	68%	5.8	12%
Brewers' grains	54%	4.5 –12.5	8%
Surplus Whey	50%*	2.3	8%*
Food surplus (retail)	50%*	N/A	8%*
Food surplus (manufacturing)	70%*	N/A	8%*
Bakery surplus mixed with ABP	85%*	1.8	12%*
Finfish by-products	50%	5.6-13.4	10%
AD food-based digestate	45%	2.7	12%
Poultry Manure	54%*	N/A	10%*

* Proxy values have been used as, to date, there have been no robust studies of BSF performance on these specific materials.

$$** \ Waste\ Reduction(\%\ Dry\ Matter) = \left(1 - \frac{residue_{mass}(g)}{feed_{mass}(g)}\right) \times 100$$

$$*** \ Bioconversion\ rate\ (\%\ Dry\ Matter) = \frac{larvae_{gain}(g)}{feed_{mass}(g)} \times 100$$

6.3.3 Price forecasting for BSF insect protein and BSF insect oil

Currently the market price for soya bean is dictated by imports, with the UK importing around three quarters of a million tonnes of soya as beans and around two million tonnes as meal for animal feed (Redman, 2019). The market price for fishmeal on the other hand is being driven by both falling supply and rising demand on a global scale. If this trend continues, aquaculture feed producers will be looking to minimize their use of fishmeal and fish oil. However, they will also be looking to maintain feed performance which is where novel ingredients such as BSF meal could be utilised.

To be commercially viable as an animal feed substitute, BSF product prices and the nutritional quality of BSF must compare favourably to other protein sources such as fishmeal and soybean meal (as discussed in section 2). If fishmeal prices continue to rise (Figure 19) and the push to replace soya because of its detrimental environmental impacts continues, then the market for BSF products in the UK will expand and prices will become more competitive.

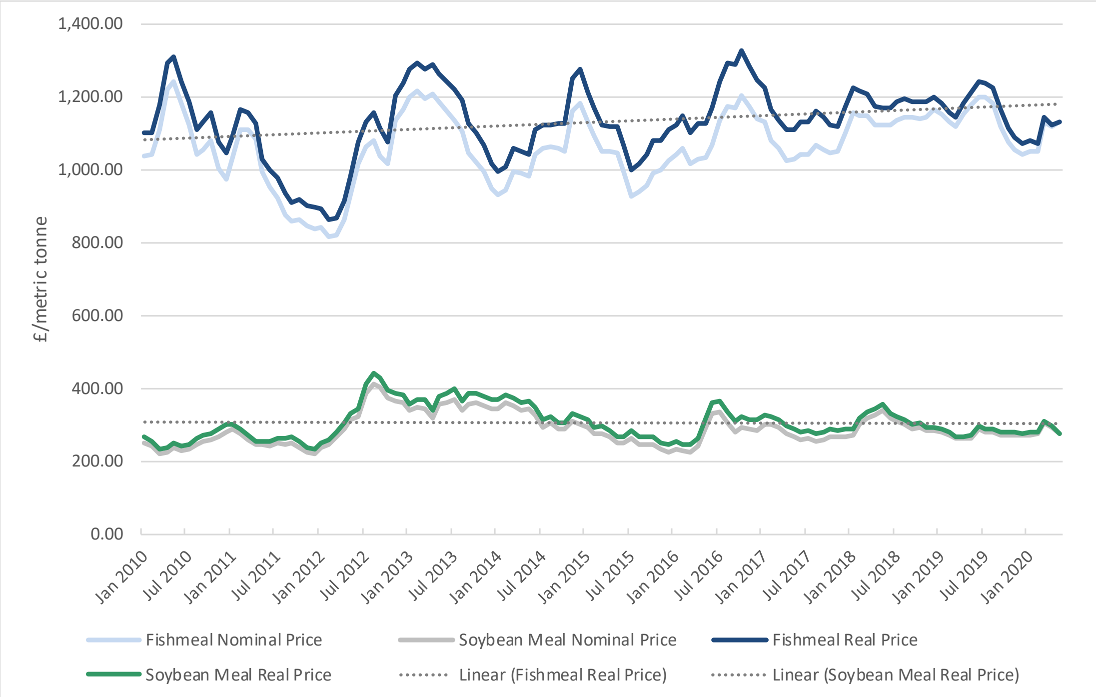

Figure 19. Historical prices for Fishmeal and Soybean meal (Nominal and Real). Source: ADAS for WWF.

The modelling process to determine potential prices for BSF protein meal and oil included the following steps:

- Identification and sourcing of historical commodity price data related to fishmeal and soybean meal in the UK (indexmundi, AHDB and Defra statistics).

- Identification and sourcing of data on fishmeal, soybean meal and BSF larvae crude protein and other key constituents (Feed*inamics*[160])
- fishmeal and soybean meal crude protein (% Wet), Gross Energy (MJ/kg wet), Dry matter (%) and Average Price (£/t) were used to calculate a £/t Dry matter and Protein cost (£/t protein) for fishmeal and soybean meal. The calculated Protein costs were then used to determine BSF equivalent prices (£/t) based on the crude protein (% DM) content of BSF.
- The same process was followed to determine a BSF equivalent oil price based on the Crude Fat (% DM) content of BSF.
- Historical nominal fishmeal and soybean meal prices for protein and oil were converted to real prices using a CPI deflator (Figure 10).
- Forecasts of fishmeal and soybean meal were determined using econometric analysis of the historical data.
- Using the results from the econometric analysis, BSF equivalent prices for protein meal and oil were forecasted over the period 2020-2050.

Results of price analysis

To be competitive, the price for BSF protein meal would need to within the commodity trading price range for either fishmeal or soybean meal as these currently tend to be the key ingredients in the majority of animal and aquaculture feed mixes due to their high protein contents. Graphically the results of the econometric modelling relating to BSF prices can be represented by Cumulative Distribution Functions (CDFs) that map the resulting values to their percentile rank in each distribution (Figure 20). The CDFs indicate that the competitive price for high-quality BSF protein meal with crude protein and crude fat contents similar to fishmeal would need to be between £960-£1020. Low-quality BSF protein meal with a protein content and fat content similar to soybean meal would need to be between £380-£432.

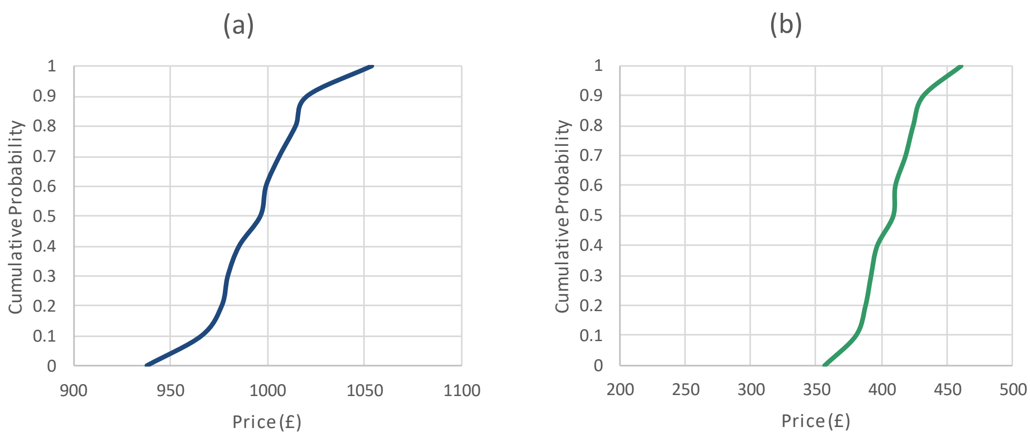

Figure 20. Forecasted price range for (a) high-quality BSF protein meal and (b) low-quality BSF protein meal. The CDFs indicate the likely price range for BSF protein meal to be

[160] https://www.feedtables.com/

competitive based on equivalent fishmeal and soybean meal crude protein contents. Note: the values between the 10th (0.1 on the y-axis) and 90th (0.9 on the y-axis) percentiles are considered robust. Source: ADAS for WWF.

In relation to BSF oil, the competitive price based on forecasted fish oil prices would need to be between £1284 and £1348. Based on forecasted soybean oil prices the BSF oil price would need to be between £624 and £666 (Figure 21).

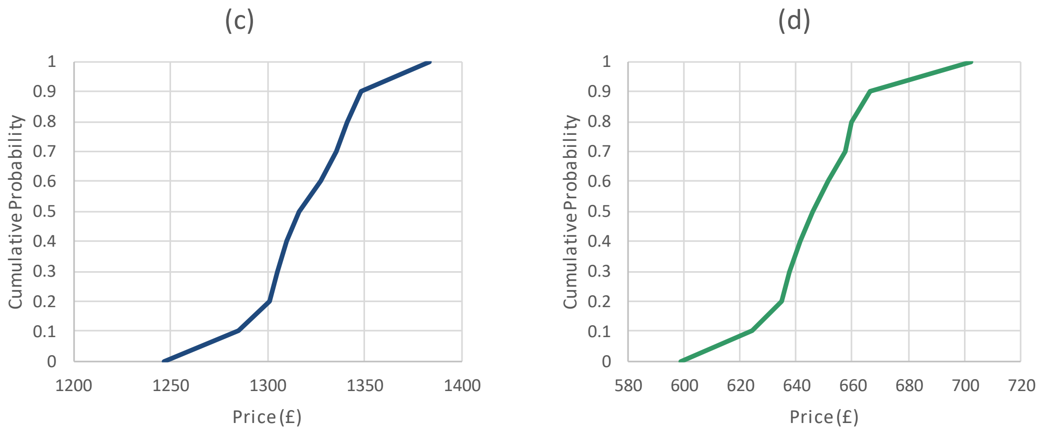

Figure 21. Forecasted price range for (c) BSF oil – fishmeal equivalent and (d) BSF oil – soybean equivalent. The CDFs indicate the likely price range for BSF oil to be competitive based on equivalent fishmeal and soybean meal crude fat contents. Note: the values between the 10th (0.1 on the y-axis) and 90th (0.9 on the y-axis) percentiles are considered robust. Source: ADAS for WWF.

6.3.4 Forecasting insect protein meal demand

The modelling process to determine the demand for BSF protein meal included the following steps:

Step 1: Identification and sourcing of historical data related to quantities of fishmeal and soybean meal traded in the UK (AHDB, Defra statistics and OECD commodity statistics)

- A similar econometric approach as outlined in section 6.2.5 was undertaken to determine annual forecasted quantities for fishmeal and soybean meal over the period 2020-2050.
- Using the results from the econometric analysis, BSF replacement of fishmeal and soybean meal in salmon feed, pig feed and poultry feed was predicted.
- Estimation of demand for BSF protein meal as a replacement in salmon feed was based on an assumed inclusion rate of 20%. It was also assumed that BSF would only replace 50% of fishmeal and 50% of soybean meal in any given salmon feed mix.
- Estimation of demand for BSF protein meal as a replacement in pig and poultry feed was based on an assumed inclusion rate of 5%. It was also assumed that BSF would only replace 25% of soybean meal in pig feed and 20% in poultry feed).

Results of demand modelling

The modelled outputs, summarised in Table 30 and Figure 22, outline the projected demand for insect meal within each of the three species (salmon, poultry and pigs).

Table 30. Projected demand for insect meal in salmon, poultry and pig feed (000 tonnes). Source: ADAS for WWF.

Feed	2020	2025	2030	2040	2050
Salmon feed	21	34	35	36	38
Poultry feed	*	336	340	378	404
Pig feed	*	82	83	92	98
Total demand	**21**	**452**	**458**	**506**	**540**

**Not permitted for use in 2020. Subsequent years are based on the demand if legislation was changed to permit processed insect meal in poultry and pig feed.*

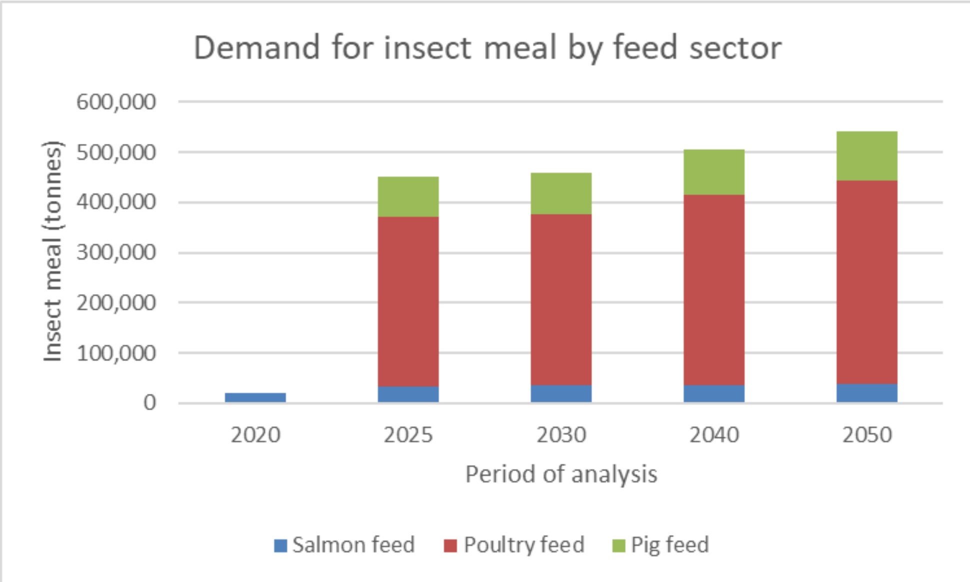

Figure 22. Forecasted BSF protein meal demand 2020 – 2050. Source: ADAS for WWF.

6.3.5 BSF production facilities and outputs

Based on the modelling of substrate material supply (section 6.3.1) and BSF protein meal demand (section 6.3.4), the number of Insect Production Facilities (IPF), likely production outputs, substrate processing capacity and substrate utilisation were estimated.

Table 31 summarises the findings. The modelling indicates the following different combinations of potential for upscaling BSF production in the UK, based on projected available substrate material supply from 2021-2050 for different sizes of facility:

- By 2050, ~ 168 **micro** scale facilities capable of processing 75 tonnes of material per day. Each facility will utilise around ~18,000 tonnes of material a year and produce ~1,250 tonnes of protein meal, 420 tonnes of oil and 3,350 tonnes of frass a year.

  or

- By 2050, ~ 126 **small** scale facilities capable of processing 100 tonnes of material per day. Each facility will utilise around ~24,000 tonnes of material a year and produce ~1,700 tonnes of protein meal, 560 tonnes of oil and 4,500 tonnes of frass a year.

  or

- By 2050, ~ 50 **medium** scale facilities capable of processing 250 tonnes of material per day. Each facility will utilise around ~60,000 tonnes of material a year and produce ~4,200 tonnes of protein meal, 1,400 tonnes of oil and 11,200 tonnes of frass a year.

  or

- By 2050, ~ 10 **large** scale facilities capable of processing 1,300 tonnes of material per day. Each facility will utilise around ~314,000 tonnes of material a year and produce ~21,800 tonnes of protein meal, 7,300 tonnes of oil and 58,100 tonnes of frass a year.

  or

- A combination of the above four facility sizes.

Table 31. Estimated BSF facilities and potential production outputs. Note: the number of facilities is the maximum potential reached in year 2050 based on supply of available food surplus and non-food materials. The modelling assumes BSF production will only utilise 50% of available food surplus and non-food material at any given time. Source: ADAS for WWF.

	BSF Insect Production Facility (IPF)			
Description	**IPF1**	**IPF2**	**IPF 3**	**IPF4**
Material Processing Capacity (tonnes/day)	75	100	250	1,300
Material Substrate Utilised (tonnes/year)	18,118	24,157	60,393	314,044
Insect Meal production (tonnes/year)	1,257	1,676	4,189	21,782
Insect Oil production (tonnes/year)	419	559	1,396	7,261
Frass production (tonnes/year)	3,351	4,468	11,170	58,084
Estimated ~number of facilities*	**168**	**126**	**50**	**10**

**To meet projected supply of food surplus and non-food materials (assessed within this study) in 2050, based on up to 50% of available materials being diverted to insect production.*

6.4 Modelling the economic viability of insect farming

Numerous studies have focused on the biological aspects of BSF production, however, the economic aspects associated with such production have not received the same level of research. Studies in the literature that have analysed the economic viability of BSF production systems have tended to use case studies or experimental data to infer likely outcomes at a commercial scale (Joly and Nikiema, 2019; Zurbrugg *et al*., 2019). The limited research on technical feasibility and scaling up of BSF production systems, especially in developing countries, means that it is not yet robustly known whether the results from laboratory studies can be replicated in field studies (Singh and Kumari, 2019).

In determining the economic viability of up-scaling insect protein production for use in animal feed it is key to point out that the production system being analysed not only depends on the scale of operation, but also on the climate of the intended region and the primary goal of the system (production of dry insects or digestion of material). Joly and Nikiema (2019), for example, found that the economic performance of BSF varied significantly depending on the substrate material used, the location and size of the BSF facility and the final intended use of BSF by-products (e.g. animal feed, biodiesel, or fertiliser).

6.4.1 Financial Viability Assessment

A Financial Viability Assessment of the four BSF production systems was undertaken to provide an indication of the feasibility of upscaling insect protein production. The Financial Viability Assessment was developed in Excel to show predicted cashflows, profits and net present values over the timescale 2021-2050. A key driver for any investor will be the probability of achieving, at minimum, some set rate of return. As such, the viability assessment also considered a modified internal rate of return (MIRR)[161] for each of the 4 alternatives.

Using information from literature, the stakeholder survey and extrapolating data from BSF production facilities in operation, the model has been developed to show the relationship between costs, level of production and the price of outputs (BSF protein meal and BSF oil).

As BSF production is still considered to be a developing industry the public, government and supply chain perceptions of safety and integrity around the use of insects in feed need to be considered. As organic material can contain faeces and former foodstuffs the bioconversion of such by BSF would involve a risk of introducing pathogens, plant disease and heavy metals into the production system. These contaminants could then be transferred into feed systems via any frass used to grow crops (Wynants *et al*., 2019). Due to these concerns and the complexity involved in modelling specific substrate requirements, environmental conditions and rearing practices, frass as an output has only been included in the financial assessment under high level assumptions. Data availability on the use and market for frass as a by-product of BSF protein meal production is limited in the UK and as such the modelling as assumed a minimal price of £5/tonne for the sale of frass.

Investment appraisal

The financial viability of the alternative BSF production systems was assessed using the following investment appraisal measures:

[161] Modified Internal Rate of Return (MIRR) assumes initial outlays are financed at the company's financing cost and positive cash flows are reinvested at the company's cost of capital.

- **Net Present Value (NPV):** the sum of the flow of annual net benefits, each of which is expressed as a present value. This sum is exactly equivalent to the difference between the present value of benefits and the present value of costs and indicates the magnitude of net benefits over the BSF facility lifetime (Equation 6-1).
- **Modified Internal Rate of Return (MIRR):** a modification of the internal rate of return that assumes positive cash flows are reinvested at the business's cost of capital, (i.e. the reinvestment rate) while negative cash flows are financed at the business's financing cost, (i.e. the finance rate) (Equation 6-2).

The following equations were used to calculate each of the appraisal measures:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \quad \text{(6-1)}$$

$$MIRR = \left[\frac{FV_R}{PV_F}\right]^{\frac{1}{t}} - 1 \quad \text{(6-2)}$$

where T is the lifetime of the BSF facility in years, B_t represents the benefits in year t, C_t represents the costs in year t, and r is the discount rate which allows the time value of money to be taken into account. A positive NPV indicates a viable alternative. The alternative with the highest NPV is the most profitable. In relation to MIRR, FV is the future value of positive cashflows at the reinvestment rate R, PV is the present value of negative cashflows at the finance rate F.

Data and assumptions

Using information from the literature review, stakeholder survey and extrapolating data from BSF production facilities in operation, a model was developed to show the relationship between costs, level of production and the price of outputs (protein meal, oil and frass). Given the limited research and available robust data on commercial scale BSF facilities currently in operation several broad assumptions had to be made. These are discussed further in the relevant sections below. The following key generic assumptions were also made:

- The financial viability assessment assumed a facility life of 30 years for all BSF production systems.
- The analysis was conducted in real terms and no inflation/deflation was included for any cost or price calculations. Nominal historical prices for fishmeal and soybean meal were converted to real prices using a CPI deflator.
- Depreciation has not been included in the cash flow analysis. It has only been included for the purpose of analysing operating Profit and Loss and determining residual values of assets.
- NPV calculations assume a central real discount rate of 3.5% as defined by HM Treasury[162].

162 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

6.4.2 Capital Costs

Capital costs included in the Financial Viability Assessment modelling for each BSF insect production facility (IPF 1-4) included construction costs, materials and production equipment, start-up and technical costs, and replacement costs. Residual value of assets in year 2050 were also taken into account.

Assumptions

- It was assumed that all IPF will require construction of buildings and acquisition of materials and equipment for operation. These capital costs were assumed to occur in Year 0.
- Construction costs are assumed to incorporate land acquisition costs.
- It was also assumed that all capital requirements would be sourced from within the UK and that the facilities would be located close to sites that have surplus heat to minimise costs and improve cost competitiveness.

Table 32 summarises the CAPEX outputs under **scenario 2** assumptions.

Table 32. Estimated CAPEX for alternative IPF (£/tonne BSF protein meal). Source: ADAS for WWF.

Description	IPF1	IPF2	IPF3	IPF4
CAPEX	£/tonne BSF Protein Meal			
Construction	£3,474	£3,068	£2,084	£1,639
Machinery & Production Equipment	£438	£387	£250	£197
Contingencies	£35	£31	£21	£16
Start-up and technical costs	£40	£36	£36	£23
Replacement Costs	£66	£58	£38	£30
TOTAL CAPEX (£/tonne of protein meal)	£4,051	£3,580	£2,428	£1,905
TOTAL CAPEX (£/tonne material utilised)	£299	£264	£179	£140
Residual Value (year 2050)	£1,982	£1,750	£1,188	£934
Return on capital invested	1.8%	2.2%	5.6%	15.2%

6.4.3 Revenues, Operational Costs, and Financial Viability Assessment

Assumptions

Several assumptions were made in order to assess the revenues, operational costs and financial viability of the insect production facilities:

- Operating revenues and expenditures were examined over a 30-year period commencing in 2021.
- Costs associated with buying in food surplus and non-food material required as part of the BSF feed mix are also included, along with other costs associated with BSF production such as electricity, water, transport and general supplies.
- Employment costs and overhead costs such as administration, marketing and communications include an allowance for technical and allocative efficiency gains in the 2 larger scale facilities.
- Revenues are determined from annual projected production quantities of protein meal, oil and frass multiplied by projected annual prices determined for each revenue item.
- For IPF 4 we assume a high degree of automation and as such an associated increase in power consumption. We considered the idea that economies of scale could reduce the unit consumption per tonne of output. However, due to a lack of validated evidence on the impact of BSF facility scale on energy consumption per tonne of protein meal we have assumed a general increase in overall energy consumption.
- To determine costs of production for the BSF facilities modelled, the notions of joint costs[163], split-off point and separable costs[164] were taken into consideration. For the purposes of the financial analysis, cost allocation was based on the revenue shares approach which uses the individual product's revenue as a proportion of total revenue multiplied by total costs divided by the relative quantity for that product.

The joint products of protein meal and oil were assumed to be sold at the split-off point without further processing. This may, in reality not be the case, however, for simplicity and due to a lack of robust data related to allocation of costs beyond a split-off point for BSF production processes, we have assumed the joint products are sold at the point of split-off.

The modelled financial outcomes under **Scenario 2** are shown for low quality BSF protein meal price assumptions (Table 33) and high quality BSF protein meal price assumptions (Table 34).

[163] Joint costs are the costs of a production process that yields several products simultaneously. For BSF production the processing of BSF larvae yields protein meal and oil which have joint costs of production.

[164] Separable costs are all costs that are incurred beyond the split-off point which occurs when the two joint products become separately identifiable. For example, once the oil and protein meal have been separated.

Table 33. Revenues and Operating Costs for IPF alternatives (£/tonne BSF Protein Meal). under Scenario 2 and LOW quality BSF protein price assumptions. Costs of production have been determined based on product share of revenue multiplied by total costs (including depreciation) divided by total tonnes of product. Source: ADAS for WWF.

Financial Summary	IPF 1	IPF 2	IPF 3	IPF 4
Revenues				
Protein Meal	£515,995	£687,993	£1,719,984	£8,943,915
Oil	£489,533	£652,711	£1,631,778	£8,485,245
Frass	£16,683	£22,244	£55,609	£289,168
Total Annual Revenue	**£1,022,211**	**£1,362,948**	**£3,407,371**	**£17,718,328**
Revenue (£/tonne protein meal)	£813	£813	£813	£813
Costs				
Operating (Excluding Labour costs)	£215,540	£262,909	£697,732	£4,139,755
Overheads	£200,193	£266,924	£633,946	£3,131,692
Employment/Labour	£421,726	£587,197	£1,317,895	£3,426,527
Total Annual Costs	**£837,460**	**£1,117,031**	**£2,649,572**	**£10,697,974**
Depreciation	£97,837	£115,243	£192,711	£788,060
Net Profit/(Loss)	**£89,256**	**£133,792**	**£574,611**	**£6,320,049**
Net Profit/(Loss) (£/tonne protein meal)	£71	£80	£137	£290
Costs of Production (£/tonne protein meal)	£376	£371	£343	£266
Costs of Production (£/tonne oil)	£1,069	£1,057	£975	£758

Table 34. Revenues and Operating Costs for IPF alternatives (£/tonne BSF Protein Meal). under Scenario 2 and HIGH quality BSF protein price assumptions. Costs of production have been determined based on product share of revenue multiplied by total costs (including depreciation) divided by total tonnes of product. Source: ADAS for WWF.

Financial Summary	IPF 1	IPF 2	IPF 3	IPF 4
Revenues				
Protein Meal	£1,252,146	£1,669,528	£4,173,819	£21,703,860
Oil	£497,505	£663,340	£1,658,351	£8,623,426
Frass	£16,683	£22,244	£55,609	£289,168
Total Annual Revenue	£1,766,334	£2,355,112	£5,887,780	£30,616,455
Revenue (£/tonne protein meal)	£1,406	£1,406	£1,406	£1,406
Costs				
Operating (Excluding Labour costs)	£215,540	£262,909	£697,732	£4,139,755
Overheads	£200,193	£266,924	£633,946	£3,131,692
Employment/Labour	£421,726	£587,197	£1,317,895	£3,426,527
Total Annual Costs	£837,460	£1,117,031	£2,649,572	£10,697,974
Depreciation	£97,837	£115,243	£192,711	£788,060
Net Profit/(Loss)	£842,649	£1,138,315	£3,085,974	£19,379,402
Net Profit/(Loss) (£/tonne protein meal)	£671	£679	£737	£890
Costs of Production (£/tonne protein meal)	£528	£521	£481	£374
Costs of Production (£/tonne oil)	£629	£621	£573	£446

The results of the financial viability assessment indicate that under scenario 2 and low quality BSF price assumptions with seven food surplus and non-food material available for use in BSF production, all 4 IPF generate a net profit after depreciation and interest. There are significant gains to be made by increasing BSF production scale, as indicated by the declining costs of production for protein meal and oil. The technical and allocative efficiencies gained through economies of scale improve the overall financial viability of BSF production in the UK.

Financial Viability Assessment Results

To determine true financial viability, NPVs for each of the 4 BSF facilities were estimated. Annual net benefits (total annual revenues less total annual costs) were discounted at a central real discount rate of 3.5 per cent to determine their present value. This was required so that the value of the future benefits and costs could be compared directly to their current value. The NPV of each alternative was then determined from the sum of these present values.

Table 35 shows the total annual discounted net benefits of the 4 BSF facilities. Under current modelling assumptions, IPF 3 and IPF 4 are viable alternatives due to their scale and capacity to handle large volumes of material. The NPV for IPF 4 is £87.8 million which equates to an annual annuity of £4,775,078 at a central discount rate of 3.5 per cent. The modified internal rate of return for IPF 4 is 5.42%. These results indicate that investment in large scale BSF production has the potential to generate significant cash flows and returns on capital over a 30-year period.

Table 35. Net Present Value (NPV), Net Present Value as an Annuity (NPVA) and Modified Internal Rate of Return (MIRR) outcomes for each IPF under scenario 2 and low quality BSF protein price assumptions. Source: ADAS for WWF.

	IPF 1	IPF 2	IPF 3	IPF 4
NPV	-£1.20	-£0.93	£4.4	£87.8
NPVA[165]	-£65,048	-£50,710	£236,572	£4,775,078
MIRR	0.13%	0.50%	2.46%	5.42%

6.4.4 Sensitivity Analysis and Modelling Uncertainty

Sensitivity Analysis

A sensitivity analysis can provide decision makers with information about the extent to which a critical variable can change before a scenario's positive NPV is reduced to zero or its negative NPV is increased to zero. This information is important in helping the decision maker decide whether a scenario is economically desirable and as such acceptable.

Identifying the major sources of uncertainty in each of the alternatives is essential if the sensitivity of outcomes to changes in data and assumptions is to be tested correctly and the financial desirability assessed to determine the potential for upscaling protein production for animal feed. For the alternatives presented here, testing the effects of changes in the assumptions and data relating to BSF protein meal prices, substrate material supply and construction expenditure were undertaken in Table 36. These variables were chosen because of their level of uncertainty and risk. As well, changes in the levels of these variables were sufficient to change the NPV for each alternative and as such alter their relative desirability.

The other variable tested was the discount factor. Sensitivity of results to changes in real discount rates of 2% and 5% were also tested.

165 NPVA represents the net present value expressed as an annual annuity.

Table 36. Sensitivity Analysis of NPV Results under scenario 2 and low quality BSF protein price assumptions. Source: ADAS for WWF.

	NPV (£M)			
Discount Rate	**IPF 1**	**IPF 2**	**IPF 3**	**IPF 4**
2%	-£0.01	£0.59	£8.3	£119.2
3.5%	**-£1.20**	**-£0.93**	**£4.4**	**£87.8**
5%	-£2.04	-£2.01	£1.5	£64.6
Benefits @ 3.5% Discount Rate				
BSF Protein Meal Price increases by 10%	-£0.27	£0.30	£7.4	£103.8
BSF Protein Meal Price decreases by 10%	-£2.12	-£2.16	£1.3	£71.8
Costs @ 3.5% Discount Rate				
Construction costs increase by 10%	-£1.55	-£1.35	£3.5	£84.3
Construction costs decrease by 10%	-£0.85	-£0.52	£5.2	£91.3
Substrate volume increases by 10%	-£0.04	£0.65	£8.6	£110.7
Substrate volume decreases by 10%	-£2.35	-£2.52	£0.1	£65.0

The results indicate that the financial viability of BSF protein meal production is highly sensitive to construction costs and substrate material availability, as would be expected. The viability of BSF production in the UK will also be influenced by labour costs, with efficiency gained through economies of scale. The ability of any potential individual facility to cover costs of production will also be dependent on their ability to generate revenues from oil and frass by-products and the potential market for such products in the UK and abroad.

Modelling Uncertainty

To determine the risk associated with likely changes in revenues and costs a stochastic modelling approach[166] was applied. Using Monte Carlo simulation[167], the probability distribution (range of possible outcomes) of NPV outcomes resulting from the risk and uncertainty surrounding insect protein demand for each IPF, was determined. A summary of the simulation results is shown in Table 37.

[166] Stochastic refers to the incorporation of a random number or probability to account for risk and volatility.

[167] Monte Carlo simulation involves simulating various sources of uncertainty affecting a certain value, and then determining their probability distributions over the range of resultant outcomes.

Table 37. Probability Distributions of Financial Viability outcomes under scenario 2 and low quality BSF protein price assumptions. Source: ADAS for WWF.

Cumulative Probability	NPV (£M)			
	IPF 1	IPF 2	IPF3	IPF 4
0%	-£1.53	-£1.37	£3.25	£82.08
10%	-£1.32	-£1.10	£3.93	£85.63
20%	-£1.28	-£1.04	£4.08	£86.43
30%	-£1.24	-£1.00	£4.19	£86.99
40%	-£1.22	-£0.97	£4.27	£87.39
50%	**-£1.20**	**-£0.93**	**£4.35**	**£87.80**
60%	-£1.17	-£0.90	£4.43	£88.22
70%	-£1.14	-£0.86	£4.53	£88.75
80%	-£1.11	-£0.82	£4.63	£89.29
90%	-£1.07	-£0.76	£4.79	£90.08
100%	-£0.83	-£0.45	£5.56	£94.13
True Mean	-£1.19	-£0.93	£4.36	£87.86
Standard Deviation	£0.10	£0.13	£0.34	£1.75

The results shown in Table 37 indicate that at a central discount rate of 3.5 per cent, only IPF 3 and IPF 4 are economically viable with 50 per cent of possible financial NPV outcomes estimated to be above £4.36 million for IPF 3 (based on true mean[168]) and £87.86 for IPF 4 when all financial costs and revenues are considered.

Graphically, the results relating to NPV for each IPF facility can be represented by a Cumulative Distribution Function (CDF) that maps the resulting values to their percentile rank in each distribution. Figure 23 shows the likely range of the NPV outcomes (the values between the 10th and 90th percentiles are robust). The range of possible NPV outcomes is expected to be between £3.93 million and £4.79 million for IPF 3 and between £85.63 million and £90.08 million for IPF 4 when risk and uncertainty are taken into consideration.

[168] The true mean will fall between the upper and lower limit – with a 95% confidence interval.

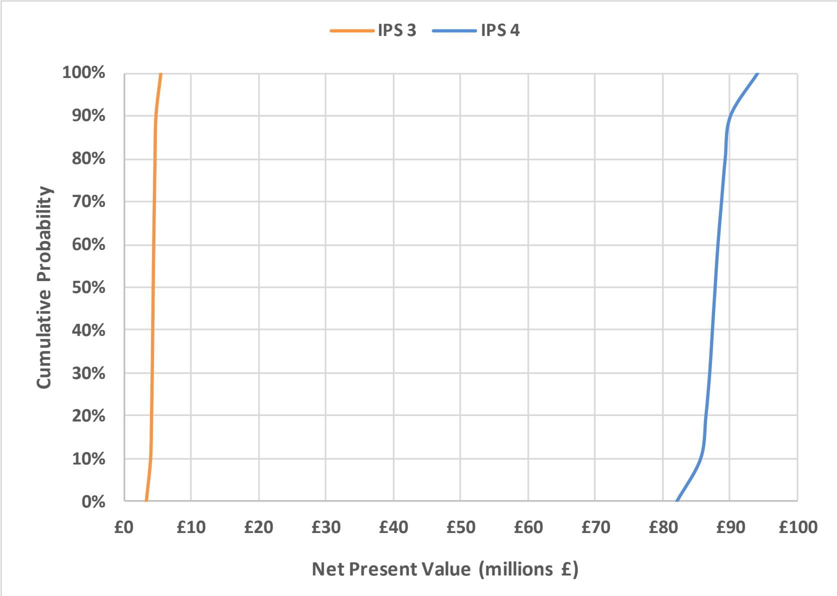

Figure 23. Cumulative Distribution of possible NPV outcomes for IPF 3 and IPF 4. Note: the more vertical the CDF is the lower the risk surrounding NPV outcomes. Source: ADAS for WWF.

6.5 Limitations of the model

There are various limitations to this model, the greatest of which is the lack of access to data from BSF commercial facilities. Currently there are a small number of private companies around the world involved in BSF larvae production such as Multibox (UK), Hexafly (Ireland), InnovaFeed (France), Enterra Feed Corporation (Canada), Agriprotein (South Africa) and Protix (The Netherlands) however, much of the data and information related to costs, benefits and operational processes are not publicly available as large scale commercialisation of BSF production is still in infancy stages and these businesses are wanting to maintain competitive advantage (Surendra, 2020; Joly and Nikiema, 2019).

In addition to this, the variability in measures cited in various literature sources related to substrate material reduction, bioconversion and feed conversion rates meant that the modelling had to rely on the use of proxy values to enable calculation of certain outputs, especially those related to larvae growth from the different substrates assessed. Variability in the nutrient content of different food surplus and non-food material will ultimately influence larval growth and as such uncertainty around this will reduce the predictive value of the modelling. The modelling however, included both sensitive analysis and Monte Carlo simulation to account for risk and uncertainty around key variables including price and material quantities.

The outputs of the modelling, while limited by data availability and suitable robust evidence for several of the food surplus and non-food material, do provide a basis for understanding the potential financial benefits from upscaling BSF production in the UK. Further in-depth bioeconomic modelling and scientific trials designed to understand the impact of different available substrate materials on the diet and growth of larvae would improve this understanding and help fill the knowledge gap surrounding insect protein production in the UK in general.

7 ROADMAP FOR UK INSECT PROTEIN

This study has outlined the risks and opportunities for insect biomass production in the UK. For the industry to be successful, insect production must be able to demonstrate that it is producing something better than other sectors (i.e. fishmeal or soybean meal) that provides greater environmental benefit, good health benefits and utilises a substrate that would otherwise be going to landfill. The roadmap demonstrates a pathway for how the UK insect value chain could develop, upscale and flourish up to 2050. Each recommendation contributes to reaching the end goal: the upscaling and establishment of a UK insect biomass sector; and the displacement of fishmeal and soybean meal from UK aquaculture and livestock feed.

7.1 Roadmap to scale up UK-produced insect protein

Table 38 summarises the key metrics and indicators that have been developed in this study to provide a roadmap for upscaling the insect biomass value chain. The data included in the table is based on the modelling conducted as part of this research (see section 6).

Table 38. Roadmap to scale up insect production: key metrics and indicators for 'Scenario 2'. Source: ADAS for WWF.

Annual UK demand		Baseline (2020)	2025	2030	2040	2050
Estimated demand for insect meal (tonnes) in animal feed and rate of inclusion (%): [1]	Salmon feed at ~11.7%	21,000	34,000	35,000	36,000	38,000
	Poultry feed at ~6.1%	Not authorised	336,000	340,000	378,000	404,000
	Pig feed at ~5.1%	Not authorised	82,000	83,000	92,000	98,000
Estimated total demand for insect meal (tonnes)		**21,000**	**452,000**	**458,000**	**506,000**	**540,000**
Facilities and substrate requirements		**Baseline (2020)**	**2025**	**2030**	**2040**	**2050**
Number of operational facilities: [2]	Micro scale	1-5	5-10	10-15	15-20	20-25
	Small scale	0	1-5	5-10	10-15	15-20
	Medium scale	0	0	1-5	6-10	10-15
	Large scale	0	0	0	1-3	3-5
Number of by-products authorised for use as substrate [3]		4	7	7	7	7
Volume of UK food surplus (wet) available (million tonnes)		3.81	5.70	5.94	6.17	6.83
Volume of food surplus (wet) required (million tonnes)		0.02 to 0.09	0.11 to 0.3	0.36 to 0.82	1.19 to 2.27	2.27 to 3.41
Utilisation of available food surplus (%)		**0.5% to 2.4%**	**2% to 5.3%**	**6.1% to 13.7%**	**19.3% to 36.8%**	**33.2% to 49.9%**
UK insect production to meet annual UK demand		**Baseline (2020)**	**2025**	**2030**	**2040**	**2050**
Volume of insect meal produced (000 tonnes)		1 to 6	8 to 21	25 to 57	83 to 157	157 to 237
Volume of insect oil produced (000 tonnes)		0 to 2	3 to 7	8 to 19	28 to 52	52 to 79
Volume of frass produced (000 tonnes)		3 to 17	21 to 56	67 to 151	220 to 420	420 to 631
Cost of Production in Medium Scale Facility (£/tonne Dry Larvae Biomass)		N/A	£554	£533	£511	£497
Estimated insect meal demand met by supply (%)		**4.8% to 28.6%**	**1.8% to 4.6%**	**5.5% to 12.4%**	**16.4% to 31%**	**29.1% to 43.9%**

[1] Estimated total demand for insect meal within animal feeds based on the current proportion of fishmeal and soybean meal that is used by these sectors. The inclusion rates are indicative only and may be higher or lower in some species feed depending on age, growth stage, diet composition etc.

[2] Number of micro-scale (~1,300 tonnes/year insect meal), small-scale (~1,700 tonnes/year insect meal), medium-scale (~4,200 tonnes/year insect meal) and large-scale (~22,000 tonnes/year insect meal) facilities that are operational in the UK. There are no known facilities larger than micro-scale that were operational in the UK in 2020.

[3] Substrates include vegetable surplus, bakery surplus, brewers' grains and surplus whey in 2020, and then the addition of surplus bakery with animal by-products, food surplus (retail) and food surplus (manufacturing) from 2025 onwards (presumes legislation changes that allow substrates to be used).

7.2 Estimated annual UK demand for insect meal protein

In this section, we outline the potential demand for insect protein (based on the modelling outlined in section 6) for inclusion within salmon, pig and chicken feed. The inclusion rates provided indicate how much of the total diet that insect meal might potentially replace. For example, a 5% inclusion rate means that it would account for 5% of the animal's whole diet, not 5% of the protein content within the diet.

The estimations are considered to be a realistic replacement of current protein ingredients with insect meal, which might be achieved by 2050, based on a combination of the animals' nutrient requirements, the amount of soybean meal or fishmeal in the diet that could currently be replaced, the time it will take for industry to implement such change, and an understanding that not all feed mixers would make the change and not all fishmeal or soybean meal would be displaced due to other benefits of these feeds (e.g. nutritional or cost of product).

Modelled potential demand for insect meal in salmon feed

Scotland's salmon farming sector is the third largest in the world, accounting for 7.6% of global production in 2015 (Iversen et al., 2020), with salmon accounting for 96% of all finfish production in Scotland (Marine Scotland Science, 2018).

Salmon production in the UK is estimated to consume 90% of all fishmeal used in UK animal feed, with a small part destined for pet food or other aquaculture. Salmon production is also estimated to consume 2% of total soybean meal used in UK animal feed (EFECA, 2020).

It is currently estimated that fishmeal accounts for approximately 20% of the total diet of salmon, with wider estimates typically ranging between 15-25% (Feedback, 2019). Soybean meal accounts for around 13.4% of the total diet of salmon (EFECA, 2020).

We estimate in this study that 25% of fishmeal and 50% of soybean meal could theoretically be replaced by insect meal in salmon diets without having detrimental effects on species nutrition and growth. This is supported by evidence in the wider scientific literature (see section 2.1).

This would create a UK demand for insect meal in salmon feed of 34,000 tonnes in 2025, increasing to 35,000 tonnes in 2030, 36,000 tonnes in 2040, and 38,000 tonnes in 2050.

Based on these assumptions, the modelled outputs project that insect meal could account for around ~12% of salmon diets, with fishmeal accounting for ~15%, soybean meal accounting for ~7% and other proteins and ingredients accounting for the other ~66% of salmon diets.

The projected inclusion rates applied are more conservative than, and thus result in a lower demand estimation to that suggested by the Insect Biomass Conversion Task and Finish Group; which estimated that the potential scale of annual UK demand for insect protein for aquaculture feed was approximately 70,000 tonnes, at a diet inclusion rate of 23% (IBCTG, 2019). This lower estimation resulted from consultation with industry stakeholders, where it was highlighted that a ~20% inclusion rate of insect meal was not realistic due to fishmeal inclusion rates being cut significantly in recent years.

Modelled potential demand for insect meal in chicken feed

Poultry production in the UK is estimated to consume 62% of total soybean meal used in UK animal feed (EFECA, 2020).

It is currently estimated that soybean meal accounts for around 20.3% of the total diet of chickens (EFECA, 2020), although it is noted there will be variation depending on whether the chickens are broilers or egg-laying.

We estimate in this study that 25% of soybean meal could theoretically be replaced by insect meal in chicken diets without having detrimental effects on species nutrition and growth. This is supported by evidence in the wider scientific literature (see section 2.1).

Legislation is however a current barrier. Processed animal proteins (e.g. insect meal) are not currently permitted for use in chicken feed in the UK (see section 4.2). However, if legislation were to change in the future, we estimate that this would create a UK demand for insect meal in chicken feed of 336,000 tonnes in 2025, increasing to 340,000 tonnes in 2030, 378,000 tonnes in 2040, and 404,000 tonnes in 2050.

Based on these assumptions, the modelled outputs project that insect meal could account for around ~6% of chicken diets, with soybean meal accounting for ~14% and other proteins and ingredients accounting for the other ~80% of chicken diets.

The projected inclusion rate applied is higher than, and thus the estimated demand, are higher to that suggested by the Insect Biomass Conversion Task and Finish Group; which estimated that the potential scale of annual UK demand for dried meal for poultry feed was 200,000 tonnes at a diet inclusion rate of 5% (IBCTFG, 2019). This difference is likely due to differences in the proportion of soybean meal allocated to chicken diets.

Modelled potential demand for insect meal in pig feed

Pig production in the UK is estimated to consume 15% of total soybean meal used in UK animal feed (EFECA, 2020).

It is currently estimated that soybean meal accounts for around 17% of the total diet of pigs (EFECA, 2020), although it is noted there will be variation depending on the pigs stage of life, with consumption of soybean meal much greater in pig starter and growing feeds, compared with finishing or breeding feeds.

We estimate in this study that 25% of soybean meal could theoretically be replaced by insect meal in pig diets without having detrimental effects on species nutrition and growth. This is supported by evidence in the wider scientific literature (see section 2.1).

Legislation is however a current barrier. Processed animal proteins (e.g. insect meal) are not currently permitted for use in pig feed in the UK (see section 4.2). However, if legislation were to change in the future, we estimate that this would create a UK demand for insect meal in pig feed of 82,000 tonnes in 2025, increasing to 83,000 tonnes in 2030, 92,000 tonnes in 2040, and 98,000 tonnes in 2050.

Based on these assumptions, the modelled outputs project that insect meal could account for around ~5% of pig diets, with soybean meal accounting for ~12% and other proteins and ingredients accounting for the other ~83% of pig diets.

The projected inclusion rate applied and demand forecast is in line with that suggested by the Insect Biomass Conversion Task and Finish Group; which estimated that the potential scale of annual UK demand for insect protein for pig feed was 100,000 tonnes at a diet inclusion rate of 5% (IBCTFG, 2019).

7.3 Opportunity for insect protein or products in other markets

This study concentrates on the opportunity for insect protein meal to displace soybean meal and fishmeal within the diets of chicken, pigs and salmon. However, we recognise there are a number of other markets that insect-based products can have. This includes alternative uses for insect protein, as well as markets for co-products (e.g. insect oil) and by-products (e.g. frass) produced within insect production systems, which could also provide other opportunities for the insect biomass sector. We briefly outline some of these here.

Insect meal for use in pet feed

We do not consider the demand for pet feed in this study. However, it is acknowledged that IBCTFG estimate a small demand from this sector; the potential scale for pet food in the UK can be estimated as 20,000 tonnes of insect protein per annum; based on a conservative estimate by the Pet Food Manufacturing Association of 5% of the current market size of total pet food protein (IBCTFG, 2019). The pet food market, albeit small in comparison to the estimated demand within livestock and fish, offers an alternative market for insect protein that could help to de-risk insect farming businesses which are seeking investment. This could be within the UK pet food market or through exports to Europe's pet food market.

Insect oil for use in livestock feed

We do not specifically cover insect oil products within the roadmap. Insect oil is a co-product produced during insect protein processing, which can be used to complement or replace vegetable oils (e.g. soybean oil) within pig and poultry feed. However, we do not explore markets for insect oil within this study.

Biofuel-driven insect farming

While this paper focusses on the role of insects in the food system, insects may potentially also be used to convert organic materials not permissible within the food value chain (e.g. post-consumer and catering food surplus, manures, sewage and water treatment sludges) into low carbon biofuels.

Frass as a by-product from insect production

We do not specifically cover frass as a commercial product within the roadmap. However, the modelling outputs suggest that around 562,000 tonnes of insect frass could be produced each year by 2050 (see section 6.2.6). Frass is key by-product of insect production. Frass provides a source of nitrogen, phosphorous and other nutrients, as well as chitin, which can be useful for stimulating plant defence systems. There is potential to use frass as fertiliser on land, subject to relevant legislation.

Live insects for use in livestock diets

We do not specifically consider farmed insects, which have not been processed, for direct use as animal feed (e.g. chickens) in the form of live insects. This report focusses on processed animal products to displace fishmeal and soybean meal. However, we recognise there is a market for live insect feed, which is already being developed in the UK and Europe (The Guardian, 2020b).

8 RECOMMENDATIONS TO ACHIEVE ROADMAP

8.1 Recommended actions, responsibility, and timeframes

In order to realise the potential upscaling of insect production in the UK and to achieve the volumes indicated possible by the modelling, a number of actions have been identified, in consultation with stakeholders within the value chain. These are outlined by theme (not priority): lobbying and driving change; legislation and regulation reform; research and development; industry collaboration; social and environmental considerations; economic incentives and financial viability; and technological advancements.

8.1.1 Lobbying and driving change

It is recognised that many of the actions identified in this study require the UK Government to explicitly support this market, through legislation, targeted funding, and ongoing support etc. The magnitude of engagement required from Government is a big challenge. To ensure that the recommendations in this roadmap are implemented within the timescales identified, an external organisation to drive and lobby for these changes would be beneficial.

RECOMMENDATION 1: Stakeholders across the insect biomass value chain to lobby Government and drive the implementation of the roadmap to support the scaling of insect protein and enhance the environmental credentials of animal feed produced and consumed in the UK

Rationale: The Government position on insect farming is critical and the actions identified require the UK Government to explicitly support this market, through legislation, targeted funding, and ongoing support etc. If current Government openly and actively support the development of a UK insect biomass sector, this will help the market to establish. However, it will also require cross-party long-term support from all Government parties. This includes recognising the indirect benefits that could be gained through insect farming, such as preventing the UK's contribution to depleting fish stocks through displacing the use of fishmeal in animal feed and preventing deforestation and the destruction of natural habitats in key sourcing regions of plant-based protein (e.g. soy) through displacing soybean meal in animal feed.

Action: To properly engage political groups in the value of insect protein and to ensure the implementation of other recommendations, it is recommended that Stakeholders across the insect biomass value chain campaign for the implementation of the roadmap and lobby Government to ensure the necessary actions are taken.

Responsibility: Stakeholders across the insect biomass value chain

Timeframe: 2020-2030

8.1.2 Legislation and regulation reform

The substantive European and domestic regulations and directives concerning animal feed were originally developed to ensure safe feeding of traditional vertebrate livestock species and minimising the risk of disease and pathogen transfer into the human food chain. However, they were developed without anticipating the use of insects as a source of protein in animal feed. Instead, insects fall within the broad category of "farmed animals" for the purposes of feed legislation and are captured by all legislation applicable to farmed animals. We provide several recommendations, in relation to changes in domestic legislation, that are required in order to enable the insect sector to upscale and become established. These include changes to regulations in relation to how the insects themselves can be fed, and also with regards how insects can be used as feed in other farmed livestock species.

RECOMMENDATION 2: To amend existing legislation, or the introduction of legislation specifically addressing the farming of insects for protein in animal feed (cross referencing existing legislation as necessary).

Rationale: New legislation is needed in the UK which caters specifically for farming insects for protein to be used in feed for livestock. It is acceptable for legislation to cross reference existing legislation, but the key is having an appropriate instrument specifically drafted with insect farming in mind.

In 2017, legislation was introduced to provide an exception for aquaculture (limited to 7 species of insects). The use of insect derived processed animal protein (PAP) in feed for livestock has not, however been addressed further by the legislature since then.

Action: UK Government to draft legislation specifically addressing the farming of insects for protein in animal feed (cross referencing existing legislation as necessary). Retailers, feed companies, and poultry and pig producers should campaign the issue, along with WWF and other environmental groups, in order to highlight the issue and gain traction for the required legislative changes within Government.

This recommendation also aligns with that suggested by IBCTFG (2019): *"For the Government to lead on delivering insect biomass legislation and regulation in line with latest science, global market developments and which acknowledges the sustainable, natural and local credentials of insect protein for the food and feed chain and waste valorisation as a critical 'clean growth' dimension of a circular economy."* (IBCTFG, 2019).

Responsibility: The industry to campaign for the changes and UK Government to amend the legislation accordingly.

Timeframe: 2021-2023

RECOMMENDATION 3: The introduction of legislation permitting the use of insect derived processed animal protein to be used in feed for farmed poultry and pigs intended for human consumption.

Rationale: Despite insects being a natural part of the diet for poultry and pigs, legislation currently prohibits the feeding of insect protein to these animals. The amendment of legislation to permit the use of insect protein in pig and poultry feed, following all necessary scientific reviews, is in accordance with industry recommendations:

- *"IPIFF welcomes the extension of the above mentioned 'legislative opening' [authorisation of the use of insect proteins] to the feeding of non-ruminant livestock animals (i.e. pigs and poultry species)…. Such a legislative change is backed by recent scientific evidence, developed under national regional or European research projects. In addition, calls from the European Parliament or national ministries support the authorisation of insect proteins for poultry and pig animals with the view to improve EU's agricultural circularity and self-sufficiency with respect to protein-rich materials."*[169] ***IPIFF***

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[169] 'IPIFF, The insect sector milestones towards sustainable food supply chains, (27 May 2020), p.9-10.

- *"Rapid clarification of UK regulatory framework and legislation with revisions to enable insect protein and associated products (e.g. chitin) in commercial scale poultry and pig feeding trials to facilitate rapid regulatory change that ensure safe use of insect products in a post-EU environment; establishment of a regulatory framework covering the use of insect residues as biofertilisers, clarity on standards and best practices to build trust and ensure safety and quality."*[170] ***IBCTFG***

- *"In view of these industry standards [(best hygiene practices, appropriate risk monitoring & management procedures and certified under the quality certification schemes)], the positive fish feeding trial outcomes of PROteINSECT & the industry as well as EFSA's recent risk assessment pointing towards the safety of Processed Insect Proteins when vegetal substrates are used, we strongly suggest to authorise their use in aquaculture, in line with other non-ruminant animal proteins."*[171] ***PROteINSECT***

Legislative reform permitting the use of insect protein in poultry and pig feed is anticipated at a European level

Action: Government to transpose European legislative reform permitting use of insect protein in poultry and pig feed if introduced before 31 December 2020. In the event that such European legislative change occurs after 31 December 2020, UK legislation should be amended to ensure parity with the European Union and permit the use of insect protein in poultry and pig feed.

Responsibility: Government

Timeframe: 2021

RECOMMENDATION 4: Future agricultural funding / subsidy schemes to specifically cater for innovative farming methods including the rearing of insects for protein for use in feed. This should include a recognition that the production of insect protein for animal feed is an agricultural activity.

Rationale: Current rural funding under the Common Agricultural Policy (CAP) in the UK is predominantly geared towards conventional farming and is largely linked to land-based production. More innovative practices, such as insect farming, do not necessitate the occupation of land and can take place in urban areas. Further, the production of insect protein does not strictly involve "traditional" methods of farming. The net result of this is that those involved in insect protein production do not have access to the same funds available to those producing protein for animal feed by more conventional methods.

Action: The inequality in the current CAP needs to be addressed - especially when considering the other benefits (e.g. environmental benefits) attached to insect farming which accord with other key government priorities. Without that, scaling up of insect protein production is significantly hampered.

Favourable interpretation of the wording of the Agriculture Act 2020 allows for support of insect protein production, but the pressure from the established farming sector and the

[170] Fera Science and Minerva Communications UK Ltd on behalf of the Insect Biomass Task and Finish Group, 'The Insect Biomass Industry for Animal Feed – the Case for UK-based and Global Business' (April 2019), p.3.

[171] PROteINSECT, 'Insect Protein – Feed for the Future. Addressing the need for feeds of the future today' (2016), p.15.

environmental lobby will be to reward the more obvious goals of carbon sequestration and direct climate change mitigation. Redressing the funding balance will require a formal recognition that protein production from insects is an agricultural activity and that the location and nature of the production base has no bearing on that classification. This will avoid confusion and technical arguments on interpretation of legislation.

The new Environmental Land Management Scheme for England under the Agriculture Act 2020 provides an opportunity to address this for rural insect farming, but to an extent that is insufficient. The opportunity for urban insect farms also needs to be addressed, as well as schemes for other regions in the UK (i.e. Wales and Scotland). Further standalone funding schemes need to be considered. As the pressure increases to adopt more sustainable methods of food and feed production, available funding will be critical to responding to that.

Of course, the Agriculture Act 2020 is an enabling Act. There will be much more detail to emerge from the underlying secondary legislation in the form of regulations and industry guidance (published by e.g. DEFRA).

Positively, in a government report from February 2020[172], the government stated as an example that new innovation, research and development (**"R&D"**) funding might extend to funding "*transformative collaborative projects seeking to develop insect based production systems*" and specifically identified "*sustainable protein*" as a "theme" it intends to develop. It waits to be seen whether further R&D funding will indeed be targeted at such "themes" and whether such themes will be carried over into ELMS or more traditional "subsidy" type funding.

Responsibility: Government

Timeframe: 2021-2025

RECOMMENDATION 5: Food Standards Agency to be mandated to research the risks associated with using certain substrates as feed in insect production for animal feed. Thereafter, where appropriate, legislation widening the categories of substrate permitted for use in insect protein production.

Rationale: The purpose of permitting further categories of substrates to be used in insect protein production is to utilise surplus food and resources that would otherwise go to waste, in line with circular economy principles. Current legislation only allows certain materials to be utilised as substrates, including vegetables surplus, bakery surplus, brewers' grains and surplus whey. When the UK leaves the European Union on 31 December 2020, the responsibility of food safety will lie with the Food Standards Agency, rather than being prescribed at the European level by the European Food Safety Authority (EFSA).

Action: Food Standards Agency to be mandated by Government to review the risks associated with using certain substrates as feed in insect production for animal feed between 2022 and 2024. Proposed priority substrates for focus include former food stuffs and food surplus from retail and manufacturing (including bakery surplus with animal by-products). This could be supported by wider research through academia and/or other funding pots such as Innovate UK (see Recommendation 7).

If the Food Standards Agency determine the parameters for demonstrating safety, there is also an opportunity for the scientific community and industry to present research to demonstrate compliance. This could be through privately funded research or wider

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[172] DEFRA, Farming for the Future: Policy and progress update, February 2020.

initiatives, such as Innovate UK or H2020 funding. Following a full risk assessment of these materials, where appropriate, legislation widening the categories of substrate permitted for use in insect protein production should be addressed by Government, with the intention of having a wider selection of substrates being made available to insect farmers by the end of 2026.

Responsibility: Government, Food Standards Agency and the scientific community.

Timeframe: 2021-2026

RECOMMENDATION 6: Legislative amendment to permit food business operators to supply permitted materials into feed chain (dual registration option).

Rationale: The bigger picture is lack of insect-specific legislation (see above). Separate to Transmissible Spongiform Encephalopathies (TSE) prohibitions, it is recommended that general restrictive Food Business Operator (FBO) obligations are reduced for insect farmers and businesses supplying food / feed products to insect farmers. In particular: permit food business operators (in addition to feed business operators) to place 'feed' on the market without feed business operator registration requirements. EC Regulation 183/2005. This would simplify by-product supply into the feed chain. These amendments would of course require the approval from the Food Standards Agency to ensure health and safety compliance was met.

Action: Government to implement a legislative amendment to permit food business operators to supply permitted materials into the feed chain (dual registration option), subject to approval from the Food Standards Agency and in-keeping the required food safety standards that the feed industry, as the customer of the insect protein sector, will require (e.g. assured products compliant with Feed Materials Assurance Scheme requirements).

Responsibility: Government and Food Standards Agency

Timeframe: 2021

RECOMMENDATION 7: Develop regulations and standards for use of frass as fertiliser and soil enhancer to support a domestic market, in order to diversify revenue stream and strengthen business model.

Rationale: While protein remains the highest value output of insect farming, frass (i.e. insect manure) is the largest output by weight and is itself a valuable fertiliser and soil enhancer. Evidence from other countries shows that a strong domestic market for frass in agriculture and horticulture provides an important secondary revenue stream within the overall insect farming business model. Using frass to return nutrients to the soil and displace fossil-based fertiliser also has considerable environmental benefits.

Action: It is recommended that regulators review the use of frass as a fertiliser and soil enhancer in other countries (e.g. France) and develop a clear framework for its use in the UK.

Responsibility: Regulators

Timeframe: 2021-2022

8.1.3 Research and development

Insect biomass is a relatively new concept in the UK and research has so far been limited. To enable the scaling up of the sector, we identify several areas where further research and development is required to help inform the value chain (including stakeholders, farmers and consumers) on the opportunities and risks associated with insects reared on a range of substrates.

RECOMMENDATION 8: Develop a research agenda that supports an increase in scientific literature and evidence on insect production and its use in animal feed. Where possible, this research should be made publicly available.

Rationale: There is currently limited and often contradictory literature available with regards to insect farming, particularly within a UK context. Further research is required to build confidence within the value chain for producing and utilising insect biomass products that are safe, sustainable and economically viable.

Action: The industry (including retailers, feed producers and insect producers) need to campaign for greater research to be conducted on insect production, including on the environmental impacts, feasibility and health and safety of insect farming. The research could be integrated into Innovate UK and UK funding schemes, including via Research Councils UK, Biotechnology and Biological Sciences Research Council (BBSRC), Natural Environment Research Council (NERC) and the Science and Technology Facilities Council (STFC). The purpose would be to build in research over the next decade that provides greater understanding on the practices, opportunities and limitations of insect farming in the UK. Areas of urgent research include:

- Research to confirm the food conversion ratio and production yields of dried insect protein for different species and substrates, to confirm economic viability.
- Research into the safety and viability of by-products (e.g. food surplus, manure, animal by-products etc.).
- Research into the environmental credentials of insect production to confirm its advantages or disadvantages (see Recommendation 14).
- Research on nutritional studies to 'benchmark' insect proteins, such that these studies can indicate the economic or biological value in different applications, including aquaculture (salmon), pet food, poultry and pig feed.
- Research to evaluate the safety of animal by-products for use as a feedstock for insects, and safe for subsequent use in animal feed and then consumption by humans.

It will be important for the industry to work with the various academic institutions already working in this space to coordinate an effective response for increasing the volume of scientific literature, to evidence the impacts of conducting insect farming in the UK.

Responsibility: The industry to work with academia already working in this space, and then to campaign Innovate UK and Research Councils to develop a research agenda around insect protein.

Timeframe: 2021-2030

RECOMMENDATION 9: Support and encourage on-farm trials that are reflective of commercial considerations to demonstrate insect production on a range of scales, utilising a variety of species and substrates.

Rationale: Small- and large-scale trials should be conducted to test and demonstrate research within a commercial context. Funding and support are required for projects to prove the operational and business model; project the unit economics at scale; and assess the market opportunity. This could include, for example, demonstrating insect production on a range of different substrate materials, with various species of insects, or within a range of different animal feeds. This will enable the feasibility of insect farming to be showcased and help to promote the potential to prospective private investors.

Action: Following dedicated research around the practices, impacts and opportunities of insect farming (see Recommendation 8), research programmes that allow test and trials and demonstrate insect farming on a range of scales will be required. This could include making use of funding pots such as Innovate UK and the UK funding bodies (including Research Councils UK, Biotechnology and Biological Sciences Research Council (BBSRC), Natural Environment Research Council (NERC) and the Science and Technology Facilities Council (STFC)) or more applied funding pots such as UK Research and Innovation (UKRI) or government-backed innovation funding.

Responsibility: Innovate UK and Research Councils

Timeframe: 2021-2028

8.1.4 Industry collaboration

For the insect value chain in the UK to grow and eventually become established as a world-leading sector, collaboration across the value chain from farm to fork will be required. We identify several recommendations to help develop collaboration.

RECOMMENDATION 10: Agricultural industry and UK Government to develop and publicise a UK protein strategy to position the requirement for protein in feed.

Rationale: There is currently no clear direction from UK Government around how and where protein for food and feed should be sourced. In Europe, the European Parliament adopted a Report in April 2018 calling for a 'European strategy for the promotion of protein crops – encouraging the production of protein and leguminous plants in the European agriculture sector'.[173,174]

Action: It is recommended that the UK Government holds a consultation with industry and stakeholders on a UK protein strategy, in order to position the requirement for protein in food and feed, whilst considering the environmental implications of imported protein sources (e.g. South American soybean meal). The strategy should consider all potential sources of protein (which would include insect protein and processed animal proteins) and assess the opportunities and markets for both domestically produced and internationally produced protein sources. There is a role for industry and stakeholders across the

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[173] Report from the Commission to the Council and the European Parliament on the development of plant proteins in the European Union. Available at: https://www.arc2020.eu/wp-content/uploads/2018/11/report-plant-proteins-com2018-757-final_en.pdf [Accessed 29 Sep. 2020]

[174] Report on a European strategy for the promotion of protein crops – encouraging the production of protein and leguminous plants in the European agriculture sector (2017/2116(INI)). Available at: https://www.europarl.europa.eu/doceo/document/A-8-2018-0121_EN.pdf [Accessed 29 Sep. 2020]

agricultural sector and supply chain to campaign for and support in the development of the strategy.

This recommendation also aligns with that suggested by IBCTFG (2019): "*The UK Government to issue a national statement of support for this innovative and emerging technology with significant potential impact for the UK economy and its sustainable agricultural productivity."* (IBCTFG, 2019).

Responsibility: Government with consultation with industry

Timeframe: 2021

RECOMMENDATION 11: Development of a formal body/organisation in the UK which represents the interests of the insect production sector towards UK policy makers, UK stakeholders and citizens.

Rationale: In Europe, the International Platform of Insects for Food and Feed (IPIFF) represents the interests of the insect production sector towards EU policy makers, European stakeholders and citizens. Composed of 66 members, IPIFF promotes the use of insects for human consumption and insect-derived products as a top tier source of nutrients for animal feed.[175] Whilst IBCTFG and the Woven Network represent key stakeholders across the insect biomass value chain in the UK, there is no organisation that is formally recognised by UK Government.

Following Britain's exit from the EU, it is recommended that a formal body/ organisation is developed to represent the interests of the insect production sector in the UK and to promote the development of the production of UK insect biomass, positioning UK derived insect production on both the UK and international markets. In addition, it should be the responsibility of the newly formed organisation to effectively position insect meal in the market, providing clear rationale and potential of the protein source as a soybean meal or fishmeal replacer.

Action: The industry needs to come together to identify how such a group should be formed and for individuals to take ownership of such a group. This will include determining the purpose of the proposed group and what it intends to do (e.g. a lobbying group, advisory group etc.). We recommend that the UK Insect Biomass Forum (formerly known as IBCTFG) or the Woven Network arrange an initial meeting with industry representatives to kick-start the process and determine the best route for the formation of a new central body. To ensure equal representation from across the insect biomass value chain, it is recommended that there are not barriers to entry for smaller businesses (i.e. through hefty membership fees) so that the central body can incorporate the best interest from the whole supply chain.

This recommendation also aligns with that suggested by IBCTFG (2019); "*Government and industry to support a central body to bring all stakeholders together to achieve aligned, rapid development of the sector for the UK and render it world leading inside the requisite national infrastructure."* (IBCTFG, 2019).

Responsibility: Industry representatives to come together to determine how and who should form a representative body. This could be kick-started via current platforms such as the UK Insect Biomass Forum (formerly IBCTFG) or the Woven Network.

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[175] International Platform of Insects for Food and Feed (IPIFF). Available at: https://ipiff.org/ [Accessed 29 Sep. 2020]

Timeframe: 2021-2025

RECOMMENDATION 12: Retailers to encourage the use of insect protein as feed within their supply chain and to release a public statement of intent

Rationale: Whilst the potential demand for insect meal in animal feed can be projected using modelling, realising this demand will require intent and action from the industry (e.g. retailers) to make this change. This will require retailers to work with and encourage their supply chain (e.g. feed producers, fisheries and farmers) to utilise insect protein as part of an animal's diets. In the first instance, this intent should focus on the use of insect meal in fish feed within aquaculture production. Emphasising that this option is already authorised under UK law and promoting that fish eat insects as part of their natural diet (insect meal just provides a more efficient way of enabling this), will enable the public to become aware of the concept. As legislation changes, a further statement of intent to include insect meal in pig and poultry feed for animal derived products (e.g. meat or eggs) should then be much easier to achieve as consumers will already be open to the idea.

Action: A public 'statement of intent' should be provided from retailers and their feed producers and suppliers, indicating that more of the feed that is fed to animals within their supply chain should contain insect meal. This should outline the associated benefits (and risks) compared with other types of animal feed (e.g. fishmeal and soybean meal). This would help to demonstrate demand for the product, show acceptability of insects as feed to consumers, and provide confidence to potential investors looking to support in upscaling insect biomass production.

Responsibility: Retailers and their feed producers

Timeframe: 2021

RECOMMENDATION 13: The development of a Publicly Available Specification to create structure and consistency within the insect value chain.

Rationale: In the absence of formal standards within the insect value chain, the development of a Publicly Available Specification (PAS) to define good practice for products, services or processes derived from insect biomass production would help stimulate growth in the sector. A PAS can improve the quality of a whole industry, encouraging mutual support and collaboration, whilst influencing the marketplace; and can accelerate innovation or create an industry solution by bringing a steering group of experts together, whilst sharing knowledge and expertise to drive industry growth.[176]

In addition, the standard would help to present the concept of insects as feed to citizens in a coherent and informed manner. Consultation with industry and some initial consumer engagement to explore what aspects of feeding insects to livestock would be of interest, concern, or help to be seen to be adding value to meat products will be required, especially if animals reared on insect meal (as part of their diet) is sold at a premium compared with other feeds (e.g. soybean meal).

Action: The development of a PAS, led by the British Standards Institute (BSI), within the next two years would help to bring conformity around the practices and expectations of the insect biomass sector in the UK. The process should include consultation and involvement from the British Retail Consortium, feed industry assurance schemes such as Feed Materials

[176] BSI – What is a PAS? Available at: https://www.bsigroup.com/en-GB/our-services/developing-new-standards/Develop-a-PAS/what-is-a-pas/ [Accessed 29 Sep. 2020]

Assurance Scheme, and UK assurance schemes such as Assured Food Standards (Red Tractor) and Lion Eggs, as well as retailers, insect farmers and other stakeholders. A collaborative effort and agreed upon position on insect feed within UK food chains, along with dialogue across the value chain from retailers to producers to produce agreed upon conditions, would help to present the concept to citizens in a coherent and informed manner.

Responsibility: BSI with representatives from industry and sponsorship or funding from industry organisations

Timeframe: 2021-2025

8.1.5 Social and environmental considerations

The acceptability of utilising insects within animal feed to consumers, retailers and other stakeholders is a key barrier that will need to be overcome. This includes understanding and promoting the benefits of insects (socially and environmentally) over alternative protein sources (e.g. soybean meal or fishmeal). We provide the following recommendation to help achieve this goal.

RECOMMENDATION 14: To conduct a standardised life cycle assessment of insect protein production to understand its true carbon and environmental footprint, which can then be compared with the footprint of fishmeal and soybean meal

Rationale: Insect protein is suggested to have a lower environmental footprint than soybean meal and fishmeal, with a lower carbon footprint, reduced land use requirement and little or no impact on biodiversity (e.g. rainforests, fish stocks etc.). However, for the industry to demonstrate these credentials, a full life cycle assessment is required to provide the evidence that backs these claims.

Action: A full life cycle assessment to be conducted that assesses the environmental and carbon footprint of insect production.

Responsibility: Industry

Timeframe: 2021-2023

RECOMMENDATION 15: Development of UK-level marketing strategy to educate consumers and promote the social and environmental benefits of insect farming compared with alternative proteins (e.g. soybean meal and fishmeal).

Rationale: As the insect value chain develops, ensuring consumers are accepting of the concept, methods and processes involved will be critical. Whilst insects are widely consumed (either directly as food or indirectly as animal feed) in many regions globally, the notion of farming them at scale for processed animal protein is relatively new and unformed in Europe. However, the concept of animals eating insects as part of their natural diet is well formed, for example, free-range chickens eat insects in the yard.

To date, the availability of scientific literature for UK insect farming is limited (see Recommendation 8). Building consumer understanding, perceptions and acceptance of insect farming will require education and awareness raising around the potential of insects as feed as an alternative source of protein for animals.

Action: It is recommended that a UK-level marketing strategy is developed to enhance consumer acceptability of insects as an alternative protein source within animal feed. This will require educating consumers on the various aspects of insect production that make this product more suitable than alternatives (e.g. fishmeal or soybean meal). This strategy could be driven by an environmental NGO and focus on key benefits for UK-produced proteins which reduce environmental impacts in key sourcing regions (e.g. deforestation in South America for soybean production). Other areas of focus may include the green agenda for sustainable use of Earth's resources, enhanced bioeconomy and better use of currently wasted materials, dietary or nutritional benefits that may arise for animals or humans through consumption of insect-based products, and the implications for animal welfare compared to current feedstocks.

Responsibility: WWF and other environmental NGOs to step up and take the lead, with support from retailers to promote animal products that have been fed on insect protein.

Timeframe: 2021-2030

8.1.6 Economic incentives and financial viability

As with many new and innovative industries, for the insect biomass sector to be both financially viable and cost competitive, financial support for early adopters will be critical whilst the marketplace becomes established. For insect meal to compete with alternative proteins, particularly soybean meal, the cost of production will need to be vastly reduced or subsidised. We identify recommendations that would support the commercial viability of insect production in the first few years whilst the sector become established.

RECOMMENDATION 16: Implementation of a platform or mechanism to support collaboration and investment, which enables private investors to have confidence in funding the commercialisation of insect production on a larger scale.

Rationale: Significant private or Government investment is required to get insect production from concept to commercialisation. In the UK there are currently no industrial-scale facilities in operation. However, the start-up Entocycle has secured funding to build the UK's first industrial scale facility; including $8 million in funding from private sources and a £10 million investment from UK Government through the Industrial Strategy Challenge Fund (ISCF). This initiative is also being backed by Tesco who may provide some of the feedstock and are working with some of their fish suppliers to use insect-based feed from the facility.[177]

For other current small-scale start-ups or prospective start-ups to enter the market, similar cash injections from either financial institutions, private investors or Government will be needed. A statement of intent from retailers and their feed producers and suppliers, indicating that more of the feed that is fed to animals within their supply chain should contain insect meal (see Recommendation 12), would help to demonstrate demand for the product and provide confidence to potential investors.

Action: A platform or mechanism should be developed that helps connect prospective insect producers to access investment and funds to support with the relatively high start-up costs. Venture companies, leading commercial organisations, government-backed investment or collaborative schemes (e.g. Innovate UK) would provide a source of funding that enables new entrants to the market to establish, as well as allow current insect producers to access funding for upscaling. In the first instance, insect meal could be used in fish feed and this should be the primary market. Subject to legislative changes, the market can then be opened up to applications within livestock feed also (e.g. poultry and pigs).

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[177] Financial Times – Industrial-scale UK insect farm secures government backing. Available at: https://www.ft.com/content/8b75a37e-ad8a-4845-978e-ca14f5fbcb59 [Accessed 30 Sep. 2020]

This recommendation also aligns with that suggested by IBCTFG (2019): *"Government to collaborate with private industry to secure dedicated funds to help insect producers reach the market, achieve cost competitiveness, respond to the identified research and process development gaps (for example in livestock welfare) and to open up new lines of commercial opportunity (for example for soil health)."* (IBCTFG, 2019).

Responsibility: Financial institutions, private investors (e.g. retailers or feed suppliers) and Government

Timeframe: 2021-2028

RECOMMENDATION 17: Government to consider short-term fiscal incentives to enable insect protein to be cost-competitive.

Rationale: Insect protein provides an alternative novel option for use in animal feed that could displace current choices, which include fishmeal and soybean meal. However, soy is currently imported from South America and other regions for comparatively low prices compared to insect meal, limiting the scope to compete on a price-only basis. Unless the environmental costs of soy are considered (e.g. deforestation) (see Recommendation 10), to become a viable alternative, insect production will require either private funding or Government driven financial instruments. In the first instance, an assessment of the environmental impacts of insect protein production (see Recommendation 8), including a full life cycle analysis (LCA) (see Recommendation 14) is required, alongside an assessment of the deforestation risk of UK imported soy.

Action: In addition to changes to farming subsidies (see Recommendation 4), and other financial incentives (see Recommendation 16), short-term financial incentives would further enhance the insect biomass industry to establish. Encouragement could come in the form of short-term fiscal incentives (e.g. tax measures geared to encourage industrial development), or through amending the taxes on the importation of commodities (e.g. soybean meal) that have come from non-sustainable sources.

This recommendation also aligns with that suggested by IBCTFG (2019): *"Government to devise and provide short term fiscal incentives for discounting domestically produced insect protein costs for early adopters/ innovators to incentivise the UK animal feed industry to introduce insect based protein as part of its feed strategies so as to help insect producers achieve cost competitiveness during the period of ramp up of scale."* (IBCTFG, 2019).

Responsibility: Government

Timeframe: 2021-2025

RECOMMENDATION 18: Review whether existing financial and regulatory structures to support AD result in unfair competition for feedstock with higher-value, environmentally preferred uses, such as insect farming.

Rationale: With the emergence of insect farming and other innovative bioeconomy sectors, it is necessary to review fiscal and regulatory supports for domestic AD to ensure they are consistent with the waste hierarchy, and support maximising economic value and environmental benefit from organic resources.

In the same way that the Government over the last decade or so has diversified energy policy away from fossil fuels to include cleaner, greener energies (e.g. nuclear, wave, wind and solar), so must the Government diversify protein. Plant-based proteins have become increasingly more important to UK food and feed but are often sourced from regions where production is both unsustainable and destructive to the natural environment. The

Government has a role to encourage other protein sources (e.g. insects) for direct and indirect consumption to be sourced in a way that is sustainable and protects the social, economic and environmental status of the region's growing these commodities (see Recommendation 10).

Action: It is recommended that a market study be conducted to determine the going rate, and destination, of substrates suitable for insect feed. These findings can then inform whether any policy changes are required.

Responsibility: Government or industry body to commission an independent review

Timeframe: 2021-2022

8.1.7 Technological advancements

Technology and facilities for insect production are currently limited to a few core methods of production, often around layered trays, which require large investment to cover up-front cost of assets, equipment and resources. Investment and innovation to drive reductions in expenditure, similar to that seen in other technology (e.g. solar panels) as the market became more developed and established, will enhance the financial viability of insect biomass production.

RECOMMENDATION 19: Development of an insect protein technology roadmap that specifically outlines a pathway for how innovation in insect production equipment, technology, processes and facilities will be developed to increase capacity and efficiencies, as well as drive down overall costs associated with capital and operation expenditure.

Rationale: For both industrial- and micro-business-scale insect biomass facilities to become economically viable, the cost of equipment and technology will need to improve, alongside advancements in the current technologies that can increase automation and lower operating costs. This includes ensuring that the production methodology is environmentally efficient and enabling off-the-shelf technologies to encourage new entrants into the sector who aren't involved in the R&D stage but seek to purchase the technology. One option to achieve this is through a technology roadmap; a flexible planning technique to support strategic and long-range planning, by matching short-term and long-term goals with specific technology solutions.

Action: It is recommended that an insect technology roadmap is produced that specifically outlines the current status of insect production technology and which develops a pathway for how innovation in insect production equipment, technology, processes and facilities will be developed to increase capacity and efficiencies, as well as drive down overall costs associated with capital and operation expenditure. This should include the potential development of technology to support micro-businesses or on-farm production.

Responsibility: Insect technology providers in collaboration with insect farmers

Timeframe: 2021

8.2 Overview of recommended priority actions

8.2.1 Top ten priority actions

The following actions, listed in priority order, have been identified as the most critical actions that need to be taken for insect biomass production in the UK to achieve the projected volumes of production outlined above:

1. Implementation of the roadmap and recommendations to support the scaling of insect protein and to enhance the environmental credentials of animal feed produced and consumed in the UK.
2. The introduction of legislation permitting the use of insect derived processed animal protein to be used in feed for farmed poultry and pigs intended for human consumption.
3. The development and publication of a UK protein strategy to position the requirement for protein in feed.
4. Development of a formal body/organisation in the UK which represents the interests of the insect production sector towards UK policy makers, UK stakeholders and citizens.
5. Implementation of a platform or mechanism to support collaboration and investment, which enables private investors to have confidence in funding the commercialisation of insect production on a larger scale.
6. Development of a research agenda that supports an increase in scientific literature and evidence on insect production and its use in animal feed.
7. Retailers to encourage the use of insect protein as feed within their supply chain and to release a public statement of intent.
8. The development of a standard (e.g. Publicly Available Specification) to create structure and consistency within the insect value chain.
9. Future agricultural funding / subsidy schemes to be developed that specifically cater for innovative farming methods including the rearing of insects for protein for use in feed.
10. Food Standards Agency to be mandated to research the risks associated with using certain substrates as feed in insect production for animal feed.

8.2.2 Priority actions by stakeholder group

As a call to action to drive the industry forward and to support the growth of a new sector with huge potential, we identify the following priority recommendations for key stakeholders groups, including UK Government, the aquaculture sector, pork and poultry sectors, retailers, researchers, financiers, and insect producers.

UK Government

Most important recommendations in priority order:

1. **The introduction of legislation by UK Government permitting the use of insect derived processed animal protein to be used in feed for farmed poultry and pigs intended for human consumption.**
2. Future agricultural funding / subsidy schemes developed by Government to specifically cater for innovative farming methods including the rearing of insects for protein for use in feed. This should include recognition that the production of insect protein for animal feed is an agricultural activity.
3. Development of a formal body/organisation in the UK which represents the interests of the insect production sector towards UK policy makers, UK stakeholders and citizens.
4. Agricultural industry and UK Government to develop and publicise a UK protein strategy to position the requirement for protein in feed.
5. Food Standards Agency to be mandated to research the risks associated with using certain substrates as feed in insect production for animal feed. Thereafter, where

appropriate, legislation widening the categories of substrate permitted for use in insect protein production.

Aquaculture Sector

Most important recommendations in priority order:

1. **Development of UK-level marketing strategy to educate consumers and promote the social and environmental benefits of insect farming compared with alternative proteins (e.g. soybean meal and fishmeal).**
2. Implementation of a platform or mechanism to support collaboration and investment, which enables private investors to have confidence in funding the commercialisation of insect production on a larger scale.

Pork and Poultry Sectors

Most important recommendations in priority order:

1. **Lobby Government and drive the implementation of the roadmap to support the scaling of insect protein and enhance the environmental credentials of animal feed produced and consumed in the UK.**
2. The introduction of legislation by UK Government permitting the use of insect derived processed animal protein to be used in feed for farmed poultry and pigs intended for human consumption.
3. Support and encourage on-farm trials that are reflective of commercial considerations to demonstrate insect production on a range of scales, utilising a variety of species and substrates.
4. Development of UK-level marketing strategy to educate consumers and promote the social and environmental benefits of insect farming compared with alternative proteins (e.g. soybean meal and fishmeal).
5. Retailers to encourage the use of insect protein as feed within their supply chain and to release a public statement of intent.

Retailers

Most important recommendations in priority order:

1. **Retailers to encourage the use of insect protein as feed within their supply chain and to release a public statement of intent.**
2. Lobby Government and drive the implementation of the roadmap to support the scaling of insect protein and enhance the environmental credentials of animal feed produced and consumed in the UK.
3. Development of UK-level marketing strategy to educate consumers and promote the social and environmental benefits of insect farming compared with alternative proteins (e.g. soybean meal and fishmeal).
4. Development of a formal body/organisation in the UK which represents the interests of the insect production sector towards UK policy makers, UK stakeholders and citizens.
5. Implementation of a platform or mechanism to support collaboration and investment, which enables private investors to have confidence in funding the commercialisation of insect production on a larger scale.
6. Legislative amendment to permit food business operators to supply permitted materials into feed chain (dual registration option).

Researchers

Most important recommendations in priority order:

1. **Develop a research agenda that supports an increase in scientific literature and evidence on insect production and its use in animal feed. Where possible, this research should be made publicly available.**
2. Food Standards Agency to be mandated to research the risks associated with using certain substrates as feed in insect production for animal feed. Thereafter, where appropriate, legislation widening the categories of substrate permitted for use in insect protein production.
3. Support and encourage on-farm trials that are reflective of commercial considerations to demonstrate insect production on a range of scales, utilising a variety of species and substrates.
4. To conduct a standardised life cycle assessment of insect protein production to understand its true carbon and environmental footprint, which can then be compared with the footprint of fishmeal and soybean meal.
5. Development of an insect protein technology roadmap that specifically outlines a pathway for how innovation in insect production equipment, technology, processes and facilities will be developed to increase capacity and efficiencies, as well as drive down overall costs.

Financiers

Most important recommendations in priority order:

1. **Implementation of a platform or mechanism to support collaboration and investment, which enables private investors to have confidence in funding the commercialisation of insect production on a larger scale.**
2. Future agricultural funding / subsidy schemes developed by Government to specifically cater for innovative farming methods including the rearing of insects for protein for use in feed. This should include recognition that the production of insect protein for animal feed is an agricultural activity.

Insect Producers

Most important recommendations in priority order:

1. **The development of a standard (e.g. Publicly Available Specification) to create structure and consistency within the insect value chain.**
2. Lobby Government and drive the implementation of the roadmap to support the scaling of insect protein and enhance the environmental credentials of animal feed produced and consumed in the UK.
3. Support and encourage on-farm trials that are reflective of commercial considerations to demonstrate insect production on a range of scales, utilising a variety of species and substrates.
4. Development of UK-level marketing strategy to educate consumers and promote the social and environmental benefits of insect farming compared with alternative proteins (e.g. soybean meal and fishmeal).
5. Implementation of a platform or mechanism to support collaboration and investment, which enables private investors to have confidence in funding the commercialisation of insect production on a larger scale.

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