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DELIVERING INSECT-BASED FEED AT SCALE

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Contents

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Glossary

Term	Definition
Anaerobic digestate	Nutrient-rich substance produced by anaerobic digestion.
Anaerobic digestion (AD)	The decomposition of organic waste material in an oxygen-free environment by microorganisms, typically used as a means of waste disposal or energy production.
Black soldier fly (BSF)	*Hermetia illucens*, a fly species, originating in South America, that is high in protein content and capable of recycling organic waste.
Broiler	A chicken bred and raised specifically for meat production (as opposed to a 'layer', which is bred and raised for egg production).
Chitin	Compound found in adult BSF exoskeletons that, with additional processing, has a range of applications including water treatment, biomedical uses and bioplastics.
De-fatting	Pressing dried BSF larvae to remove oil and prepare them for grinding into meal.
Frass	The excrement or waste produced by insects and larvae after they consume organic matter. Frass can be used in agriculture and gardening as organic fertiliser.
Gate fees	Fees that operators of waste processing facilities charge to process waste (usually given in £ per tonne).
Landspreading	The practice of spreading food waste onto agricultural land, enriching the soil by releasing the nutrients in the food waste back into the soil.
Meal	Powdery substance made by grinding.
Organic waste	Waste originating from living organisms.
Poultry litter	Mixture of poultry excreta, spilled feed, feathers and material, used as bedding in poultry operations.
Price premium	The percentage by which the price charged for a particular good or product exceeds a reference price for a similar good or product.
Processed animal protein	Meat and bone meal, meat meal, bone meal, blood meal, dried plasma and other blood products, hydrolysed protein, hoof meal, horn meal, poultry offal meal, feather meal, dry greaves, fishmeal, dicalcium phosphate, gelatin and any other similar products – including mixtures, feedingstuffs, feed additives and premixtures – containing these products.
Substrate	The material from which an organism lives, grows or obtains its nourishment.
Thermal recovery	The process of incinerating food (and other) waste to capture and reuse the energy released in the form of heat.

Executive summary

The case for insect-based animal feed

The environmental impact of food systems is increasingly in focus for industry, policymakers and consumers and is recognised explicitly in the UK government's food strategy.[1] Reducing this impact will require widespread changes in production methods and consumption patterns, across food supply chains. One such area of potential change relates to animal feed, in particular the use of soy as an input to feed for poultry and pork.

Soybean, the main protein input into poultry and pig feed, requires large tracts of land, much of which is converted from ecologically important forest, savannas and grassland.[2] World soybean production has almost doubled over the last two decades. This reflects its performance as a high-protein crop with multiple uses in food supply chains, but has increased the burden it places on local ecosystems and the climate.

The UK food industry is already taking steps to mitigate the environmental impact of soy, through for example the UK Soy Manifesto.[3] However, there is pressure to do more, including a search for alternatives to displace soy. In this context, Frontier Economics has been engaged by Circular Food Systems to explore the potential for black soldier fly (BSF) to become an economically viable alternative to soy as the protein input to animal feed. BSFs can be processed into meal for animal feed (and fish feed), and can be reared on a range of organic waste streams, including household and agricultural waste.[4] BSF has the potential to embed meat production within the circular economy, which could carry environmental benefits that include displacing soy.

Although permitted in the EU for pigs, poultry and aquaculture, UK feed safety regulations currently prohibit the use of BSF in feed for livestock (aquaculture is permitted) – and recent regulatory change, to align with the EU, has stalled. This report explores the opportunity presented by using BSF in animal feed, considering the economic feasibility of its use and highlighting the barriers to overcome if it is to scale – including regulation. This will form the basis of the next stage of Circular Food Systems, to engage with stakeholders and agitate for change in the context of the climate emergency.

The necessary conditions for scaling up

The outlook for scaling up BSF is positive. BSF is a high-performance protein source with potentially positive impacts on animal health; animal feed producers are open to exploring alternatives to soy as a protein source; BSF meal would be relatively straightforward to

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[1] https://www.gov.uk/government/publications/government-food-strategy/government-food-strategy

[2] https://wwf.panda.org/discover/our_focus/food_practice/sustainable_production/soy/

[3] https://www.uksoymanifesto.uk/

[4] https://www.betabugs.uk/

integrate into current feed production processes; and investors have a keen appetite to finance initiatives with environmental benefits.

"We are very open to and recognise the need to consider alternative protein sources. Ensuring consistency of volume and quality, alongside commercial viability, will be the main factor needed to integrate insect protein in the supply chain."
Managing Director, UK traditional feed manufacturer

"There is a lot of investor interest, both for equity and debt investments, in this space – investors are looking to deploy private capital in European tech with a positive impact."
Partner, early-stage venture capital firm

BSF is a promising alternative to soy in principle. To make this a reality, two changes in the market are required:

- **BSF protein must become price-competitive with soy**. BSF meal is currently five to six times the price of soybean meal. Protein is a core ingredient in animal feed, and animal feed represents the biggest cost in the production of chicken and pork. At current prices, switching from soy to BSF would have a major impact on retail prices: BSF-fed meat would be c.50% more expensive. Although consumers are increasingly paying attention to sustainability, there is a limit to how much of a premium consumers will pay for sustainable food. For example, less than 1% of UK poultry meat produced is organic. Put simply, from the consumer perspective, the cost differential between soy and insect-based feed would need to be considerably narrower for any switch to take place at scale.

- **Further investment in capacity is needed**. The current UK production capacity for BSF-based protein is very small; negligible volumes are produced, and what is produced is used in niche applications such as luxury pet food. By contrast, an estimated 6 million tonnes of pig and poultry feed, containing c.550,000 tonnes of protein, was required in 2022 to meet demand for chicken and pork production. Substantially more investment in capacity is required if BSF is to become a credible alternative to soy.

These two requirements are related. If the cost of production for insect-based feed can be reduced, then the volume of demand will increase, which will in turn increase the incentives for BSF operators to invest in increasing their production capacity. So, the key question is whether there is a feasible way to reduce the cost of production for insect-based feed.

"Cost, availability and continuity of supply are the most important factors for farmers when it comes to feed. Soy is the benchmark against which other feeds are measured."
Senior Consultant, UK agricultural consultancy

"Supermarkets are keen to engage in this type of innovation, but for change to happen at scale the impact on the price for consumers will need to be limited."
Director, UK grocery retailer

Overcoming regulatory barriers to scaling up

The regulatory regime for animal feed in the UK is the main driver of the high cost and low capacity of current BSF production. Two regulatory changes would be needed to support future scaling up of BSF in animal feed:

- **Allow insect-based feed for land-based livestock**. It is clear this needs to happen for insect-based feed to scale (for the purpose of this report we do not focus on the detail of this change). However, this change alone will not be sufficient to unlock change at scale. This is demonstrated by recent experience in EU: legislation now permits the use of insect-based feed for poultry and pigs, but the market has not scaled.

- **Expand the range of allowable waste streams for insect farming to include cheaper and more plentiful options**. BSF can feed on any form of organic matter, opening up a wide set of potential waste streams (substrates) that can be used to feed it. However, current regulations mean that several major categories of waste cannot be used, including household waste, catering and some farm food waste, chicken litter, cattle manure, and digestate from anaerobic digestion (AD). Only a small volume of waste substrates are permitted for use in BSF production, and these are more expensive. Even if the full 3.8 million tonnes per year of these permitted substrates were diverted to BSF, this would only be enough to displace around one-third of soy demand – and the price would be too high to scale.

> *"Regulation is the single greatest barrier to bringing down the cost of insect protein in the UK."*
>
> **CEO and Founder, UK BSF farming company**

At present, waste substrate is the main cost in BSF production, as regulations restrict BSF producers to more expensive substrates that have alternative uses. Unlocking more substrates, many of which would come at much lower cost, could significantly reduce the cost of BSF production (BSF could even create additional income from some of this waste, the producers of which would otherwise have to pay to dispose of). This would lower the cost of insect-based feed relative to soy-based feed. In addition, assuming demand increased in response to the reduced cost, this could unlock further economies of scale in production. Finally, unlocking wider waste streams for use in BSF production would also increase total production capacity, as the total volume of BSF that can be produced depends on the total volume of substrate consumed.

Beyond regulation

Regulatory change is the first step in the path to scaling up BSF production, and is the basis from which to develop commercially viable models to scale production. A wide range of BSF business models are feasible in principle, both in terms of the waste sources used and the scale of site – from micro sites at chicken farms to larger sites close to major waste producers, or the waste collection systems of whole towns.

One of the key operational factors is how the waste streams would be collected, sorted and transported to the BSF production facilities. This could be difficult for some waste streams. For example, around half of UK local authorities do not carry out separate household food waste collection. For other waste streams, different operating models for BSF production may result – for example, locating a facility close to a specific waste producer, with the size of site scaled accordingly. It is not in the scope of this report to define a single future state for BSF production, other than to note a mix of models is likely to emerge.

Charting a path to scale

To give a sense of scale, for insect-protein to displace a quarter of annual UK demand for soy protein, with minimal impact on retail price, c.140,000 tonnes of insect protein would be required, priced at around £500 per tonne of BSF meal, and potentially requiring £500 million to £1 billion in upfront production capacity investment.

Assuming the regulatory barriers can be overcome, one promising route to accomplishing the above would be to focus on retail, manufacturing and farm food waste, as well as anaerobic digestate. The economics of these waste streams are favourable relative to others, given the combination of cost, availability and practicality of access – in particular for retail and manufacturing waste, given the scope to generate revenue from waste processing and existing consolidation of some waste processes.

As an illustration, if 25% of each of the above waste sources was used for BSF production, our initial cost modelling indicates that up to 157,000 tonnes of protein, at around £650 per tonne of BSF meal, could be produced.[5] This would be sufficient to displace c.28% of current annual UK demand for soy protein in poultry and pig feed, with relatively low impact on the overall cost price for pig or poultry production. Adding wider waste streams could increase the production potential further (although these may face additional barriers of cost and complexity).

Displacing this volume of soy would represent a promising opportunity. It could support an insect-farming industry worth between c.£130 million and £170 million, transform over 3.1 million tonnes of waste into productive material, and support broader objectives to improve UK food security. While there is not a necessarily a direct link between UK soy consumption and deforestation,[6] displacing this volume of soy would also be equivalent to the output of c.165,000 hectares of rainforest cleared for soy production.

If soy prices were to increase in the future, this would make it easier for BSF to become cost-competitive. This could happen if climate change or policy developments increased the relative price of soy, and there may be early indications of such a change – deforestation rates are

[5] The protein content of BSF meal and soy meal is not the same, so figures for their price per tonne are not directly comparable. The competitiveness of BSF against soy is determined by price per kg of protein.

[6] In practice, soy will come from a range of sources and countries, with a UK Soy Manifesto commitment by industry *"to work together to ensure all physical shipments of soy to the UK are deforestation and conversion free".*

generally falling and there is an emphasis on conserving land, which may hinder greater soy production. There is no evidence yet of significant price changes on the horizon, but nonetheless, this demonstrates an additional benefit of preparing BSF as an alternative to soy, from a food security perspective.

A way forward: calls to action to unlock change

BSF is an exciting space with a wide array of potential operators and investors. A number of UK-based operators focused on advancing the technology have emerged, and some UK retailers are trialling the wider use of BSF in permitted applications. To scale its use in animal feed, we have identified five calls to action that could help pave the way:

1. **Regulatory change on use of insect-based feed for livestock**. Legislative progress to overcome the initial regulatory barrier on the use of BSF protein in poultry and pig farming stalled in 2020. This needs to be addressed to unlock any change.
2. **Regulatory change on permitted waste streams for BSF**. Defra and the Food Standards Agency should consider making regulatory changes to open up cheaper and more plentiful waste streams for BSF. Achieving this would require political support for change and adequate resourcing for the necessary trials, to satisfy any safety concerns about the range of possible substrates.
3. **BSF site trials**. Trialling different operational models will be key to establishing which models are economically viable and identifying the best partners across the food and waste value chains. There are already signs of UK-based BSF operators exploring different options, based on commercial incentives. A sponsor could help to encourage further trials. This may be a role for Circular Food Systems, or those with a view on food system innovation.
4. **Food retailer engagement**. Retailers and restaurants play an important role in shaping meat supply chains – they set the product specification and how it is positioned with consumers. Circular Food Systems may wish to engage with the sector to explore ways of trialling new feed types, repurposing food waste to BSF sites, or even testing consumer appetite for ‘soy-free’ product ranges. All of these could help ignite meaningful change.
5. **Capital support**. Subject to the BSF models that emerge, financing support for BSF farmers could help to kick-start production on a wider scale. Current evidence indicates there is sufficient investor interest. As the market evolves, this may be an area where the government could help, given that scaling up BSF aligns with Food Strategy goals and could help achieve net zero targets. Alternatively, philanthropic donations could be a way of accessing the necessary kick-starter funding.

Achieving the positive change that BSF could unlock is possible. It is likely to be a longer-term project – in particular, the required regulatory change will take time to achieve. That means that building a groundswell of support for the above calls for action will be crucial in generating momentum. Given the urgent need to address the climate and biodiversity crises, immediate action is required to unlock the substantial benefits of BSF. With the UK regulatory regime currently under review, the time to act is now.

1 Introduction

Purpose of this report and inputs

This report explores the economic feasibility of delivering insect-based feed at scale in the UK. It draws on a variety of inputs including interviews carried out with stakeholders from across the supply chain;[7] publicly available information from previous work in this area, including the WWF Future of Feed report; cost modelling of the economics of BSF production and path to scale; and wider Frontier expertise on food supply chain and policy issues.

The report does not focus on detailed technical requirements or food safety assessments, other than noting where regulations currently present a barrier to scale and where regulatory change in these areas would be required to make progress. Further research into the microbiological, health and safety considerations of the most abundant organic substrates could significantly aid in scaling insect protein production.

Report structure

The following sections build out the executive summary:

- **Section 2** sets out the case for BSF-based animal feed. It gives an overview of the current role of soy as an input in animal feed and its environmental impact, and introduces what an alternative closed loop for BSF-based feed could look like in principle.
- **Section 3** describes the necessary conditions to scale up BSF-based animal feed, based on the requirements of different actors in the food supply chain.
- **Section 4** identifies the key barriers that exist today that limit the ability to scale up BSF-based feed in the UK.
- **Section 5** highlights potential ways to overcome the barriers identified, and outlines calls to action to enable expansion of the role of BSF-based animal feed in UK.
- The supporting **annexes** contain additional information referenced in the main body of the report, including: (A) overview of UK legislation relevant for BSF-based feed and (as a comparator) the EU regulatory environment; (B) further detail on the modelling used in the report; (C) commentary on the future price of soy; and (D) examples of collaborative sustainability efforts in food supply chains.

[7] Interviewees were chosen on the basis of their experience working in senior roles at organisations that operate at different points in the food supply chain – including BSF producers, traditional feed manufacturers, farmers and retailers. Additional interviews were conducted with investors and regulatory experts.

2 The case for insect-based feed: what it could look like

The environmental impact of the food system is increasingly in focus for industry, policymakers and consumers and is recognised explicitly in the UK government's food strategy.[8] Reducing this impact will require widespread changes in production methods and consumption patterns, across food supply chains. One such area of potential change relates to animal feed, in particular the use of soy as an input to feed for poultry and pork. Exploring sustainable alternatives to soy, such as insect-based proteins, could alleviate the environmental pressures associated with the production and transportation of soy.

Soy production has a large environmental footprint

In recent years, the environmental impact of soybean cultivation has come under scrutiny in food supply chains as sustainability and climate change have risen up the list of public concerns. Soybean is an important source of protein for animal feed and the increased demand for meat and dairy products has led the demand for soy to double in the last two decades. While a sign of its success as a protein source to support affordable food, this growth is associated with extensive deforestation and habitat destruction in some of the world's most ecologically sensitive regions, such as the Amazon rainforest. As a consequence, the production of soy-based feed is associated with increased greenhouse gas emissions in addition to loss of biodiversity from habitat destruction and water pollution from pesticide use.

Just over two-thirds of soy meal and soy cake imported into the UK in 2022 came from Brazil, Argentina or Paraguay.[9] The increase in soy farming is the second largest driver of deforestation and land conversion in these countries (after the expansion of grazing land for cattle).[10] The removal of forests and transformation of native vegetation in Brazil affected 1.6 million hectares in 2018, rising to 1.83 million hectares in 2020; this includes ecologically diverse biomes such as the Amazon, as well as lesser-known regions, such as the Cerrado and the Pampas, that also play an important role in sequestering carbon. Similarly, the Gran Chaco region in Argentina and Paraguay (which also spans Bolivia and Brazil) lost 7 million hectares of native forest between 1998 and 2021 as a result of land clearances for soy and beef farming. This region is an often overlooked but still highly important carbon sink.[11]

The UK consumes approximately 45kg per capita of chicken and pork every year and demand is set to remain stable.[12] To meet this demand, domestic farming and industry requires significant amounts of feed. In 2022, an estimated 1.3 million tonnes of soy meal and soy cake

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[8] https://www.gov.uk/government/publications/government-food-strategy/government-food-strategy

[9] ITC Trademap.

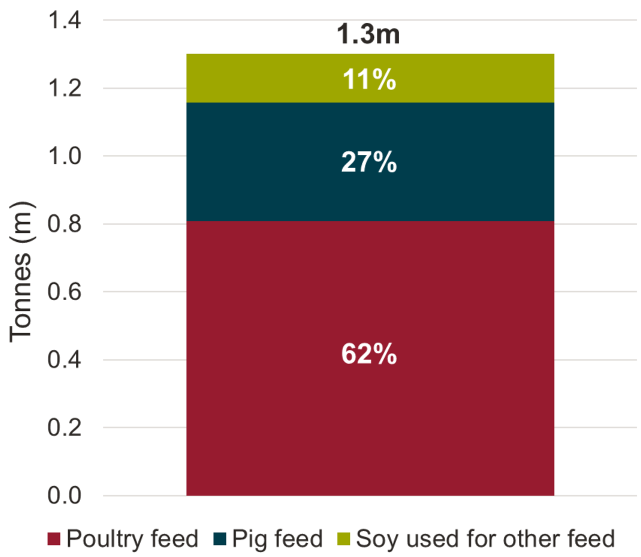
[10] https://www.sei.org/features/connecting-exports-of-brazilian-soy-to-deforestation/

[11] https://www.reuters.com/investigates/special-report/argentina-environment-chaco

[12] OECD-FAO Agricultural Outlook (Edition 2021), data available at https://data.oecd.org/agroutput/meat-consumption.htm, accessed 4 August 2023.

were used for feed production, most of which was for raising poultry and pigs (see Figure 1).[13] Given soy's estimated 48% protein content,[14] this amounts to c.624,000 tonnes of protein, of which around 555,000 tonnes went to poultry and pig feed.

Figure 1 Volume of soy used in UK feed production by type, 2022



Source: AHDB, Defra, WWF; Frontier Economics calculations.
Note: Volume of soy is made up of soy cake and soy meal and does not include beans.

As awareness of the environmental impact of soybean cultivation increases, there have been efforts by British industry to reduce its contribution to this, such as the UK Soy Manifesto launched in 2021.[15] This is a collective industry commitment aimed at ensuring that all soy shipments to the UK are free from deforestation and conversion by 2025 at the latest. However, taken at a global level, this may simply re-direct deforestation-linked soy to other markets lacking similar industry commitments. This underscores the benefit of reducing demand for soy through the use of substitutes – if the UK is able to take a lead on this, others may follow.

Similarly, alternative feed methods exist, such as rearing poultry and pigs on a free-range diet. However, this does not represent a large-scale solution to the problem. For instance, in 2017 only an estimated 3.5% of chickens in the UK were raised using free-range methods,[16] while only an estimated 3% of pigs will spend their entire lives outdoors.[17] Free-range husbandry

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[13] https://ahdb.org.uk/cereals-oilseeds/cereal-use-in-gb-animal-feed-production

[14] Development of a roadmap to scale up insect protein production for use in animal feed, available online here: https://www.wwf.org.uk/sites/default/files/2021-06/the_future_of_feed_technical_report.pdf

[15] https://www.efeca.com/uk-soy-manifesto-launched-on-tuesday-9th-november-2021/

[16] British Poultry Council.

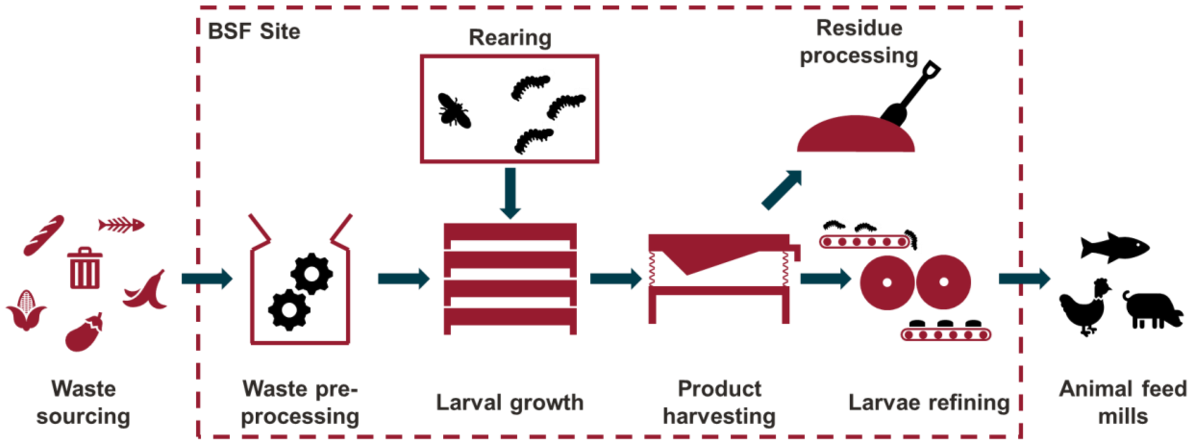
[17] https://www.rspca.org.uk/adviceandwelfare/farm/pigs/farming

requires a significant amount of land, which is becoming a scarce resource in the UK, where other land requirements (from housing to preserving conservation areas) must be factored in. The environmental concerns associated with soy therefore provide the impetus to go further and present a clear need for an alternative protein source for poultry and pig feed.

Black soldier fly as an alternative protein source in animal feed

Black soldier fly (BSF) protein has emerged as a promising and sustainable alternative to soy protein in animal feed. Production of BSF involves a controlled breeding process to rear and harvest BSF larvae; these larvae are a rich source of protein that can be used as an alternative to soy in animal feed. The steps are illustrated in Figure 2 and described below.

Figure 2 Steps in BSF farming



Source: Adapted from Dortmans et al. (2017), Black Soldier Fly Biowaste Processing - A Step-by-Step Guide.

Note: Product harvesting and larvae refining usually include drying and de-fatting steps. Illustration is for a site that includes all necessary steps to get from waste input to meal output that can go to a traditional feed mill.

- **Waste sourcing and processing**. A BSF site requires organic waste – that is, waste originating from living organisms – as one of its primary inputs. This material is referred to as ‘substrate’. In principle any form of organic matter can be used, subject to availability, cost and regulatory restrictions. Currently used examples include fruit and vegetable scraps, brewers’ grains or bakery surplus. The waste needs to be mixed and processed to ensure it has the correct moisture content to be suitable for use.
- **Rearing**. A BSF site provides suitable conditions for adult flies to lay eggs, typically using the substrate to feed the adult flies.
- **Larval growth**. Once the eggs hatch into larvae, they are raised using the substrate, which they convert into protein and fats. The larvae undergo several growth stages before reaching maturity.

- **Product harvesting**: Once mature, the larvae are harvested and separated from by-products.[18] At this stage, while still alive, they are permitted for use as feed since they have not been processed.[19] Indeed, animals raised using organic or free-range methods can and do eat live insects as part of their natural diets. Once processed into animal feed that meets a greater range of an animal's nutritional requirements, insect protein is no longer permitted for use as feed, except in aquaculture.
- **Larvae refining**: The larvae are processed and dried. Although whole dried larvae can be used as a protein source in animal feed formulations, to replace soy meal used in existing feed manufacturing processes in feed mills, a further step needs to occur to create insect meal. The dried larvae are pressed to remove oil, increasing the protein concentration per gram of output, and allowing the larvae to be ground into meal. This step is known as 'de-fatting'.

Varied potential operating models for BSF production

As noted in the executive summary, a wide range of BSF model options are feasible in principle, both in terms of the waste sources used and the scale of site – from micro sites at chicken farms, to larger sites close to major waste producers, to trials involving the household food waste collection systems of whole towns. One of the key operational factors to consider is how the waste streams would need to be collected, sorted and transported to the BSF production sites. Various potential models are available, linked to the waste streams in focus:

- **Vertical integration at smaller sites**. For certain substrates, vertical integration of existing businesses in the food supply chain may offer a way to reduce transportation costs – for instance, 'micro' facilities to process chicken litter on poultry farms. The output from vertically integrated BSF sites could cater to the business's own BSF consumption, or could be sold to feed producers. However, the micro-scale model presents its own challenges. Yields are typically lower due to the reduced waste processing capacity, and to use the BSF larvae as the source of protein in feed manufacturing would still require further processing, and a centralisation of the processing facilities. Having these facilities on-farm would add significantly to the cost because of the purchase of the additional necessary equipment, which can run into the tens of thousands of pounds.
- **Larger on-site facilities**. Farms may consider an alternative model where they construct and operate a larger BSF site on-farm, similar to the approach taken to construction of anaerobic digestion (AD) sites (for further explanation, see 'anaerobic digestate' in section 4). The proximity to a consistent source of substrate for rearing BSF would still help reduce transport costs. Farms located near one another could work together to share the costs of developing these facilities, the revenues they generate and the waste they produce, to create a larger supply of substrate. If operating at sufficient scale, additional processing

[18] The main by-product is 'frass', which is the excrement or waste produced by the flies and larvae after they consume organic matter. Frass can be used in agriculture and gardening as organic fertiliser.

[19] Processed animal protein is animal protein derived from certain material as classified in government regulations. See, for example: https://www.gov.uk/guidance/animal-by-product-categories-site-approval-hygiene-and-disposal

could be added to the site, avoiding the need for separate, centralised processing facilities to convert larvae into meal (saving costs as a result).

- **Integration with existing processes**. Retailers may consider integrating BSF sites into their supply chains. This would provide both a way to process the food waste generated within their operations, and a source of protein that could be incorporated back into their own food supply chains. Retailers are well placed for this given their sophisticated supply chains, existing waste processing and close working relationships with their suppliers.

This variety of models is reflected in the firms focused on insect farming, and BSF specifically, that have begun to emerge in the UK and EU. For instance, UK-based start-up Better Origin has developed shipping container-sized facilities to rear BSF. These facilities are automated and oversee the entire rearing process, including feeding and inspections. They offer an example of the 'vertical integration at smaller sites' approach.

In comparison, in Denmark, Enorm is developing one of the largest BSF production facilities in Europe, targeting an annual production of 11,000 tonnes of BSF meal, which will be used primarily in aquaculture. Enorm received €50 million in funding in January 2022 from a consortium of investors, including DLG (a large agribusiness company), a Danish bank and the Danish government's Export and Investment Fund (EIFO).[20] The investment was made following Enorm's successful pilot of its technology in a plant, which had begun in 2018. The latest round of support is aimed at establishing its testing facilities, scaling up the production facilities and developing its BSF products further. The estimated size and production output of the Enorm facility highlights another favourable point of comparison for BSF versus soy. As an illustration, the Enorm site in Demark will yield just under an estimated 460kg of BSF meal per m^2 per year.[21] In contrast, the average soybean yield for farms is 0.25kg per m^2 per year[22] – implying the annual protein output per square metre for BSF sites is over 2,200 times greater.[23]

Better Origin and Enorm are just two examples among several others driving innovation in insect farming in Europe, with the emerging business model exploring how different site types can be suited to different locations. To pave the way forward, it will be essential to remove regulatory barriers and enable pilot projects to test various business models. These examples show what is possible and underscore the need for regulatory change to enable the roll-out of these innovations at a larger scale and meaningfully displace soy.

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[20] The EIFO provides access to government finance for Danish companies and has a stated ambition of ensuring sustainable growth.

[21] https://www.feedstrategy.com/business-markets/company-news/article/15442720/enorm-biofactory-a-s-to-start-denmarks-first-insect-production

[22] https://www.fao.org/land-water/databases-and-software/crop-information/soybean/en/

[23] When factoring in the respective protein content of BSF meal (59%) and soy (48%), 460kg of BSF meal contains approximately 270kg of protein, while 0.25kg of soy contains approximately 0.12kg of protein.

BSF use in aquaculture

We note that BSF protein can also be used as a replacement for fishmeal in aquaculture. Like soy, fishmeal can be associated with problematic environmental effects, such as overfishing, ecosystem damage and biodiversity impacts. Although this report's findings are also applicable to fishmeal, the remainder focuses on the displacement of soy in poultry and pig feed for two reasons: first, the relatively smaller scale of UK fishmeal use (around 130,000 tonnes in 2022), and second, the fact that fishmeal's higher price (approximately £1,400 per tonne) means that cost is less of a barrier and BSF is more likely to displace fishmeal before soy. Progress in the aquaculture industry can serve as an aspirational blueprint for change in poultry and pig farming.

Other BSF uses by UK food businesses: waste processing and live feed

Beyond the potential use of processed BSF as an input to feed, there is evidence of initial steps being taken to use BSF in other ways in the food supply chain, both as a waste processing technology and by using the live larvae as feed where permitted.

- Morrisons has trialled the use of Better Origin facilities to feed egg-laying hens a BSF-based diet, supplemented with British beans, peas and sunflower seeds. The BSF are fed on fruit and vegetable waste from farms in Morrisons' own supply chain. The eggs produced by BSF-fed hens were rolled out in 2022 in 50 stores in Yorkshire.[24]
- Tesco has been supporting UK start-ups that are exploring the use of BSF protein in chicken and fish feed, and trialling the use of insect feed in its aquaculture supply chain.[25]

These examples highlight steps being taken towards integration with existing processes.

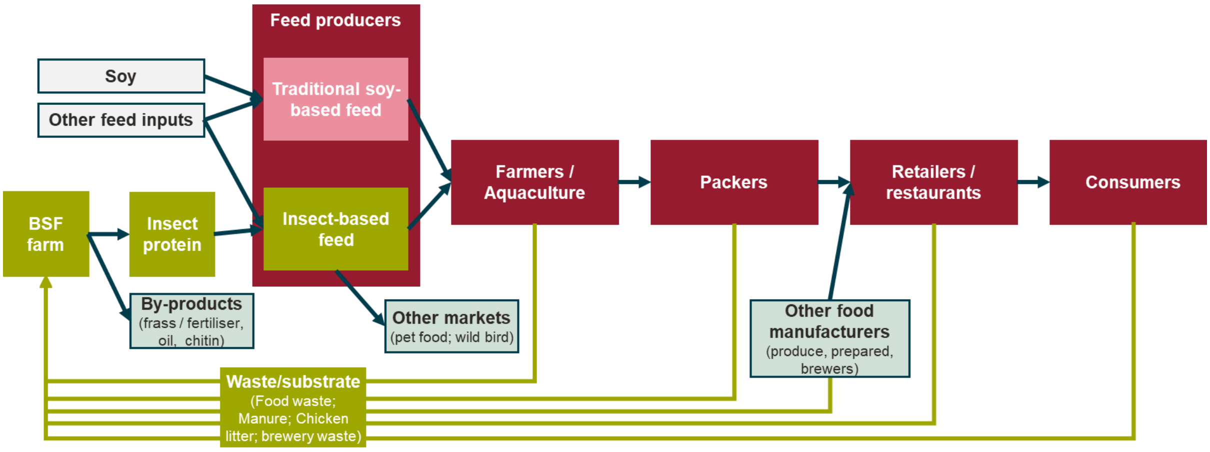
BSF can support the move towards a closed loop in production

The use of BSF has the potential to support a move towards 'closing the loop' in UK food production, as shown in the figure below.

[24] https://www.theguardian.com/business/2022/aug/02/hens-will-be-fed-insects-to-lay-carbon-neutral-eggs-for-morrisons

[25] https://www.tescoplc.com/exploring-the-use-of-insects-as-an-alternative-protein-for-animal-feed/

Figure 3 The role of BSF in a 'closed loop' food production system



Source: Frontier Economics.

Figure 3 sets out a simplified view of a supply chain in which BSF protein, produced using waste streams including food waste, is used as an alternative to soy protein and fishmeal. At each stage, different organic waste streams are generated, which could be processed by BSF farms to produce protein and useful by-products such as frass, insect oil and chitin.[26] The insect protein (derived from the BSFs) that is generated is fed back into the supply chain, enhancing food security by reducing reliance on traditional protein sources and efficiently recycling organic waste materials. This sustainable approach has the potential to contribute to a more resilient and secure food production system in the UK, which is less reliant on imports.

The next section sets out the conditions that are necessary for this circular model to be established around BSF production, to allow BSF-based feed to displace soy-based feed at scale.

[26] Chitin is a compound found in the exoskeletons of adult BSFs. With additional processing, it has a range of applications including water treatment, biomedical uses and bioplastics.

3 Necessary conditions to scale up insect-based feed

Animal feed is a key input to meat supply chains. Any change to feed composition – in this case to change the protein source from soy to insect – would need to meet the requirements of the different actors along the supply chain. These can be split into demand-side and supply-side, as illustrated in Figure 3 above, in which the red boxes represent the demand side and the green boxes represent the supply side. For each side there is a set of conditions that are necessary in order to switch from soy to BSF, and therefore to scale up BSF-based feed. These conditions are outlined in this section.

Demand-side conditions

The key demand-side factors that shape the potential to switch from soy to insect-based feed are: (1) its cost-effectiveness compared to soy; (2) the availability and consistency of supply, as feed producers need a reliable supply of large volumes of protein for feed; and (3) customer acceptance or willingness to try an alternative (applying to farmers and, potentially, consumers). Each of these is explored below.

Cost-effectiveness

Meat production is a highly competitive, slim-margin sector. The price of protein in animal feed affects the end retail price, as protein is an important input in animal feed, and animal feed constitutes a key cost component in meat production (of chicken, pork and aquaculture fish). For example, the cost of the soy component of feed is c.16% and c.25% of total feed cost for pigs and chickens, respectively; and animal feed accounts for just over half of the total cost of rearing a chicken, on average.[27] For BSF to become a credible substitute to soy as a protein source, the price of protein from BSF needs to be comparable to that of protein from soy.

Availability and continuity of supply

As outlined in section 2, total UK demand for soy for use in animal feed is c.1.3 million tonnes per year, of which almost 1.2 million tonnes goes into poultry and pig feed. To displace a meaningful amount of this would require significant volumes of BSF production, well above current levels. For example, to displace 10% would require c.55,000 tonnes of BSF protein per year; to displace 25% would require around c.140,000 tonnes. In addition to the large volume itself, the BSF protein supply would need to be sustained to support a significant change in the inputs that feed mills used for production – in other words, gaps in the BSF protein supply would need to be avoided.

[27] Peter van Horne and Luuk Vissers (2022), Economics of slow growing broilers, Memo Eurogroup for Animals.

Customer acceptance and willingness to switch

Cost and availability are two of the key factors that affect the scaling up of BSF, which in addition would require a broader willingness for change in behaviour by animal feed producers, farmers, retailers, restaurants and potentially end consumers.

"We are very open to and recognise the need to consider alternative protein sources. Ensuring consistency of volume and quality, alongside commercial viability, will be the main factor needed to integrate insect protein in the supply chain."	*"Cost, availability and continuity of supply are the most important factors for farmers when it comes to feed. Soy is the benchmark against which other feeds are measured, so better performance feeds will command a higher price per tonne."*	*"Supermarkets are keen to engage in this type of innovation, but for change to happen at scale, the impact on the price premium for consumers will need to be limited."*
Managing Director, UK traditional feed manufacturer	**Senior Consultant, UK agricultural consultancy**	**Director, UK grocery retailer**

The considerations involved for each group in changing behaviour are summarised as follows:

- **Animal feed producers** are in principle open to exploring alternative feed sources. Provided it arrives in the correct format (dried, ground), BSF protein would be relatively straightforward to integrate into feed production processes – it does not need any special equipment. However, producers require a consistent protein input, a stable source of supply, and are responsive to competitive forces shaped by their customers (the farmers and end purchasers, retailers and restaurants) and input prices.
- **Farmers** produce to meet the downstream demand of retailers, restaurants and end consumers, and do not have flexibility for higher-priced inputs unless their customers are willing to pay for it in higher prices. Additionally, farmers need consistent feed performance, so would need to have confidence in any alternative feed type before making a switch.[28]
- **Retailers and restaurants** typically set the product specification that their suppliers produce to, both in terms of price and quality, to meet consumer demand. Given this, they would likely need to be supportive of any change that could affect the price and/or quality of the product. But if supportive, they can play an important role in shaping decisions further up the supply chain, as illustrated by the UK Soy Manifesto and other food-related sustainability marks (e.g. MSC-certified fish).

[28] The superior feed performance of BSF means that some price premium may be tolerated – this is further explored in section 4.

- **End consumers** are increasingly conscious of the sustainability of their food, with some willing to pay a premium for more sustainable products. However, there is a limit to how much of a premium they will tolerate and in practice this is unlikely to be the case for the entire market. For example, less than 1% of total UK poultry meat produced is organic, and less than 4% is free range.[29] This indicates relatively limited demand for sustainable meat products with an associated premium. These buying habits may change over the timeframe in which BSF could be rolled out more widely, but would have to change dramatically to be able to support a large price differential to soy. Realistically, consumers are more likely to switch if there is price parity for the end-protein.

Supply-side conditions

In addition to the level of demand, the key supply-side factors that will shape the switch from soy to insect-based animal feed protein include the availability of inputs, specifically organic waste streams for BSF to consume; the capacity of BSF sites; and investor attraction and potential to increase capacity. Boosting the supply of BSF would help to move it closer to price parity, which would address cost-related barriers.

As outlined in the demand section above, to displace a meaningful amount of soy will require significant volumes of BSF protein – far above current levels of supply. Most inputs (labour, energy) are not constrained. However, the most important input is organic substrate, as the volume of BSF protein that can be produced is dependent on this. Meeting higher volumes would require sufficient production capacity. Investment would be therefore be needed to scale the current limited capacity, with a range of operating models available in principle, from smaller to larger sites. However, if the market were to find an economically viable path to scale, evidence from stakeholder interviews indicates that this would be an attractive area for investors, particularly those with an appetite to finance initiatives with environmental benefits.

> *"There is a lot of investor interest, both for equity and debt investments, in this space – investors are looking to deploy private capital in European tech that will have a positive impact."*
>
> **Partner, early-stage venture capital firm**

Current position and barriers

In many areas, demand and supply-side criteria are met. From our primary research with stakeholder groups, there is acceptance throughout the supply chain of BSF as a potential input in animal feed, and that BSF could be integrated into current feed production methods; a range of BSF operators are testing their own technologies; and investor interest is present.

[29] https://britishpoultry.org.uk/what-is-free-range-and-organic/

Nonetheless, this is a market where cost and volume of supply are very important – and where at present BSF production does not meet the requirements to displace soy at scale. The next section explores these barriers further.

4 Overcoming the barriers to scaling up

As set out in section 3, to scale insect-based feed to meet the demands of farmers, retailers and restaurants (and end consumers) will require BSF protein that is comparable on cost to soy and produced in large volumes. Neither of these conditions are met today: BSF protein is substantially more expensive than soy, and production volumes are minimal (these two points are related – reducing cost will increase the potential for volumes to scale, and vice versa).

This section explores the main driver of this higher price: regulation that limits BSF production to higher-cost waste streams, making it unviable to scale to a level at which it could displace soy-based feed. This section also outlines how unlocking cheaper waste streams could in principle bring costs down to support future scaling.

The context of the current (high) price of insect protein – which limits demand

Soy meal's growth is due to its high protein content, low cost and ample supply. As a globally traded commodity, its market price fluctuates, but even its recent peak remained below £450 per tonne. By comparison, BSF meal is considerably more expensive than soy, with a current market price of around £1,800 per tonne.

At current market prices, substituting soy-based feed for BSF-based feed would lead to a c.50% increase in the retail price of the meat, as shown in the figure below.[30] This level of cost premium would prohibit widespread adoption. If prices for BSF meal could be reduced to as little as £500 per tonne, the price premium of a switch to BSF would be reduced to 2–3%.

Figure 4 Estimated end-protein price increase from switch to BSF meal

Source: AHDB; Farm Business Survey 2021/22; Frontier Economics calculations.

Note: Calculations based on wholesale (farming) costs. Assumes 100% cost pass-through from wholesale to consumer retail prices. Assumes soy meal price of £351 per tonne.

[30] See Annex B for related methodology.

Despite BSF protein's significant premium over soy, views from stakeholder interviews indicate that the full impact on the total supply chain costs would likely be reduced, due to the quality of BSF meal compared to soy and consequent impact on animal health and welfare:[31]

- **Higher protein content**. BSF meal contains a higher amount of protein (50–65%) than the equivalent weight of soy meal (40–50%). This means that animal feed producers and/or farmers would need to purchase fewer tonnes of BSF meal than soy meal in order to obtain the same amount of protein.

- **Improved animal gut health**. Since BSF contains nutrients that are not always added to mixed soy-based feed, the Food Standards Agency notes evidence that insect meals improve animal gut health.[32] There is additional evidence that chitin, a compound in insect exoskeletons, may help to reduce the quantity of harmful bacteria in the guts of broiler chickens, reducing the need for antibiotics. Consequently, farmers may see reduced veterinary bills for animals fed on BSF.

- **A closer approximation of natural behaviour**. Behavioural trials indicate that poultry species prefer diets containing insects, most likely due to their taste and nutritional value. Moreover, recent evidence indicates that incorporating insects into poultry diets allows the birds to express their natural behaviour, which reduces aggressive behaviour such as feather pecking. This could reduce veterinary bills and improve the quality of the meat.

To the extent that these different factors reduce other costs in the supply chain (for animal feed producers and farmers), the supply chain may tolerate a premium for BSF meal over soy meal. This would effectively mean that the supply chain could absorb some premium on BSF such that consumers would not even pay an extra penny. Additional trials would establish the extent to which this is the case. However, the amount that the supply chain will be willing to pay any premium *beyond* that which can be compensated by other cost reductions will ultimately be constrained by the prices that end consumers wish to pay for meat.

Taken together this retail price modelling shows that, for BSF to be able to displace soy at any sort of scale, costs of production would need to fall by over 70%, from c.£1,800 to c.£500 per tonne of meal. This price factors in the higher protein content of BSF meal.

Currently permitted BSF substrates are expensive, but cheaper options are available

As explained in section 2, rearing BSF requires organic matter, in order to grow the larvae. Although in principle BSF could feed on purposely grown crops, the most economically efficient form of organic matter is waste products.

[31] IPIFF, Nutritional benefits of insects in animal feed.

[32] Food Standards Agency, The Future of Animal Feed: Animal by-products and insects.

BSF farmers would ideally produce using low-cost waste streams…

The most economically efficient input-sourcing model would be for BSF farmers to rely as much as possible on the substrates that do not have an existing secondary market, such that they occupy a 'niche' in the waste ecosystem.

- The price of different waste streams as inputs is largely determined by whether there is an existing secondary market for that particular waste stream. There is a wide variety of economic activities that already use organic waste (fertiliser production, biogas from AD and energy from waste), some of which are already established markets. Waste streams (and therefore potential substrates) with an existing market tend to be more expensive to purchase because of the competition between various demand sources.
- By contrast, substrates without an existing market but in need of disposal may even generate revenue for the collector. This occurs when the owner requires a service (i.e. the removal of the waste).
- When owners have no need for disposal (e.g. some farm food waste), they are unlikely to pay for waste removal. However, the price of purchasing such waste would still likely be lower than that of waste with an established secondary market.

…but current regulations limit the waste streams that can be used…

"Regulation is the single greatest barrier to bringing down the cost of insect protein in the UK."

CEO and Founder, UK BSF farming company

The UK maintains strict regulations governing what can be fed to farmed animals, primarily aimed at ensuring the safety of animal products for human consumption. These regulations, specifically regarding the use of insects in animal feed, were originally based on EU regulations and directives. Despite Brexit, the UK opted to retain the pre-existing EU legislation pertaining to insect use in animal feed, incorporating it into the UK's domestic law. This retention appears to be a legacy of the UK's EU membership rather than a deliberate decision by the UK government. Although the UK often references EU regulations and directives, post-Brexit it has the flexibility to establish its own domestic laws, and EU-level legislative changes no longer automatically apply to the UK. As a result of Brexit, there have been regulatory divergences, with the EU permitting the use of BSF in poultry and pig feed but the UK continuing to prohibit it.

Beyond the direct prohibition of using insects in animal feed, a further important regulatory constraint on the scaling up of BSF stems from the Feed Ban Rules (or the 'TSE Regulation'), which prevent certain animal-derived products being fed to other animals (see Annex A for a full list of the relevant regulations which impact on scaling up BSF). BSF is currently classed as a farmed animal, which means that its production and what can be fed to BSF and BSF larvae fall within the scope of this regulation. The impact of this is that:

- Many substrates are directly prohibited for the purposes of rearing BSF which is ultimately destined for human consumption (as an input into animal products). Here, the UK remains in alignment with the EU, as the EU has yet to permit additional (and lower-cost) waste streams to be used in BSF production.
- Certain streams (such as household food waste) which may contain permitted feed substances (such as vegetable waste) are unavailable because they may be contaminated with prohibited feeds (such as processed animal products). This is largely an artefact of the waste-sorting infrastructure in the UK, which currently does not enable the sorting of certain organic waste forms.

…and those currently permitted are expensive (and in short supply)

Table lists the forms of substrate that are permitted as feed for BSF under current regulations and the volumes of each that are produced per year. These are grouped between those with existing secondary markets (so more expensive to access) and those without (so cheaper, and even with potential to act as an income stream).

Table 1 Summary of estimated UK waste stream availability per year

Category	Input substrate	Volume (tonnes)	Permitted?
By-product with established existing market (i.e. more expensive / reduced availability)	Brewers' grains	2,200,000	Yes
	Dairy by-products	870,000	Yes
	Vegetable by-products	600,000	Yes
	Bakery by-products	135,000	Yes
Waste product needing disposal and limited / no alternative use (i.e. cheaper, or potential form of income through disposal)	Cattle manure	59,800,000	No
	AD digestate	7,500,000	No
	Household food waste	6,600,000	No
	Pig manure	6,500,000	No
	Wastewater sludge	4,100,000	No
	Poultry manure (layers, broilers)	3,600,000	No
	Farm food waste	3,300,000	Partial
	Manufacturing food waste	1,500,000	Partial
	Hospitality food waste	1,100,000	No
	Bakery with animal by-products	500,000	No
	Retail food waste	300,000	Partial
	Finfish by-product	31,900	No

Source: WRAP; WWF; Defra.

Note: In practice, most waste streams have some alternative uses, and disposal can either be a cost or a small income stream for the producer, depending on their agreements with waste processors.

This shows how the currently permitted waste streams (mostly non-food waste such as brewers' grains and dairy, bakery and vegetable by-products) have an established secondary market and are therefore in high demand – with associated cost to access. For example, spent brewers' grains are in high demand from fertiliser producers and cattle farmers (for use as feed) and therefore carry a high cost (c.£40 per tonne wet weight).[33] In addition these permitted waste streams are relatively small; even assuming that 100% of them could be re-directed to BSF, the protein produced would cover only an estimated 30% of demand for protein in poultry and pig feed. As explained in the previous section, the cost to access these permitted waste streams would prohibit scaling given the implied premium on the end retail price. To achieve a tolerable price of c.£500 per tonne, a large site would actually need to charge c.£20 per tonne of waste for its waste disposal service, enjoying an additional stream of revenue that would allow it to price insect meal at a more competitive level against soy.

Further waste streams are permitted in theory but difficult to use in practice, such as vegetable waste from manufacturing, farms and retail. These waste streams are only useable for BSF if adequate sorting facilities exist, such that the waste received by BSF farmers is guaranteed to be uncontaminated by waste streams that are not permitted.

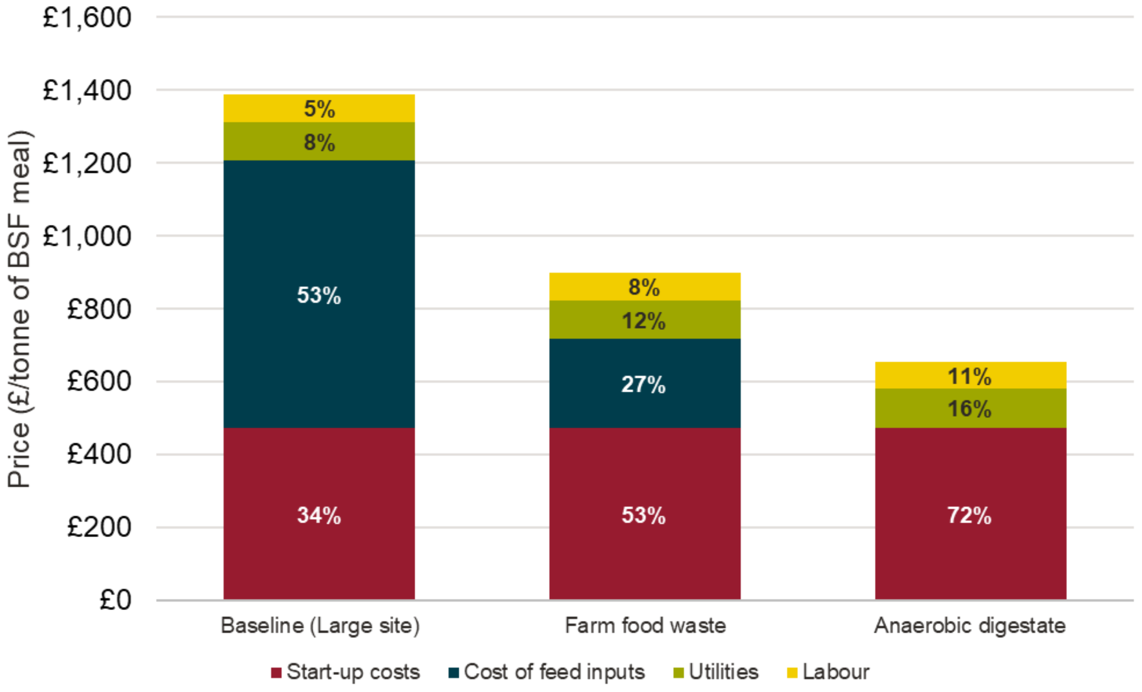
Regulatory change to permit wider substrates could reduce BSF feed cost

Table 1 above highlights a range of additional waste streams – many of which are substantial – that could in principle be used for BSF production, but that are not permitted under current UK regulations. Unlocking these additional waste streams to allow the use of cheaper sources could reduce the cost of BSF protein (reducing any premium on retail price) and increase the production potential.

Illustrative cost modelling undertaken for this report shows how the high price of BSF is mainly driven by the cost of the substrates used to rear the larvae – and how this price could be lowered through the use of cheaper substrates, currently not permitted. This is illustrated by Figure 5 below, which shows how (1) switching to lower-cost forms of substrate, such as farm food waste or manufacturing food surplus, could reduce the cost of inputs substantially and thereby bring down the overall cost of BSF protein; and (2) using waste inputs where the cost of access could effectively be zero, such as anaerobic digestate, could bring down the cost even further if the BSF site were located near to the AD site.

[33] The Future of Feed: Technical Report prepared by ADAS and Michelmores for WWF-UK and Tesco.

Figure 5 BSF price falls as cheaper waste streams are used



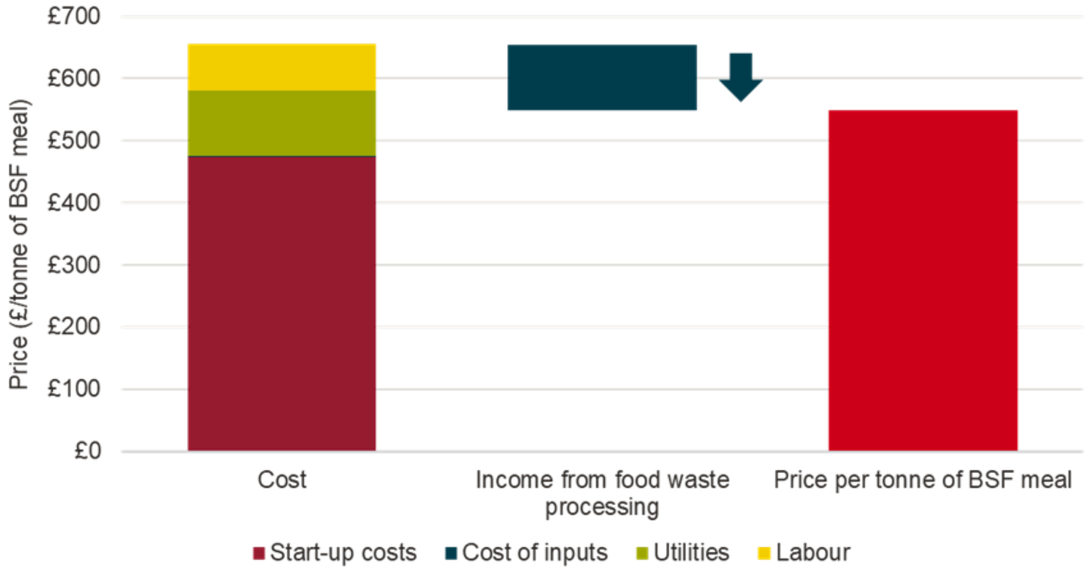
Source: Frontier Economics.

Note: A 'large' site is assumed to process 250,000 tonnes of waste per year; 5-year payback period assumed. For set of data and assumptions used in the modelling, see Annex B.

Extending the illustrative cost modelling further, in the case of waste streams that require disposal and do not have existing markets or other uses (except potentially AD), a BSF site could generate income via gate fees for processing the waste.[34] While there are significant challenges to achieving this – not least the initial regulatory hurdle – the business model for BSF sites would change if waste streams such as household food waste (or others that generate gate fees) could be used in this way. Under this scenario, the price of BSF protein would fall as the income generated from processing waste would effectively subsidise the production process, as shown in the figure below.

[34] Gate fees (usually given in £ per tonne) are fees that operators of waste processing facilities charge to process waste.

Figure 6 Certain waste stream inputs could generate an income for BSF farmers

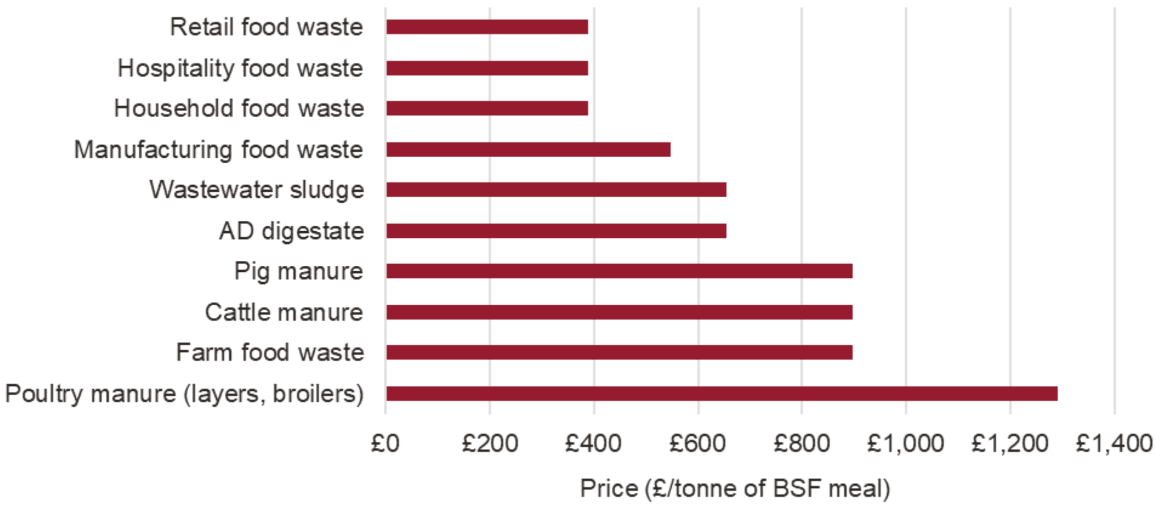


Source: *Frontier Economics.*

Note: *Assumes gate fee of £20 per tonne and processing cost of £10 per tonne (borne by the BSF farm). See Annex B for further detail.*

Figure 7 illustrates the estimated price per tonne of BSF meal that could be achieved for different waste streams based on their current cost to access. However, as set out above, each of these waste streams has existing regulatory and/or practical barriers to overcome before they can become workable solutions.

Figure 7 Estimated BSF meal price per tonne for different waste streams



Source: *Frontier Economics.*

Note: Assumes large site size, 100% use of relevant waste stream from the start of production and a 5-year payback period. For input cost assumptions, see Annex B.

Practicality of different waste streams

Even if regulations are relaxed, some waste streams will remain operationally complex (and costly) to use for BSF production – so not all of the potential substrates will be feasible in practice. The sector will need to test and learn using varied models.

This subsection discusses the most abundant sources of waste that are prohibited under the current regulatory framework – food waste (of various sources), manure, anaerobic digestate and wastewater sludge – and the main issues that would arise in making them available for BSF. Table 2 below summarises the key themes for each, in terms of their relative availability, practicality to access for use in BSF production, and cost to access. Each is then explored further in the subsequent subsections.

This discussion is based on economic considerations such as availability and cost to access – microbiology, livestock and human health considerations are beyond the scope of this report. While initial safety evidence on these aspects is becoming available and has been discussed elsewhere,[35] an important step on the path to scale is ensuring the UK Food Standards Agency and other regulatory bodies are able to conduct trials to assess any safety concerns that may arise from the use of different substrates.

Table 2 Summary of abundant but currently prohibited waste streams

Input substrate	Availability	Practicality	Cost of access
Household food waste	Good availability, with limited alternative uses.	Challenge given variation in local authority approaches to collection. Where collected, contamination with prohibited substances impedes use for BSF (without regulatory change).	Potential income stream via gate fees from local authorities.
Farm food waste	Good availability, with limited alternative uses.	Large number of farms, but co-location offers potential way to overcome some challenges. Requires sorting, but achievable in principle due to existing infrastructure, with additional volumes available with regulatory change.	Low cost of access if coordination challenges are addressed. May require transport costs to be borne by BSF sites, depending on location.

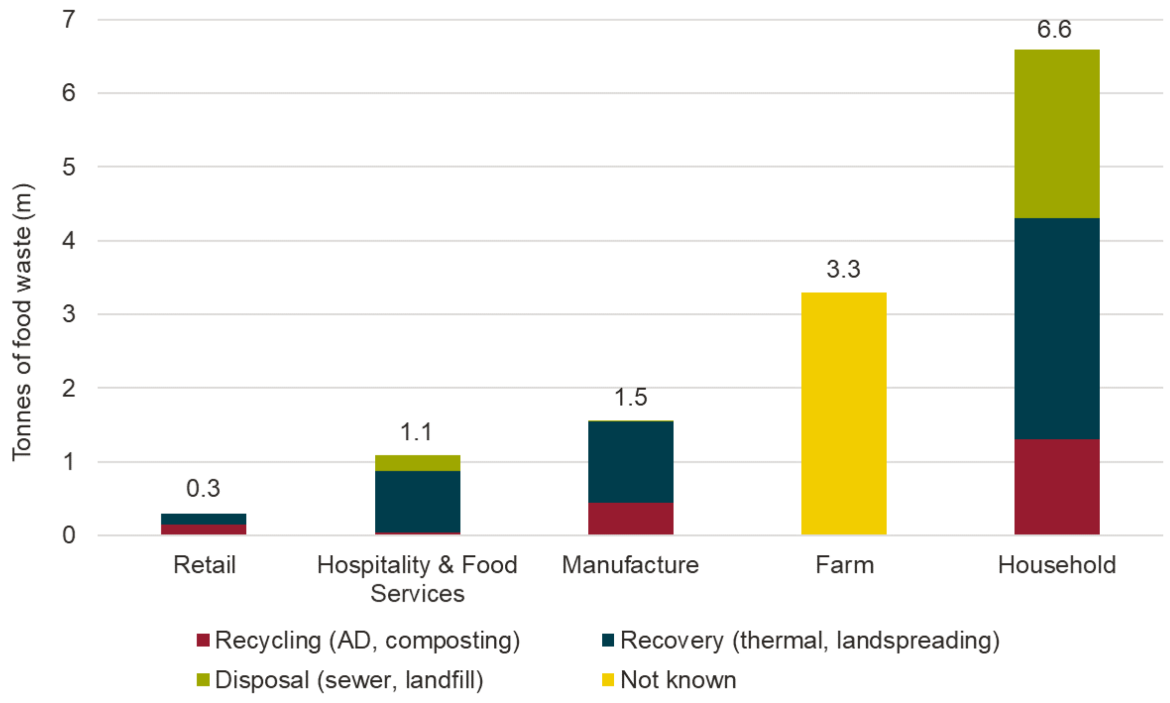
[35] Including in The Future of Feed: Technical Report prepared by ADAS and Michelmores for WWF-UK and Tesco and the European Food Safety Authority's risk profile related to production and consumption of insects as food and feed.

Input substrate	Availability	Practicality	Cost of access
Manufacturing food waste	Good availability, with limited alternative uses.	Large number of sites, but potential to focus on largest. Potential to use existing infrastructure where relevant. Contamination risk where sites also process prohibited substrates.	Low cost, potentially generating income for BSF sites. Gate fees range from £20 to £150 per tonne.
Hospitality food waste	Good availability, with limited alternative uses.	Similar coordination and contamination issues as household. Fragmentation challenge may be reduced if focus on larger operators.	In line with household food waste costs, with potential for BSF sites to charge gate fees.
Retail food waste	Good availability, with limited alternative uses.	Large retailers have existing food waste collection and disposal methods, which could be used for BSF collection.	Relatively low cost, aligning with other disposal methods' gate fees.
AD digestate	Good availability, likely to grow given steady increase in AD sites.	Relatively consolidated. Easy to collect from tanks and specific sites. Possible challenges in separating out forms of digestate appropriate for BSF use.	Relatively low cost of access, with some sites paying to dispose of digestate and others selling it as fertiliser. Co-location may mean cost falls to zero.
Cattle manure	Abundant source of waste, used as fertiliser, although significant volumes left where deposited.	Existing manure collection processes exist for manure used as fertiliser; challenge to collect deposited volumes.	Relatively low cost of access at c.£13 per tonne.
Pig manure	Less abundant than cattle manure, used as fertiliser, but deposited volume as a share of overall volume is smaller.	Large number of sites, but potential to focus on largest. Existing manure collection processes exist for manure used as fertiliser.	Relatively low cost of access at c.£13 per tonne.
Poultry manure (layers, broilers)	Less abundant than cattle and pig manure, sometimes used as fertiliser and AD feedstock.	Large number of sites, but potential to focus on largest. Existing manure collection processes exist for manure used as fertiliser, facilitated by high proportion of poultry raised in sheds.	Transportation will be a factor. Broiler litter has a higher cost of access due to use in energy generation.
Wastewater sludge	Limited availability as most treated wastewater sludge biosolids are used as fertiliser, with remaining small amounts used for other applications.	Co-location could be practical and reduce transportation costs. Requires adherence to strict usage regulations even when used as fertiliser.	Relatively low cost of access. Ofwat seeking to create market for sludge. Co-location may mean cost falls to zero.

Food waste: overview

One of the main waste streams that could be processed by BSF sites is food waste.[36] The UK produces an estimated 12.8 million tonnes of food waste per year.[37] There are five different sources of food waste within the economy – the majority (9.9 million tonnes) comes from households and farms, as illustrated in Figure 8. We discuss the availability of each category of food waste below.

Figure 8 Estimated annual volume of UK food waste by source and disposal



Source: *WRAP, Food Surplus and Waste in the UK Key Facts; farm food waste is sourced from Hidden Waste: the scale and impact of food waste in primary production, WWF report, 2022.*

Household food waste

Household food waste is the most abundant source of food waste in the UK, with every household producing just over an estimated 230kg on average per year. Household food

[36] WRAP, a climate action NGO, defines 'food waste' as any food and inedible parts that are sent to be used in any of the following processes: anaerobic digestion, composting, incineration/thermal recovery, landspreading, landfill, sewer treatment, ploughing in or unmanaged disposal. This does not include food redistributed via charities or sent directly to animal feed. While the quantity of food waste is significant and the cost of access is low, this may change in the future. In the medium term, the Courtauld Commitment – a voluntary agreement aimed at improving resource efficiency and reducing the environmental impact of food and drink production and consumption in the UK – means that the volume of food waste may reduce, as the commitment targets a 50% per capita reduction, by 2030, versus the 2007 UK baseline. A reduction in the supply of food waste and increased demand from (potentially) BSF farms and other industries that use food waste as an input – such as AD – may also mean the cost of access increases over time.

[37] This total does not include food that has been redistributed or re-used as animal feed directly.

waste is most commonly disposed of via thermal recovery or landspreading,[38] and then via landfill. The remainder is recycled via AD[39] or composting. The use of household food waste as a substrate for BSF faces two challenges concerning its accessibility:

- Firstly, there is the huge practical challenge of collecting and processing the waste. At present, an estimated 42% of local authorities (LAs) in England offer separate food waste collections, while 11% offer mixed food and garden waste collection.[40] The situation could soon change as a result of the Environment Act 2021, which stipulates that recyclable waste, including food waste, must be collected separately from other household waste at least once a week.[41]

- Secondly, despite potential progress on separate household food waste collection, household food waste is prohibited from use as a substrate because it is not sorted and would therefore almost certainly be contaminated with meat and other prohibited animal products, even in LAs where food waste is collected separately. Even in South Korea, the world leader in food waste recycling, the system does not separate different types of food waste (for example, vegetable waste and meat), as would be necessary for BSF processing under current UK regulations.

Food waste generally has a low cost of access and could even represent a possible source of revenue for BSF sites, since food waste processing offers the possibility of charging gate fees. Currently, where LAs do collect food waste, gate fees for processing that waste via AD range between £0 to £75 per tonne if transport is excluded (i.e. the LA is responsible for transport) and -£10 (meaning the LA takes payment for accessing the waste) to £60 per tonne if transport is included.[42]

Therefore, the key barrier to using household food waste is regulatory, with a secondary barrier presented by a lack of consistency in waste collection services that LAs offer and the practical coordination required to collect, inspect for contamination and process the waste.

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[38] Thermal recovery is the practice of incinerating waste and capturing, in the form of heat, the energy that is released. Landspreading is the practice of spreading food waste onto agricultural land, enriching the soil in the process by releasing the nutrients in the food waste back into the soil.

[39] See subsection on anaerobic digestate below.

[40] Government statistics showing which LAs run food waste collections are not published. However, WRAP operates a portal database (‘Local Authority Recycling Scheme Updater’) on its website where UK LAs submit annual updates on the recycling and waste collection services they are running. WRAP holds data for 295 out of 317 LAs in England, of which 136 run a food waste collection scheme, and 35 run a mixed food and garden waste collection service. A small number of LAs run both types of schemes.

[41] Environment Act 2021, Part 3. Available at: https://www.legislation.gov.uk/ukpga/2021/30/part/3/enacted, accessed 16 August 2023.

[42] WRAP Gate Fees 2021/22 Report. Note, estimates based on responses from local authorities that have entered into agreements where transport is either included or excluded. Therefore, prices including or excluding transport are not directly comparable.

Farm food waste

Farm food waste is food – both crops and animals – that is or was intended for human consumption, but which ends up either not being harvested or sent to one of the other 'food waste' destinations. Farm food waste can occur in-field (i.e. pre-harvest) or post-harvest, with an estimated 48% of the UK's 3.3 million tonnes of farm food waste lost pre-harvest, often for reasons beyond the control of the farmer.[43] Pre- and post-harvest farm food waste from animal agriculture arises for reasons such as loss to injury, disease or rejection from the slaughterhouse, and is not permitted for use as a BSF substrate. Crops are lost for reasons such as surplus with no secondary market, lack of labour to harvest, unmet specifications, disease or damage, or becoming over-ripe during transport or storage post-harvest. While crops, as a subset of farm food waste, are permitted for use as a substrate for BSF, crops that are lost pre-harvest are often ploughed back in to the soil – i.e. buried to recover the nutrients so that they return to the soil. However, the cost of access can be low, since the estimated cost to the farmer of ploughing in is around £3 per tonne.[44] The cost to the farmer may be offset by the fertiliser value of ploughing the crop back in, which will depend on the crop – so a farmers' willingness to sell their food waste for use rearing BSF will be shaped by this.

Consequently, while farm food waste can be more easily separated into permitted and prohibited types of waste, the key barriers are:

- the challenge in coordinating collection and transport of permitted farm food waste, as with other forms of food waste; and
- related to this, the cost of access when factoring in collection and transport for BSF sites compared to the relatively low cost to the farmer of ploughing waste back into their fields (estimated at around £3 per tonne). This would therefore require a BSF site to take on most (if not all) of the cost of transportation.

Overall, farm food waste is a promising option as a substrate for BSF, provided it is appropriately sorted and collected. Moreover, as set out in section 2, farms may be well placed to develop BSF sites on-farm. The parallels between BSF farming and AD as waste disposal methods mean that farms are favourably positioned to make use of BSF.

Manufacturing food waste

Manufacturing food waste is food surplus resulting from the manufacture of processed foods. WRAP estimates that 1.5 million tonnes of food waste from manufacturing is generated in the UK annually, covering multiple categories of food. However, as with household food waste, manufacturers do not typically separate and segregate food waste, meaning it is unsuitable for feeding to BSF under the current food safety regulations. Collecting and processing the waste presents less of a challenge than it does for household food waste, due to existing

[43] WWF, Hidden Waste: The scale and impact of food loss and waste in UK primary production.

[44] Farm food waste that can be ploughed in is assumed to cost the same per tonne as landspreading. The Future of Feed: Technical Report prepared by ADAS and Michelmores for WWF-UK and Tesco.

processes for removing the waste from manufacturing plants. These processes mean that just over 70% of food waste from manufacturing is thermally recovered or landspread, and the rest is recycled via AD or composting.[45]

The cost of access will again be relatively low as the food waste does not have secondary markets to drive up the price – and may indeed generate income for a BSF site in its role as a waste processor. Large manufacturing plants may enter separate waste collection and processing agreements with waste processing facility operators and, like LAs, may pay gate fees. For energy from waste plants (i.e. thermal recovery), gate fees excluding transport range from £20 to £150 per tonne, while the range of gate fees including transport is £65 to £145 per tonne.[46] Therefore, BSF producers may be well positioned to take advantage of this waste stream if BSF sites are able to offer gate fees that are lower – similar to those charged by AD sites – than those charged by waste-to-energy plants.

The key challenge is therefore regulatory, as the waste is not segregated and risks being contaminated with meat and other prohibited animal products.

Hospitality and food services food waste

As with the above sources of food waste, the hospitality and food services sector generates non-segregated food waste. Restaurants, catering businesses and other hospitality and food services businesses in the UK produce an estimated 1.1 million tonnes of food waste per year. While there are fewer businesses than households, there is nonetheless a coordination challenge with food waste management, given the very large number of businesses and premises from which they operate. For example, there are an estimated 170,000+ food and drink services businesses in the UK. Within these there is a long tail of small operators, but even limiting the focus to medium and larger businesses there are c.4,000, each with their own estate of locations.[47]

Commercial premises are also covered by the Environment Act 2021, which stipulates that businesses must present food waste for collection separate to other recyclable waste streams. Therefore, hospitality and food services food waste is similar to household food waste in that:

- local authority collection may be a challenge, although with fewer premises to coordinate;
- it is prohibited as a substrate because the food waste is mixed and may be contaminated with animal products; and
- the cost of access for BSF will be in line with the cost of access for household food waste.

[45] WRAP estimates that a very small amount (~2,000 tonnes per year) is disposed of via landfill or sewers.

[46] WRAP Gate Fees 2021/22 Report, based on a survey of local authorities and the gate fees they pay for thermal recovery. Figures including and excluding transport are not directly comparable as contracts are negotiated separately among different local authorities and waste processors according to their specific operating conditions.

[47] House of Commons Library, Hospitality industry research briefing (2022).

Therefore, as with household food waste, the key barrier to using hospitality and food services food waste is regulatory. A secondary barrier is a lack of consistency in waste collection services that LAs offer and the practical coordination required to collect, inspect for contamination and process food waste from this source.

Retail food waste

Retail is the smallest source of food waste in the UK, generating an estimated 300,000 tonnes per year. Around half of this is sent to AD, while the remainder is recovered thermally or via landspreading.

Retailers have existing waste processing procedures and infrastructure and are therefore well placed to coordinate the collection, separation and use of the food waste they generate. Preliminary evidence indicates that some UK retailers have already started to consider alternative disposal methods beyond AD, thermal recovery or landspreading.

As with other sources of food waste, the cost of access will be relatively low and will likely align with gate fees paid to other disposal methods.

The key challenge in using retail food waste is again regulatory, since regulations limit the full extent of retailers' food waste from being processed by BSF due to some products containing processed animal products.

Anaerobic digestate

Anaerobic digestion (AD) is a process that uses microorganisms to break down organic materials such as food waste, agricultural residues and sewage sludge, which takes place in an oxygen-free environment. The process produces biogas and a sludge residue referred to as 'digestate'. Digestate can be categorised as 'whole' (slurry-like), which can be separated into 'liquor' (where solids have been mostly removed) and 'fibre' (compost-like solids). Biogas is composed primarily of methane and is typically used to generate electricity or heat, while leftover digestate can be used as a fertiliser in agriculture. AD sites are typically located on farms as a waste processing method, but are also operated as commercial sites and in industrial areas.

In 2019/20, the UK had 579 operational AD sites, of which 418 were farm-based, rather than waste-fed. All 579 together processed approximately 13.8 million tonnes of feedstock, and in the same period, an additional 331 projects (228 farm-based) were under development. For the same period, the breakdown of feedstocks was 30% crops, which were purpose-grown for AD,[48] 29% food waste, 20% other waste, 17% manure or slurry and 4% crop waste. According

[48] While we note the inefficiencies of growing crops to use as a substrate for BSF, in the case of AD, purpose-grown crops are converted to biogas and then to energy, which is classified as renewable, in the form of electricity (93% of energy produced from AD in 2020 according to Defra) and heat (the remaining 7%).

to WRAP, 7.5 million tonnes of digestate were produced in 2018, and this volume has likely increased – although its permissibility for BSF will depend on the feedstock used.

AD currently fulfils a purpose in disposing of food waste which BSF is as yet unable to due to the regulatory barriers. Nevertheless, AD could be complementary to BSF and thereby create some synergies which could be economically beneficial. In particular, AD can use frass as an input and therefore provide a potential market for BSF by-products. Furthermore, BSF can process digestate, so AD may be a further potential source of waste input. Commercial sites typically pay users to remove nearly all digestate they produce, but otherwise farms tend to use the 'whole' digestate they produce. While there appears to be an established market for digestate from fertiliser producers, survey evidence from WRAP indicates that the price for digestate is low – ranging from -£8 to £3 per tonne for whole digestate, -£2.80 to £5 for fibre for agricultural destinations, and £5 per tonne for liquor used for agricultural use.[49] This means digestate may have a reasonable cost of access for BSF farmers, which could to an extent be offset by the sale of frass to AD sites.

There is however initial evidence suggesting a potentially more valuable application for fibre AD digestate. This involves processing the digestate into fuel pellets for further energy recovery, which can be done where a site invests in the necessary equipment. The value of these pellets is estimated against a benchmark price for wood pellets (also used for 'renewable' heating), which cost £185 to £206 per tonne.[50] While not all facilities possess this processing capability, and this additional valorisation of waste appears to be nascent, if the process becomes more widespread, it could substantially increase the cost of access to AD digestate for BSF farmers.

However, the current regulatory framework prohibits the use of AD digestate, as it is considered a form of waste. An exception may be made if the digestate is handled in accordance with the UK quality protocol for AD.[51] If source-segregated (i.e. sewage sludge was not used as a feedstock) anaerobic digestate is used, and the criteria set out in the protocol are met, the digestate will usually be regarded as having ceased to be waste.

Manure

Farms in England and Wales produce an estimated 145 million tonnes of manure. Around half of this is used as fertiliser and spread on fields after being handled from slurry tanks, or removed from farmyards or poultry sheds. Cattle account for 59.8 million tonnes of solid and slurry-like manure handled and spread, pigs account for 6.5 million tonnes, and poultry 3.6 million tonnes. The remainder is left where it lands in fields in order to be assimilated into the soil – of the estimated 73 million tonnes of deposited manure, cattle account for 42.2 million.[52]

[49] WRAP, AD and Composting Industry Market Survey Report 2020.

[50] Cathcart et al. (2021), An economic analysis of anaerobic digestate fuel pellet production: can digestate fuel pellets add value to existing operations?

[51] https://www.gov.uk/government/publications/quality-protocol-anaerobic-digestate

[52] Nicholson et al. (2016), Estimates of manure volumes by livestock type and land use for England and Wales.

The practice of using manure as fertiliser, while useful in adding nutrients to the soil, can also negatively impact aquatic ecology and the quality of drinking water where the nutrients make their way into water sources. Defra estimates that agricultural run-off affects around 40% of water bodies in England.[53] Therefore, using excess manure as a substrate for BSF has a potential secondary benefit in improving water quality and aquatic environmental health.

The cost of access for manure will depend on the demand for manure as fertiliser. Estimates of the financial value of cattle and pig manure as fertiliser average c.£13 per tonne.[54] Therefore, BSF sites would need to at least match the value of these for any manure diverted away from use as fertiliser. Any excess manure not used as fertiliser could be accessed at a lower cost, since it would need to be disposed of, and costs would largely be transport-related, unless the sites are located on-farm. Broiler litter has a higher average value as fertiliser at an average of c.£55 per tonne. It also has some value in renewable energy plants, where it can be sold to the plants as an input. Poultry litter from layers (i.e. egg producers), on the other hand, has a lower cost of access, averaging c.£45 per tonne, and is typically only used as fertiliser.

Despite its potential as a plentiful source of organic waste, manure is prohibited by regulation for use as a substrate. In addition, while abundant and in some instances relatively low-cost, manure presents a challenge in that some (but not all) is already used as fertiliser and the remainder requires collection and transport – which will incur additional cost to access.

Wastewater sludge

In principle, wastewater sludge ('sludge') is a waste stream that could be used for BSF production. According to Water UK, the water industry trade association, sludge is rich in energy and contains a number of useful by-products. Around 53 million tonnes per annum of untreated sludge is collected from about 8,500 wastewater treatment works, then transported and processed at around 200 sludge treatment centres usually located at the larger wastewater treatment works.[55] The sludge is treated by removing water to reduce weight and volume, which produces methane to generate energy. This is most commonly done via AD.

There are economic barriers to the use of sludge. This is evident in Water UK's estimate that 87% of treated sludge[56] – around 3.6 million tonnes per year – is recycled to agricultural land.

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[53] Defra, Water Targets Detailed Evidence Report.

[54] These figures are based on the estimated nitrogen, phosphate and potash content of cattle, pig and poultry manure – available here: https://cawood.co.uk/wp-content/uploads/2021/08/The-Value-of-Manure-and-Slurry-2018.pdf – and the price per kg of each of these fertiliser components. In March 2023, according to AHDB these prices were £2.24 per kg for nitrogen, £1.71 per kg for phosphate, and £1.13 per kg for potash. Manure's financial value can vary depending on its nutrient content and current prices of the nutrients. For example, using March 2023 prices, the value of cattle, pig, broiler and layer manure could be as low as £0.90 per tonne, £1.20 per tonne, £4.90 per tonne and £12.00 per tonne, respectively. Prices are rounded to the nearest £0.10.

[55] Biosolids Assurance Scheme.

[56] Of the remaining 13% of treated sludge, 4% is incinerated, 3% is used in industry, often as a fuel for cement production, and 6% is used for land reclamation. Total annual volumes of treated sludge are therefore estimated at just over 4.1 million tonnes.

Sludge is used to improve soil and provide nutrients and organic matter to support crop growth, but its use is strictly regulated to ensure risks to the environment, soil, plants, animal and human health are understood and addressed. For example, untreated sludge may not be spread on land, and even when treated, restrictions exist on the timing of application, and storage before use is permitted.[57]

In 2019, England and Wales's water sector regulator, Ofwat, reformed its regulatory regime to encourage the development of a sludge market, with the explicit aim of developing *"more low-carbon energy generation and reduc[tion] of water bills"*.[58] In addition, the Environment Agency's strategy for safe and sustainable sludge use aims to design a new regulatory framework to improve the beneficial use of sludge, and allow for new and emerging science and technology.

Given treated sludge is most likely to originate from an AD facility, the cost to access sludge will most likely be similar to the cost to access other types of AD digestate.

As with other substrates discussed in this subsection, wastewater sludge is prohibited for use as a substrate.

Potential for economies of scale in BSF production

In addition to the choice of waste stream to use in production, another factor that will determine BSF cost of production is the operating model and scale of production. As production volumes increase, cost savings could be unlocked through better utilisation of production sites, and potential economies of scale on BSF production at larger sites.

Approximately half of the cost base for producing BSF protein is accounted for by costs that are 'fixed' (or not fully variable) in the short term – capital expenditure, utilities and labour – which must be recouped in the unit price for BSF protein. If BSF farmers produce small volumes at any particular site and the site capacity is not fully utilised, a higher per-unit margin must be charged in order to recover these 'fixed' costs. On the other hand, if BSF farmers are able to fully utilise their sites and produce at greater capacity, these costs are spread over as many units as possible which brings down the unit costs. Higher utilisation could be achieved with an improvement in the efficiency of processing waste at a given site – for example, by making better use of existing space to produce output. However, the effects on the price of BSF protein would be relatively muted. We estimate that for a medium-sized site, increasing the volume of waste processed by 20% would reduce the price per tonne by only 7.5%.

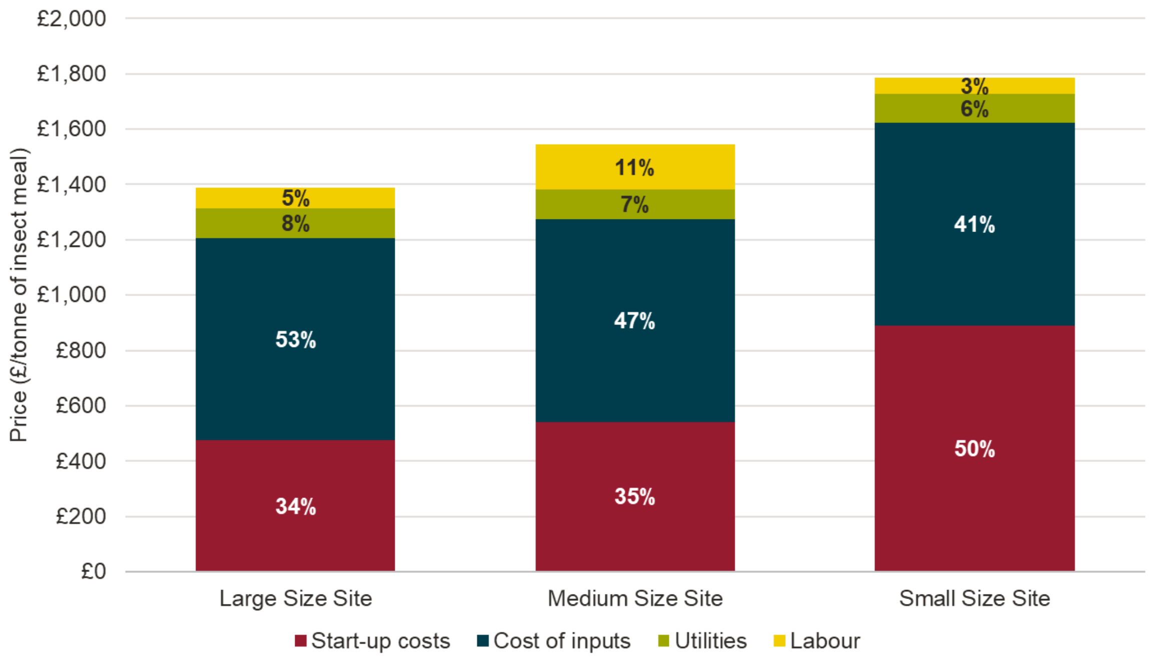
At present, BSF farmers are not able to produce large volumes, so are constrained to the point on their cost curve which does not benefit from these economies of scale. We have expanded our cost model to explore the potential benefits of scaling up production from a small-sized

[57] 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

[58] https://www.ofwat.gov.uk/regulated-companies/markets/bioresources-market/

site to a large-sized site to reduce unit costs, for a given mix of the currently permitted substrates. See Annex B for further detail on methodology and assumptions used in our cost model.

Figure 9 Breakdown of costs under different site sizes



Source: Frontier Economics.
Note: For set of data and assumptions used in the modelling, see Annex B.

This analysis shows that while in absolute terms the overall start-up costs are greater for a large site, because of the increased volumes produced, these costs are spread more widely. We estimate that scaling up from a small- to a large-sized site could reduce production costs by approximately £400 per tonne of BSF protein.

Further price reductions could arise from improvements in technology as the industry develops – in other words, improving the rate at which a given volume of waste is converted to output. Improvements in the flies' genetics, increased automation in feeding and rearing and improved monitoring and analytics to optimise operations could all contribute to better conversion rates and therefore an increase in the output over which costs are spread (if appropriately balanced against any increased costs of improved technology). For instance, improving the average bioconversion factor[59] from 25% to 30% implies a reduction in BSF meal price of c.15% and increased protein output of c.20%.

[59] The conversion of organic materials, such as plants or animal products, into wet larvae. A bioconversion factor of 10% implies that 1 tonne of feed input translates into 100kg of wet larvae.

Charting a path to scale

For insect-based feed to scale, BSF production needs to be able to access waste streams that are plentiful and cheap. To give a sense of scale, for BSF protein to displace 25% of soy with minimal impact on retail price would require c.140,000 tonnes of BSF protein priced at around £500 per tonne (to be comparable with current soy protein cost).[60] In principle, the cost of soy could increase over time, but for now the relevant benchmark is the current market price – see Annex C for further exploration of this.

This section has outlined a range of potential waste streams that could be drawn on to achieve this, with detail on their relative cost and ease to access, as well as existing regulatory barriers to their use that affect the economic potential for BSF production. The decision on which substrates can be used in feed production will be shaped by food safety regulation, and subject to this there is a commercial decision to make for BSF operators on the substrates and operating model to use, based on their view of the market opportunities. There is likely no 'one size fits all' approach, but we have shown that there is a wide range of possibilities.

Setting aside regulatory barriers, Table 3 below illustrates one potential route: using food waste from retail, manufacturing and farms, plus anaerobic digestate. As set out in the earlier section, these waste streams appear promising given their relatively low cost and availability, and the practicality of accessing them (in comparison to other waste streams). In particular:

- **Retail and manufacturing food waste** streams would have the most promising economics given the potential to generate revenue from waste processing, and their consolidation of locations would help collection – although the small size of these waste streams means that additional substrates would be required.
- **Anaerobic digestate** is relatively plentiful and cheap to access, plus there are potential synergies to be gained by co-locating BSF and AD sites on farms. Further evaluation to determine any restrictions needed on the type of AD digestate used would be required.
- **Farm food waste** is another stream with a low cost of access, and could be an attractive source in a model of small BSF sites located at farms (to overcome the need to consolidate waste across a large number of sites for processing).

As shown in the table below: (1) taking 25% of each of these for conversion to insect protein through BSF production could yield c.157,000 tonnes per year, equivalent to c.28% of current demand for soy protein in poultry and pig feed (c.550,000 tonnes); (2) a 50% share of each substrate could yield c.56% of current demand; and (3) if 100% of these waste streams were used, it could in principle yield c.112% of total demand (with any excess potentially exported).

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[60] Cost comparisons between the meal and protein of BSF and soy reflect their relative protein content. BSF meal has a slightly higher protein content than soy meal, so to obtain a given volume of protein requires less meal, which prices reflect. For example, paying £500 for one tonne of BSF *meal* is equivalent to paying c.£850 for one tonne of BSF *protein* (as BSF meal is c.59% protein). Similarly, paying £500 for one tonne of soy meal is equivalent paying c.£1,040 for one tonne of soy protein (as soy meal is c.48% protein). Therefore, in protein terms, BSF meal becomes cost competitive with soy meal (priced at c.£350 per tonne) at a price of c.£430 per tonne of BSF meal.

If the protein from soy in all feed is considered (c.624,000 tonnes) then these yields could almost exactly displace the soy used in UK animal feed (excluding aquaculture).

Table 3 Scaling potential for the most promising waste substrates

Waste substrate	Total annual volume	Protein equivalent based on share of waste processed (tonnes)		
		25%	50%	100%
AD digestate	7,500,000	93,000	187,000	373,000
Farm food waste	3,300,000	41,000	82,000	164,000
Manufacturing surplus	1,500,000	19,000	37,000	75,000
Retail food waste	300,000	4,000	7,000	15,000
Total	**12,600,000**	**157,000**	**313,000**	**627,000**

Source: Frontier Economics.

Note: Figures in table are rounded. Scaling on basis of regulatory change to permit use. In practice, achieving 100% diversion of any waste stream to a single use may be very challenging.

Based on current prices for these substrates, this BSF meal could in principle be produced at around £650 per tonne, leading to a relatively low premium on the end retail price of meat (9% and 5% for chicken and pig, respectively). Converting 25% of the waste streams and assuming that consumers were willing to accept a relatively modest premium on the end-protein price, at a price of £650 per tonne of BSF meal, the market would be worth around £170 million per year. At £500 per tonne, which would reduce the premium further, the market would be worth an estimated £130 million per year. In this scenario, the volume of soy displaced would be equivalent to the output of c.165,000 hectares of rainforest cleared for soy production.[61]

While exact costs and operating models remain uncertain due to the technology's nascent commercial scale, we can estimate investment needs based on stakeholder input to this work. To satisfy 25% of annual protein demand – around 140,000 tonnes – in poultry and pig feed and displace the soy within that feed, 11 large sites, costing around £550 million, or nearly 40 medium-sized sites at about £650 million, would be required. Around 140 small sites, totalling c.£1 billion, are an alternative. The equivalent figures to meet all demand for protein in poultry and pig feed would be c.45 large sites (c.£2 billion), c.160 medium sites (c.£2.5 billion) or c.560 small sites (c.£4 billion).[62] However, in all cases, as sites are built and the technology improves, the investment required per site is likely to fall. Moreover, in practice, a mix of site sizes is likely to be used based on the practicalities of processing a given waste stream.

[61] Given average yields of 0.25kg of soy per m^2 and the conversion rate of soy beans to soy meal. In practice, soy imported to the UK comes from a range of sources and countries, with a UK Soy Manifesto commitment by industry to "*work together to ensure all physical shipments of soy to the UK are deforestation and conversion free*".

[62] As set out in Annex B, figures informed by interviews with BSF site operators: start-up costs for large, medium and small sites estimated at £50 million, £16 million and £7.5 million, respectively; output of 12,500k tonnes, 3,500k tonnes and 1,000 tonnes of protein per year.

As the operating model emerges, it is worth noting that micro facilities – of the sorts that could be used to partially meet a farm's own feed requirements – also require relatively high capex in and of themselves. A single unit costs c.£100,000 – around 75% of the average UK farm's annual fixed costs, and around twice the average annual profit. This means the payback periods are likely to be long.[63] The savings compared to purchasing BSF protein externally would need to be large to be able to justify this level of investment.

Moving beyond the waste streams highlighted above, Table provides an overview of the potential for other plentiful waste streams: manure, as well as wastewater sludge.

Table 4 Scaling potential for other plentiful waste streams

Waste substrate	Total annual volume	Protein equivalent based on share of waste processed (tonnes)		
		25%	50%	100%
Chicken manure	3,600,000	45,000	90,000	180,000
Pig manure	6,500,000	38,000	76,000	152,000
Cattle manure	59,800,000	744,000	1,488,000	2,976,000
Wastewater sludge	4,100,000	51,000	102,000	204,000
Total	**74,000,000**	**878,000**	**1,756,000**	**3,512,000**

Source: Frontier Economics.

Note: Scaling on basis of regulatory change to permit use. In practice, achieving 100% diversion of any waste stream to a single use may be very challenging.

The total volume of manure means that in principle it could meet total demand for protein in poultry and pig feed. However, access would be costly and potentially complex, so it is hard to see an economically viable way to scale BSF production unless this can be unlocked. For example, based on prices for cattle and pig manure used as fertiliser, this BSF protein could be produced at around £1,400 per tonne, which would lead to a much higher premium on the end retail price of meat (40% and 24% for chicken and pig, respectively) compared to the waste streams highlighted in Table 3.

In contrast, the total volume of treated wastewater sludge would be sufficient to displace c.35% of protein demand, but at a more accessible price of £650 per tonne (with a premium on chicken and pig meat at 9% and 5%, respectively – this is similar to the other waste streams mentioned previously), given an estimated cost of access comparable to anaerobic digestate.

[63] Defra estimates average annual fixed costs of £132,600, and an average annual profit of £50,900 for farms in the UK – Agriculture in the UK Evidence Pack, September 2022 update.

5 A way forward

BSF is an exciting space with a wide array of operators and potential investors. But equally it is an innovation that has not yet broken through. Our work has highlighted that there are a variety of ways in which the market could develop from here, as is the case with many nascent markets, and it is not in the scope of this work to define a roadmap for them all. We have engaged with operators who see potential for models of different scales, tapping in to different waste streams, to serve different parts of the market.

Calls to action

For all of these there is a core requirement for regulatory change, both to permit the use of insect-based feed in the production of poultry and pigs, and to widen the set of waste streams that can be used in BSF production to include cheaper and more plentiful options. Beyond this, to unlock the benefits of any regulatory change there will be a need for various actors in the supply chain to show willingness to engage in the process to test and learn the new innovation. It is too early to know whether further policy support may be required beyond the initial regulatory change. However, if there is evidence of market failure later down the line – in particular, if a 'chicken and egg' problem emerges between demand for BSF and supply of BSF (and associated capex required to scale), then there could in principle be a further role for policymakers to play.

We have identified five calls to action (CTAs), as outlined in the executive summary to this report and reiterated here.

1. **Regulatory change on use of insect-based feed for livestock**. Legislative progress to overcome the initial regulatory barrier on the use of BSF protein in poultry and pig farming stalled in 2020. This needs to be addressed to unlock any change.

2. **Regulatory change on permitted waste streams for BSF**. Defra and the Food Standards Agency should consider making regulatory changes to open up cheaper and more plentiful waste streams for BSF. Achieving this would require political support for change and adequate resourcing for the necessary trials, to satisfy any safety concerns about the range of possible substrates.

3. **BSF site trials**. Trialling different operational models will be key to establishing which models are economically viable and identifying the best partners across the food and waste value chains. There are already signs of UK-based BSF operators exploring different options, based on commercial incentives. A sponsor could help to encourage further trials. This may be a role for Circular Food Systems, or those with a view on food system innovation.

4. **Food retailer engagement**. Retailers and restaurants play an important role in shaping meat supply chains – they set the product specification and how it is positioned with consumers. Circular Food Systems may wish to engage with the sector to explore ways

of trialling new feed types, repurposing food waste to BSF sites, or even testing consumer appetite for ‘soy-free’ product ranges. All of these could help ignite meaningful change.

5. **Capital support**. Subject to the BSF models that emerge, financing support for BSF farmers could help to kick-start production on a wider scale. Current evidence indicates there is sufficient investor interest. As the market evolves, this may be an area where the government could help, given that scaling up BSF aligns with Food Strategy goals and could help achieve net zero targets. Alternatively, philanthropic donations could be a way of accessing the necessary kick-starter funding.

CTAs 1 and 2 are urgent and necessary for change. The key focus initially needs to be on the regulatory changes required to unlock potential for growth. CTAs 3 and 4 set out further actions to help scale the industry and can be undertaken in parallel. The final CTA should be considered once additional progress has been made with the first four and once more is understood about how the industry will work in practice.

Examples from other contexts

More broadly, and as the previous sections suggest, creating and scaling up a new industry presents a range of challenges. However, there are learnings from similar efforts undertaken in other contexts that provide insight on how to engage and coordinate with key stakeholders in setting up a sustainability-focused value chain, and the role of policy action in unlocking change. This section, and the supporting Annex D, sets out some examples of this.

Role for policy action

When crafting policy support for a nascent industry, policymakers typically consider a range of principles to support the industry’s growth and address any market failures. Policymakers will evaluate the presence of any significant barriers – such as high entry costs, regulatory barriers, technological uncertainties or information asymmetries – which may impede the industry’s development. If identified, they will consider where there is potential for policy action to help overcome these barriers. A market failure could involve situations where beneficial spill-over effects to society are not fully reflected in market transactions. In the case of BSF’s displacement of soy, this might be the reduction in carbon emissions from switching the feed’s protein source, which if not compensated appropriately would lead to underinvestment by private actors.

Before enacting any policy support, an economic cost-benefit analysis is also undertaken. Policymakers weigh the potential benefits of any regulatory change or action to address a market failure – such as reducing carbon emissions, creating new jobs, fostering innovation and enhancing national competitiveness – against the costs of intervention, which may include direct financial expenditure and potential distortions in market dynamics. Depending on the type of intervention, policies are periodically reviewed and may be adapted to reflect changing industry dynamics and technological advancements. The aim for government is often for the market to eventually reach a point where policy support is no longer necessary.

As mentioned in section 2, investor interest in the space does not appear to be a barrier and private capital can be deployed to fund the expansion of the BSF farming industry. However, BSF farming offers the UK the opportunity to take a leading role in setting up a circular economy in its agricultural sector and reduce its reliance on imported soy. The current regulations, which limit its growth, were drawn up at a time when BSF farming was not known about. As such, beyond evaluating the appropriate regulatory regime needed to support the industry, the government may consider policy support options much as it has offered in other key sectors. One option could be for the government to offer tax incentives or debt financing aimed at offsetting the capex portion of BSF costs, since this will be crucial to address once all stakeholders are satisfied with BSF's ability to deliver and the necessary infrastructure needs to be built at scale. An alternative policy support instrument is to offer grants to projects to fund the capital portion. Recent examples of government support include for electric vehicles (including both demand- and supply-side support) and the Covid vaccine response.

Collaborative efforts with retailers and restaurants

The role of retailers and the out-of-home food sector will be key in shaping the market for BSF-fed meat, especially within the context of existing meat supply chain dynamics. Over 90% of meat sold by UK supermarkets is 'own-label' – that is, the meat displays the retailer's brand. Given this, retailers play an important role in setting specifications within the meat supply chain to ensure the desired quality and taste of the products and their nutritional profile – for example, reduced fat content – and to maintain a consistent supply. The support of retailers in trialling new product development can help to unlock innovation in the supply chain. In addition, retailers can influence consumer purchasing decisions at point of sale, and therefore can play a role in driving demand for novel food options. Similarly, large out-of-home food businesses, such as restaurant chains, could in principle play a role in promoting the switch to BSF-fed meat.

There are a number of supply chain sustainability efforts that have emerged in other contexts. These supply chain initiatives have become more prominent as consumer awareness about sustainability issues has risen, but they can also have price effects to offset the increased cost of certification, which ensures the products have been sourced sustainably and communicates this to consumers. Specific examples of collaborative efforts and certification and labelling programmes include the UK Soy Manifesto, the Marine Stewardship Council and the Roundtable on Sustainable Palm Oil. These are each discussed in more detail in Annex D.

Annex A – UK and EU regulatory regime

Current UK legislation governing the use of insects in animal feed

As outlined in the main report, the current regulations that apply to animal feed are a key barrier that limit the potential for insect-based animal feed to scale. Various regulations govern animal feed, including composition, hygiene and handling of animal by-products. Insects bred for animal feed fall under “farmed animals” and are subject to these regulations, which impact the substrates used for rearing insects and their use in feed. The relevant regulations that currently apply are as follows, although a more detailed treatment of the relevant regulations is set out in the WWF’s report.[64] A comprehensive review of the relevant legislation in the UK is outside the scope of this report.

- **General Food Law (EU Regulation 178/2002)**. Outlines the overarching principles governing food and feed safety within the EU, emphasising the protection of human and animal health, the environment and consumers’ interests. It lays down general objectives and the precautionary principle, guiding the safety of both food and feed products, including those involving insects.

- **Feed Ban Rules/TSE Regulations (EC Regulation 999/2001)**. Prohibit the feeding of certain animal-derived materials to animals, including processed animal protein, blood products and more. Insects derived from animal by-products have specific processing methods defined in EC Regulation 142/2011. There are exceptions for non-ruminant animals and specific conditions for hydrolysed proteins from insects.

- **EU Regulation 56/2013**. Introduced an exception to the Feed Ban Rules, allowing the use of processed animal protein (PAP) from non-ruminant animals for feeding aquaculture animals, with conditions such as sourcing from certified slaughterhouses. This exception does not apply to PAP derived from insects.

- **EU Regulation 2017/893**. Introduced specific amendments to EC Regulation 999/2001 and EU Regulation 142/2011 to permit the use of insect-derived protein in aquaculture feed. It defines “farmed insects” and sets conditions for their production, processing, storage, labelling and more.

- **Animal By-Product Regulations (Regulation (EC) No 1069/2009)**. Categorises animal by-products based on risk, with different requirements for each category. Insects and insect by-products can be used as feed under certain conditions, primarily falling under Category 3. Compliance with specific processing conditions and the Feed Ban Rules is essential.

[64] Available online here: https://www.wwf.org.uk/sites/default/files/2021-06/the_future_of_feed_technical_report.pdf

- **Regulation (EC) No 767/2009**. Sets out relevant animal feed legislation, and expands the principle of feed safety to all animals beyond just food-producing ones. The regulation also mandates the establishment of a "Community Catalogue of Feed Materials". The Catalogue sets out the list of authorised feed materials, which also covers products derived from these materials. Annex III to the regulation sets out a list of forbidden materials for use in animal nutrition.

- **EU Regulation 2017/1017**. Amends previous EU regulation. Update includes specific reference to "invertebrates", and live insects are included in the Catalogue of Feed Materials, subject to compliance with various regulations, including those related to animal by-products and safety.

- **The Animal Feed (England) Regulations 2010**. Cover various aspects related to the manufacture, sale and labelling of animal feed in England, specifying requirements for labelling, marketing and the use of certain feed additives. There is separate but parallel legislation for Scotland, Wales and Northern Ireland.

- **The Animal Feed (Composition, Marketing and Use) (England) Regulations 2015**. Govern the composition, marketing and use of animal feed in England. For each of these aspects, the regulation covers areas such as ensuring the animal feed meets the nutritional needs of the animals for which it is intended, providing consumers with accurate, transparent information about content and intended use, and rules and restrictions on certain feed additives, medication and other substances that can be included in animal feed. There is separate but parallel legislation for Scotland, Wales and Northern Ireland.

- **The Animal Feed (Amendment) (EU Exit) Regulations 2019**. Established following the UK's exit from the EU to maintain EU feed regulations domestically. These regulations grant powers to UK authorities for future amendments and maintenance of the feed catalogue, indicating how the UK will uphold EU animal feed law principles, while any future changes at the EU level will be adopted at the UK's discretion.

Status of EU legislation and progress

As indicated above, much of the UK's regulation was carried over from EU legislation governing food safety and animal feed. In April 2021, the EU Member States voted to authorise insect processed animal proteins (PAPs) in poultry and pig feed. The new regulation in question was Regulation (EU) 2021/1372 amending Annex IV of Regulation (EC) No 999/2001 authorising insect, poultry and pig processed animal products as feed for poultry and pig feed.

Currently this is the main source of divergence from the UK, where the use of insects remains prohibited in poultry and pig feed. However, both the EU and the UK permitted the use of insect protein in aquaculture in 2017. Despite this, to the best of our knowledge, take-up remains low, likely driven by the cost.

This cost-related challenge is evident from the results of consumer surveys and stakeholder interviews. For example, a survey of aquaculture companies in Greece in 2021 noted that the trading price of insect meals, such as BSF meal, is significantly higher (ranging from €3 to €9 per kg) than that of fishmeal (around €1.5 per kg). This cost disparity poses a significant obstacle for the adoption of insect-based feeds in aquaculture.

Similarly, a consumer survey in Scotland from 2017 shows most are open to insect use in farmed salmon, but less willing to pay more for insect-fed products, indicating the importance of making the cost of the end-protein comparable to end-protein raised using soy-based or fishmeal-based feed. Stakeholder interviews carried out as part of the same research revealed that feed- and salmon-producing companies were willing to incorporate insect-based feeds into their practices contingent on proven safety, reliability and affordability. This underscores the ongoing challenges posed by the high costs of insect meal.

Despite these previous findings of favourable attitudes towards the use of insect-based feeds and the potential benefits they offer in terms of reduced fishing pressure, enhanced sustainability and improved ecological footprint, the practicality of insect meal as a cost-effective alternative to traditional feed sources remains a significant barrier. Therefore, addressing the cost issue and achieving competitive pricing for insect-based feeds is essential for accelerating the adoption of BSF-fed meat in aquaculture – and more broadly.

Annex B – Modelling methodology

BSF site cost modelling overview

The BSF site cost model uses information collated from a combination of stakeholder interviews and publicly available information. Our modelling is used to provide estimates of the following aspects of BSF production:

- Capital and operating expenses of the site over a 5-year window, to then calculate the net present value (NPV) of such costs.[65]
- BSF meal output over the 5-year payback period, based on the site's annual waste processing capacity, the average bioconversion factor, the BSF refresh rate (i.e. what share of the insect population is kept for breeding), and the BSF meal conversion factor.
- The breakeven price per tonne of BSF meal is obtained by dividing the NPV of total costs by BSF output over the 5-year period.

We consider three BSF site sizes: small, medium and large. These are characterised by a set of variables, some of which are size-specific, while others are assumed to be common across all site sizes. The assumptions held in common regardless of site size are: conversion factors, BSF refresh rate, BSF meal protein content and input feed cost. All variables of the cost model are listed below and shown in Table and Table .

- **Waste processing capacity** – tonnes of feed inputs managed for BSF farming.
- **Average bioconversion factor** – conversion of organic materials, such as plants or animal products, into wet larvae. A bioconversion factor of 10% implies that 1 tonne of feed inputs translate into 100kg of wet larvae.
- **BSF refresh rate** – share of insect population that instead of being processed into meal is kept to repopulate.
- **BSF meal conversion factor** – conversion of wet larvae into insect meal. A BSF meal conversion factor of 20% implies that 1 tonne of wet larvae translates into 200kg of BSF meal.
- **BSF meal protein content** – percentage of protein in BSF meal.
- **Start-up costs** – capital expenditure to set up the BSF site. This includes items like the construction of the BSF farming site, installing specialised equipment required for insect rearing, purchase of land and regulatory compliance.
- **Investment payback period** – period to recoup the investment made.
- **Utilities cost** – annual costs of electricity, gas and water. Drying and de-fatting processing costs are included in this cost.
- **Full-time workers** – number of employees at the site. Assumed 56 working hours per week (as the sites need a staff presence every day) at an hourly wage of £15.

[65] The UK 10-year bond yield from May 2023 (3.9%) is used as the discount rate.

Table 5 BSF farm cost modelling variables

Model variables/Site size	Large	Medium	Small
Waste processing capacity (tonnes p.a.)	250,000	70,000	20,000
Average bioconversion factor	25%	25%	25%
BSF refresh rate	25%	25%	25%
BSF meal conversion factor	45%	45%	45%
BSF meal protein content	59%	59%	59%
Start-up costs	£50,000,000	£16,000,000	£7,500,000
Investment payback period (years)	5	5	5
Utilities cost (p.a.)	£2,500,000	£700,000	£200,000
Full-time workers	40	25	10

Source: Frontier Economics estimates based on stakeholder interviews; WWF.

- **Feed input cost per tonne** – total cost of each substrate considered is made up of:
  a. its market price/cost of access;
  b. transport costs, which amount to £20 per tonne or £0 if such costs are borne by the waste producer; and
  c. processing costs, i.e. any cost incurred by the BSF site to prepare the substrate before feeding it to BSF by, for example, adding or removing moisture, or breaking it down to the appropriate consistency.

Under current legislation, there are four substrates that can be used: bakery surplus, dairy by-products, vegetable by-products and brewers' grains. We assume that – under current legislation – a BSF farm would draw evenly from these four substrates, at an estimated weighted price of £69 per tonne.

Table 6 Estimated cost of waste streams considered in the cost model

Substrate	Total cost (per tonne)	Transport cost (per tonne)	Processing costs (per tonne)	Cost of access (per tonne)
Bakery surplus	**£53**	*£20*	*£0*	*£33*
Dairy by-products	**£25**	*£20*	*£0*	*£5*
Vegetable by-products	**£25**	*£20*	*£0*	*£5*
Brewers' grains	**£174**	*£20*	*£0*	*£154*

Substrate	Total cost (per tonne)	Transport cost (per tonne)	Processing costs (per tonne)	Cost of access (per tonne)
Household food waste	**-£25**	*£0*	*£10*	*-£35*
Farm food waste	**£23**	*£20*	*£0*	*£3*
Hospitality food waste	**-£25**	*£0*	*£10*	*-£35*
Manufacturing and retail food surplus	**-£10**	*£0*	*£10*	*-£20*
Retail food waste	**-£25**	*£0*	*£10*	*-£35*
Anaerobic digestate	**£0**	*£0*	*£0*	*£0*
Cattle manure	**£23**	*£0*	*£10*	*£13*
Poultry manure	**£60**	*£0*	*£10*	*£50*
Pig manure	**£23**	*£0*	*£10*	*£13*
Wastewater sludge	**£0**	*£0*	*£0*	*£0*

Source: Frontier Economics; WWF.

Note: Where a range of costs were observed (e.g. anaerobic digestate), we have taken the average. Assumes zero transport costs for waste streams that could be more easily co-located such as anaerobic digestate and wastewater sludge.

Retail cost model overview

The methodology adopted to estimate the impact of a switch from soy-based to BSF-based feed on poultry and pig retail price is as follows:

- First, we source data on estimated costs of poultry[66] and pig[67] production in the UK.
- We then assume the proportion of soy protein within the total feed used in poultry and pig feed (20% and 17% respectively). High-protein soy meal containing 48% protein implies a tonne of poultry feed contains 97kg of soy protein, while a tonne of pig feed contains 80kg of soy protein.
- We calculate how many tonnes of BSF meal are required to reach the soy protein equivalent. Since the protein content of BSF meal is higher than soy, replacing one tonne of soy-based feed will require less than a tonne of BSF-based feed.
- We fully substitute the protein provided by soy-based feed with BSF protein, but keep all other costs unchanged. The cost of soy is assumed to be £351, the 2-year average cost

[66] Farm Business Survey 2020/2021, Poultry Production in England.

[67] https://ahdb.org.uk/pork-cost-of-production-and-net-margins

of soybean meal from January 2021 to December 2022. Price data was obtained from the IMF, and converted from USD to GBP using the average monthly exchange rates during the relevant period. Exchange rate data was obtained from the Bank of England.

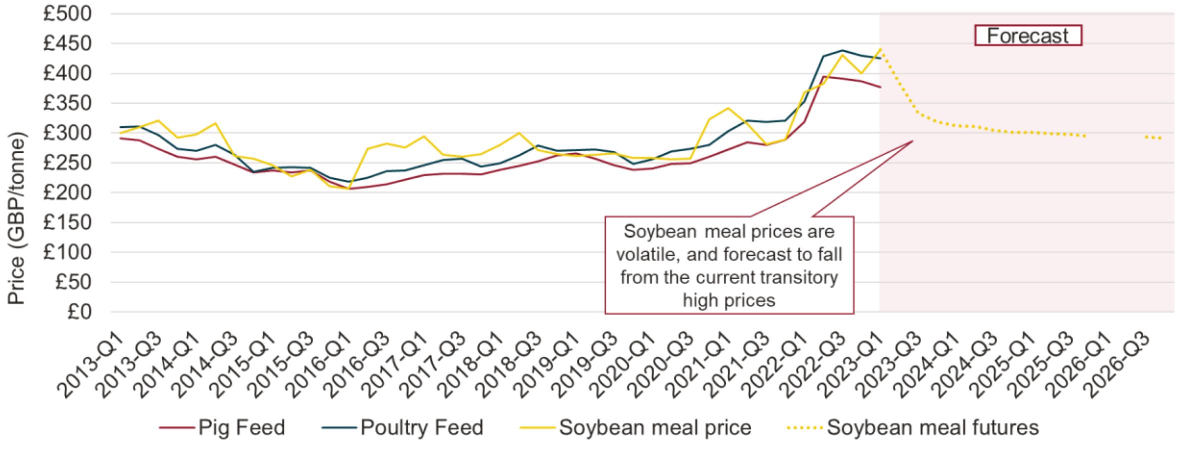
- We then compare the estimated cost of production under different levels of BSF protein price per tonne to the costs using soy-based feed.
- All increases in production costs are assumed to be passed through to consumers and therefore reflect fully in the price of the end-protein.

Annex C – Future price of soy

The conclusions in this report are based on the current price of soybean meal. However, soy is a globally traded commodity, with volatile prices that fluctuate. As it would likely take several years to roll out BSF meal as a potential replacement, it is relevant to consider how the price of soybean meal is likely to develop in the near and medium terms. If the price of soy were to increase in the future, this would bring up the 'replacement threshold' price of BSF, ultimately making it easier for BSF farmers to increase their market reach.

Figure 10 shows the price per tonne of UK compound feed prices and the global soybean meal commodity price. In Q1 2023, the price of soybean meal was over 25% higher than its longer-term average price of just over £300 per tonne, reducing the premium that BSF commands over soy. However, as soy futures prices indicate, this increase is expected to be transitory, barring any further shocks to the global supply of soybean meal. This means that the premium between BSF meal and soy is unlikely to fall in the short to medium term.

Figure 10 UK compound feed prices vs soybean meal global price, 2013–2026



Source: *Defra; IMF; Chicago Mercantile Exchange; Frontier calculations.*

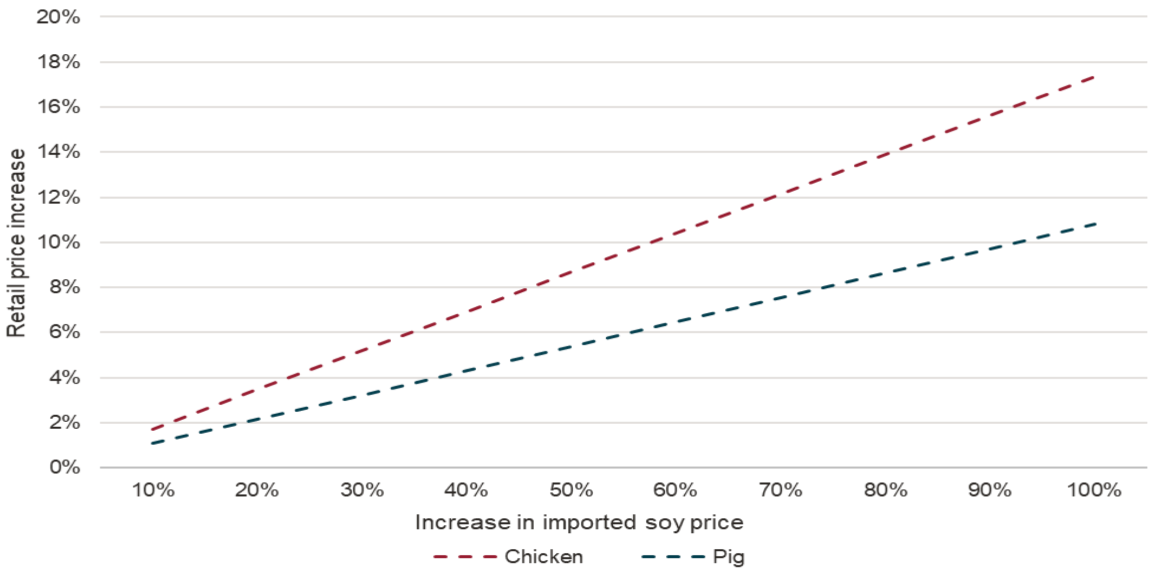
Note: *Soybean meal and soybean meal futures quoted in USD. Exchange rates from BoE. For futures prices, average GBP/USD exchange rate for 12 months to June 2023 used. Futures prices obtained on 28/06/2023.*

However, there are reasons to believe that in the longer term, soy could become more expensive if supply constraints bite – for example, through geopolitical or climate risk in regions where soy is farmed. There is initial evidence that rates of deforestation are falling, particularly in soy-growing regions, which may hinder greater soy production.[68] In addition, policy interventions could increase the cost of soy. These might include the imposition of tariffs as part of trade disputes, or deliberate intervention aimed at mitigating the effects of climate change, such as the EU's Deforestation Regulation, whose main prohibitions and obligations

[68] https://www.sei.org/features/connecting-exports-of-brazilian-soy-to-deforestation/#:~:text=Trase%20data%20shows%20the%20amount,and%2037.2%20Mha%20in%202020

will apply from the end of 2024.[69] Although the exact impact of these interventions on price are inherently uncertain, some scenario modelling points towards the potential impact they may have. For instance, we estimate that a 30% increase in soy price would translate into a 5% and 3% retail price increase for chicken and pig meat, respectively.

Figure 11 Estimated retail price increase from increased imported soy price



Source: Frontier Economics analysis.

While such a dynamic could feasibly play out in the long term, particularly if security of supply concerns over soy did manifest themselves, this is unlikely to significantly affect the animal feed market in the immediate future. In practice, feed manufacturers seek to manage price volatility of inputs by adjusting the composition of their feed, for instance by increasing the content of other components and decreasing the protein content when soy protein becomes more expensive (within certain performance and composition requirements).

Nevertheless, the uncertainty around future soy prices does illustrate the potential that switching to BSF protein offers to increase food security by reducing the UK's reliance on imported soy. By using locally available organic waste streams as feed sources for BSF, the UK could strengthen its self-sufficiency in protein production. Doing so would reduce the burden of importing feed components, but also insulate the agricultural sector from potential disruptions in global soy markets and contribute to a more stable food supply chain, which ties in with the government's Food Strategy.[70]

[69] Regulation (EU) 2023/1115 mandates extensive due diligence on the value chain for all operators and traders dealing with certain products derived from cattle, cocoa, coffee, oil palm, rubber, soy and wood.

[70] Defra, Government food strategy.

Annex D – Collaborative efforts with retailers and restaurants

UK Soy Manifesto

The UK Soy Manifesto is a collective industry commitment aimed at ensuring that all soy shipments to the UK are free from deforestation and conversion. Launched in November 2021, the Manifesto built on the work of the UK Sustainable Soy Roundtable.[71] The target date for meeting this commitment is no later than January 2020 – meaning that conversion of native vegetation after this date is considered to be non-compliant with the Manifesto. For signatories, full implementation is encouraged immediately where possible, but by no later than 2025. Signatories have pledged to work together to achieve this objective, and also encourage their suppliers to adopt the same commitments and incorporate them into their own commercial contracts. Furthermore, all signatories are obliged to provide annual public reports on their progress.[72]

The Manifesto takes a pragmatic approach, promoting coordinated efforts across supply chains to develop implementation plans based on established industry practices. It complements other soy-related initiatives in the UK and Europe and supports alignment with broader sustainability goals. While the primary focus is on ensuring deforestation-free soy for the UK, the Manifesto also aspires to encourage global adoption of responsible supply chain practices.

Signatories commit to specific actions: setting a commitment to deforestation-free soy, engaging suppliers to adopt the same commitment, incorporating commitments into contractual requirements, ensuring compliance, reporting progress publicly, and encouraging harmonised monitoring, verification and reporting.

Take-up appears to be growing, with 43 company signatories across the UK supply chain, including producers (e.g. 2Sisters, Moy Park), manufacturers (e.g. Hilton Food Group), food service companies (e.g. McDonald's, Nando's) and grocery retailers (e.g. Tesco, Sainsbury's) – three of these signatories were new in 2021. Moreover, 93% of signatories have set a deforestation and conversion-free soy commitment (with the remaining 7% being new signatories), up from 81% in 2022. Similarly, in 2022, only 39% of signatories had publicly disclosed progress, with the share rising to 81% in 2023.[73]

The UK Soy Manifesto is illustrative of the role that retailers and the out-of-home food sector play in shaping market demand. The involvement of food service companies, grocery retailers and other signatories in adopting and promoting responsible supply chain practices indicates

[71] https://www.efeca.com/uk-soy-manifesto-launched-on-tuesday-9th-november-2021/

[72] UK Soy Manifesto.

[73] UK Soy Manifesto, Annual Progress Report 2023

their influence in driving sustainability efforts, which could extend to shaping the sourcing and market landscape for alternative protein sources like BSF-fed meat.

Marine Stewardship Council

The Marine Stewardship Council (MSC) was introduced in 1997 as an independent, global non-profit organisation aimed at addressing the issue of overfishing and promoting sustainable seafood practices. The MSC established a certification and labelling programme to identify seafood products that are sourced from sustainable fisheries.[74]

The MSC labelling on products is designed to be easily recognisable by consumers and features a blue logo with a white tick mark and fish outline, along with the MSC's name. The labelling is intended to clearly indicate that the product comes from a sustainable fishery and has met the organisation's standards for environmental sustainability.

There are a number of factors that influence the retail prices consumers pay for products, so it is challenging to establish the direct impact that MSC certification may have had on prices. However, there is evidence that the introduction of the MSC certification has led to price effects on seafood products for customers in the UK, with quayside[75] price rises apparent in some species and areas[76] as well as evidence of a premium in retail prices.[77] This is likely due to the costs associated with certification and commitment to sustainable practices. MSC asserts that consumers place the value of an MSC label at an average premium of 11% globally.[78]

The widespread adoption of MSC certification and labelling in the UK has increased over time as concerns about overfishing and sustainable sourcing gained prominence in public discourse, and as more fisheries achieved MSC certification. For example, in 2016, MSC estimated that £1 in every £6 spent on seafood in UK supermarkets was spent on an MSC-labelled product.[79] Similarly, the share of all consumers indicating that they had often or occasionally seen the MSC label increased from 40% in 2016 to 48% in 2022.[80]

Today, the MSC label is increasingly recognised by consumers in the UK as an indicator of sustainable seafood sourcing, with 33% of all seafood consumers reporting at least some understanding of the MSC label.[81] Its introduction and gradual expansion have played a

[74] https://www.msc.org/about-the-msc/our-history

[75] The price paid for fish after it comes off the fishing vessel.

[76] https://fishery-certification-benefits-uk.msc.org/

[77] Roheim et al. (2011), The elusive price premium for eco-labelled products: evidence from seafood in the UK market.

[78] https://www.msc.org/media-centre/press-releases/press-release/seafood-consumers-put-sustainability-before-price-and-brand

[79] https://www.msc.org/media-centre/press-releases/press-release/sustainability-trumps-price-and-brand-for-uk-seafood-shoppers

[80] https://www.msc.org/docs/default-source/uk-files/msc-uk-consumer-insights.pdf

[81] Ibid.

significant role in raising awareness about the importance of responsible fishing practices and promoting the consumption of seafood that is harvested in an environmentally sound manner.

Roundtable on Sustainable Palm Oil

The Roundtable on Sustainable Palm Oil (RSPO) was founded in 2004 as a collaborative, non-profit organisation, with the objective to advance the production and use of sustainable palm oil. It pursues this by developing and implementing standards for sustainable palm oil production, and providing a certification system for producers, processors and traders.

The RSPO label does not appear to be recognised as broadly as the MSC label is. In fact, survey evidence indicates that only 5% of consumers recognise the label.[82] This may be driven by the label being less widespread, partly due to reluctance among consumer goods manufacturers and retailers to draw attention to the fact that they are using palm oil, to avoid consumer boycotts.[83]

While the RSPO operates globally and sets standards for sustainable palm oil production, the UK Roundtable on Sourcing Sustainable Palm Oil (UK Roundtable) focuses on promoting sustainable palm oil sourcing within the UK and engaging stakeholders within the UK palm oil supply chain. The UK Roundtable was formed in 2012, and regularly reports on progress made in sourcing sustainable palm oil. Around 72% of imports in 2021 were certified to meet an RSPO sustainable supply chain model, up from 16% in 2010.[84] These imports mainly supplied the food sector, while volumes of palm oil destined for other uses, such as animal feed and energy, are harder to trace because of data quality and reporting issues.

There are costs associated with the transition to RSPO-certified sustainable palm oil, including assessments, audits, training, documentation and the premium paid on the oil itself. However, the impact on the unit cost of products appears to be very limited – ranging from fractions of a penny (for example, on a 70g packet of instant noodles) to around 5p on a 1kg box of laundry detergent.[85]

The RSPO's efforts offer some insights for increasing the supply of BSF-fed meat in the UK. Firstly, the supply chain in the UK has changed despite limited consumer recognition of the RSPO label, indicating that, while consumers recognise the need for sustainability in palm oil supply, consumer engagement with the products they ultimately purchase can in some instances be limited. Secondly, while retailers and the out-of-home food sector wield significant power in shaping market demand, a collaborative and stakeholder-driven approach appears to have successfully re-shaped the UK supply chain for palm oil.

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[82] The same survey indicated recognition for the MSC label was 27%.

[83] Ostfeld et al. (2019).

[84] UK Roundtable on Sourcing Sustainable Palm Oil, Annual Progress Report 2021.

[85] WWF, Business Case for Certified Sustainable Palm Oil.