D6.7 Technical guidelines animal feed

The safety, environmental and economic aspects of feeding treated surplus food to omnivorous livestock

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List of abbreviations

ABP	–	Animal By-Product
AD	–	Anaerobic Digestion
APHA	–	UK Animal and Plant Health Agency
ASF	–	African Swine Fever
BSE	–	Bovine spongiform encephalopathy
CO2eq	–	Carbon dioxide equivalent
CTEs	–	Critical Tracking Events
EC	–	European Commission
EU	–	European Union
DEFRA	–	Department for Environment, Food & Rural Affairs (UK)
EFFPA	–	European Former Foodstuff Processors Association
EFPRA	–	European Fat Processors and Renderers Association
EFSA	–	European Food Safety Authority
EUROSTAT	–	European Statistical Office
FAO	–	Food and Agriculture Organisation
FEFAC	–	European Feed Manufacturers' Federation
FEMAS	–	Feed Materials Assurance Scheme (UK)
FITs	–	Feed-In Tariffs
FMD	–	Foot and Mouth Disease
FSA	–	Food Standards Agency (UK)
GHG	–	Greenhouse gas
GIS	–	Geographic Information Systems
GM	–	Genetically Modified
GTH	–	Glycerol triheptanoate
HACCP	–	Hazard Analysis and Critical Control Points
INRA	–	National Institute for Agricultural Research (France)
JFEC	–	Japan Food Ecology Centre
JLTA	–	Japan Livestock Technology Association

KDEs	–	Key Data Elements
LCA	–	Life Cycle Assessment
LCC	–	Life Cycle Costing
MBM	–	Meat and bone meal
MJ	–	Mega-joule
MS	–	Member states
NPA	–	National Pig Association (UK)
OIE	–	World Organisation for Animal Health (Office International des Epizooties)
PAPs	–	Processed animal proteins (PAPs)
PAS	–	Publicly Available Standard
PRRS	–	Porcine Reproductive and Respiratory Syndrome
REFRESH	–	Resource Efficient Food and dRink for the Entire Supply cHain
RFID	–	Radio Frequency Identification
RHI	–	Renewable Heat Incentive
RO	–	Renewables Obligation
ROCs	–	Renewables Obligation Certificates
SDG	–	Sustainable Development Goal
SHPA	–	Swine Health Protection Act - US
TSEs	–	Transmissible spongiform encephalopathies (also known as prion diseases)
UK	–	United Kingdom
UNEP	–	United Nations Environment Programme
VPHA	–	Veterinary Public Health Association (UK)
WRAP	–	Waste and Resources Action Programme
WRI	–	World Resources Institute

1 Executive summary

This report sets out the safety, nutritional, environmental and economic aspects of potential EU legislative change that would allow omnivorous non-ruminant livestock to be fed with surplus food sourced solely from specialist licenced processing facilities. Of the 88 million tonnes of food that currently leave the food supply chain as waste, a minimum of 14 million tonnes of surplus food could become immediately available to be processed into non-ruminant feed if we were to change legislation to ensure the safe treatment of such surplus (see Table 13). These 14 million tonnes are additional to the 5 million tonnes of permissible surplus such as cereal and confectionary foods already recycled into livestock feed by the former foodstuffs processing industry.

Preventing the production of food that will not be eaten by humans must be our absolute priority. This is reflected in the prioritisation of resources within REFRESH to prevent food waste in households and along the food supply chain. As progress is made in such prevention, total volumes of surplus food theoretically available for animal feed will reduce. This is only right. However, it may be possible to maintain volumes of surplus available for animal feed by increasing the proportion of unavoidable leftovers used as non-ruminant feed.

A consequential life cycle assessment carried out by REFRESH shows that using these 14 million tonnes of surplus food to replace pigfeed could lead to an estimated annual reduction of greenhouse gas emissions of 5.8 million tonnes of CO_2 eq. This estimate is based on current pig farming and waste handling conditions in France and the UK. We have considered the environmental cost of the heat treatment necessary to render the feed safe, as well as the need to turn to other sources of energy and fertilizer where anaerobic digestion of food waste is reduced.

If we were to increase efficiencies in the transport of surplus food to treatment plants and feed to farms, further GHG savings could be made. The key reason that using unavoidable surplus in pigfeed results in GHG emission savings is a reduced reliance on conventional feed crops such as soya. Findings by REFRESH on the environmental benefits echo those of other studies.

A life cycle costing assessment by REFRESH shows that when surplus food is generated in locations relatively close to pig farms, using surplus food in pigfeed can result in economic savings. Furthermore, a tecno-economic scaling evaluation by REFRESH suggests that small to medium-sized treatment plants could be commercially viable. All these calculations worked with existing market conditions. If conventional feed crop prices increase, using surplus food as feed will become more viable. It will be important to consider the ownership models of treatment plants so that savings can be passed on to farmers and even pigs themselves in the shape of improved animal welfare.

For these environmental and economic gains to be truly beneficial, we need adequate risk management to prevent major livestock disease outbreaks. The 2001 Foot and Mouth outbreak, which led to the ban on feeding surplus food to livestock, started with the illegal feeding of untreated food waste to pigs in the UK. With this experience and current threats such as African Swine Fever in mind, Chapter 3 demonstrates that heat treatment, acidification and biosecurity processes can achieve adequate pathogen inactivation and deliver safe feed for non-ruminants. We propose that in the European context, treatment and biosecurity requirements should be more rigorous than those currently applied in Japan. **Central to the safety premise of our proposal is that surplus food can only be treated in specialist licenced treatment plants which comply with the same stringent biosecurity measures currently required of the rendering industry.**

Preventing the accidental or deliberate breaking of the law is as important as effective pathogen inactivation and biosecurity. Chapter 4 explores the way in which small additions or modifications to existing official controls can provide the enforcement regime needed to ensure safety. Legislation for the prevention of Transmissible Spongiform Encephalopathies (TSE) and controls for ruminant feed need to remain as they are. Controls also need to remain the same for non-ruminant feed on unlicensed farms. For controlling feed on farms licensed to use surplus-food-based feed, control tools will need to differentiate between surplus food in feed from licensed treatment plants and that introduced illegally or accidentally. Further research is needed to establish the most appropriate method, we propose three possible approaches to test for the presence of untreated animal proteins.

After safety, the extremely precise nutritional requirements of the modern pig are the biggest concern of the pig industry. These concerns are addressed in Chapter 5 which shows that nutritionally adequate feed can be produced by blending conventional and surplus food ingredients. In addition, we discuss the strategies and know-how of the Japanese ecofeed industry which has been producing nutritional feed from surplus food for over fifteen years. Acidification through fermentation provides added nutritional and probiotic benefits. However, heat treatment could affect digestibility and nutritional values and further research might be needed to determine the best time – heat combinations that guarantee pathogen inactivation whilst minimising loss of nutritional value.

With regard to the potential presence of traces of pork in surplus food, an EU scientific opinion issued prior to the introduction of the intraspecies recycling ban states that *"no scientific evidence exists to demonstrate the natural occurrence of Transmissible Spongiform Encephalopathy ("TSE") in farmed pigs, poultry and fish, which may create a basis for an intra-species progression of a TSE infection due to intra-species recycling"* (EC Scientific Steering Committee 1999). Researchers have fed infected material to pigs in a controlled experiment and found no infectivity (Wells 2003). A new opinion by the European Food Safety Authority (2007) confirms that there is no natural occurrence of TSE in pigs. There is no intraspecies recycling ban for non-ruminants in the United States, New Zealand, Australia and Japan, where only ruminant livestock is subject to TSE legislation.

However, due to European consumer demand, it may be desirable to ensure feed is produced in single-species treatment plants where common-sense measures can reduce the presence of same species material in the feed. Whilst a precautionary ban on intraspecies recycling was necessary in the context of the BSE crisis, we suggest that such a ban should be reviewed for non-ruminants by considering global practice and a wider risk-benefit analysis that considers the climate mitigation and food security benefits of this proposal.

2 Introduction

Over fourteen million tonnes of food currently wasted from the manufacturing, retail and catering sectors in the European Union could be kept in the food supply chain as animal feed (figure explained in section 7.4). If we do better than the Japanese, who currently recycle 52% of food industry surplus into animal feed (FAO 2017), this figure could increase.

However, a lot of the food currently wasted contains or may have been in contact with meat or fish, which was taken off the menu for omnivorous livestock following the Foot and Mouth and BSE crises. This was done through the following legislation:

- **Regulation (EC) 999/2001** which bans using animal protein in animal feed (specifically amendments 1923/2006 and 56/2013 which extend this ban to non-ruminant omnivorous livestock)
- **Regulation (EC) 1069/2009** and implementing Regulation (EC) 142/2011 which ban using kitchen left-overs and catering waste for feed

While safety and prevention of disease remain of central concern, the European Commission and European Parliament have both pointed to the need to prevent food leaving the supply chain when it could be used as livestock feed, as follows:

- **The EC's Circular Economy Action Plan** sets out to increase the use of surplus from the food chain in livestock feed without compromising feed and food safety
- **The European Parliament's Committee on the Environment, Public Health and Food Safety own-initiative report** (Borzan 2017) calls on the Commission "to analyse legal barriers to the use of former foodstuffs in feed production and to promote research in this area" while also bringing "food safety risk down to zero". It notes "the potential for optimisation of use of food unavoidably lost or discarded and by-products from the food chain, *in particular those of animal origin*, in feed production".

Likewise, to reduce the environmental impact of livestock, the Food and Agriculture Organisation (FAO) recommends increasing the feeding to livestock of by-products or waste that humans cannot eat. Regulatory frameworks should be reviewed "to consider the sanitary and technical requirements for including […] waste from households or the food service industry into livestock feed rations" (FAO 2017, 6).

A related issue is the desire to increase the EU's self-sufficiency in feed proteins, as discussed in the EU Protein Plan. The EU imports annually around 17 million tonnes of crude proteins – of which 13 million tonnes are soya based and which mainly come from Brazil, Argentina and the USA. Despite increased soya cultivation in countries such as Italy, France and Romania, the EU's self-sufficiency in soya, which continues to be a pivotal plant-based protein source in livestock feed, is only 5% (European Commission 2018b).

These guidelines aim to respond directly to the challenge set out by both the Circular Economy Action Plan and the Borzan report: how can we increase the use of unavoidable surplus food no longer suitable for human consumption in livestock feed without compromising feed and food safety? These guidelines also show REFRESH calculations on the potential environmental and other gains.

Box 1: Scope of the guidelines at a glance

These guidelines focus on surplus food that may contain meat or fish which is:

- Heat-treated and acidified in licenced, tightly controlled treatment facilities that are located **off-farm**
- Sourced **only** from domestic catering sources, retail and manufacturing
- Destined **only** for non-ruminant, omnivorous livestock

The following are *excluded* from these guidelines:

- Ruminant feed
- Surplus food from households
- Surplus food from international catering, or international transport
- Surplus food treated **on-farm** or in other unlicenced premises
- Former foodstuffs which are legally defined in Regulation 2017/1017 (European Commission 2017a) to exclude surplus from catering sources. Combined with Regulation 1069/2009 this means that former foodstuffs do not contain animal by-products that are currently prohibited and this is how the European Former Foodstuffs Processors Association uses the term. Former foodstuffs already processed into animal feed are NOT the focus of these guidelines.
- While there is some discussion of accidental or illegal feeding of untreated surplus food, the prevention of illegal and accidental feeding of untreated food waste falls outside the scope of these guidelines.

Poultry, farmed fish and pigs

Whilst surplus food can supplement the diets of other omnivorous non-ruminant livestock, particularly poultry and farmed fish, these guidelines primarily focus on pigs.

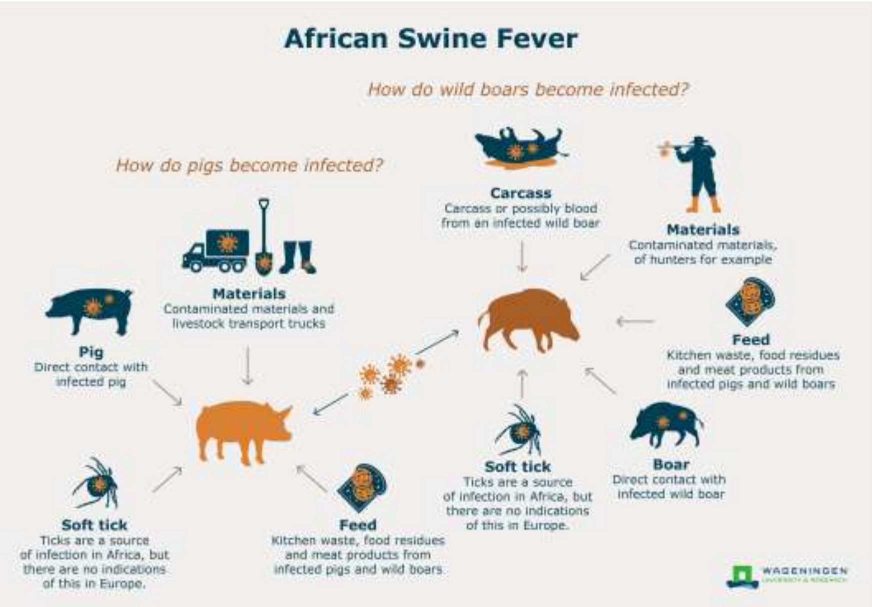
Why focus on one species? In the European context, researching the safe use of surplus food in animal feed is ground-breaking work. Legislating for the feeding of meat-containing surplus to omnivores was all but unthinkable even a few years ago. The general principles of the risk management strategies laid out in these guidelines can be applied to poultry and farmed fish. Some poultry specific pathogens are considered in section 3.1.4 on heat treatment. However, we decided that it was best to focus REFRESH's limited resources on pigs because of the complexity and species-specific nature of disease risks and nutritional requirements.

Why pigs? More than any other farm animal, pigs have evolved to eat humankind's leftovers. In comparison to poultry, pigs are able to digest a more diverse range of food industry by-products and leftovers (McDonald et al. 2011; van Hal et al. 2019). Pigs are essentially descendants of wild boar whose omnivorous foraging habits near human settlements were capitalised upon by our ancestors who domesticated the pig as the quintessential domestic recycler. Pigs' appetites can cope with almost anything; from food leftovers to animal viscera (Nemeth 1995; Sauer 1972). Pigs even eat faeces: the Chinese ideogram for pigsty and privy is the same because prehistorically, single structures combined human latrines with pig pens into "pigsty toilets" (Nelson 1998). Pigs played a central role in the prevention of diseases and pests.

Prevention of accidental or illegal feeding of untreated food waste

This does not mean that pigs are unaffected by disease. Arguably, modern pig breeding has to some extent sacrificed the sturdiness of the breeds we inherited from our ancestors in exchange for faster growth and better feed conversion ratios. The presence of African Swine Fever (ASF) in Eastern Europe and the ASF outbreak amongst wild boar in September 2018 in Belgium shows that the risk of disease is real for all EU MS and that the virus can make significant geographical jumps.

Figure 1: Infection routes for African Swine Fever



Source: https://www.wur.nl/en/newsarticle/African-Swine-Fever-in-Belgium-what-does-it-mean-for-the-Netherlands.htm

The cause of the ASF outbreak in Belgium is unknown or inconclusive (OIE 2018). Disease control strategies in areas bordering on the outbreak areas, focus on the prevention of contagion through direct contact between boar and pigs and the spread through materials such as farm vehicle wheels or hunter's boots (Ministere de L'Agriculture et de L'Alimentation - France 2018). Elsewhere, the industry and authorities are raising awareness about the risks arising from the illegal or accidental feeding of food waste (AHDB 2018a). Such prevention and control strategies would not change regardless of whether we legislate for the treatment of feed in specialist, licenced control plants located off-farm. While **the prevention of accidental or illegal feeding of untreated food waste is out of the scope of these guidelines**, there is brief consideration of smallholders as they are considered high-risk by authorities (see section 4.3).

The Schematic Overview in Table 1 gives an outline of what we have aimed to cover in these Technical Guidelines on Animal Feed. As this is the first concerted effort to produce a document of this kind since the FMD and BSE crises, the guidelines have intended to be as broad as possible in scope. We have indicated where we believe further research is needed, most of which can be covered in a next research project centred around a pilot treatment plant.

Table 1 Schematic Process Overview of the REFRESH animal feed guidelines

	How To		Justification	
Process Steps	**Nutrition**	**Safety**	**Environment**	**Costs**
1. Sourcing of residual food from manufacturing, retail and catering	Section 5.1.2 Sourcing and separation by food type.	Sections 3.5 Traceability, and 3.4 Intraspecies Recycling. Section 5.1.1 Meat in pig feed.	Volumes of food available Section 7.4	Chapter 6 Business Case
2. Transport	Separation at source. Section 5.1.2	Traceability 3.5. Biosecurity 3.2.	Section 7.5.2 and REFRESH deliverable D5.5 (De Menna et al. 2018)	Section 6.1, Section 6.5 Plant scale evaluation and REFRESH deliverable D5.5 (De Menna et al. 2018)
3. Treatment plant biosecurity		Section 3.2 and 4.2.1 Official controls treatment plant		
4. Sorting / prevention of contamination	Section 5.1.2 and 5.1.3 Separation and feed formulation	Section 3.2 and 3.3 prevention of contamination		
5. Shredding or grinding		3.1.6 Legal framework		

		processing method		
6. Heat treatment	Section 5.1.5 Effect of treatment on nutrition	Sections 3.1.3 Level of Protection 3.1.4 Heat treatment	Section 7.5 Life Cycle Analyses and REFRESH D5.5 (De Menna et al. 2018)	Section 6.1 Overall costs, Section 6.5 Plant scale evaluation and REFRESH D5.5
7. Acidification	Section 5.3.1 Probiotics in fermented liquid feed	Section 3.1.5 Acidification		
8. Monitoring of inactivation parameters		Sections 3.1.6 Legal framework processing method		
9. Official controls treatment plant level		Section 4.2.1 Treatment plant controls		
10. Transport			Section 7.5.2 and REFRESH deliverable D5.5 (De Menna et al. 2018)	Section 6.1, Section 6.5 Plant scale evaluation and REFRESH deliverable D5.5
11. Feed mixing by final feed manufacturer	Section 5.1.3 Feed formulation	4.2.2 Final feed manufacturer controls	Chapter 5 introduction	Section 6.1 Overall cost evaluation
12. Farm level / feeding	Chapter 5 Nutrition. Section 8.5 Welfare. Section 8.3 Pig farming industry acceptance	Sections 4.2.3 Farm level controls and 4.3 Farm scale.	Section 7.2 Impact of conventional feed and 7.5 LCA	Sections 6.2 Conventional feed costs and 6.4. Farm level economic feasibility
13. Retail	8.4 Food industry acceptance	8.1.1 Meat quality		
14. Consumer level	8.1 and 8.2 Consumer acceptance	8.1 and 8.2 Consumer acceptance, Certification	8.1.3 and 8.2 Ecofeed acceptance / consumer interest	8.1.2 Cost for consumers

3 Safety

In 2017, REFRESH convened an expert panel with veterinary epidemiologists, microbiologists and pig nutritionists from the Universities of Leeds, Cambridge and Wageningen, APHA-DEFRA and an expert from the European Food Standards Agency FEEDAP committee to review existing evidence and the Japanese model of feeding treated surplus food to pigs. These experts agreed that from a technical point of view it is possible to produce safe feed from surplus food through heat treatment, potentially complemented with acidification (fermentation or adding lactic acid for example) (Luyckx 2018). This chapter describes our findings to date and the next steps needed to finalise adequate risk management recommendations for the use of surplus food as pig feed.

3.1 Processing: Inactivation of Pathogens

3.1.1 Feed as a route for disease transmission

The transmission of disease through contaminated feed is the main hazard considered in these guidelines. Dee et al (2018) found that "contaminated feed ingredients may represent a risk for transport of pathogens at domestic and global levels". Foot and Mouth Disease, Swine Vesicular Disease Virus and African Swine Fever (ASF) viruses were found to survive long journeys particularly well, with Porcine Epidemic Diarrhoea Virus also often surviving depending on the food carrier. ASF survived well in conditions simulating a cross-Atlantic journey, even in the absence of a protective feed matrix. Environments which were especially conducive to enabling viruses to survive long journeys were conventional soybean meal, lysine hydrochloride, choline chloride, vitamin D and pork sausage casings (Dee et al. 2018).

3.1.2 Background on diseases of concern to the pig industry

In the heat treatment and acidification sections we will discuss a wider group of diseases, but here some background on those currently of most concern to the industry:

African Swine Fever (ASF)

ASF was first identified in Kenya in the 1920s and is an acute haemorrhagic fever with a close to 100% mortality rate for pigs. Since then, it has remained endemic in sub-Saharan Africa, spreading between pigs, and also in some cases transmitted from wild boar to pigs through ticks (Costard et al. 2009). From Africa, it has periodically spread overseas. Since 2007 it has appeared in Eastern Europe and Russia. The outbreak originated in Georgia, and is thought to have been caused by infected meat taken from ships in the Black Sea port of Poti and then fed to domestic pigs (Beltrán-Alcrudo et al. 2008).

Common means of the disease spreading between countries have been food waste from airline flights from Africa being fed to pigs in the destination country, animal products accidentally imported by tourists, and perhaps most importantly, illegal smuggling of meat which may then be consumed by animals (Costard et al. 2009). To our knowledge there was no treatment of the food waste prior to feeding in any of these cases. African Swine Fever has also been spreading from Russia to Eastern Europe with wild boar eating untreated food waste as a cause of transmission (Kolbasov et al. 2018). The ongoing ASF epidemic in China could have devastating consequences due to the scale of Chinese pork production and its role in food security (FAO 2018b). By October 2018, over 200,000 pigs had already been culled, with new outbreaks ongoing and making significant geographical jumps. China is not approved for the import of fresh or frozen pig meat to the EU (Farming UK 2018). There are currently no commercial vaccines available for ASF, making disease control once introduced far more difficult (Einstein-Curtis 2018).

Foot and Mouth Disease (FMD)

The last major outbreak of Foot and Mouth Disease in Europe happened in 2001, is estimated to have cost up to €12 billion and had a severe social and economic impact on the affected agricultural communities (European Food Safety Authority 2006). The outbreak started in the UK with the illegal feeding of untreated contaminated catering waste. More generally, the movement of infected animals is the most important contagion route for FMD, which is one of the most contagious diseases affecting livestock. FMD can also spread through air over distances up to 60km over land and much more over sea (OIE 2013), and can be contagious shortly before the disease becomes clinically apparent. See section 4.1 for further information on the Foot and Mouth epidemic affecting Europe in 2001.

Highly Pathogenic – Porcine Reproductive and Respiratory Syndrome (HP-PRRS)

The pig industry considers PRRS as one of the most damaging porcine diseases in economic terms (Pig Progress 2018b). PRRS virus is easily spread following direct contact between infected and uninfected pigs. This virus can be detected in saliva, urine, milk, colostrum, and faeces of infected animals. The primary sites of PRRS virus persistence are in the lymph nodes and tonsils (Boehringer Ingelheim 2019). Transmission by semen or airborne transmission over shorter distances is also possible. Transmission of PRRSV to pigs fed infected pig meat has been experimentally reproduced, but whilst “there is a theoretical risk posed by fresh meat, there has been no documented case of such” (OIE 2008, 4). However, because of the importance of this disease in the industry and the theoretical possibility of transmission via infected meat in feed, we need to consider PRRS in the risk management strategies proposed in these guidelines.

Please see section 3.1.4 for a more complete discussion of all pathogens of concern and the related inactivation strategies.

3.1.3 Appropriate Level of Protection for Food and Feed Safety

In food and feed safety risk management it is not realistic to aim for the total destruction of the micro-organisms considered to be a hazard. Zero risk does not exist, but a risk of once in a million years does. We therefore look at the Appropriate Level of Protection and Food Safety Objectives as follows:

> *“The concept of Food Safety Objectives (FSOs) has been introduced to facilitate the application of meaningful food safety management practice to the interpretation of public health goals – often described as an Appropriate Level Of Protection (ALOP.* (Bean et al. 2012)

"Food Safety Objectives can be defined as "the maximum frequency and/or concentration of a microbiological hazard in a food at the time of consumption that provides the appropriate level of health protection" *(International Commission on Microbiological Specifications for Foods 2002)*

The Feed Safety Objective depends on the infectivity of a virus, the presence of other controls and the severity of the outcome should there be a disease outbreak. The performance objective is the desired level of inactivation which is set depending on the initial contamination level – which would be estimated based on estimated illegal and legal imports of infected meat - and the Feed Safety Objective.

For example, milk pasteurization standards today aim for at least 6 log reduction of *Coxiella Burnetti*, which is the most heat-resistant milk-borne zoonotic pathogen known. In other words, the performance objective or desired level of inactivation is 99.9999% (which is 6-log) of bacteria destroyed. However, for a toxin producing pathogen *Clostridium botulinum* in canned foods, sterilisation aims for a 12-log reduction (99.9999999999%) due to the severity of the disease and the absence of other control measures preventing its growth.

Box 2: Risk management approaches to food poisoning caused by campylobacter

Campylobacter is the most frequently reported food-borne illness in the European Union (EU). The European Food Safety Authority estimates that around nine million people each year suffer from the disease. Mitigation strategies focus on the farm, slaughterhouse and consumer levels. Some MS implement mitigation strategies through legislation setting process hygiene criteria for the poultry industry, others take a voluntary approach in coordination with the industry. Awareness raising with the consumer is also important given that the handling, preparation and consumption of chicken meat may directly account for 20% to 30% of human cases of the disease. However, **the production, sales and consumption of chicken is not prohibited, even though the cost of campylobacteriosis to public health systems and to lost productivity in the EU is estimated by EFSA to be around EUR 2.4 billion a year.** Campylobacter is therefore a good example of where risk managers accept a certain level of risk in the food system. We do not suggest that a similar risk management approach is applied to feed-borne animal disease but describe the campylobacter example to help contextualise the risk management measures proposed in these guidelines.

Source: (European Commission 2017b; European Food Safety Authority 2018)

In the case of pig diseases, the oral infectious dose of FMD in feed is small, to the extent that some studies report infection of cattle fed with milk where the virus could not be detected after a heat treatment of 95°C for 36 sec (Tomasula et al. 2007). This means that for FMD high inactivation targets will be necessary. More generally, t**he appropriate level of health protection will need to be stringent in the case of feed made from surplus food, because of the severity of the impact and cost of an outbreak of diseases such as ASF and**

FMD, as well as uncertainties regarding volumes and viral load of infected meat.

Thermal processes are the key tool to achieve food and feed safety. Heat treatment can be combined with other product parameters, such as acidity, water activity and preservatives to achieve product safety and stability, and storage parameters such as refrigeration. Furthermore, "the severity of the heat treatment can be balanced against the level of control in the other parts of the process, or even the level of control in preceding or subsequent steps in the food processing chain" (Bean et al. 2012, 12). Thus, after discussing our findings on heat treatment, we will discuss the role of acidification, biosecurity and traceability.

3.1.4 Heat Treatment

In Japan, any by-products and former foodstuffs containing Animal Origin Protein, and all catering and kitchen waste, must undergo heat treatment to inactivate pathogens (30 minutes or more at 70 °C or 3 minutes or more at 80 °C) (MAFF 2006). In the US, surplus must be heated throughout at boiling (212 °F or 100 °C at sea level) for 30 minutes before being fed to swine (US Department of Agriculture 2009).

Box 3: Safety margin in US heat treatment requirements

In the US, "the requirement that the material be heated throughout at boiling takes into account a margin of safety to ensure that disease organisms of concern are inactivated. Although the scientific literature recognizes that heating meat throughout at 167 °F (75 °C) for 30 minutes is sufficient to inactivate the disease organisms, in many cases it is difficult on a practical level to determine precisely when every piece of meat in the garbage being treated has been heated to 167 °F throughout. Larger pieces of meat may take longer than smaller pieces to reach that temperature throughout. By requiring that garbage be heated at boiling throughout for 30 minutes, the regulations have provided a documentable and easily visible way to ensure that meat has been heated to a temperature sufficient to inactivate disease organisms of concern."

Source: (US Department of Agriculture 2009)

Similarly, most thermal processes applied by the food industry include significant safety margins even beyond the safe margins developed by regulatory authorities (Bean et al. 2012). The assumptions behind these standards and safety margins are now being "debated in light of many regulatory changes at the start of the 21st century concerning the management of the safety of the whole food chain, which have shifted the focus from end-product control to a preventive approach including a greater effort on improvements in hygiene and application of HACCP principles by the meat and poultry processing industries" (Bean et al. 2012).

In defining the heat treatment parameters for processing surplus food into feed, the following treatment and whole chain measures need to be considered:

- Available technology for temperature monitoring to ensure that the required temperature is indeed consistently achieved throughout the heated food. Precise and continuous monitoring of temperature will allow for a smaller safety margin.

- Particle size as set in the current ABP legislation (see section 3.1.6). Ensuring that meat present in the surplus food is reduced to a certain size will contribute to achieving the required temperature in all parts of the surplus food under treatment
- Traceability standards for the meat ingredients in the surplus food to support monitoring of the origin of the meat as most high-risk ingredient (see section 3.5)
- Acidification as a complementary strategy to inactivate and/ or prevent outgrowth of disease organisms (section 3.1.5)

Selection of pathogens of concern

To identify the pathogens of concern for these guidelines, we looked at:

- The "Assessment of risk management measures to reduce the exotic disease risk from the feeding of processed catering waste and certain other food waste to non-ruminants" carried out by the UK Animal and Plant Health Agency (Adkin et al. 2014).
- Recommendations made to us by experts at the REFRESH expert seminar in Wageningen in 2017 (Luyckx 2018) and at the REFRESH expert seminar in Brussels in 2018 (Luyckx et al. 2018)
- Swine diseases and infections and multiple species diseases, infections and infestations listed on the World Organisation for Animal Health's site "OIE-Listed diseases, infections and infestations in force in 2019" (OIE 2019)
- A-Z of Pig Diseases in the Pig Progress Health Tool created with Dr David Taylor, Veterinary Medicine, University of Glasgow (Pig Progress 2018a), the Index of Diseases by Iowa State Universtiy (2018) and the list of Swine Diseases and Resources of the Centre for Food Security and Public Health of the University of Iowa (CFSPH 2018). Disease Information produced by the CFSPH of the University of Iowa is frequently used by the OIE (see for OIE example technical disease card for Avian Influenza). We reviewed these sources together with the information on oie.int to double check for any additional infectious diseases that can be transmitted via feed and which affect pigs. Pig Progress and CFSPH also provided information on heat sensitivity of various pathogens when we were unable to find this on oie.int
- To include a food safety perspective in addition to a feed safety perspective we looked at the food-borne pathogens studied in the meta-study of global inactivation parameters for food pathogens carried out by Van Asselt and Zwietering (2006).

In the UK risk assessment (Adkin et al. 2014), the mean **risk of infection** per year from the industrial processing of catering waste and former foods (domestic included) with no species segregation was **found to be negligible for** the following diseases: Brucellosis, Fowl Typhoid (Salmonella Gallinarum), Chronic

Wasting Disease, **Aujeszky's Disease and Swine Vesicular Disease,** even at a very low heat processing standard of 70°C for 30 minutes. We have therefore **not considered these diseases any further in these guidelines**.

In setting thermal processes in food manufacturing it is accepted practice to focus on those organisms that are most heat resistant – such as the example of *C Burnetti* in milk as mentioned in section 3.1.3. In other words, the heat treatment parameters are set for the worst case scenario, on the basis of the organisms most difficult to inactivate. In these guidelines we therefore first list the diseases that are highly heat-sensitive, accepting that any heat treatment parameters set for the more heat-resistant organisms will achieve inactivation levels well beyond the performance objective for the heat-sensitive ones.

Table 2: Heat-sensitive diseases which can be transmitted via feed

Disease	Inactivation according to APHA	Inactivation according to OIE	Inactivation according to other sources in absence of more official data / other information
African Swine Fever	70°C for 30 min	60°C for 20 min	
Highly pathogenic - Porcine epidemic diarrhoea	70°C for 30 min	Virus loses infectivity above 60 °C	
Classical Swine Fever	70°C for 30 min	65.5°C for 30 min or 71°C for one min	
Porcine cysticercosis*		Heat treatment to a core temperature of at least 60°C	Cysticerci can be killed by cooking meat to 56°C throughout (CFSPH, 2018)
Nipah virus encephalitis*		Other animal Paramyxoviruses inactivated by 60°C for 60 min	100°C for 15 min (CFSPH, 2018). Transmission unlikely feed-borne, Nipah has only been reported in Malaysia, Bangladesh and India.
Transmissible gastroenteritis*			45 minutes at 50°C (Pig Progress, 2018) We could not find any indication of feed-borne spread.

*Porcine cysticercosis, Nipah virus encephalitis and Transmissible gastroenteritis are included here because they are officially listed by the OIE on the Swine Diseases and Infections list for 2019.

Please see Supplementary Materials Part 2 for a longer list of diseases affecting pigs which are highly heat-sensitive, not normally considered to be transmitted via feed, but for which we did not have the expertise to determine whether transmission via feed is a theoretical risk.

Important diseases that are more heat-resistant

In this section we discuss two important diseases for pig farming, Foot and Mouth Disease and Porcine Reproductive and Respiratory Syndrome. We also add information on two important diseases for poultry since plenty of data was available to produce useful heat inactivation options, but these would need to be considered in the context of a more thorough study on poultry.

Food-borne pathogens that could be transmitted through pork

There are many human pathogens of concern in this category, for example, pathogenic *Escherichia coli*, *Campylobacter* or *Salmonella*. These pathogens are easily inactivated by heat (van Asselt and Zwietering 2006). The REFRESH expert panel at Wageningen University recommended that we include spore forming bacteria such as *Clostridium spp.* in our analysis, given the high heat resistance of certain *Clostridium* spores. *Bacillus cereus* is also of concern (Byrne, Dunne, and Bolton 2006).

Table 3: Heat resistance of important diseases *without acidification*

Disease	Inactivation according to APHA	Inactivation according to OIE	Inactivation according to other sources in absence of more official data / other information
Foot and Mouth Disease	100°C for 1 hour	70°C for 30 min	
Highly pathogenic - Porcine reproductive and respiratory syndrome	100°C for 1 hour achieves 15 log reduction (99.9999999999999%)	Not available	Inactivation parameter predictions were done based on limited experimental data from the studies referenced by APHA. As an example, a 5 log reduction is achievable at 80°C for 30 mins. (Hayrapetyan, Nierop Groot, and Zwietering 2018).
Newcastle Disease	70°C for 30 min achieves 4 log reduction in eggs	60°C for 30 min	Based on inactivation parameter predictions by Hayrapetyan, Nierop Groot and Zwietering (2018) – as an example - a 14 log reduction is achievable at 80°C for 30 using the upper 95% predicted value which is a more cautious value.
Highly Pathogenic Avian Influenza	70°C for 30 min achieves 2-3 log reduction in eggs	56-60°C for 60 min	Based on inactivation parameter predictions by Hayrapetyan, Nierop Groot and Zwietering (2018) – as an example - a 7 log reduction is achievable at 80°C for 30 mins using the upper 95% predicted value which is a more cautious value.

Spores of *Clostridium perfringens* and *C. botulinum*	Heating at 121°C for ca 3 min eliminates spores of *C. botulinum* (12-log reduction of Group I spores – the most heat resistant). That process would also eliminate spores of *C. perfringens*. Elimination of the less heat-resistant Group II spores is achieved by heating at 90°C for 10 min (6-log reduction). (EFSA 2005b)
Bacillus cereus and *Bacillus anthracis*	The process used to eliminate *Clostridium botulinum*, 121°C for *ca* 3 min would also eliminate spores of *B. cereus*. (EFSA 2005a) and of *B. anthracis* (Whitney et al. 2003).

The final recommendation on the heat treatment parameters for pig and poultry feed will depend on the inactivation objectives set for the diseases of most concern. **We assume that higher inactivation objectives will be needed for highly contagious livestock diseases that are more heat resistant such as Foot and Mouth Disease or HP-Avian Influenza, and that lower inactivation objectives can be set for pathogens of concern from a food safety perspective given that the surplus food to be used as feed was already considered sufficiently safe for the human food chain**. An additional reason is that many human food-borne diseases are not epidemic, as in they do not easily spread person to person, whereas the animal diseases of concern here can result in large epidemics.

Once risk managers decide on the final inactivation objectives, we can use microbiological modelling based on large numbers of thermal sensitivity studies to calculate different options. These options can then be analysed from an energy and cost-efficiency perspective. Some example options are listed in Table 4. These examples do not consider the additional impact of acidification but are useful to illustrate some of the possibilities and show how the time of treatment exponentially reduces when temperature is increased.

As already mentioned in Table 3, the matrix in which the pathogen finds itself can significantly affect the heat resistance, for example, the water content tends to decrease heat resistance, whereas certain dry matrices such as dried egg white can increase the heat resistance. A high fat content and the presence of salt or clumping proteins, such as in chicken meat homogenate can protect viruses from heat inactivation (Hayrapetyan, Nierop Groot, and Zwietering 2018). Only data for liquid products or meat slurry was included for the calculation of the inactivation options for Foot and Mouth Disease and HP-PRRS, as no data for dry products was available from the obtained literature on these pathogens.

Table 4: Example heat treatment options for inactivation of diseases of concern, using the upper 95% prediction interval for more conservative parameters instead of averages

Disease	80°C for 30 mins	100°C for 10 mins	121°C for 3 mins
Food and Mouth Disease	17 log reduction	60 log reduction	211 log reduction
Highly pathogenic - Porcine reproductive and respiratory syndrome	5 log reduction	33 log reduction	215 log reduction
Newcastle Disease	14 log reduction	145 log reduction	1586 log reduction
Highly Pathogenic Avian Influenza	6.9 log reduction	425 log reduction	29,550 log reduction

Source: Examples developed from (Hayrapetyan, Nierop Groot, and Zwietering 2018) on the basis of data from 24 scientific papers

3.1.5 Acidification

Acidification is a useful complementary strategy for preventing germination and outgrowth of bacterial spores, and prolonging shelf life of the feed. Heat resistance of some of the more challenging pathogens can also be modified by the pH. "Survival of *Bacillus cereus* spores at 95 ºC decreased by three-fold when the pH of the heating substrate was decreased from 6.2 to 4.7" (Fernandez *et al* 2002 cited in EFSA 2005a). Mazas *et al* (1998) found that acidification from pH 7 to 4 produced a fivefold decrease in $D_{103°C}$ values" (EFSA 2005a). Similarly, *Clostridium* spores are more heat sensitive at low pH values (below ca pH 4.5); hence acidic canned fruits are made safe and shelf-stable without refrigeration by much lower heat processes than those applied to low acid canned foods (Stumbo, 1973; ICMSF, 1998 cited in (EFSA 2005b)). While not in itself destroying spores, a pH of 4.5 or lower also inhibits any spore outgrowth of both *Bacillus* and *Clostridium*. In the case of Japan, heat-treated materials are cooled down to about 40℃ and inoculated with lactic acid bacteria. The culture is kept over 30℃ over-night, achieving a pH of about 4 (JLTA 2011). Overall, it is important to control the pH. For example, if the heat-treated and acidified surplus food is then mixed with other feed components, a rising pH may allow germination and outgrowth of spores.

Therefore, heat inactivation objectives for *Bacillus* and *Clostridium* - which are significantly more heat resistant than any of the pig and poultry diseases we are concerned with - could be set bearing in mind that:

- **Surplus food will have already met safety standards for human consumption, before being repurposed to animal feed**
- **Acidification – as long as the desired pH level is maintained - is proven to prevent the germination and outgrowth of spores between the heat treatment and feeding**

In addition, Foot and Mouth Disease appears to be the most heat resistant animal disease of concern, even at higher temperatures, and is also one of importance given the low oral infectious dose and the consequences of infection. It is therefore of interest that Foot and Mouth Disease is extremely sensitive to pH and quickly inactivated by pH lower than 6 (OIE 2013). The further away the pH value shifts from a neutral pH of 7 – 7.5, the faster the virus is inactivated. For example at pH 6 and 10 there was a 90% reduction in infectivity every 14 hours (D=14 hours), whereas at pH=5, a similar reduction was observed in less than 1 min (Bachrach et al. 1957) as cited in (Hayrapetyan, Nierop Groot, and Zwietering 2018).

However, acidification alone is not enough as a small surviving fraction (~1 millionth part) has been observed in some studies, particularly in the case of non-severe acidification. Consequently, acidification can act as a complementary strategy to heat treatment. If acidification is done by adding consumable acids such as citric acid or propionic acid, for example in the case of milk, a very precise pH value needs to be achieved. As shown for the FMD virus (Sonder et al. 1990), if the pH does not drop low enough (i.e. below 5.5) then complete inactivation is not achieved, but if it drops too low (i.e. below 5) then flocculation of milk proteins provides protection to the virus.

The only study we were able to find for PRRS shows that infectivity of PRRS is rapidly lost at pH below 6 and above 7.5 (Bloemraad et al. 1994). More research may be needed to further establish the heat and pH resistance of PRRS, as well as the combined effect of pH and temperature on PRRS.

Fermentation

Fermented foods, including meat, fish and vegetables, have historically prevented the growth of a wide range of pathogenic bacteria. This is a consequence of rapid development of a “low” pH, below ca pH 4.5. FMD virus (5 logs) in milk was completely inactivated after the production of yoghurt (pH 4.3) by using the contaminated milk, and was not further detected during 2 days of refrigerated storage (pH 4.0) (Aly and Gaber 2007) as cited in (Hayrapetyan, Nierop Groot, and Zwietering 2018). Traditional fermentations are not always under control and slow development of the low pH value has led to botulism. Reaching the "low" pH value as quickly as possible is essential and can be facilitated by using starter cultures and a fermentable carbohydrate such as glucono-delta-lactone (GDL) (EFSA 2005b).

Although the exact modes of action of the acids are not clear, their addition to pig diets has proved beneficial in terms of nutrient digestibility, growth and food conversion efficiency (McDonald et al. 2011). More on the nutritional, health and probiotic aspects of fermentation in section 5.3.1.

3.1.6 Next steps and legal framework for Processing Method

The overarching next step is the building and experimental running of a pilot processing facility. To determine the treatment parameters to use for further testing, the following steps are needed:

- Set desired levels of inactivation for *Clostridium* and *Bacillus* spores, bearing in mind expected low initial contamination levels after food was processed for human consumption prior to being repurposed as feed, and that outgrowth can be controlled with acidification
- Set desired levels of inactivation for the target pathogens: FMD and PRRS in the case of pig feed, and ND and Avian Influenza in the case of poultry feed, again bearing in mind the option of acidification as additional risk management strategy
- Use the data provided by Hayrapetyan, Nierop Groot and Zwietering (2018), and Van Asselt and Zwietering (2006) to develop heat treatment and time combination options as demonstrated in Table 4 (ie lower temperatures for longer or higher temperatures for shorter time)
- Model the most energy- and cost-effective options, including estimates on particle size necessary to achieve the desired temperatures
- Test these options in a laboratory (using surrogate organisms if necessary) and in the target matrix (different types of surplus food ground down the certain particle size and with the expected moisture content, etc) to further confirm pathogen inactivation
- The Japan Livestock Technology Association (JLTA) found that treating both low and high-risk materials may generate unnecesarily high energy costs. Instead, the JLTA (2011) ecofeed manual recommends that "only the materials, which may contain meat or may be contaminated with harmful microorganisms, should be separated, heat-treated, and prepared as fermented liquid feed. And the other safe materials can be mixed into the fermented liquid feed without." We therefore recommend that the pilot treatment plant facility explores the possibility of segregation of low- and high-risk food surplus. High-risk surplus food would be all the surplus that is prohibited under the current legislation, ie that which contains or may have been in contact with meat, fish, uncooked eggs etc.
- If higher temperatures for shorter times are preferable from a cost and energy perspective, test the impact of these temperatures on the digestibility and nutritional values of the treated surplus food. Then account for the additional conventional ingredients that need to be mixed in to achieve the adequate nutritional composition (see section 5.1.3 for more information)
- Outcomes of such further testing and research should result in processing method recommendations which can be set in line with the existing legal template as exemplified in Box 4.

Box 4: Example Processing Method in EC Regulation 142/2011 (p.31)

Processing method 6 (for Category 3 animal by-products originating from aquatic animal or aquatic invertebrates only)

Reduction

1. The animal by-products must be reduced to a particle size which is no greater than:

(a) 50 mm, in case of heat treatment in accordance with point 2(a); or

(b) 30 mm, in case of heat treatment in accordance with point 2(b).

They must then be mixed with formic acid to reduce and maintain the pH to 4,0 or lower. The mixture must be stored for at least 24 hours pending further treatment.

Time, temperature and pressure

2. After reduction, the mixture must be heated to:

(a) a core temperature of at least 90 °C for at least 60 minutes; or

(b) a core temperature of at least 70 °C for at least 60 minutes.

When using a continuous flow system, the progression of the product through the heat converter must be controlled by means of mechanical commands limiting its displacement in such way that at the end of the heat treatment operation the product has undergone a cycle which is sufficient in both time and temperature.

3. The processing may be carried out in batch or continuous systems.

3.2 Biosecurity and HACCP

The APHA risk assessment highlights the risks from potential errors in transport, storage or manufacturing that could allow for the re-introduction of pathogens through cross-contamination between treated and untreated product (Adkin et al. 2014). Similarly, the REFRESH Expert panel (Luyckx 2018, 4) emphasizes "the importance of sound system design to prevent cross-contamination using biosecurity measures and proven logistical and Hazard Analysis and Critical Control Point measures for segregation in storage and transport" such as zoning, one directional process flows and dedicated sealed storage.

Box 5: Existing biosecurity requirements

The technical requirements for biosecurity in the treatment of surplus food can be adapted from those applicable to the animal by-product industry. Commission Regulation (EU) No 142/2011 lays out comprehensive safety requirements for animal-by product processing plants (European Commission 2011)– for example:

- One directional process flows such as a "a conveyer system" with "separate entrances, reception bays, equipment and exits"
- Careful monitoring of heat-treatment such as "measuring equipment to monitor temperature against time" and "recording devices to record continuously the results of these measurements in a way so that they remain accessible for the purpose of checks and official controls"
- Zoning, through "clear separation between the area of the plant where incoming material for processing is unloaded and the areas set aside for the processing of that product and the storage of the derived product"

For a complete list, see: Commission Regulation 142/2011, Annex IV, Chapter 1 "Requirements for Processing Plants and Certain Other Plants and Establishments, as applicable to Category 3 materials. (pp. 27 – 29).

The rendering industry has emphasised the importance of creating a level playing field between rendering and the processing of surplus food for feed. The rendering industry knows how to manage risks when handling Category 1 ABP-materials, and there is therefore no doubt that they can transfer their knowledge to ensure the safety and prevention of cross- or recontamination of feed made from meat-containing surplus food.

The feed industry also has relevant know-how. For example, in the UK, there is the Feed Materials Assurance Scheme FEMAS run by the Agricultural Industries Confederation which sets out industry guidance on how to implement Hazard Analysis Critical Control Point principles in the feed sector. In essence, a risk assessment must be carried out of all the separate cross-contamination risks from different food products which may be illegal or harmful in feed, along the whole journey of the food from the point it is designated for feed use (FEMAS 2015).

FEMAS already has specific guidance for the former foodstuffs sector, for example on how to prevent confusion between former foodstuffs and waste through clear identification of containers and the need to seek adequate evidence that rejected products are suitable and safe for use as feed ingredients, and otherwise dispose of them safely and legally (FEMAS 2015). If heat-treated products *do* come into contact with products which haven't been heat-treated, all affected product should be treated as if it is raw. Operators must prevent any process or cleaning water which may contain microbiological contaminants from coming into contact with feed ingredients (FEMAS 2013). Guidance for the former foodstuff sector, in combination with existing operational procedures for the rendering industry, can be developed into sector guidance for the processing of meat-containing surplus food into non-ruminant feed.

3.3 Preventing contamination from other substances like packaging and toxins

Packaging

Additional risks such as plastics or dioxins must be managed as is done in the existing feed industry. As noted by WRAP (2016), food surpluses must not contain prohibited materials nor exceed restricted ingredients, this includes any trace of packaging which can contaminate the resulting feed material when de-packaging surplus food. Like other EU MS, the UK Food Standards Agency operates a tolerance of 0.15% by weight for the presence of packaging residue, including plastic food grade packaging material (Grant 2018).

There is a zero tolerance on glass packaging and former foodstuffs in glass packaging should not be used in animal feed. If the food surplus is a product packaged in glass, it cannot be diverted for animal feed, nor can the product be released from its packaging, due to the obvious risks from glass shards entering the feed supply chain. To further use the example of the UK, FEMAS sets out how packaging should be carefully removed from former foodstuffs, and measures should be taken to coordinate with suppliers to minimise the amount of packaging entering into the raw material containers in the first place (FEMAS 2015).

Metal used in food factories is usually non-ferrous and not magnetic, so it should be carefully considered whether magnets are the most appropriate tool, or sieves, screens, filters, separators or metal detectors should be used instead (FEMAS 2015). Different types of packaging which may be present in former foodstuffs should be identified by hazard analysis, and their different risks assessed separately, so appropriate controls can be implemented. Regular measurement of any residual food packaging should be conducted on an at least weekly basis, with sufficient size and number of samples to be representative (FEMAS 2015).

Again, the industry already holds significant know-how and is continuously researching improvements. For instance, Paul Featherstone of UK former foodstuff processor Sugarich noted that they "are currently evaluating optical sorting technology that can show up bright colours and the reflective properties of metalite packaging to screen for any packaging residues. It is a bit like the technology used to check for discolouration of product in a chip or crisp factory" (Byrne 2017a).

Concerns have been raised about microplastics further accumulating in the food chain through the presence of the legally tolerated level of 0.15% of plastic packaging material in feed (Grant 2018). The former foodstuffs industry is continuously working to develop improvements in the area. However, it is important to balance requirements on the feed industry with wider requirements to reduce the use of plastics in the food industry more generally, and with the need to keep surplus food in the supply chain. This balancing of risks and environmental objectives is further discussed in section 10.6.

Mycotoxins

Mycotoxins are toxic compounds produced by different types of fungus, which develop on cereals used in food and feed, and nuts such as almonds or hazelnuts. Given that mycotoxins mainly enter the food chain through fresh food and feed crops, no additional guidelines can be developed in addition. Of course, surplus food-based feed needs to meet the same requirements as conventional feed, in terms of the legislation on mycotoxin testing in feedstuffs (Walker 2017).

Dioxins

Dioxins, however, merit further consideration because dioxin accumulates in the fatty tissues of beef and dairy cattle, poultry, pork or seafood. Dioxins are unintentional pollutant by-products of various industrial manufacturing processes such as incineration, manufacturing of pesticides or exhaust emissions.

The Irish dioxin crisis in 2008 resulted directly from feed contamination during the processing of former foodstuffs. The contaminated pig feed was produced by direct (hot air) drying of raw baker's dough and leftover bread products sent for recycling to a licensed feed mill. Two different types of feed material were produced, bread-crumb which was produced as pig feed, and biscuit, which was produced as cattle feed. The exhaust from the furnace used for drying, which was fired using contaminated oil, acted as transfer medium and the bread itself acted as a filter, adsorbing the contaminants from the circulating hot air (Tlustos 2009). We understand that one of the reasons the European Former Foodstuffs Processors Association was formed was to apply the learning from the Irish dioxin crisis and prevent such contamination from occurring again.

In an assessment on pig meat inspections, the European Food Safety Authority has concluded that dioxins, dioxin-like polychlorinated biphenyls and chloramphenicol are unlikely to pose an immediate or short-term health risk for consumers (EFSA 2011). The biggest concern relates to fish oil and fish meal which are the most heavily dioxin contaminated feed materials. However, Garcia et al. (2005) analysed municipal food wastes per category (meat, fish, fruit and vegetable, restaurant and household wastes) and identified dioxins, furans and polychlorinated biphenyls (PCBs) in the restaurant and household waste streams, but not retail surplus. Animal fat may also carry significant but lower dioxin contamination. Therefore, it is important that we bear in mind the lessons learned from the Irish dioxin crisis in the design of treatment facilities. This means that we need to test for dioxins, especially in catering surplus, in addition to microbiological contaminants in the pilot treatment facility that is recommended as next step in these guidelines.

Heavy metals

Contamination with heavy metals such as arsenic, lead or mercury is a concern in the feed industry. Such metals can accumulate in certain tissues of the pig. We have not been able to find any evidence to suggest that the use of surplus food increases the risk of unacceptable heavy metal accumulation in feed. Research points instead to feed additives, feed material of mineral origin, feed material of marine origin, especially fish meal, seaweed and algae, as well as feed additives belonging to the functional groups of (1) trace elements (notably cupric sulphate, zinc oxide and manganese oxide for arsenic) and (2) binders and anti-caking agents (Adamse, Fels-Klerx, and Jong 2017). Mycotoxin binders are also of interest. Feed made from surplus food should therefore be tested for the presence of heavy metals in the same way as conventional feed. Similarly, prevention strategies for the manufacturing and blending of feeds should bear in mind industry know-how to avoid the accumulation of heavy metals in surplus-food based feed.

3.4 Intra-species recycling

Intraspecific predation, the process of both killing and eating an individual of the same species, is commonly observed among many animals (Schutt 2017) and has been observed in about 1300 species, from fish and insects to mammals (Polis 1981). Intraspecific predation is "not an aberrant behaviour limited to confined or highly stressed populations, but is a normal response to many environmental factors" (Fox 1975).

Ethical aspects of intraspecies recycling

For a discussion of the ethical aspects of intraspecies recycling in pigs and poultry, please see section 8.5 on animal welfare.

Safety aspects of intraspecies recycling

Omnivorous animals eating feed that contains traces of meat from their own species increases the risks of animals contracting diseases that affect their species. One of the main reasons for the introduction of EC Regulation 999/2001 was the fact that the presence of ruminant protein in ruminant feed was directly responsible for the spread of Bovine Spongiform Encephalopathy, or BSE.

However, when it comes to non-ruminants, a first EC scientific opinion states that

> *"no scientific evidence exists to demonstrate the natural occurrence of Transmissible Spongiform Encephalopathy ("TSE") in farmed pigs, poultry and fish, which may create a basis for an intra-species progression of a TSE infection due to intra-species recycling" (EC Scientific Steering Committee 1999).*

This was re-affirmed by EFSA in 2007,

> *Even recognising that significant amounts of BSE infectivity have been fed to pigs in the UK and additionally that intra-species pig to pig recycling could have happened, no naturally occurring TSE, including BSE, have been detected so far in pigs.(European Food Safety Authority 2007).*

In a UK study, disease failed to occur in pigs retained for 7 years after exposure by feeding BSE-affected brain on three separate days, at 1–2 week intervals. The amounts fed each day were equivalent to the maximum daily intake of meat and bone meal in rations for pigs aged 8 weeks. No infectivity was found in tissues assayed from the pigs exposed orally to BSE (Wells 2003). The Japanese and US models do not have an intra-species recycling ban for non-ruminants which means that traces of pork may be found in feed. In the US, rendered materials from porcine origin are used in pig feed (Cho et al. 2010; Cromwell 2006). Pure porcine protein is exempted from prohibitions in relation to BSE and guidance for feed inspectors focusses on how to avoid cross-contamination between swine and cattle feed, given that the swine feed may contain prohibited animal proteins (Association of American Feed Control Officials 2017). Similarly, Australia permits the feeding of pigs with commercially manufactured meatmeals and tallow, from any species, produced according to the Australian Standard for the Hygienic Rendering of Animal Products (Government of Western Australia 2019).

While from a TSE perspective there is currently no reason to ban the feeding of porcine proteins to pigs, pig-disease risks such as African Swine Fever need to be adequately managed. Central to such management is the setting of sufficiently high levels of pathogen inactivation as discussed in section 3.1.3. Tight biosecurity and adequate HACCP throughout the supply chain also need to form part of the risk management strategy. In section 3.5, we propose additional traceability measures regarding the presence and origin of pork products in the surplus food to be processed into pig feed.

In addition, in response to consumer demand, common-sense measures could be taken to reduce the proportion of pork that goes into pigfeed, for example by ensuring that the processed animal proteins from single species rendering plants go to other species (i.e. chicken to pig and vice versa). According to Martin Alm, technical director of European Fat Processors and Renderers Association (EFPRA), a number of PAP producers in the EU have already embraced the changes necessary to deliver high-quality, species-specific and traceable PAPs, moreover their products placed on the aqua feed market are exceeding regulatory requirements (Jedrejek et al. 2016). We recommend that surplus-food to feed treatment plants are species-specific and seek out suitable suppliers. For example, a restaurant chain serving primarily chicken-based food might be particularly suitable for sending its leftovers to pigfeed, and less so for poultry feed. Pigfeed processors may choose to require manufacturers, caterers or retailers who handle both pork products alongside other meat products, to separate out those products where the primary ingredient is pork, for consumer sensibility reasons. However, there would be no need to implement severe segregation measures like those required for former foodstuffs where even the smallest trace of animal protein is unacceptable. In other words, **from a safety perspective, if the inactivation and additional risk management measures discussed in this chapter are adequately implemented, there is no requirement to prevent the presence of pork in pigfeed, or poultry protein in poultry feed.**

3.5 Traceability

The objective of this section is to provide a starting point to develop further recommendations on traceability, should the use of mixed food wastes for non-ruminant feed be allowed in Europe. A more detailed discussion of traceability principles is available in the Supplementary Materials Part 3. The first part of this section discusses traceability as defined in the GS1 Global Traceability Standard (GS1 2017) in an "open" system where feed treatment plants can source surplus food from different suppliers across different sectors. This part also refers to the report of the DG SANCO traceability working group (GS1 2013). The second part discusses the closed loop circular system used by some parts of the Japanese food / feed industry.

3.5.1 Traceability in an "open" system

About traceability

Traceability is the ability to trace the history, application or location of an object (ref. ISO 9005:2015). In the context of managing mixed food wastes in non-ruminant feed, the need for traceability is particularly driven by the need to ensure safety and to meet market expectations and the regulatory framework from the food sector. Mixed food waste involves high risks ingredients such as meat, fish, or eggs. Heat treatment during processing is expected to address the risks yet it is the expectation of the food, feed and farming industry to have traceability and to know were food and its ingredients come from. Moreover, there is no risk zero (risks are not only microbiological) and it is important to be ready to handle recalls just like for any food and feed product.

Responsibilities

Traceability across the supply chain relies on the responsibility from each successive operator. Each member of the supply chain should, at a minimum, be able to trace back to the direct suppliers of the products they received, to what happened (critical tracking events) while the products were under their responsibility and to track forward to the direct recipients of the products. This enables all parties to gain access to relevant data further upstream and downstream through queries to direct trading partners, often referred to as a "one-step-up, one-step-down" approach.

Figure 2: Supply chain for mixed food waste to non-ruminant feed

The surplus food supplier can be a retailer, food manufacturer, caterer, rendering processor or slaughterhouse. Wholesalers, carriers or third-party logistics can be involved in between these key actors.

Traceability principles

A few principles are core to traceability whatever the technologies, sectors and applications of traceability. Foundational functions from traceability systems are:

- identification of products, locations and parties;
- labelling of all products and levels of packaging;
- data capture and recording;
- enabling access to the data, i.e. data sharing

Traceability data

Traceability is powered by data. Each organisation should first identify which steps in its internal business processes are important from a traceability perspective. Subsequently, the organisation will need to define and capture all of the relevant data about these business process steps.

At the core of this are two concepts:

- Critical Tracking Events (CTEs): These are the actual events that occur to the traceable objects during their lifecycle, such as receiving, transforming, packing, shipping, transporting.
- Key Data Elements (KDEs): These are the pieces of data that describe the actual instances of the CTEs. The data will commonly cover five dimensions: Who, What, Where, When, Why.

Interoperability

Traceability data are spread among many stakeholders along the chain. All these stakeholders have different traceability systems. In order to access information from upstream or downstream trading partners need to have visibility across the chain, these traceability systems need to be able to talk to each other or be “interoperable”.

Figure 3: The GS1 system of standards

Source: GS1 Global Traceability Standard (GS1 2017)

GS1 standards are the common language for traceability solutions. The GS1 system of standards provides a comprehensive set of standards to identify, capture and share information about objects throughout their lifecycle, providing the core foundation for interoperability. They already power information sharing for more than one million companies across supply chains. GS1 standards are developed and maintained by GS1, a neutral, not-for-profit, global organisation.

Collaboration is fundamental to traceability. Each company will need to define the exact data they will manage for traceability and to decide how they will capture, record and potentially share them (process, technology and tools). Discussion with direct trading partners and within the sector with all stakeholders including authorities best enables efficient traceability systems that meet everyone's needs and constraints, and ensures the sustainability of everyone's investments.

Questions about data to be recorded by each operator, data accessibility, duration of the records, data quality, data authentication and technologies may be collectively addressed to facilitate the interoperability and reliability of the traceability across the chain.

3.5.2 Traceability recommendations

More work needs to be done by each business operator to determine the exact traceability requirements for the use of meat-containing surplus food in feed. The detailed "how-to" of data capturing and sharing will need to be set out in the contractual arrangement between the surplus food supplier and the treatment plant. However, drawing on the traceability discussions in the REFRESH multi-stakeholder expert panels (Luyckx et al. 2018) and assuming that feed treatment plants will produce feed for a single species, **we recommend that in the pilot phase of this project the following traceability requirements are applied**:

- For pig feed treatment plants, any **pig meat ingredients should be traceable to source**. If the surplus food supplier cannot provide origin data on the pig meat, then at this stage, such supplier should not be contracted to provide surplus food, unless full segregation can be guaranteed from any products containing pig meat. A **similar principle should be applied to poultry feed**.
- For all other ingredients, **the "one-step-up, one-step-down" traceability approach, which is standard in most of the food and feed sectors, should be applied by all operators in the supply chain**. This chimes with a key learning from the Irish dioxin crisis, where such an approach to traceability was recommended to avoid the situation of a 100% recall of all pork products even though only 8% of total Irish pig production had been using contaminated feed which came from one feed manufacturer alone (Tlustos 2009).
- The above traceability requirements will need to be stipulated in the contractual arrangements between the feed treatment plant and surplus food suppliers. This may mean that retailers and manufacturers who already operate with a well-established traceability system will be the likely first sources for surplus food for feed.

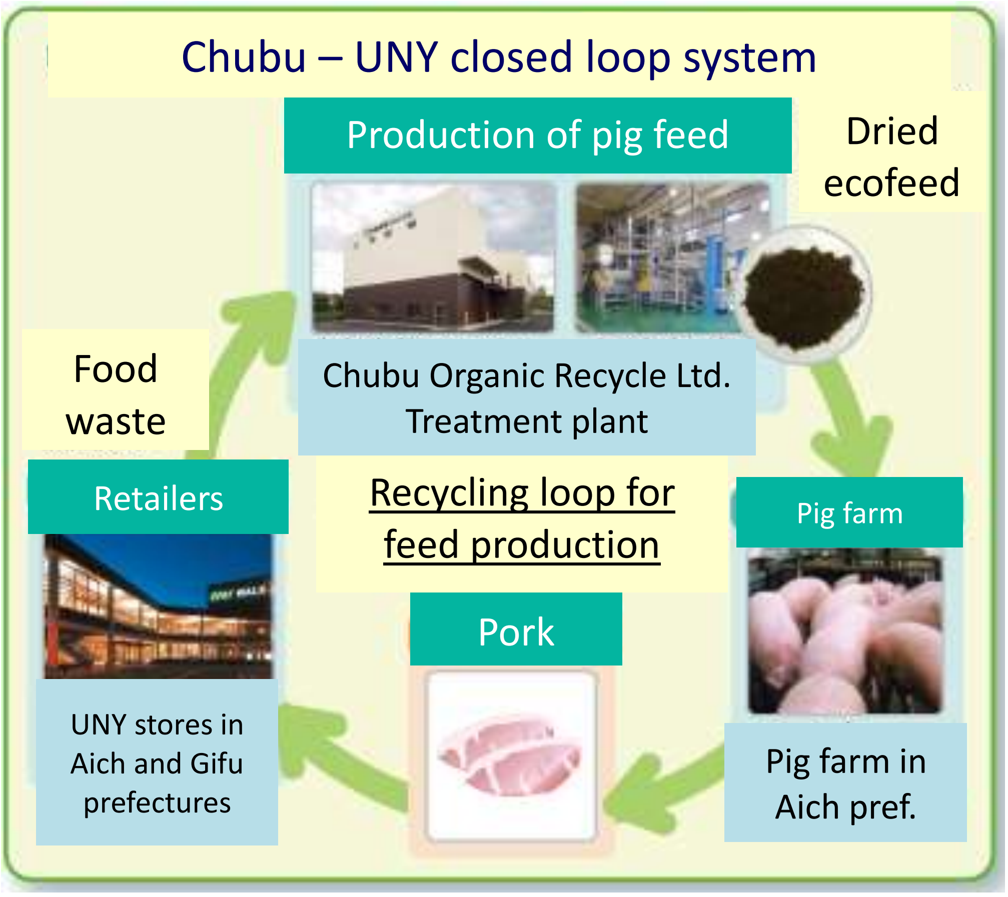
- Major players, such as fish feed company BioMar Group have noted that "new technologies like blockchain will find their way into the traceability arena as chain-of-custody continues to increase in importance" (Byrne 2017b). Some further research may be useful to understand whether a blockchain approach may help to ensure surplus food meets the traceability requirements for safe feed.
- All players in the chain should be allowed to choose the specific tools and softwares that will enable them to best achieve traceability in their environment. It is critical for these tools to be able to communicate with each other owing to global data standards. Technical guidance could be developed collaboratively in the industry to support the implementation of an ecosystem of interoperable traceability systems while embracing innovations such as Blockchain and the digitalisation of the supply chain.

3.5.3 The closed loop approach in Japan

In Japan, certain feed processing plants and retailers have formed a closed loop partnership. For instance, the Odakyu Group is a Japanese company operating a chain of department stores, hotels, restaurants and rail transport. They deliver unused food from their supermarkets, restaurants and train lines (including meat products), but not from households, to the Japan Food Ecology Centre factory to be turned into pig feed, and they buy back the pork from the farms using the JFEC feed to sell as a premium-quality eco-product in its own stores. Unused food is separated before it gets to the factory. When the bins arrive at the factory, the bins' barcodes are scanned and weighed to record the surplus food composition and ensure traceability. Currently, JFEC also processes surplus food from suppliers not part of the Odakyu group.

A closed-loop system exists between the UNY supermarket chain and Chubu feed processor. The stores separate the food out into key categories, and then using a registration system weigh the food and log its content. This aspect is further discussed in the chapter on nutrition. Businesses must submit plans for the recycling loop to the Japanese government, which the government approves/certifies if it is deemed safe. This closed loop reduces risks and simplifies traceability.

Figure 4: The Closed Loop System



4 Official controls

We have explained how meat-containing surplus food can be treated and handled to ensure its safety for omnivorous livestock. Experts agree that this is technically feasible (Luyckx 2018) but lessons learnt from the Foot and Mouth crisis at the beginning of the century show us that the role of official controls is equally important. The direct cause of the FMD outbreak was the deliberate illegal feeding of uncooked food waste to pigs, which was allowed to go on for too long because of lax official controls. After a brief discussion of the circumstances of the FMD outbreak, we look at existing official control approaches and how these could be complemented and adapted to ensure the safe use of higher-risk materials such as meat in omnivore feed.

We suggest that plenty of the existing legal requirements applying to the feed manufacturing, farming and rendering sector can apply to a new surplus-food-to-feed sector and need not bring significant changes or additional costs. The lifting of the intraspecies recycling ban for omnivorous non-ruminant livestock would bring the EU in line with many other parts of the world, where a feed ban only applies to ruminant livestock (see Supplementary Materials Part 4 for a review of legislation in the US, Japan, New Zealand).

Lifting of the intraspecies recycling ban would therefore **not change the feed control mechanisms applying to ruminant feed for the prevention of BSE.** It would also take away the technical challenges regarding testing for species-specific animal protein in non-ruminant feed, which are currently holding up the approval of the use of non-ruminant PAPs in non-ruminant feed. However, a new challenge appears in the form of testing whether animal proteins in non-ruminant feed were subjected to the required treatment. In other words, how will inspectors determine whether feed comes from a licenced treatment plant or not? This question will be discussed towards the end of this chapter.

Table 5: Overview of most important applicable European regulations

Regulation	Keep	Add or Change
999 / 2001 TSE	Ruminant feed ban	Lift non-ruminant feed ban
1069 / 2009 Animal By- Products		Lift ban on catering waste for non-ruminants
142 / 2011 Implementing Reg 1069	General principles on biosecurity, processing and ABP categories	Add processing method 8 for surplus food that may contain or have been in contact with meat, fish, raw eggs, etc.
183 / 2005 Feed Hygiene		Add licencing requirement for FeBEs supplying, processing, mixing or using non-ruminant feed with surplus food ingredients

4.1 Learning from Foot and Mouth crisis

The last major outbreak of Foot and Mouth Disease in Europe happened in 2001 and is estimated to have cost up to €12 billion as well as a severe social and economic impact on the affected agricultural communities (European Food Safety Authority 2006). The outbreak is thought to have started with the illegal feeding of untreated contaminated catering waste to pigs in the UK where the outbreak cost £8 billion (£5 billion in the private sector and over £3 billion from public finances) and led to the slaughter of over six million animals (Bourn 2002). The exact source of entry into the country in 2001 was never established. However, it was most likely that the virus was imported from the Far East, either in the form of imported meat (almost certainly illegally) or in the form of catering waste from ships or airlines (Anderson 2002) and then fed as swill to pigs. The crisis was traumatic to the farming community, and images of burning animals shocked the public. The UK countryside was closed off to prevent spread of the disease, and two thousand UK military were deployed across the country to help with containment (Anderson 2002, 82). Import bans were placed on the UK by other countries wary of catching the disease.

The cause of the UK Foot and Mouth Disease outbreak was primarily one of lax enforcement of a law that was difficult to apply, asking farmers to boil surplus food for at least 60 minutes and asking inspectors to monitor large numbers of farmers to make sure this was done adequately. Extremely unhygienic conditions were found during inspections of the farm where the outbreak is thought to have started, but the State Veterinary Inspector only offered informal warnings and did not report the problem or conduct more thorough inspections which should have found containers with unprocessed swill (Parliamentary and Health Service Ombudsman 2007, 35–36). Between 1995-2001 the farm was only ever visited by one inspector (Parliamentary and Health Service Ombudsman 2007, 34), although complaints had been made about the farm repeatedly by concerned individuals to Newcastle Trading Standards officers, environmental health inspectors, the local branch of Ministry of Agriculture, Fisheries and Food and the Royal Society for the Prevention of Cruelty to Animals (Cook 2001, 13).

This was indicative of a general situation where regulation was strict, but it was weakly enforced. Government policy and the State Veterinary Service's approach was to encourage improvement rather than prosecute under the Animal Health Act 1981 (Danby 2015). The EU's Food and Veterinary Office inspected some UK swill processing plants in 2001, and found that the "standards" and "proximity to animals" would "have given cause for concern if a ban had not been introduced following the FMD outbreaks in 2001" (European Commission 2002, 10 para 4.4.3).

4.1.1 Containment of the FMD outbreak

The infection was discovered on 19th February 2001 and confirmed by the Pirbright Institute one day later. A second test took until the 23rd February to confirm the case and introduce national livestock movement restrictions. The official government inquiry into the crisis indicates that if a ban on livestock movement had been put in place the day the disease was first confirmed, the extent of the epidemic would have been a third to one half of what it became (Anderson 2002) Furthermore, slaughtering of animals to prevent further contagion was conducted in a piecemeal and erratic way which was unsupported by any clear scientific basis and often "not in proportion to the nature of the risks" (Anderson 2008). A "slaughter on suspicion" approach was applied without requiring clinical confirmation of infection. The scale resulting from the extensive culling resulted in a significant backlash from the public and trauma amongst farmers (Danby 2015).

The EU permitted the UK to use emergency vaccination in some regions, but despite this, the UK did not actually carry out any vaccination because of industry concerns that retailers, exporters and the public might not buy food products from vaccinated animals (Anderson 2002). The British National Pig Association are still opposed to vaccination on the grounds that it would harm British exports and animals infected shortly after vaccination can still spread disease without showing symptoms (National Pig Association 2013).

In contrast, Uruguay brought its own 2001 Foot and Mouth outbreak under control in nearly half the time as the UK (European Commission 2001), and the cost was estimated at US$13.6 million, compared to a cost to the UK economy of £8 billion (Bourn 2002). Uruguay responded very rapidly with livestock movement restrictions through road blocks and vaccination of all cattle within a 10 km radius of affected farms followed by mass vaccination some days later (European Commission 2001). Although no pigs or sheep were vaccinated, probably because of their small numbers, the comprehensive vaccination of cattle proved effective.

4.1.2 Reasons for banning the feeding of catering surplus

In the UK, with the scale of the crisis and local elections looming, the urgency to contain the outbreak was extreme. As a result, government issued a flurry of legislative changes including the ban on feeding swill to all livestock (Danby 2015). The government's **main argument for the ban was that whereas previously the main risk of infected material came from imported feed, the UK FMD outbreak now meant there was a high risk of feed infected with domestic meat, and this may continue for some time** (Parliamentary and Health Service Ombudsman 2007 Annex B). They also argued that the EU were already considering a ban on feeding swill to livestock. The government also pointed to a lack of capacity to inspect premises using surplus food and that an immediate and total ban would be much easier to enforce (Parliamentary and Health Service Ombudsman 2007, 56 Annex A).

The immediate ban on feeding surplus food, treated or not, following the UK Foot and Mouth outbreak was understandable. However, the real problem was not the type of feed fed to pigs, but rather one of a poorly designed regulatory framework and of lax enforcement. If we are to reintroduce meat-containing surplus food in feed for omnivorous livestock, we need a robustly regulated system that can be properly enforced.

4.2 Licencing and official controls

While additional resources and capacity will be needed to ensure adequate official controls of the use of surplus food in feed, official control practice already takes a risk-based approach. For example, in the UK, if a farmer uses feed with former foodstuffs or fishmeal, this farmer is more likely to be inspected. Such risk-based approach could easily be adapted to include additional feeding materials. In Chapter 8 we suggest that the environmental gains of using surplus food in feed, in the context of urgency to reduce greenhouse gas emissions, merit government support to establish a modern surplus-food-to-feed industry inspired by the Japanese example.

The National Pig Association in the UK have rightly raised the concern that whereas Japan has "a culture of regulatory compliance", the same may not be said for European countries like the UK (National Pig Association 2013), and so extra precautions may be needed. Therefore, costs and capacity related to additional official controls need to be considered. REFRESH has not been able to do extensive research on this aspect but collected expert views during workshops on the issue with over 70 professional members of the British Association of Government Veterinarians and the Veterinary Public Health Association (VPHA 2018). We have also repeatedly spoken with experts at the UK Animal and Plant Health Agency. Our learning from these workshops and conversations has been incorporated in this chapter. Below, we look at the licencing and control aspect for each stage of the pigfeed supply chain.

4.2.1 Treatment plants

In the European context it will be necessary to **limit the production of feed from surplus food to licensed treatment plants that are located separately from farm premises** (Luyckx 2018, 2). For instance, there are currently around 17 rendering plants in the UK (Fabra UK 2018), which means regular comprehensive inspections are possible. We recommend the same controls apply to surplus-food treatment plants as currently apply to the animal by-product processing (rendering) and feed manufacturing sectors. See box 5, for a brief summary of how the UK Animal and Plant Health Agency applies EC Regulation 142 / 2011 regarding requirements for rendering plants.

Box 6: Summary of applicable control measures carried out by the UK Animal and Plant Health Agency on animal by-product processing facilities (rendering)

- As with Animal By-Product processing facilities, APHA to approve Surplus Food treatment premises and maintain central register
- Treatment plant site inspections by APHA inspectors on a monthly basis, plus unannounced visits
- Hygiene and Processing Requirements to be as for ABP-approved processing (Rendering) facilities:
  - ✓ **One directional process flows** such as a "a conveyer system" with "separate entrances, reception bays, equipment and exits"
  - ✓ Measuring equipment to **monitor temperature against time, pressure and particle size continuously** and keep records (add **pH** if this forms part of inactivation parameters)
  - ✓ **Zoning**: between incoming material, processing, and storage of derived product
  - ✓ **Standard Operating Procedure**
  - ✓ **HACCP**: Identification of most hazardous risk areas on site,
  - ✓ Hygiene in common areas like canteens
  - ✓ **Action plan for cross-contamination** event
  - ✓ **Action plan for ABP spillage** event
  - ✓ **Equipment maintenance**
  - ✓ **Staff training**

Source: Guidance for the animal by-product industry (APHA 2014)

In addition to the controls applicable to the rendering industry, it may also be of interest to apply controls relevant to feed manufacturers. In the case of the UK, the Food Standards Agency Feed Law Practice Guidance brings together requirements from EC Regulations on ABPs, Feed Hygiene, TSEs, Placing on the Market and Use of Feed (Reg 767/2009) and other relevant regulations. To this Practice Guidance we also need to add monitoring of Mycotoxin, Dioxin and Nickel according to Commission Regulation (EC) No 152/2009 and Recommendations 2006/576/EC and (EU) 2016/1110.

Box 7: Summary of applicable control measures in the UK's Food Standards Agency Feed Law Practice Guidance

- As with Feed Business Operators, Local Authorities to register surplus food treatment premises.
- Competent authorities must have a risk-based feed sampling program, looking at hygiene, undesirable components (heavy metals), fraudulent use of dangerous additives, and other aspects.
- Feed Hygiene requirements to be applied as for existing feed manufacturers:
  - ✓ **Hazard Control Systems (HACCP).** What Critical Control Points have been identified? Written procedures, hazard controls, management records
  - ✓ **Personnel -** organisational chart, communication of duties to staff
  - ✓ **Production -** qualifications of staff, following procedures, cross contamination measures, accurate measuring devices, measures to isolate prohibited items, traceability system, packaging contamination measures
  - ✓ **Complaints and Recall -** written procedures
  - ✓ **Quality Control -** qualifications of staff, Sampling plan, access to lab, storage of samples, storage of ingredients documents
  - ✓ **Facilities & Equipment –** clean premises & equipment, lighting, drainage, clean water, control of sewage, waste and pests
  - ✓ **Storage & Transport -** zoning, approval of additives, restricted access to feed, identification method for feed, storage temperature
  - ✓ **Labelling -** compliance
  - ✓ **3rd Country Imports - Export of unauthorised additives to 3rd countries**
  - ✓ **Is the test listed in the National Enforcement Priorities?**
  - ✓ **Traceability** (here inspectors could inspect how treatment facilities monitor the implementation of traceability requirements with their suppliers as discussed in section 3.5.2)

Source: (Food Standards Agency 2018)

Approved assurance schemes and industry standards

The UK Food Standards Agency also provides guidance on when the number of controls can be reduced as result of earned recognition through participation in an FSA approved assurance scheme such as FEMAS (Feed Materials Assurance Scheme). As discussed in section 3.3, FEMAS has already produced helpful guidance for former foodstuff processors on preventing contaminants (FEMAS 2015). A new surplus-food-to-feed industry may wish to develop its own industry standards as a way of supporting the industry to uphold the highest standards and to protect against rogue operators.

One approach may be to develop a Publicly Available Standard (PAS), adapted from standards developed for similar industries like the Japanese Ecofeed certification (Kawashima 2018) or PAS110:2014 which is currently used for anaerobic digestion plants (WRAP and BSI 2014). This is a voluntary, industry-led specification which ensures that digestates are of consistent quality and fit for purpose - it sets requirements for input materials, process management controls and monitoring, and digestate sampling, testing, validation checks and information for end users. In the case of a new surplus-food-to-feed industry, a PAS would need to be set within the legal framework and outline treatment criteria for animal by-products as discussed above and in section 3.1.6.

Industry standards and schemes could also provide guidance on contractual agreements with suppliers of surplus food in terms of safety (eg. traceability section 3.5.2) and nutrition as discussed in Chapter 5. One aspect of such guidance could cover separation of poultry and pork products. While there are no safety or nutritional grounds to maintain an intraspecies recycling ban for non-ruminants (sections 3.4 and 5.1.1), it may still be desirable from a consumer perspective to produce feed in single species treatment and feed manufacturing plants. To do so, contractual agreements with suppliers will need to stipulate requirements to separate poultry from pork products, without necessitating strict segregation as currently applies to traces of prohibited animal by-products in the former foodstuffs industry.

Environmental permits and controls

Surplus food treatment plants will also need to get environmental permits and controls to ensure safe disposal of wastes, odour controls, etc. Research into this aspect is out of the scope of REFRESH, but we note that the UK Environment Agency already sets out specific permit and inspection requirements for sectors such as Biowaste Treatment, Anaerobic digestion etc. Environmental permitting and controls in the UK are paid for by the business whose activities require an environmental permit. A very specific list of charges is detailed in the table of charges provided by the (UK Environment Agency 2018). In a nutshell, UK businesses will **pay for an initial application to obtain the permit, followed by annual subsistence charges to pay for ongoing inspections**. For example, at the time of writing the subsistence activity charge for an anaerobic digester, or a treatment plant treating 10 tonnes or more of animal waste or hazardous waste per day was £11,019.

A significant change for environmental permitting is that the Environment Agency has introduced extra charges that some customers will need to pay on top of the fixed application and annual subsistence charges. These **supplementary charges apply** if the Environment Agency needs to do extra or unusual regulatory work. Charges for this extra work will either be a **fixed cost or calculated on a time and materials basis** (UK Environment Agency 2018). **This finance model could be wholly or partially applied to a new surplus food to feed industry both from an environmental and safety perspective, depending on government decisions regarding their support for the industry based on its wider environmental credentials on greenhouse gas emission savings.**

4.2.2 Final feed manufacturer

If treated surplus food is blended with conventional feed ingredients to deliver feed that meets the nutritional requirements of the existing industry (see Scenario 1 in Chapter 5 on Nutrition), then a final feed manufacturer may undertake this blending and sell compound feed to the farmer. Safety and environmental permits and controls would be like those discussed in the previous section on treatment plants, with one significant addition: **from this stage in the supply chain onwards, authorities need to have the tools to control whether the surplus food used by feed manufacturers and farmers comes from specialist licenced treatment plants**.

The customary mammalian muscle fibre tests can continue to be applied without the need for species identification in the following situations:

- feed manufacturers that also produce ruminant feed
- farmers that breed ruminant livestock. Authorities may deem it necessary to not allow the feeding of treated surplus food on to pigs on farms where there are also ruminant livestock to minimise the risk of cross-contamination
- non-ruminant feed manufacturers and farmers not licenced to use meat-containing surplus food

For premises licenced to use treated surplus food, existing tests for mammalian muscle fibre will not apply but we could develop a mix of the following control approaches:

- Assuming on-farm mixing will not be allowed (see next section): detailed documentation on animal production volumes and feed volumes: develop feeding volume / production volume parameters as a first level control to ensure no deliberate illegal feeding is taking place.
- For farms moving to liquid feeding systems (see section 5.3), investigate the possibilities to develop closed pipelines and feeding infrastructure to allow strict control of input from feed-tanks delivered from licenced manufacturers
- Possibly testing for the presence of unprocessed meat proteins.

4.2.3 Testing for the presence of unprocessed meat proteins which did not originate from licenced treatment plants

If authorities deem it necessary from a risk-management perspective to develop additional controls to avoid accidental or deliberate feeding of unprocessed surplus food, we will need to look at possible technologies to do this. REFRESH has not been able to fully research this but found three possible avenues to explore:

Immunoassay

"Immunoassay is a highly selective bioanalytical method that measures the presence or concentration of analytes ranging from small molecules to macromolecules in a solution through the use of an antibody or an antigen as a biorecognition agent (ScienceDirect 2019)". Immunoassay methods can be used to detect the effect of heat treatment on certain proteins. For example, de Luis et al. (2009) used two different enzyme-linked immunosorbent assays (ELISA) to determine the effect of heat treatment on immunoreactivity of the milk protein bovine β-lactoglobulin. Similarly, Dominguez et al. (1997) studied the heat resistance of the antigen-binding region of certain immunoglobins in bovine colostrum, and found that the degree of denaturation of the antigen-binding region in the immunoglobin molecule can be determined because this region is directly involved in the reaction process of the assay. It should therefore be possible to develop immunoassay formats focussed on meat proteins that can be found in human food but denature when heat treatment is applied. Antibodies for species-specific albumins – a type of protein - are already commercially available, so albumin is one type of protein that may be useful to consider.

Vibrational or Infrared Spectroscopy

There are myriad applications of vibrational spectroscopy to meet a diverse range of analytical needs in food science. For example, vibrational spectroscopic techniques are being applied in conjunction with various chemometric tools for the determination of food or beverage composition, authentication, or adulteration, the assessment and prediction of quality and process-induced changes, and the detection of chemical or microbiological contaminants related to food safety (Li-Chan 2010). The structural alterations in a protein to be studied using infrared spectroscopy methods range from simple changes in temperature and pressure to extremes in pH and the addition of denaturants (Fabian and Mäntele 2006).

The Japan National Agriculture and Food Research Organisation and the French National Institute for Agricultural Research are collaborating to develop an infrared micro spectroscopic approach that could simultaneously detect and visualize the effects of heat and pH on proteins (Japan National Agriculture and Food Research Organisation 2018). This last research project aims to develop methods to improve cooking parameters for ensuring better digestion of proteins in the human diet, but it may be worthwhile exploring its applicability to the detection of raw, unprocessed mammalian proteins in non-ruminant feed.

Chemical markers

The second avenue to explore is that of marker technology as used by the rendering industry to separate high-risk (Category 1 and 2) from low-risk (Category 3) animal by-products. Within the European Union, marker substance glycerol triheptanoate (GTH) needs to be added to the portion of processed ABPs that must not enter the feed and food chain (Categories 1 and 2) at a minimum concentration of 250 mg kg^{-1} related to the fat fraction of the test samples analysed (Boix, Bellorini, and Holst 2010). Testing for this marker then ensures that low-risk Category 3 ABPs are free from high-risk ABPs. GTH itself can obviously not be used for our purposes, but the research that happened to develop this marker can give us clues to what type of marker could be developed (Woodgate 2018). The research is complex and expensive, but once a marker is developed, the cost of adding the marker could be low. In the case of GTH, it is £1 per tonne of material. For testing whether animal proteins in feed were adequately processed, the marker would need to be non-toxic and easily detectable (Woodgate 2018). It would also need to resist low pH, but not necessarily high temperatures as it could be added after heat treatment.

4.2.4 Farms

In an initial roll-out of new legislation, from a control perspective it may be easier to not yet allow on-farm feed mixing with surplus food ingredients. As suggested in the previous section, we envisage that only farms with special licences would use feed from licenced treatment plants. In the case of the UK, existing farm-level controls, which already take a risk-based approach, could continue to be applied.

Table 6: Overview of existing farm-level controls in the UK

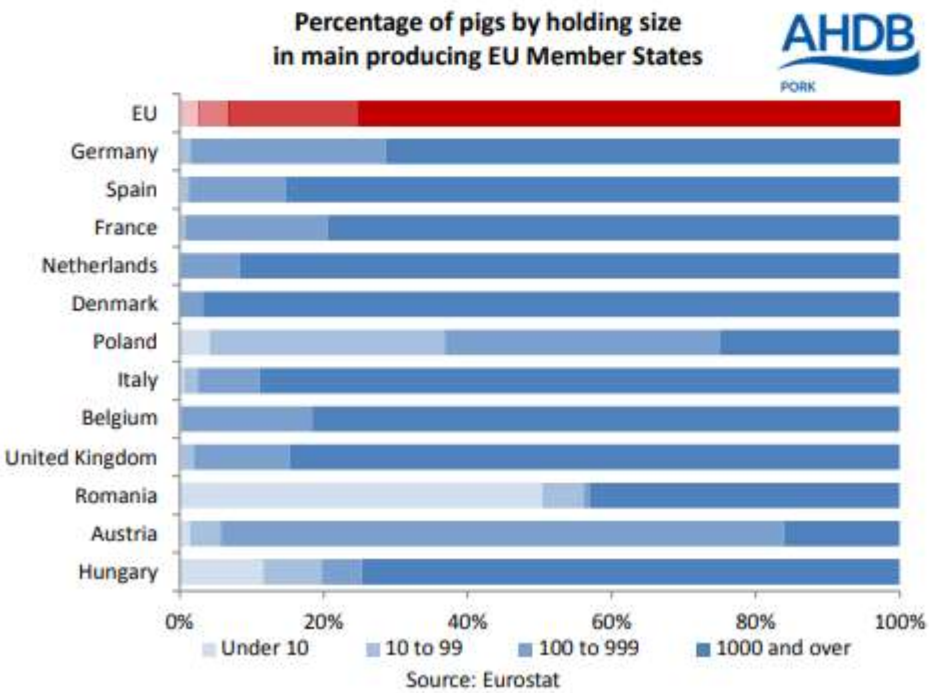
Local Authorities	FSA feed law guidance	APHA National Feed Audit
Relevant risk-based guidance is highlighted in blue **Proposed additional control measures highlighted in green**		
The local authority can inspect any livestock farm on: • Animal welfare and housing conditions • Animal identification, livestock records and movement controls • Animal by-product disposal • Food and feed hygiene	FSA guidance has a form template for officers inspecting livestock producers with detailed questions on: • Use of former foodstuffs / co-products. **Add detailed questions for farmers licenced to use treated surplus food**. • HACCP in storage, facilities, equipment etc. • Record-keeping • How does farm avoid wrong feed going to wrong species of animal (avoid cross-contamination)	(APHA) inspects farms to make sure they're following feed rules to prevent animal disease, including TSEs. Approximately 2,500 feed businesses, including farms, are inspected per year. Inspection of on-site records (such as fish meal purchases), feed, and feed storage. **On-site records to be checked for livestock production and feed volumes to ensure only licenced surplus food feed is used.** 5,600 samples collected annually and analysed for presence of animal proteins. **Samples collected from licenced farms to be tested for untreated proteins**.
Some higher risk inspections may be carried out on a more regular targeted basis.	**Competent authorities must have a risk-based feed sampling program,** looking at hygiene, undesirable components (heavy metals), fraudulent use of dangerous additives, and other aspects. Animal Feed Law Risk-Rating System highlights use of former foodstuffs, **the same could be done for farms using licenced surplus food feed**. On-farm feed mixing and mixed species farms also highlighted.	**Risk-based inspections prioritising farms with:** • Known welfare issues/ known cattle identification issues • the use of mobile mixers on farm / presence of ruminant on-farm mixers • farms with multiple species • pig farms using fishmeal. **Non-ruminant farms using surplus food could also be prioritised**. • farms using organic feeds • 10% of visits reserved for hobby farms where the use of kitchen scraps as feed is a higher risk • **Mixed farms with both ruminant and non-ruminant livestock.** Authorities may not grant licences for the feeding of treated surplus food unless stringent biosecurity measures are in place to prevent cross-contamination with ruminant feed.
Most inspections agreed in advance. Any complaints that suggest a major breach may lead to an unannounced inspection.	Registration and approval of a farm as Feed Business (EC Reg 183). Currently, the use of former foodstuffs does not need approval, but **an approval or licencing mechanism could be introduced for the use of surplus food feed**.	A complaint or report of mis-feeding animals also leads to prioritisation of farms.

Source: Developed from National Feed Audit (APHA 2017) and Feed Law Practice Guidance (Food Standards Agency 2018)

4.3 Different risk strategies for different scales of farming

Globally, most pig farmers are very small in scale. About half of the 770 million people surviving on less than USD 1.90 per day depend directly on livestock for their livelihoods (FAO 2018a, 4). Backyard pig farms (farms with under 50 pigs) are mainly concentrated in Europe, China and South East Asia, with very low concentrations comparatively in India, most of Russia, the Middle East and Africa (FAO 2018b, 3). In the UK alone there are 30,000 premises with pigs, including those with pet pigs, but 92% of pork production comes from about 1600 farms (AHDB Pork 2018). Romania, Hungary and Poland have significantly higher numbers of pigs kept in smallholdings as can be seen in Figure 5.

Figure 5: Percentage of pigs by holding size in pig-producing EU member states



Source: (AHDB Pork 2014)

It is important to consider smallholder pig farming due to their number, but also because small agroecological farms are an indispensable piece of the puzzle when designing a sustainable food system that can feed the growing global population (Altieri 2009; Pretty et al. 2006).

4.3.1 Farm scale and disease

Researchers have pointed to the role of poor small-scale pig farmers in the spread of African Swine Fever in countries such as Mozambique, Nigeria and Russia as they practice emergency sales of their animals as soon as they suspect disease (Costard et al. 2015). A survey of 313 smallholder farms in the UK found that 24% of smallholders fed uncooked household food waste to their pigs, despite the ban

(Gillespie, Grove-White, and Williams 2015) and efforts by the government and National Pig Association to raise awareness that this is not permitted. As discussed in Chapter 2, authorities are currently raising awareness on the risks of feeding untreated food waste to pigs in terms of spreading African Swine Fever, with special attention to small and backyard farms. However, the relation between farm-scale and disease is more complex.

Large numbers of animals found in large-scale intensive and highly concentrated farms are more susceptible to infection and increase the risk of emergence of more virulent disease strains, including influenza (Garner, Hess, and Yang 2006; Mennerat et al. 2010; Jones et al. 2013; Saenz, Hethcote, and Gray 2006; Casey et al. 2013; Lunney, Benfield, and Rowland 2010; McOrist, Khampee, and Guo 2011). In contrast to high-density pig production, village pig production may result in virus fitness loss and manifest as lower virulence viruses (Drew 2011). Drew also found that the high density and almost clonal nature of pig genetics can provide a 'monoculture' environment detrimental of natural resistance to pathogens and which may lead to explosive outbreaks of novel disease (Drew, 2011, p.101).

Because animal genetic diversity is critical for food security and rural development, there are growing concerns about the erosion of genetic resources in livestock (Ajmone-Marsan 2010). Through the maintenance of rare breeds, smallholders play a crucial role in protecting the EU's food security (RBST 2018). Maintaining genetic diversity allows farmers to select stock or develop new breeds in response to changing conditions, including climate change and new or resurgent disease threats (Hoffmann 2010). Furthermore, rare-breed smallholders also make important contributions to the rural economy, education, and national heritage (RBST 2018).

Finally, although pigs left to their own devices can be destructive to eco-systems – for instance, their rooting behaviour can damage forests if done excessively – with human direction their natural habits can be harnessed for ecological purposes within an agroecological system. Some key uses Robinson (2013) identifies are feeding pigs food waste, using pigs to till fields by letting them graze on them as part of a crop rotation system, and grazing them in forests, where their rooting behaviours (if regulated) can perform useful ecological functions like helping forests regenerate by clearing weeds (Robinson 2013).

Legally defining the smallholder:

EC Regulation 183/2005 states that the following activities are currently outside its scope and that farmers only engaged in the activities mentioned in Article 1(2)(c) of Regulation (EC) No 852/2004 on the hygiene of foodstuffs, do not require registration as a feed business operator:

Keeping / feeding of food-producing animals kept for:

- *private domestic consumption*
- *the direct supply by the producer of small quantities of primary products to*
    - *the final consumer*
    - *local retail establishments directly supplying to the final consumer*

In the US, a family farm can directly supplement the diet of its pigs with its own kitchen scraps, including those that contain unprocessed meat, without first undergoing the SHPA boiling procedure (US Department of

Agriculture 2009; Leib et al. 2016). **With the presence of ASF, such an exemption will not be possible in the EU**. Because of both the important role of smallholders and the fact that uncooked household food waste continues to be fed to pigs at the smallholder level, it is important to develop further recommendations that support smallholders.

Risk management at the smallholder level will need to be proportionate to the scale of risk. For example, in their discussion on farm scale, disease epidemics and antibiotic resistance, (Gilchrist et al. 2007) consider "a definable, small farm size with minimal numbers of animals" less risky in terms of disease prevention (p.315).

It is important to recognise the positive roles that smallholders perform. Even though necessary in the current European context, a highly controlled surplus food to feed system is unlikely to benefit these small farmers. We therefore recommend that additional support is given to smallholders wishing to feed treated surplus food to their pigs, bearing in mind the role of farm-scale in relation to emerging disease.

A lifting of the ban on feeding meat-containing surplus only from licenced processing plants is expected to generate significant media interest which could be capitalised upon in terms of the awareness raising on the risks of feeding untreated food waste.

4.4 Early warning and emergency preparedness

Early warning and emergency preparedness are important on two levels: first in relation to known diseases such as FMD and ASF and second in relation to "unknown unknowns".

4.4.1 Known diseases

In the case of the 2001 Foot and Mouth crisis, the outbreak was only discovered when an abattoir reported signs of infection an estimated three weeks after the first likely onset of clinical signs. Had the signs been detected earlier, the spread of the disease could have been dramatically more contained – but by this stage it had already spread to more than 50 locations, form Devon to Scotland. The farm on which the disease originated failed to report any symptoms. New technologies are rapidly evolving for animal disease identification, such as a new automated electronic microarray assay, which has been shown to simultaneously detect and differentiate identify seven important viruses that affect swine accurately, including FMD and ASF (Erickson et al. 2017).

Since the 2001 Foot and Mouth Disease outbreak, the EU has updated its regulations concerning FMD containment and its recommended best practice. Council Directive 2003/85/EC sets out that the core of the EU's approach is still the slaughter of infected and contaminated animals of susceptible species without delay. However, Council Directive 2003/85/EC now also requires immediate careful monitoring of animal movement following reported infection (European Council 2003 recitals 21, 23 and 26). The use of emergency vaccination without the necessity for subsequent slaughter (European Council 2003 recitals 21, 23 and 26) is now allowed in circumstances where an outbreak of FMD has been confirmed and threatens to become widespread within the EU member state, or if neighbouring member states are at risk of infection, particularly in densely populated livestock areas (European Council 2003 Article 50). Preventative FMD vaccination is still prohibited by EU law, because preventive or prophylactic vaccination of livestock protects against FMD but does not stop animals becoming carriers of the disease.

Since the 2001 outbreak, a lot has been learned about early warning and emergency preparedness. New measures and crisis plans have been designed and new detection technologies are available. The question is whether in times of austerity, the relevant authorities have enough resources to fully implement such learning across the board. This is a challenge that extends far beyond the scope of this proposal.

4.4.2 Unknown and emerging diseases

The first REFRESH expert panel on animal feed highlights the need for robust disease monitoring systems especially on farms feeding surplus food and early crisis management plans in order to be vigilant of "unknown unknowns" (Luyckx 2018, 6). We have already suggested that farms should be licenced to use surplus-food-based feed and could be subject to additional controls, or at least be prioritised in routine controls. How such controls monitor for unknown and emerging diseases goes well beyond the challenges posed by feeding treated surplus food. On the one hand there are the emerging disease challenges that come from intensive large-scale farming as discussed in the previous section. On the other hand, there are the emerging and moving diseases associated with climate change. See section 10.6 (balance of risks) for more information on this. Considering these wider challenges, we posit that the use of treated surplus food in feed is only one relatively small aspect of a set of conditions that could lead to new disease.

5 Nutrition

There are two scenarios that influence the way in which to approach the nutrition question:

Scenario 1: Status quo or insufficient change in human meat consumption patterns

In this scenario, we can use a set of strategies (sourcing, separation by food type, blending with conventional feed ingredients and additives) to achieve the highly precise and homogeneous nutritional composition required by modern fast-growing pig breeds which have high feed conversion ratios. If meat production and consumption remain at environmentally unsustainable levels, then this is the preferable approach to maximise the uptake of surplus food in feed and help reduce the environmental impact of the pig industry.

Scenario 2: Surplus food as feed within planetary boundaries

In this scenario, a new surplus-food to feed treatment industry would be developed within a framework of an environmentally sustainable human diet. From an environmental perspective, the most sustainable human diets include some animal-source food (meat and dairy) – though considerably less than is consumed currently in Europe (Van Zanten et al. 2018; Röös et al. 2017; Schader et al. 2015). The sustainable amount of animal source food in the human diet is determined by the available sources of animal feed that do not compete directly for arable land with human edible crops. In other words, we only feed livestock with unavoidable by-products and surplus food. Please see section 5.2 for a more comprehensive development of this point. For the purposes of this chapter, we need to look at the nutritional aspect of feeding pigs with a diet near to 100% sourced from unavoidable by-products and surplus food. This may only be possible with more robust, traditional pig breeds.

5.1 Nutrition scenario 1: Meat production and consumption status quo

The pig industry has very precise requirements for the nutritional content of feed. Although slower growth rates might theoretically be offset by lower feed costs, the requirements of modern fast-growing pig breeds mean that for the mainstream pig industry, little compromise on nutrition is possible. Whereas the wild pig's diet is low density, low dry matter concentration (around 20- 25%) and high in crude fibre the commercial sow's diet is high in dry matter (85-90%) with a crude fibre content of less than 10% and frequently less than 5% (Peter H. Brooks 2005). Furthermore, there are welfare implications from slower growth rates in commercial pig breeds. Building on the experience of the Japanese ecofeed industry and the European former foodstuffs industry, we can develop strategies to deal with the nutritional variability of surplus food through

- sourcing and separation of different food categories
- blending with conventional feed ingredients
- use of conventional feed additives

While the above strategies will be necessary in the status quo scenario, there is significant nutritional value in surplus food. Dou et al (2018) reviewed 23 studies for nutritional components in consumption-stage food waste and found an average protein content of 19.2% (Dou, Toth, and Westendorf 2018) which is sufficient for growing and finishing pigs (Edwards 2002). Maeda et al tested feeds made from food waste on pigs which had the same level of crude protein (16%) and lysine (0.58–0.75%) and found that varying the lysine/protein ratio (0.035 and 0.046) and fat (3.3% and 6.0%) had no impact on growth performance (Maeda et al. 2014), although intra-muscular fat increased when the lysine/protein ratio was lower.

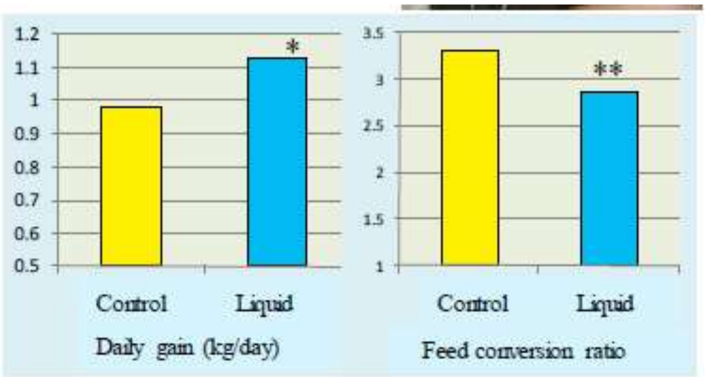
Kawashima compared fermented liquid feed entirely prepared from expired foods and residues with conventional feed, and found that it increased daily weight gain, although it had a slightly lower feed conversion ratio (see Figure 6):

Figure 6: Daily gain and feed conversion ratios on a conventional diet compared to a liquid surplus-food based diet

Feed formulation

	FM%	DM%
Rice	10	17.5
Rice ball	10	17.7
Sweat bread	10	28.0
Vegetable	30	7.8
Soybean curd residue	2.7	9.9
Milk	35	16.9
Calcium phosphate	0.5	2.1
Water	10	0.0

DM21.9%, CP14.7%, TDN98.4%, EE14.6%



Source: (Kawashima 2018)

In terms of meat quality, a review of 18 studies on the effect of surplus food feeds on the quality and nutrition of pork, including blinded taste trials, found that increasing the proportion of surplus food in pig diets had no effect on overall palatability, flavour, colour and fat composition, among other traits (zu Ermgassen et al. 2016).

5.1.1 The role of animal proteins in pig diets

It is important to note that from a wider meat waste perspective, the priority is to promote "nose-to-tail" eating, where we use underrated cuts, offal and other neglected bits of the animal that currently go to waste (Xue et al. 2019). For the use of unavoidable animal by-products in feed, EU regulations are amongst the most stringent in the world, resulting in a very small volume of total ABPs being used in animal feed (Jedrejek et al. 2016). Outside of the EU, animal proteins are commonly used in pig diets as they have useful amino acids and crude protein levels and are excellent sources of digestible calcium and phosphorus (Rojas and Stein 2012; Lewis and Southern, Lee L. 2000). Traylor, Cromwell and Lindemann (2005) note that meat and bone meal (MBM), when supplemented with tryptophan, is an excellent protein source for pigs. Lysine is the amino acid that is most likely to be deficient in most pig diets, and many of the feedstuffs (especially cereal grains) are very low in lysine. However, animal protein supplements are particularly good sources of lysine (Cromwell 2006; McDonald et al. 2011).

In the EU, there has been some relaxation of the feed ban with the authorisation of pig and poultry processed animal proteins (PAPs) in fish feed and there is significant expectation that the use of porcine PAPs in poultry feed will be authorised soon (Byrne 2018d). The authorisation of poultry PAPs in pig feed is still facing some challenges in the diagnostic methods for ensuring no porcine material is present in the feed, essential given the intra-species recycling ban. This challenge would be removed by lifting the intra-species recycling ban; see section 3.4 for information on the safety aspects of doing this and section 8.5.1 for the ethical aspects.

Pig proteins in pig feed

An examination of existing research into the nutritional aspects of using surplus pig proteins in feed illustrates that **intraspecies recycling in pigs is simply not an issue outside the EU**. In the US for example, Rojas and Stein (2012) discuss the nutritional advantages of processed pig proteins produced from hydrolysed porcine intestinal mucosa and roller-dried small intestines, and which may be used as replacements for fish meal in diets fed to weanling pigs. Myers (2011) did 10 feeding experiments with a total of 5,480 pigs and found that inclusion rates of up to 6% of these products in phase 2 diets do not negatively influence pig growth performance. Cromwell (2006) discusses a comparison of meat and bone meal of bovine origin with meat meal of porcine origin, and found the former to have more bioavailable phosphorus. South Korean researchers studied the nutritional aspects of using swine skin meal in pig diets and found that used in small amounts, supplementation of swine skin meal improved growth rate and feed intake (Mohana Devi, Devi, and Kim 2014). Whether or not we decide to process unused pig proteins into feed in such ways in the EU was not considered by REFRESH, but we conclude that the presence of some pork in pig feed is nutritionally acceptable or even beneficial, if safety requirements are met.

5.1.2 Sourcing and separation by food type

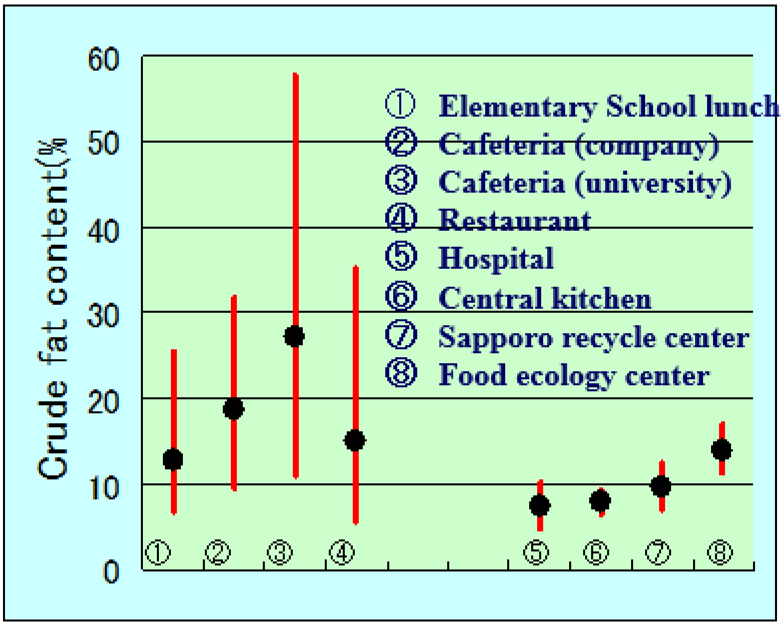
In terms of the challenge of producing nutritionally adequate and consistent feed from surplus food, the Japanese experience is the most relevant. The Japan Livestock Technology Association has produced a *Technical Manual for the Feed Utilization of Agriculture and Food Manufacture By-products* (JLTA 2011). The manual describes the following strategies to enable more precise nutritional values in the final product:

- collecting food waste from sources with less variation (e.g. food processing by-products, co-products from factories producing a predictable product),
- balancing variation through addition of conventional feed ingredients,
- collecting food wastes from a diversity of sources to balance out overall variation. For instance, the Sapporo Recycle Centre and Food Ecology Centre both collect from a variety of restaurants, food companies and retailors in order to make overall nutritional fluctuations smaller.
- separating resources based on their chemical composition and then mixing them to achieve a nutritional balance.

Selecting suppliers

When contracting suppliers, it may be of interest to survey the typical surplus food contents from each potential supplier. For example, Saeki (unpublished) studied the chemical composition of food waste streams from different sources.

Figure 7: Crude fat content of surplus food and its fluctuation



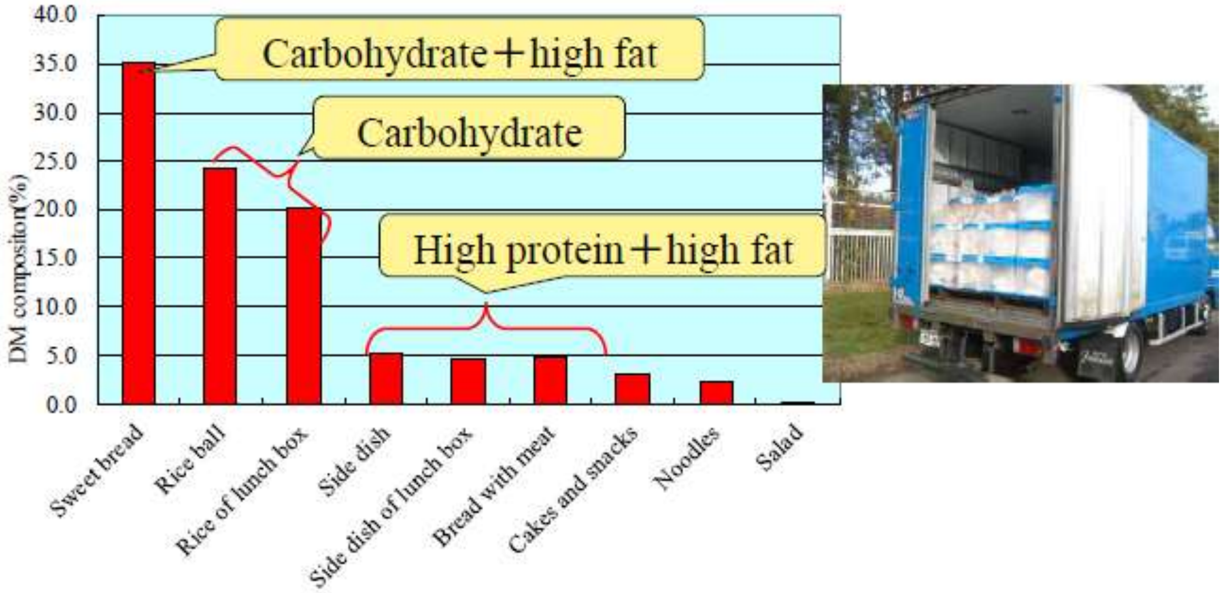
Source: (Kawashima 2018) based on Saeki, unpublished

The red lines indicate the maximum and minimum values of crude fat content, with the averages shown by black circles. The results show that some institutions have high, and very variable, crude fat content in their surplus food – for instance, school lunches are prepared for a 2-week menu, so the nutritional content of surplus varies greatly. Hospital catering and central kitchen preparing convenience store meals show low variation and low fat content. These latter sources of surplus are preferred by Japan's ecofeed producers who favour "uniform, less-fat-content, high-carbohydrate, and easy-handling materials" and less favoured materials are those with "high moisture and fat contents, difficulties in proper separation and handling" or "safety issues". Japanese eco-feed producers are relatively small in scale treating around 40 to 100 tonnes of surplus food per day. In highly populated areas in the EU, it may be preferable to have larger treatment plants, both from a cost and from a nutritional perspective so that variation can be dealt with through volume.

Separating surplus food streams within suppliers

A study of 900 Seven-Eleven stores in Japan found the following composition of their food waste:

Figure 8: Food waste compositions of 900 Seven-Eleven stores in Japan



Source: (Kawashima 2018)

Because of this variation, sorting the food into different categories is preferable, but can be costly at convenience store level – particularly if food is in packaging that is more difficult to remove, or the sorting of different food types is difficult because foods are initially mixed together. The Japan Livestock Technology Association recommends that as a minimum the food is sorted into higher fat and lower fat lines, then further sorting can be done if necessary (JLTA 2011, 65).

Some Japanese treatment plants operate within closed loop systems with specific suppliers (see section 3.5.3) and require these suppliers to separate surplus into specific categories (carbohydrates, meat and fish, etc). Barcoding is used to track the weight and content of each container of surplus which comes into the factory and allows for automated blending of nutritional categories. This enables them to combine different types of surplus food to optimise nutritional content according to different pig farmers' feed requirements.

Figure 9: Surplus food separation, measurement and tracking at Japanese retail chain UNY Co. Ltd.

Source: Kawashima (2018)

5.1.3 Feed formulation

While technology in the Japanese system is making great progress in homogenising the nutritional content of surplus food-based feeds, for the European pig industry under Scenario 1 (little change in meat consumption and production volumes), it will be necessary to mix conventional and surplus-food based feed. The Japanese Livestock Technology Association suggests that the chemical composition of the feed can be adjusted by "addition of protein sources, mineral and vitamins" (JLTA 2011, 11).

Researchers at Salamanca University studied the suitability of fishmonger and greengrocer surplus for pig feed and found that fish surplus provided more fat, and fruit and vegetable surplus more fibre than recommended in feedstuffs. As a result, surplus food needs to be mixed with conventional feed ingredients to achieve nutritional requirements (Esteban et al. 2007). Supplementation with vitamins and amino-acids is standard in conventional pig feed production (McDonald et al. 2011), and would need to be equally considered when mixing in surplus food ingredients.

Even though little variation was found in the composition of surplus from fishmongers and greengrocers across the city of Salamanca, Esteban et al. (2007) used only 20% surplus food in their experimental pig feed formulation (see Table 7). Table 7 shows that in this way it was possible to achieve very similar nutritional composition between the experimental and control diet. The only difference was a slightly lower moisture, fibre and fat content in the control diet, and a slightly higher content of carbohydrates.

Table 7: Example formulation developed by Esteban et al. (2007)

Ingredient	Experimental diet with 20% surplus food	Control diet
	% in the formula	
Fish waste	5	-
Fruit – Vegetable waste	15	-
Soybean meal	12	16
Corn	26	0
Barley	0	55
Wheat	40	26
Animal Fat	2	3

Table 8: Nutritional composition for 20% food surplus diet compared to conventional control diet, as developed by Esteban et al. (2007)

	Dry Matter (%)	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Ash (%)	Nitrogen free extract (%)	Digestible energy (kcal/kg)
Experimental diet	88.5	16.0	5.0	4.3	3.8	59.4	3400
Control diet	89.7	16.0	5.0	4.1	2.6	62.1	3400

As mentioned above, the nutritional content of the surplus food will need to be measured and monitored per supplier and category to allow computerised mixing with conventional ingredients. Once the nutritional composition of the surplus food is known, the same feed formulation tools that are routinely used by the industry such as EvaPig.com (INRA, AFZ, and Ajinomoto Animal Nutrition Europe 2018) can be used to calculate the necessary ingredients to add to the feed in order to create the required nutritional profile in the overall mix. Nutrition guides which discuss byproducts such as the book by McDonald et al. (2011) or the organic pig ration guide by Edwards (2002) will also be useful. It may also be helpful to adapt the specialist eco-feed formulation program of the Japan National Institute of Livestock and Grassland Science (JLTA 2011) for use in the EU and develop further technical collaboration with experts such as Professor Kawashima from Miyazaki University.

Figure 10: Example ecofeed formulation spreadsheet (Kawashima 2018)

Requirement calculation sheet

Table 1 Data input		
Body weight	75	kg
Daily gain	0.85	kg/day
No. of pigs	30	head

Feed calculation sheet

Feed No.	Name of Feed	Amount FM kg	DM %	DM amount kg	DM ratio %DM	TDN kg
88	Rice	30.00	40.0	12.01	16.7	11.26
73	Bread crumbs and stale bread (D	20.00	89.2	17.84	24.8	17.60
108	Vegetable	50.00	7.4	3.69	5.1	2.50
92	Japanese noodle (boiled)	25.00	33.3	8.33	11.6	7.46
61	Milk	70.00	12.3	8.61	12.0	10.92
35	Wheat bran	4.00	86.8	3.47	4.8	2.34
52	Soybean curd residue (Wet)	10.00	22.5	2.25	3.1	1.59
115	Barley tee residue (Dry)	20.00	94.1	10.00	13.9	7.00
82	Alfalfa meal (Dehydrate)	5.00	90.7	4.54	6.3	1.92
83	Dicalcium phosphate	1.00	96.0	0.96	1.3	0.00
87	Water	100.00	0.0			0.00
67	Lysine hydrochloride	0.15	98.5	0.15	0.2	0.14
1	Corn		85.5			0.00
1	Corn		85.5			0.00
1	Corn		85.5			0.00
1	Corn		85.5			0.00
	Amount	335.15		71.85		62.73
	Conent(%DM)			21.4		87.3
	Sufficiency, %			101.4		103.0

Feed table

Feed tables							
Nutrient contents are expressed on fresh matter basis.		DM %	CP %	EE %	TDN %	Ca %	Lysine %
	Co-products						
88	Rice	40.0	2.661	0.352	37.54	0	0.084
89	Rice cooked with various ingredients	57.8	2.671	0.468	51.77	0.01	
90	Fried rice	54.3	3.836	2.838	50.46	0.02	
91	Rice ball	41.7	4.182	1.251	39.21		0.171
92	Japanese noodle (boiled)	33.3	4.52	0.343	29.83	0.02	0.097
93	Chinese noodle	66.1	7.901	0.434	58.11	0.05	0.178
94	Pasta	38.0	6.618	1.138	36.91	0.02	0.106
95	Japanese noodle (Wet)	70.8	6.123	0.149	66.56	0.04	0.198
96	Noodle (Dry)	87.6	9.9	0.482	77.25	0.12	0.245
97	Sidedishe bread	49.2	8.705	13.31	57.47		0.305
98	Cake	83.1	10.03	9.405	84.22	0.05	0.128
99	Potato skin	15.6	1.807	0.164	9.339	0.03	0.08
100	Mashed potato	21.1	1.569	0.041	17.03	0	0.08
101	Fried potato	96.9	7.634	29.34	109.8	0.12	
102	Chocolate	98.7	6.567	39.92	133.8	0.25	
103	Corn frake	97.3	5.821	0.451	86.12	0.05	0.067
104	Cady	98.8	0.435	0.543	94.8	0.07	
105	Sidedishes	25.0	8.444	6.894	25.91		0.372
106	Simmered veeetable	72.9	2.905	1.154	64.1	0.05	
107	Raw material of fried tofu	25.0	14.39	8.026	33.31	0.15	
108	Vegetable	7.4	1.49	0.293	5.005	0.04	0.024
109	Dried vegetable	79.7	15.36	2.429	46.71	0.93	0.255
110	Dried salad	91.3	16.07	22.06	97.17	0.1	0.538
111	Tomato juice	7.5	2.142	0.669	5.691		
112	Greentee residue (Wet)	22.2	6.124	1.245	13.14	0.13	0.347

The Japanese industry has know-how on adapting surplus food feed mixes to pig growth phases. The JLTA (2011) manual notes that high carbohydrate foods can be used without problem from early stage to late stage of fattening. However, when it comes to high carbohydrate and high fat foods, more caution is required. Only surplus foods low in fatty acids should be used at the late stage of fattening. High protein, high fat surplus foods should only be used in the early stage of fattening. Alternatively, a defatting process can be applied to the food before feeding. The extracted fat can be used as a biofuel for the heating process (Kawashima 2018).

Figure 11: Monitoring feed composition through separated blending of food categories at the JFEC plant in Japan


Lysine

Lysine is the first limiting amino acid in pig nutrition; its intake is one of the main factors which determine pig growth rate (McDonald et al. 2011). Reduced lysine content in pigfeed has been found to lead to significantly higher intra-muscular marbling in pork (Katsumata et al. 2005). Japanese consumers like pork with marbling. For instance, the Kurao pork brand advertises the advantages of the use of dehydrated ecofeed, with large amounts of bread to produce this marbling.

In Europe, where marbling is less favoured, it may be important to guard against lower lysine in pigfeed. This can be easily rectified by adding synthetic lysine which is a common practice in most existing conventional pigfeeds (McDonald et al. 2011). Market researchers expect the global lysine market to reach USD 6.96 billion by 2020, primarily driven by the usage in the manufacturing of animal feed (Million Insights 2018). However, REFRESH analysis of the overall composition of surplus food in the UK and France showed that significant lysine is available in surplus food streams.

5.1.4 Case study: pork production potential from surplus food in the UK and France

This case study used national averages for surplus food nutritional composition to demonstrate overall potential. Feed manufacturers and treatment plants will need to reformulate feeds depending on the actual composition of surplus food provided by their suppliers as explained in the previous section.

In order to calculate the amount of protein from pig meat we used the energy and lysine required to produce a growing pig of 116 kg calculated by Van Zanten et al. (2015). The start phase of the growing pigs started at 70 days, with a weight of 23.6 kg and a final age of 180 days. The energy and lysine for growing pigs in the required ratio as based on Van Zanten et al. (2015) is summarised in Table 9. In addition, feed is needed for piglet production which includes rearing gilts and sows. In our calculation we assumed all food waste is used to feed growing pigs and additional conventional feed is need for piglet production (i.e. this feed has not been considered in this case study).

Table 9: Energy (NE) and digestible lysine required to produce a grower-finisher pig of 116 kg, and the production of piglets and the related sows and gilts

	Feed intake kg	NE MJ / kg of feed	LYS g/kg of feed	NE (MJ)	Lysine, g	Lysine/MJ
Piglets	30	9.68	11.70	290	315	1.08
Gilt	6.7	9.24	8.99	62	32	0.60
Sow	40	9.06	7.42	362	297	0.82
Grower-finisher pig	226	9.59	7.59	2167	1715	0.79
Notes	226kg is total feed intake for growing period from the point the pig weighs 25kg to slaughter	Net energy per kg of feed	Grams of digestible lysine per kg of feed	2167 MJ are needed throughout growth of pig from 25kg to slaughter	1715 grams of digestible lysine needed for growth of pig from 25kg to slaughter	

Source: Van Zanten et al., 2015.

The total amount of surplus food from catering, manufacturing and retail in the UK that would be theoretically suitable for pigfeed is estimated to contain 18 x 10^9 MJ. The total amount of lysine is about 27 388 ton. Given that a growing pig needs about 2 167 MJ NE and about 1 715 g of lysine, it is energy that becomes the limiting factor. Our detailed analysis of nutritional content of surplus food prior to treatment shows that the ratio of lysine is too high compared to energy, at least prior to heat treatment. Our calculations therefore focus on energy content.

Based on the energy content of the available surplus food, a total of 8 395 277 grower-finisher pigs can be reared (973 852 tonnes of live weight pigs). The total amount of surplus food from catering, manufacturing and retail in France that would be theoretically suitable for pigfeed contains 25.4 x 10^9 MJ. The total amount of lysine is about 23.6 thousand tonnes. A grower-finisher pig needs about 2 167 MJ NE and about 1 715 g of lysine. Based on the energy content of the available surplus food, a total of 11 727 768 grower-finisher pigs can be reared. The relation between the volume of surplus food and pigs that could be reared is linear. **If France and the UK were to achieve recycling rates similar to Japan, we could rear about 4 million finishing pigs in the UK and nearly 6 million finishing pigs in France based on the available energy and lysine in the surplus food currently leaving the food supply chain**.

The above figures do not take account of the impact of heat treatment and acidification on nutritional values. Further calculations could provide insight on how farm level surplus, and by-products such as spent brewers' grains and wheat middlings would affect the balance and allow us to use all the available lysine. It is still possible that lysine will become the limiting factor after treatment, but the next section explains why this is not a serious issue.

5.1.5 The impact of heat treatment and acidification on nutrition

Garcia et al. (2005) found that low heat treatment to render surplus food safe for feed also minimises any anti-nutritional factors such as lectins, alkaloids or tannins which could be present in surplus food with legume seeds, peels, root tubers etc. However, Esteban et al (2007) tested the impact of heat treatment on fish, fruit and vegetable surplus and found that temperatures over 65°C for fruit and vegetable surplus and 105°C for fish surplus negatively affected the digestibility of these foods in treated feed.

This is a wider issue in the food industry which is currently the subject of a research collaboration between the Japan National Agriculture and Food Research Organisation and INRA, the French National Institute for Agricultural Research (INRA). In this collaboration, an infrared micro spectroscopic approach that could simultaneously detect and visualize the effects of heat and pH on proteins involved in the digestion of meat has been developed (Japan National Agriculture and Food Research Organisation 2018). This technology is useful for developing an appropriate cooking method that does not reduce the digestibility of meat for humans as well as for developing easily digestible meat products, as overcooking and pH can both impact on digestibility. It would be useful to investigate the applicability for pigs.

With regard to additives, the Japanese ecofeed manual recommends that vitamins and amino acids should be mixed into fermented liquid feed just before feeding, as they might be broken down by the process of fermentation (JLTA 2011).

Once test combinations of acidity, temperature, time and particle size are determined (see section 3.1.6), it will be important to test treated surplus for digestibility and change in nutritional composition.

Finally, viscosity can be a challenge during heat treatment and transport of certain surplus food streams, such as rice and bread. In Japan, amylase has been successfully used to lower the viscosity of the material to enable easier movement through pipelines (JLTA 2011).

5.2 Nutrition scenario 2: Surplus food as feed within planetary boundaries

In this scenario, the number of non-ruminant livestock farmed is limited by the volume of unavoidable surplus food and by-products available to feed non-ruminant animals. As is further explained in Chapter 7, there are significant environmental issues with using arable land for feed crops and in this scenario, such competition is eliminated as pigs would be fed on a near-100% surplus food and by-product diet with minimal blending.

Pig farming models using a 100% surplus food diet are already viable in Japan. For example, 15 medium-sized pig farmers (300 to 2,000 pigs each) feed their pigs 100% eco-feed because JFEC can guarantee a protein content of 15 to 17 per cent through computerised composition monitoring and the addition of a very small amount of soya (about 1% of total feed) as well as some synthetic lysine and calcium-vitamin premix (Takahashi 2018). The pork from pigs fed on JFEC-feed is sold at a premium in the Odakyu retail stores who claim that pork produced by JFEC has "10 per cent more unsaturated fatty acids and 20 per cent less cholesterol" and is "tender, delicious, and juicy" (Stuart 2009, 280).

Most of the farmers using JFEC feed, work with the LWD cross-breed (Landrace, Large White and Duroc). European commercial crossbreeds also commonly go back to these breeds (Laval et al. 2000). Others using JFEC feed work with the traditional British Berkshire breed whose meat is particularly popular in Japan and the slower-growing, but prolific breeding Meishan pigs. It has been suggested that Meishan pigs are resistant to some diseases and able to consume large amounts of roughage (Johnson 1996). While it is beyond the scope of the REFRESH project to research which breeds are most suitable for surplus-food feeding, conversations with experts suggest that some breeds may indeed be more tolerant of short-term nutritional variations (Luyckx et al. 2018). Similarly, Van Hal et al. (2019) compared low-, medium, and high-productive pig systems and found that low-productive pigs provided the most optimal conversion of available low-cost feeds such as surplus food. When this study considered only high-productive animals, pigs could no longer use surplus food to meet their specific nutrient requirements.

With the environmental impact of commercial livestock farming in mind, it may therefore be beneficial to further research pig breeds for their suitability for 100% surplus food feeding. Such research can also look at nutritional choice from a welfare perspective (see section 8.5) and from a nutritional perspective. Research shows that pigs have the ability to select a diet of "suitable protein content when given a choice between pairs of foods differing in protein content" and that "related experiments have shown that choice-fed pigs reduce the protein content of their selected diet as their protein requirements decline with increasing liveweight" (McDonald et al. 2011). Such research may point us in a different direction compared to the increasing genetic homogenisation of the commercial modern pig where high feed conversion ratios are the priority.

Finally, it is important to monitor and control salt levels when formulating 100%-surplus food diets given current unhealthy salt-levels in processed foods. McDonald et al. (2011) note that salt is also important in the diet of hens, and it is known to counteract feather picking and cannibalism. Salt is generally given to pigs on vegetable diets, but if fishmeal is given the need for added salt is reduced. Swill can also be a rich source of salt, although the product is very variable and can contain excessive amounts of salt. Too much salt in the diet is harmful and causes excessive thirst, muscular weakness and oedema. Salt poisoning is quite common in pigs and poultry, especially where fresh drinking water is limited (McDonald et al. 2011)

5.3 Dry or liquid?

Because drying feed is energy intensive, it appears that liquid feed is more beneficial from an environmental perspective (Salemdeeb et al. 2017; Ogino et al. 2007) (see section 7.5.1). From an economic perspective, energy costs for feed drying need to be balanced against costs related to shorter shelf-life and more expensive transport costs associated with liquid feeds and nutritional benefits of liquid feed. For instance, one study found that liquid feed improved daily weight gain and reduced feed intake, leading to an improved feed conversion ratio of 2.27 compared to 2.53 for dry feeds, and reducing the cost of production by 4.6p/kg dead weight (BPEX, Defra, and MLC 2004, 4). One can find plenty of industry sources on the internet comparing liquid to dry feeding systems. Some industry sources told REFRESH that logistical and hygiene challenges may prevent the theoretical advantages of fermented liquid feeding bearing out in practice.

Liquid feeding systems are more popular in certain countries. Experts estimated in 2009 that over 60% of slaughter pigs in Denmark and Sweden are liquid-fed, as well as a majority of Danish and Swedish sows. Both the Netherlands and France are said to be at around 33% liquid feed in the grow-finish phase on a national basis, but this disguises rates of 50-60% in their main pig regions. Relatively few of their sows are wet-fed, by contrast, with a maximum of 15-20% being suggested for the current situation in Dutch sow herds. Nationally in Germany, the proportion is probably around 40% for grow-finish, although considerably lower for sows. The German finishing market share itself masks a regional difference in that all the big units in the east of the country and most of those in the north-west are wet-feeders, whereas smaller farms in the south are less likely to have such an installation. The national average percentage is described locally as increasing almost daily, as small farms quit and the larger ones expand (Best 2009).

Where liquid feeding is not commonly used currently, infrastructure investment costs may be an initial barrier and farmers may need support to overcome this.

The Japan Livestock Technology Association (JLTA 2011) notes that "dry matter content of dry feed is about 87%, that of liquid feed is about 20%", but pigs need dry matter content of at least 20% - in this case, the dry matter content can be increased through using enzymes to reduce viscosity.

5.3.1 Nutritional and probiotic aspects of fermented liquid feed

There is a growing body of evidence on the nutritional and probiotic advantages of fermented liquid feed (Jakobsen et al. 2015; Winsen et al. 2001; Canibe and Jensen 2003; Hu et al. 2008) which, alongside the energy and environmental costs, may tip the balance in favour of liquid feeding systems.

Fermented liquid feed may "strengthen the role of the stomach as the first line of defence against possible pathogenic infections by lowering the pH in the gastrointestinal tract thereby helping to exclude enteropathogens" (Missotten et al. 2015; McDonald et al. 2011). Moreover, fermented liquid feed can reduce coliform levels in the lower gut (P H Brooks, Beal, and Niven 2001) and prevent the proliferation of other pathogens such as *Salmonella* (Missotten et al. 2015). *Lactobacilli* ferment lactose to lactic acid, thereby reducing the pH to a level that harmful bacteria cannot tolerate. Hydrogen peroxide is also produced, which inhibits the growth of Gram-negative bacteria. It has also been reported that lactic acid producing bacteria of the *Streptococcus* and *Lactobacillus* species produce antibiotics (McDonald et al. 2011).

Liquid feeding generally has been found to lead to the following beneficial impacts: a significantly lower incidence of pigs testing for Salmonella at slaughter, a decrease in the microbial loading of the gut, a reduction of gastric ulceration, and a favourable change in the lactic acid bacteria to coliform ratio in the gut and faeces of pigs (BPEX, Defra, and MLC 2004, 5). Fermented liquid feed from food by-products were also found to contribute to enhanced bacterial diversity in the gastrointestinal tract (Tajima et al. 2010), to stimulate the systemic or mucosal antibody response without unnecessary inflammatory reactions in piglets (Mizumachi et al. 2009), and lead to an increase in the number of lactic acid bacteria in the intestines, suggesting the possibility of reduction of antibiotic-resistance bacteria (Kobashi et al. 2008).

McDonald (2011) recommends that in the case of digestive upsets which are common at times of stress (e.g. weaning), feeding desirable bacteria such as *Lactobacilli* is preferable to using antibiotics, which destroy the desirable bacteria as well as the harmful species. In a review of the response of pigs of various ages to the administration of probiotics, it was concluded that probiotics were effective for young pigs, in which the digestive tract is still developing after weaning. However, probiotics were less effective for growing and finishing pigs, which already have a balanced population of microorganisms. Oral inoculation of young pigs with *Lactobacilli* results in elevated serum protein and white blood cell counts. This may aid the development of the immune system by stimulation of the production of antibodies and increased phagocytic activity (McDonald et al. 2011).

According to McDonald (2011), "formic and propionic acids are more effective than fumaric or citric acids at the same rate of inclusion because the former have a lower molecular weight. Suggested levels of inclusion of acid (kg/tonne diet) are formic acid 6–8, propionic acid 8–10, fumaric acid 12–15 and citric acid 20–25, but recommendations vary. The diets of young pigs may include organic acids, which reduce gut pH, with beneficial effects on protein digestion and control of the gut microflora." And JLTA (2011) found that fermented liquid feed which was properly prepared, contains 109 cfu/g of lactic acid bacteria which has probiotic effects.

There is also renewed industry interest in fermented liquid feed for piglets in light of the upcoming EU-wide ban on zinc oxide and the trend away from the use of antibiotics (Byrne 2019). A research collaboration between Aarhus University and the Danish government points to the advantages in feeding liquid fermented feed to piglets while they are being weaned in terms of feed intake and pathogen reduction in piglet guts.

6 Economic feasibility

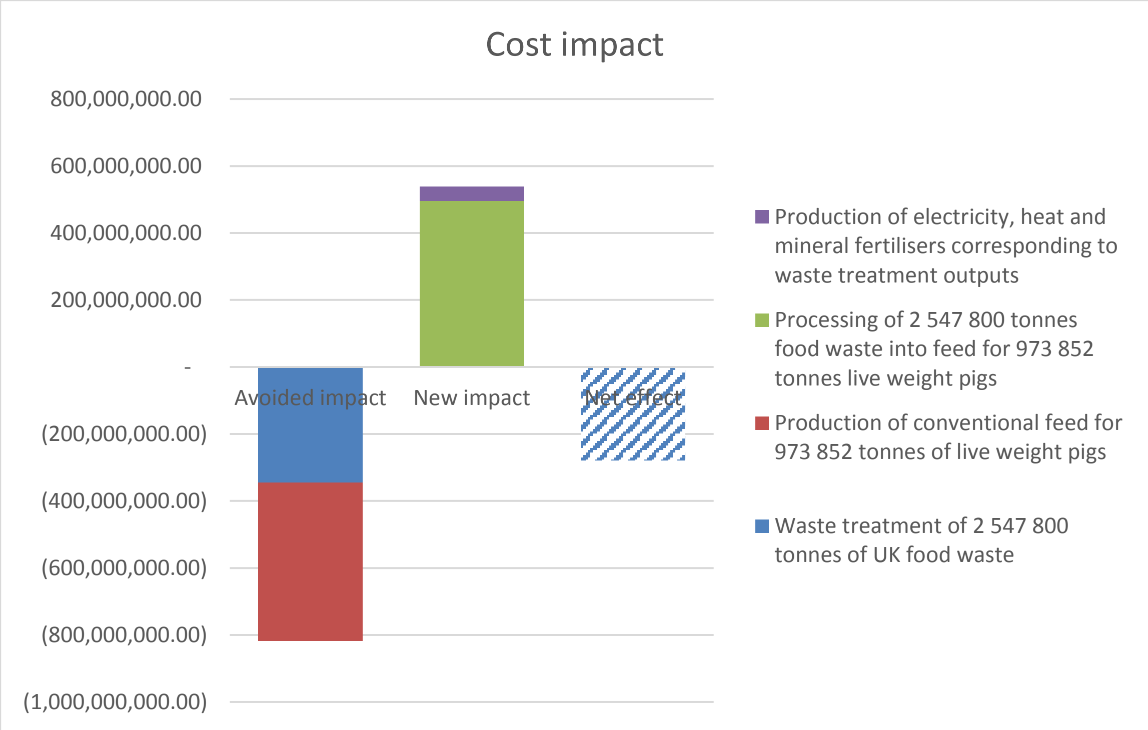
According to the first REFRESH expert panel, economic feasibility is not only important in itself but crucial to establishing an industry that prioritises safety within its long-term business strategy (Luyckx 2018).

6.1 Overall costs and savings

REFRESH has carried out Life Cycle Costing (LCC) calculations for the UK and France based on detailed food waste data and existing market conditions in the feed, farming and waste handling sectors. REFRESH calculations were done for a liquid feeding system because earlier research shows that liquid systems are more beneficial from an environmental perspective due to the additional energy needed to dry feed (Salemdeeb et al. 2017; Ogino et al. 2007). See further information on liquid feeding in section 5.3.

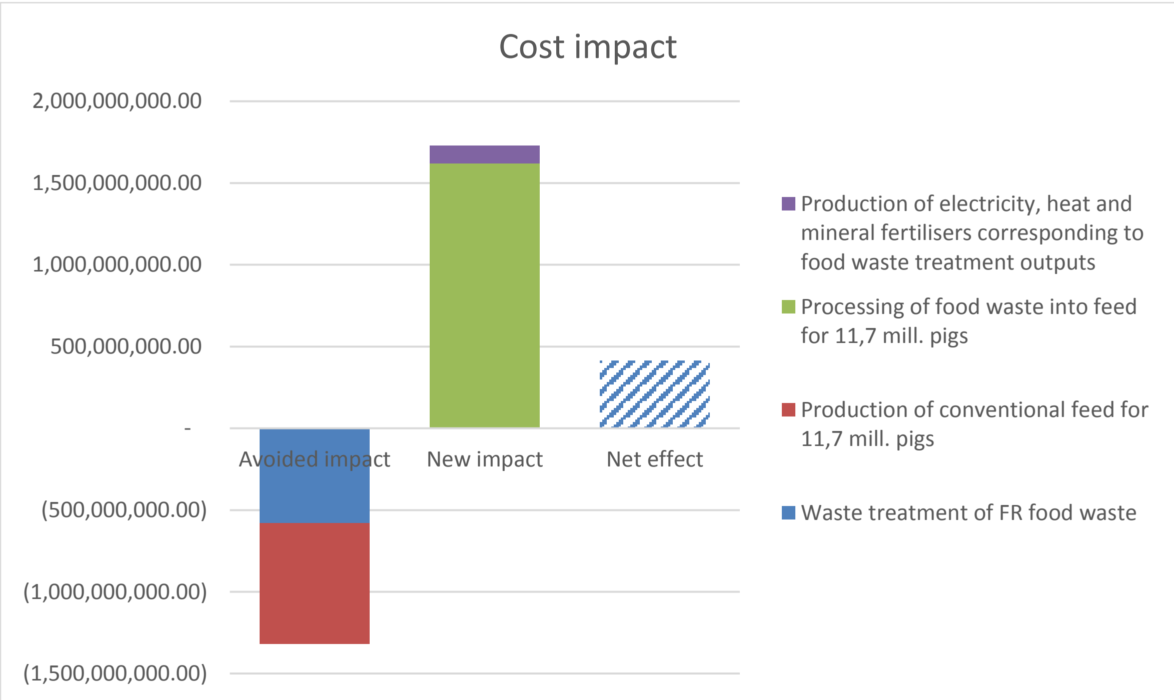
The REFRESH LCC carried out by De Menna et al (2018) **shows a net financial cost saving of €278 million per year in the UK, but an additional cost of €413 million per year in France**. See figures 12 and 13 below. A further breakdown of financial costs is provided in De Menna et al (2018). These results were derived for plants with processing capacity of 680 tonnes of surplus food per day.

Figure 12: Net cost impact of using processed food waste as pig feed in UK



Source: de Menna et al. 2018

Figure 13: Net cost impact of using processed food waste as pig feed in France



Source: de Menna et al. 2018

Overall cost differences between the UK and France can largely be explained by longer distances between surplus food suppliers and pig farms in France. However, the cost of surplus food collection is a more important factor than the cost of transporting liquid feed to farms. **Efficient collection and feed transport systems will therefore be paramount to the economic feasibility of a surplus-food-to-feed industry**. Further research, for example through GIS planning models, could help to determine the most transport efficient locations for treatment plants. Exporting surplus-food-based-feed to Belgium and the Netherlands from the north of France, or to Italy from the areas of Lyon and Marseille, may reduce transport costs, compared to taking feed to Brittany, France's main pig producing region. These options were not considered in our calculations, which assumed solely domestic systems, and need further research.

The Japan Livestock Technology Association recommends lowering the viscosity of the feed which allows an increase of dry matter content of the liquid feed which in turn lowers the fuel costs for heat treatment and transportation (JLTA 2011). The enzyme alpha amylase can be added into a feed mixture before heat treatment, in order to lower viscosity of the resultant liquid feed. This also helps lower viscosity of high carbohydrate feeds - for example bread and rice which are heated with water – to be channelled more easily through pipelines in the treatment plant, during transport and on farms.

In Japan, cost savings have been made by separating out food that contains meat or may have come into contact with meat or harmful microorganisms, and only heat-treat these foods. Safe materials that do not contain meat or can be guaranteed not to have come into contact with meat or pathogens (such as those currently permissible as feed in the EU, like vegetables, whey and brewers grains from manufacturing or farms) do not need similar treatment, and can be mixed into the fermented liquid feed as long as pH levels are maintained. However, potential cost savings for energy requirements should be balanced against the possibility of increased labour hours that could be necessary to check and eventually separate materials.

REFRESH calculations used cost data from a relatively small Japanese processing plant – JFEC who process about 40 tonnes of surplus food per day. These data were then adapted to the UK and France assuming a plant 20 times larger in size. Several cost items were upscaled by a 0.6 exponential factor. See De Menna et al. (2018) and Kitani (2018) for more information.

6.2 Conventional feed prices

The calculations in section 6.1 of this report were based on current conventional feed prices. The EU predicts that "demand will drive compound feed use up to 275 million tonnes by 2030, an increase of nearly 4% over the period 2017-2030. Feed prices are expected to rise slightly, mainly for medium-protein feed, but not exceeding the high prices of recent years" (European Union 2017, 35)

Figure 14: EU Compound Feed Prices (EUR/t)

Source: (European Union 2017, 36) - Abbreviations stand for low, medium and high protein feed

However, there is considerable uncertainly in these EU price estimates. For instance, in one alternative scenario "an increased demand for other low-, medium- and high-protein meals is observed, and average feed prices rise by 7 %" and a further scenario sees average feed prices drop by 8 % (European Union 2017, 29). The level of uncertainty is illustrated by the graph below, the European Commission's predictions for wheat prices under different scenarios:

Figure 15: Possible price paths for common wheat in the EU (EUR/t)

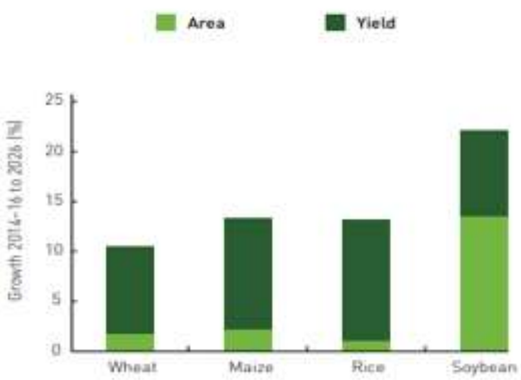
Source: (European Union 2017, 27)

Weather is one important factor contributing to uncertainty in agricultural yields. For example, the EU recently saw its milk production adversely affected by high feed prices as a result of drought conditions in Northern and Western Europe in 2018 (Byrne 2018c). Extreme weather events are projected to grow more frequent and more severe if we do not stay within safe limits of climate change. Price volatility in global food markets have historically been highly affected by extreme weather events (World Bank Group n.d.).

Agricultural commodity price increase and volatility forecasts are increasingly complex, not just because of the uncertainty driven by environmental factors but also because of the way markets operate, for example regarding the influence of commodity speculation (Prakash 2011). What is important in the context of this report is that **conventional feed price increases are quite possible and will increase the economic feasibility of using surplus food in feed**. Similarly, DEFRA (2013) concludes that there is greater uncertainty associated with the realisation of AD benefits and that the financial benefits of feeding surplus food to livestock increases as the cost of cereal based animal feed continues to rise.

Moreover, the scenarios forecast by the EU assume that world soya bean production will expand considerably (+28 %) by 2030, to reach nearly 434 million tonnes and that this expansion will mainly occur in Brazil (which will become the largest producer), the US and Argentina. These forecasts also assume that the EU will import more soya beans and meals which, because they are available at a more competitive price on the world market, will replace imports of other protein meals (European Union 2017, 33–34). More than any key crop, soya production is projected to grow by increasing land use (see figure 16).

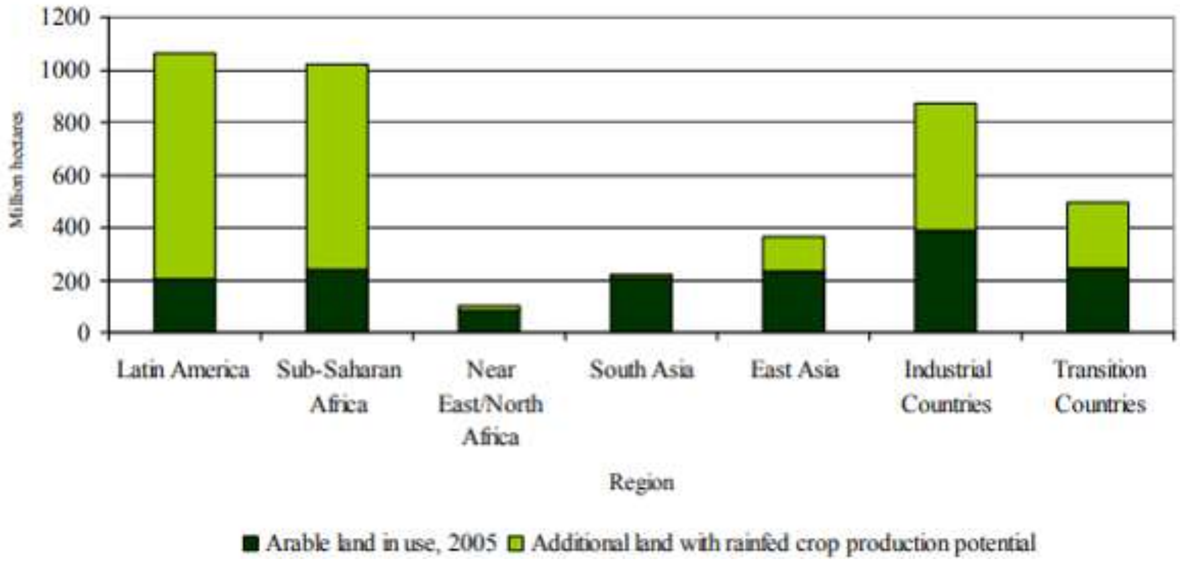
Figure 16: Relative growth shares of area and yield



Source: (OECD-FAO 2017)

Moreover, a high proportion of the world's land frontiers exist in South America (see figure 17) where soy production is predominantly located. Chapter 7 discusses the climate impact of land use change related to soy farming in Brazil and Argentina.

Figure 17: Potential for Cropland Expansion?



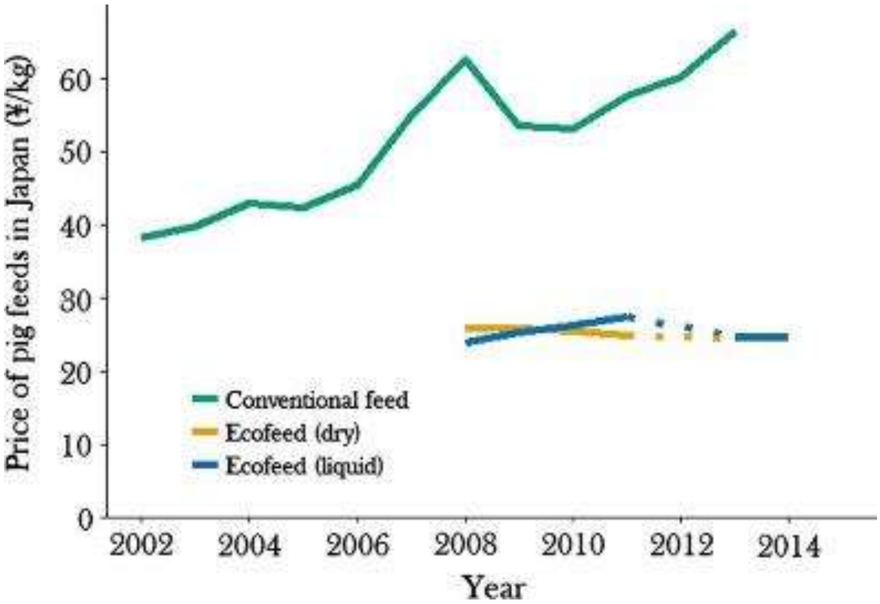
Source: (FAO 2010)

Bearing in mind environmental and other factors, relying on the expansion of soybean cultivation globally seems unrealistic (World Bank Group n.d.; Government Office for Science 2011) .

6.3 Processing industry

The production of ecofeed in Japan has more than doubled from 0.48 million tonnes in 2003 to 1.19 million tonnes in 2016 (Japan Ministry of Agriculture, Forestry and Fisheries 2018). In Japan, there are currently 360 eco-feed producers, of which 47 process surplus from retailers and 29 specialise in the processing of meat-containing surplus food (Japan Ministry of Agriculture, Forestry and Fisheries 2018). In Japan and South Korea, industrial food-to-feed recycling plants deliver safe surplus-food-based feed at 40-60% of the cost of conventional feed (Takahashi et al. 2012, 36) (Nam et al. 2000).

Figure 18: Price of Feeds in Japan (Yen/Kg)



Source: (zu Ermgassen et al. 2016)

However, growth in the sector has slowed down because of competition over surplus food streams. Whereas previously ecofeed producers could receive these ingredients for free, now they are increasingly having to pay for the ingredients, as competition over the more popular types of ingredients increases (JLTA 2011, 10).

See section 6.1 for information on transport costs as a central factor in the economic feasibility.

The gate fees that surplus food processing facilities will be able to charge for collection of surplus food will be another factor in whether they are financially viable, and this will depend significantly on what gate fees Anaerobic Digestion and composting plants charge, since they could compete for access to surplus food.

In 2017 the average UK commercial contract gate fee for Anaerobic Digestion was £11 per tonne (median) with the range from -£13 to £60 (Wrap, 2018). A negative gate fee exists where a payment is made from the AD facility to the waste supplier (two contracts cited in the Wrap report). These fees reflect a continuing fall in AD gate fee prices.

Currently subsidies across the EU artificially lower the gate fee charged by AD plants. For instance, the British AD industry receives 4 key government incentives, which skew incentives for food companies to send their surplus food to AD rather than to animal feed. This is a potential barrier to the uptake of surplus food processing facilities for animal feed. It is important to continue to provide incentives to the AD sector to avoid food waste ending up in landfill or incineration. However, additional incentives will need to be created to ensure that any surplus food suitable for animal feed, goes to animal feed and not to AD.

The 4 key government incentives currently used in the UK are:

1) Renewables Obligation (RO): provides financial support for large-scale renewable electricity projects in the UK (Ofgem 2016b). Renewables Obligation Certificates (ROCs) are issued to operators of accredited renewable generating stations for the eligible renewable electricity they generate. The scheme began offering support to AD in 2002. In 2016/17 AD plants received 1.8 ROCs for every MWh produced. The value of ROCs in 2016/17 was £49.87 (Ofgem), therefore, AD plants commissioned between April 2016 and March 2017 would receive the equivalent of 8.98p per kWh.

2) The RO closed to all new generating capacity on 31 March 2017 and was replaced by Contracts for Difference (CfD), available for plants with a capacity over 5MW. Recipients are paid the difference between a strike price for each type of generation and a reference market price. The first two allocation rounds did not award contracts for Anaerobic Digestion plants and the third Contracts for Difference Allocation Round is planned to open by May 2019.

3) The Non-Domestic Renewable Heat Incentive (RHI) provides support for renewable heat technologies for 20 years. Biomethane injection and biogas combustion are both eligible however the majority of recipients are Solid Biomass Boilers. Tariffs depend on a plant's capacity. The scheme covers England, Scotland, and Wales, while the Northern Ireland scheme was suspended for new applicants in February 2016. Biogas plants receive between 1.36 to 4.64p/kWhth while methane injection projects receive from 2.53 to 5.60p/kWhth

Table 10: Tariffs that apply for installations with an accreditation date on or after 22 May 2018

RHI Type	Technology	Range	Tariff (pence per kWhth)
Non-domestic	Biogas combustion	Less than 200 kWth	1.36
		200 kWth and above & less than 600 kWth	3.64
		600 kWth and above	4.64
	Biomethane injection	First 40,000 MWh of eligible biomethane	5.60
		Next 40,000 MWh of eligible biomethane	3.29
		Remaining MWh of eligible biomethane	2.53

4) The Feed-In Tariffs (FITs) Scheme incentivises the export of electricity to the national grid from small-scale generation plants, with a capacity up to 5MW (Ofgem 2016c). FITs for AD began in 2010 and together with the RHI has caused the biggest sector growth. The Scheme is now heavily capped so that only a certain number of beneficiaries can enter the scheme at once. The Department of Business Energy and Industrial Strategy (BEIS) intend to close the FIT scheme to new applicants from 1 April 2019. This would have no effect on installations currently accredited under the scheme. FIT support is payable for 20 years. Plants between 0.5 and 5MW commissioned in 2019 receive 1.54p/kWh.

Table 11: Feed-In Tariffs (FITs) for Anaerobic Digestion

Year	Total Installed Capacity (kW)	Tariff (p/kWh)
2011	0-500 500-5,000	14.17 11.06
2014	0-250 250-500 500-5,000	16.41 15.18 10.00
2018	0-250 250-500 500-5,000	4.45 4.22 1.57
2019	0-250 250-500 500-5,000	4.50 4.27 1.54

According to the Anaerobic Digestion and Bioresources Association there are currently 475 plants in operation in the UK, not including water treatment facilities or those treating sewage sludge. This includes 80 biomethane-to-grid plants. There are a further 327 anaerobic digestion projects under development (NFCC, 2018). There are 91 food waste AD facilities operational in the UK which is 31.9% of the 285 CE plants treating biowaste, agricultural waste and industrial waste (not including landfills and sewage sludge) (De Clercq et al., 2017). **Given the environmental advantages of using surplus food in feed and not for energy** (see section 7.3)**, it will be important that policy makers ensure a balanced incentive regime that prevents food surplus suitable for feed from going to AD and prevents food waste unsuitable for feed from going to landfill or incineration.**

6.4 Farmers

6.4.1 The importance of feed costs

In December 2016, feed costs in 14 EU pig producing countries made up between 50% and 67% of total production costs (AHDB 2018b). Figure 19 shows how important feed is as part of the total production cost.

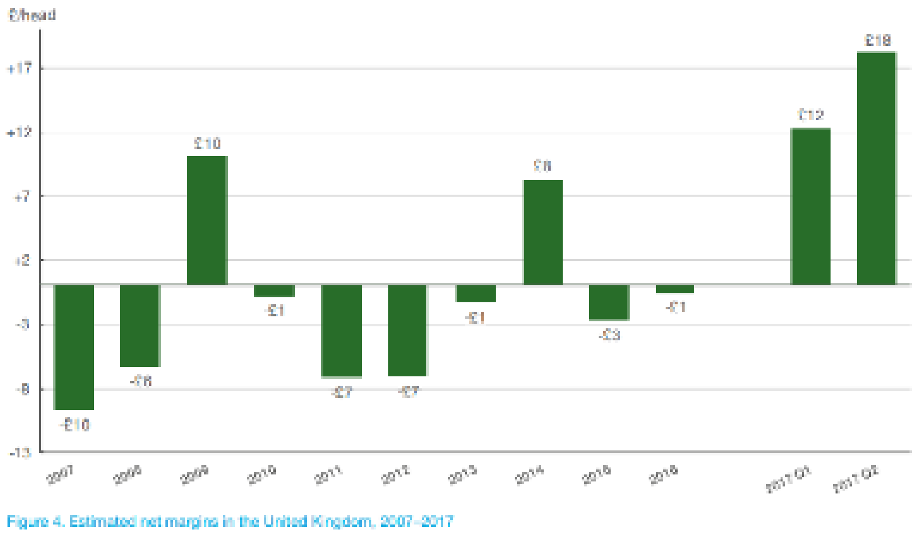
Figure 19: Cost of pig production in selected countries

Figure 1. Cost of production in selected countries, 2016

Source: *(AHDB 2017)*

Feed prices are important as they can determine the viability of pig farmers' livelihoods. A EUROSTAT analysis of 2014 data for the EU observed that "during this last period there has been a high volatility in feed prices resulting in high prices for both cereals and compound feeding stuffs" and this "has created a difficult situation which has forced an important number of pig farmers to cease production" (EUROSTAT 2017). The estimated net margins for UK pig farmers show in Figure 20 highlight the precarious situation of these farmers.

Figure 20: Estimated net margins for pig farmers in the UK



Source: (AHDB 2017)

The cost of conventional feed ingredients such as soya, barley and wheat may increase from pressure on scarce land and global resources, so the production of feed that does not rely directly on global markets may help the EU farming industry be more resilient.

6.4.2 Passing on savings to farmers and pigs

Whilst the economic feasibility for the treatment plants is important, we also need to make sure that savings are passed on to farmers and to pigs through investment in pig welfare. Surplus-food to feed producers may wish to peg their feed price to that of conventional feed. For example, Dutch traders of liquid feeds have linearly correlated the feed price to the dry matter percentage of their feed - typically €2 per % dry matter per ton product.

Further research is needed to develop recommendations on the ownership and operational models of treatment plants to allow for financial benefits of surplus-food-based feed to be shared between a new surplus-food to feed industry and farmers.

6.5 Analysis of scale size effects on price competitiveness of animal feed valorisation

The previous sections have shown that converting food waste to animal feed is economically relevant at the assumed scale size (reference scale size: converting 260 ktonnes food waste per year, collected in a region with radius 100km).

Collection transport (refrigerated) is by far the highest contributor to the total costs of the waste-to-feed chain (Figures 21 and 22). Based on this observation it is expected that the total costs can be further reduced through scaling down the factory (with corresponding reduction of sourcing region area and average collection transport distance).

Figure 21 Estimated costs with a total of € 34 /kg liquid feed for a plant of reference capacity (260 ktonnes FW/y).

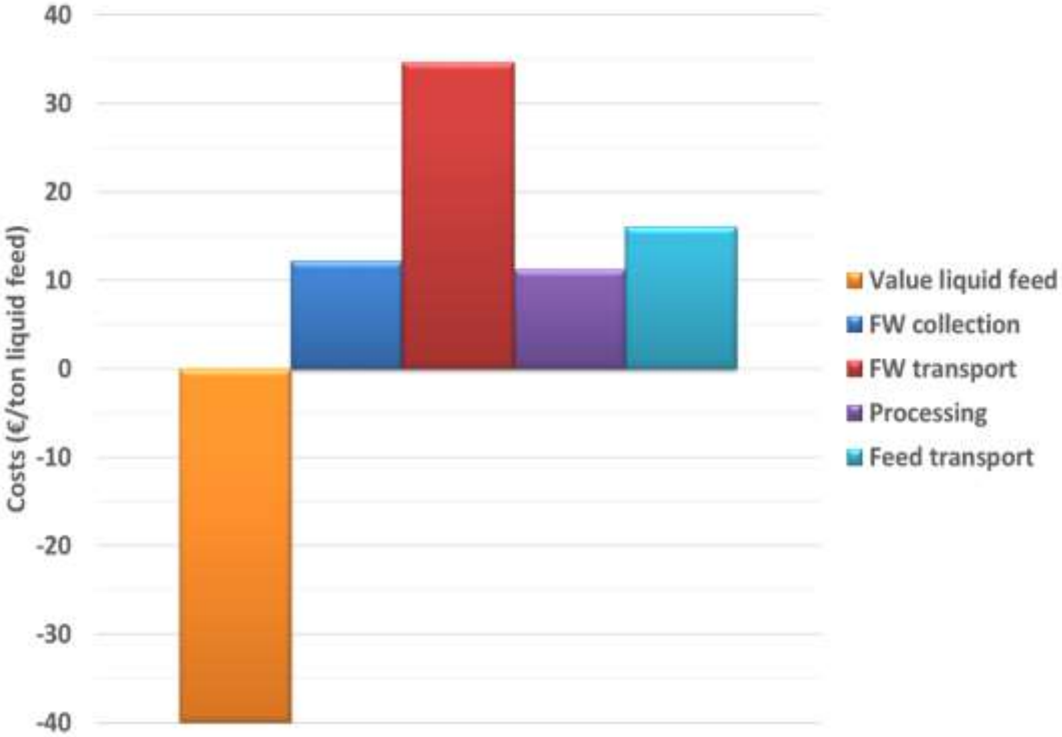
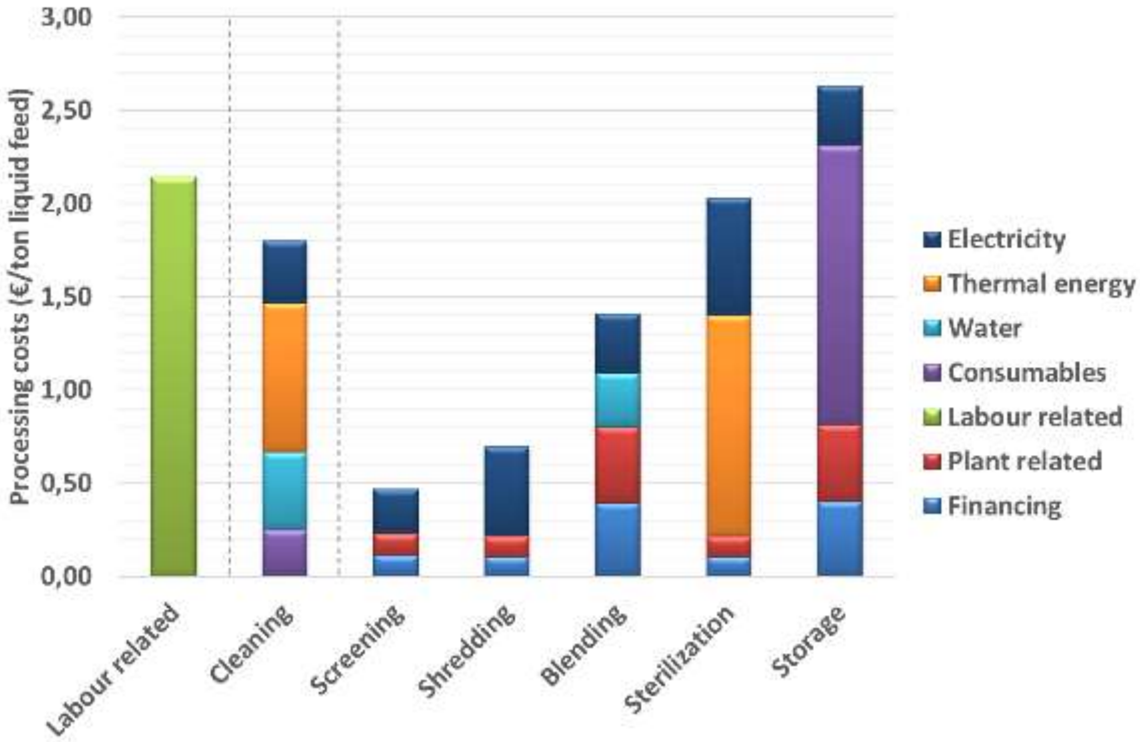


Figure 22 Estimated processing costs for the plant with reference capacity.



Below, the potential effect of factory scale size is analysed, based on the following assumptions:

- The sourcing area is scaled proportional to the processing capacity; consequently the average transport distance is scaled with scaling factor 0.5 of the processing capacity.
- The total fixed plant costs scale with scaling factor 0.6 of the processing capacity.
- Labour costs are minimised at 3 operators per plant (with an eye on full-time operations).
- Other variable costs are linear in plant capacity.
- Liquid feed distribution costs are kept fixed.
- A reference price for the liquid feed of €0.20 per kg dry matter is used, based on minimum prices for liquid feeds currently made from food industry by-products (Duynie 2019; Trident Feeds 2019). Industry expects liquid feed prices to be on the rise (Nijsen-Granico 2018).

Total costs for various scale sizes are presented in Figure 23 and Figure 24 including comparison with current food waste disposal routes (the weighted average of currently used routes as well as the least expensive route: anaerobic digestion).

Figure 23 Estimated total costs of food waste disposal (AD and weighted average of current disposal processes) and for food-waste-to-animal-feed-processing scenarios with different scale sizes; expressed in Euro per ton food waste.

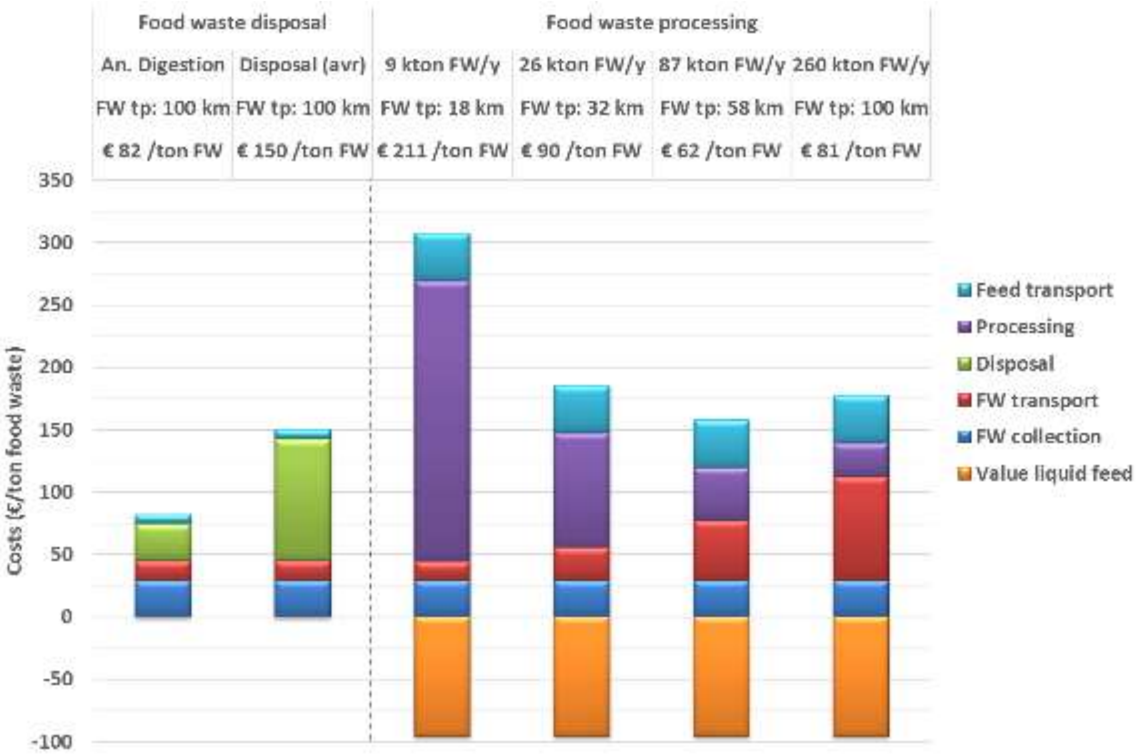
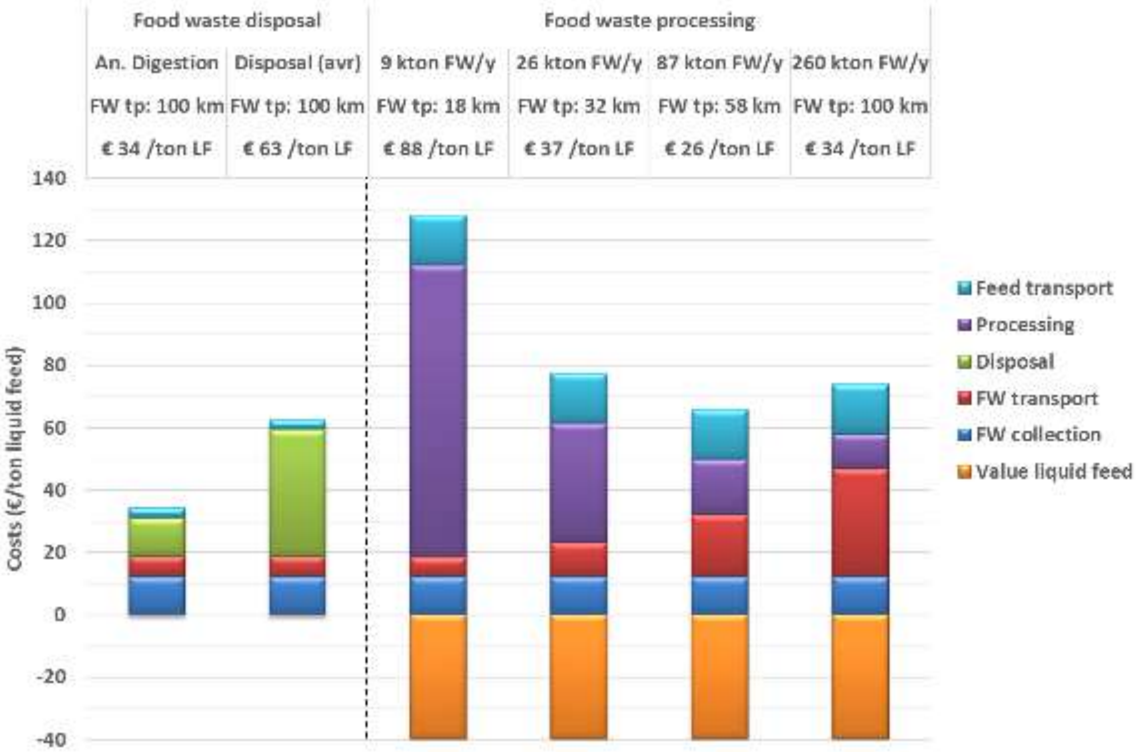


Figure 24 Estimated total costs of food waste disposal (AD and weighted average of current disposal processes) and for scenarios with a different number of feed processing plants in the UK. Expressed in Euro per ton liquid feed produced.



For medium to large sized processing plants, the sum of total costs minus feed value for all presented food-waste-to-animal-feed are lower compared to both of the disposal options. Due to trade-offs between logistic efficiency and plant scale efficiency (Figure 25), a medium-sized plant configuration gives best results.

The high cost prices for small-scale processing are mainly due to labour costs (Figure 26).

Figure 25. Trade-offs between FW collection transport (refrigerated) and processing costs.

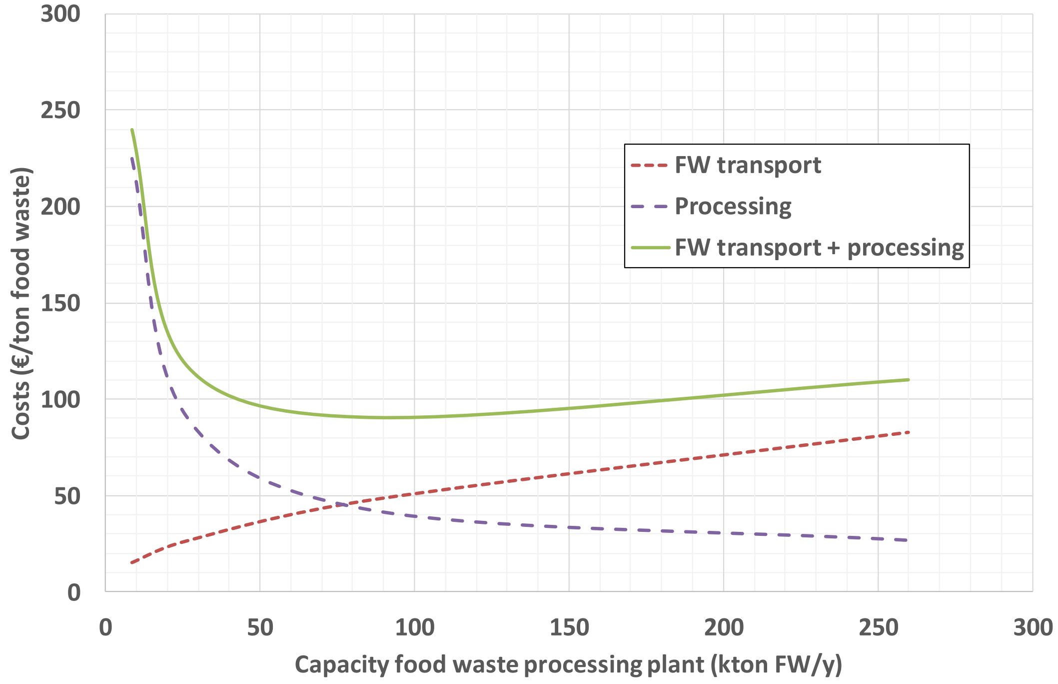
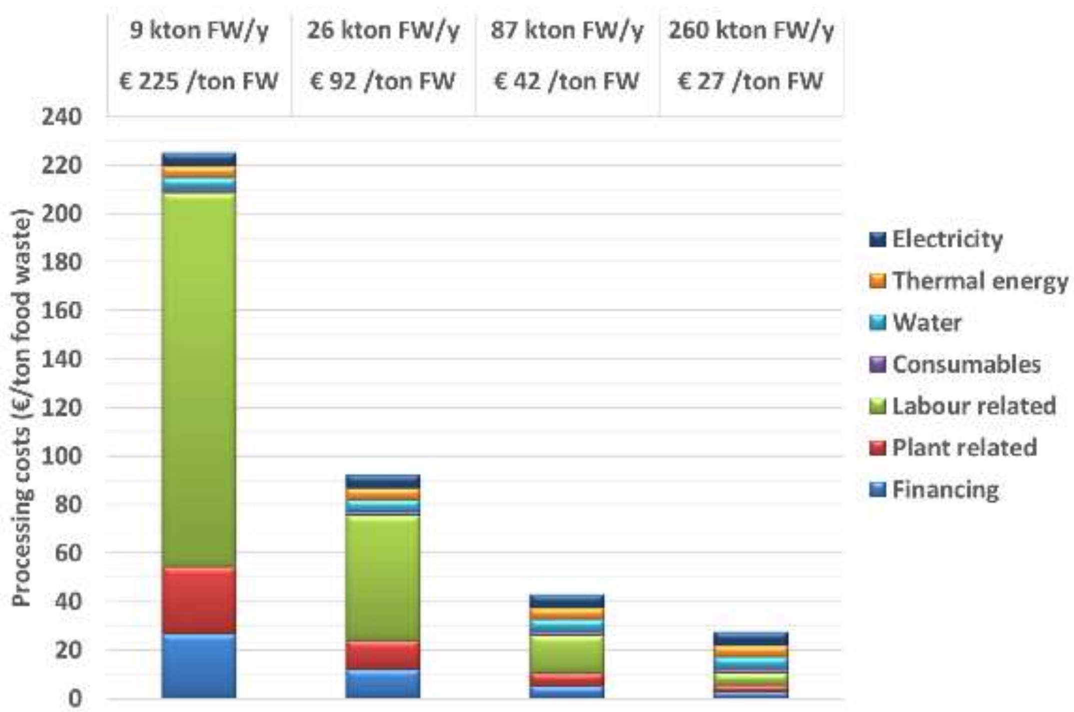


Figure 26 Distribution of processing costs over various fixed and variable cost categories.



The cost-benefit margin in the envisaged valorisation chain could be used for either lowering the food waste intake price and/or offering the feed at a lower price than reference prices for liquid pig feed. Indicative margin comes from analyses with the cost model:

- If the party that generates the food waste pays the same fee as for the cheapest current waste processing route (anaerobic digestion, AD), the liquid feed can be offered at a competitive price starting from plant capacity around 25 kton food waste per year (Figure 27).
- Assuming the reference market price for animal feed applies, costs for waste disposal through the food-waste-to-animal-feed will be very competitive compared to existing waste handling routes starting from plant capacity 25 kton food waste per year (Figure 28).

Figure 27. Plant scale-size effect on cost price of food-waste-derived feed compared to reference market price, with fixed waste intake price.

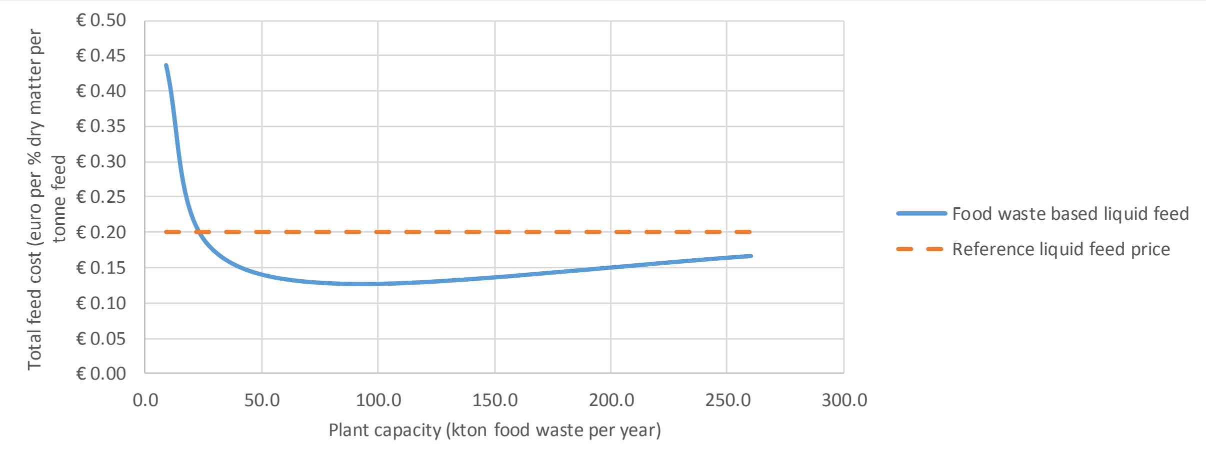
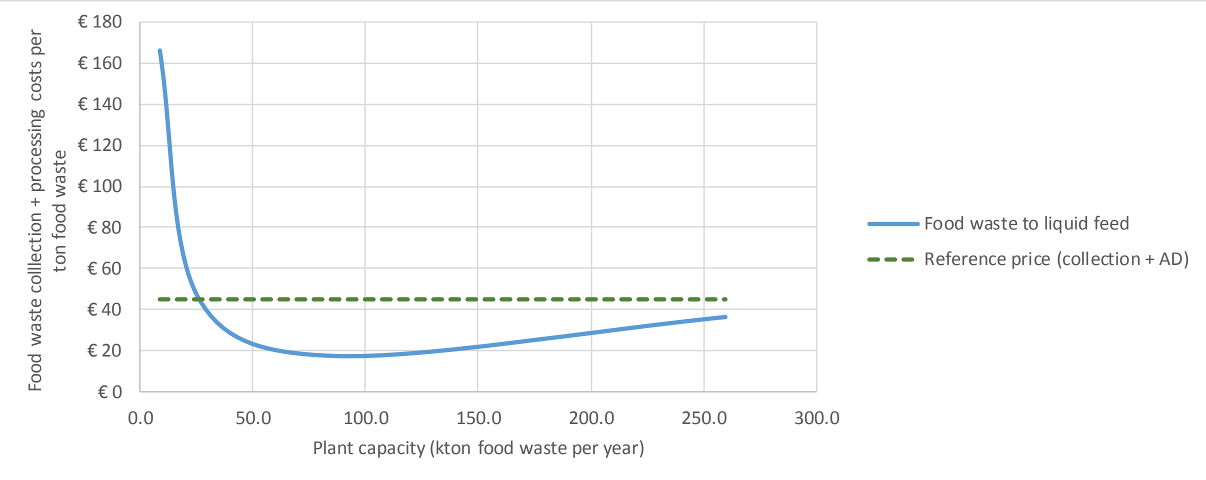


Figure 28. Plant scale-size effect on food waste intake price compared to price for least expensive reference waste processing route, AD.



In sum, processing food waste to animal feed is more competitive at smaller scales because of logistic efficiency. At very small scales, however, labour costs become a dominant factor. In the trade-off analysis, based on the assumed cost data, the concept appears most attractive around 100 kton waste processing capacity per year.

6.6 Imports and Exports

Several EU countries, including France, Spain, Italy, Poland and Ireland, imported pork products from Japan in the past 4 years (European Commission 2018c). More importantly, countries like China, New Zealand and Japan are important export markets for EU pork. The safety requirements regarding the use of treated surplus food in feed proposed in this report are stricter than in those countries where surplus food feeding is allowed. It is therefore unlikely that there would be repercussions from a change in legislation in the EU (European Commission 2018c).

7 Environmental case

In this chapter, we first set the theoretical framework for the environmental case for using surplus food as feed, followed by a discussion of the impact of current feed production. We have a look at the food use hierarchy to confirm that feed is indeed the preferable option for unavoidable surplus food no longer destined for human consumption. Then we present findings of the REFRESH life cycle assessment followed by a comparison with insect production and aquaculture.

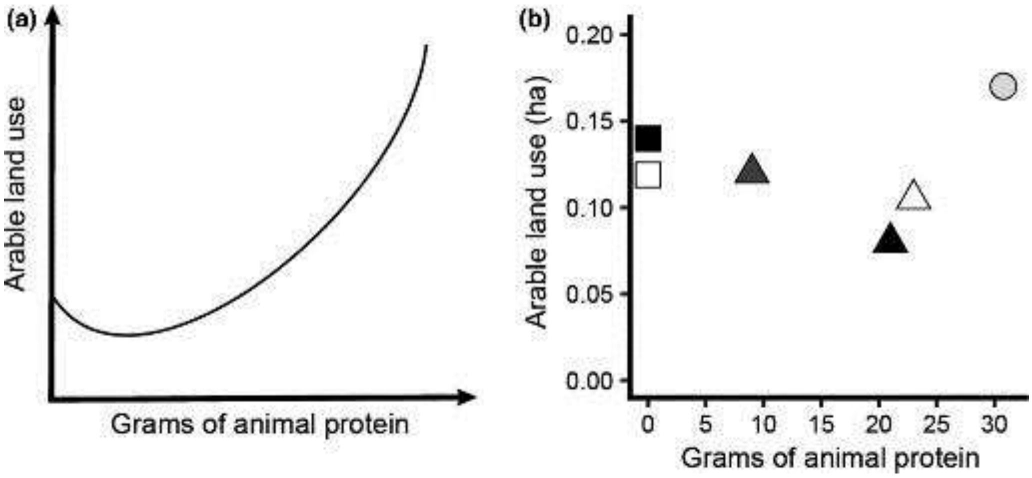
7.1 Dietary change - Ecological leftovers model

Drastic dietary change including the reduction of animal source food is unavoidable if we are to keep the global food system within planetary boundaries (Godfray et al. 2010; Aleksandrowicz et al. 2016; Poore and Nemecek 2018a; Van Zanten et al. 2018). A significant reduction of food waste is equally important (Bajželj 2014; Röös et al. 2017; Godfray et al. 2010). Cutting food and agricultural waste by half could reduce the area of global cropland by around 14% and GHG emissions by 22-28% compared to a scenario achieving optimal yields through sustainable intensification alone. Adding healthy diets - with a significant reduction in energy-rich foods such as sugars and saturated fats, including livestock products - to a scenario of reduced waste and optimal yields, would lead to a further reduction in the area necessary for cropping by an estimated 5%, pasture by 25% and the total GHG emissions by 45% (Bajželj 2014).

Until recently, the vegan diet had been found to provide the theoretical maximum reduction of land use and greenhouse gas emissions on a global level. In this scenario crop residues stay on the field to feed the soil–food web; co-products from the food industry become a bio-energy source or are wasted; and grasslands are not utilized for food production. Because animals do not recycle these biomass streams back into the food system, additional crops have to be cultivated to meet the nutritional requirements of the vegan population.

Therefore, the most effective dietary change mitigation scenario consists of limiting animal-source foods to non-ruminant meat and eggs from livestock produced solely from feed that does not compete directly for arable land with human edible crops: unavoidable food waste and by-products (Van Zanten et al. 2018) – see Figure 29. Some dairy production on marginal grasslands is also included in this scenario (Röös et al. 2017; Schader et al. 2015), which would produce limited amounts of meat from dairy herds. The trade-off between the land use savings from using marginal grasslands for dairy and greenhouse gas emissions from ruminant methane production needs further research. Importantly, results to date show that this scenario allows for restricted growth in consumption of animal source food in Africa and Asia (Van Zanten et al. 2018).

Figure 29: Comparing vegan diets with limited animal-source food fed on "ecological leftovers"



Source: (Van Zanten et al. 2018) The squares represent a vegan diet; triangles represent the diets with limited animal source food fed on "ecological leftovers"; and the circle (light gray) represents a current diet. It clearly shows that arable land use is most efficient with a moderate consumption of protein from livestock with low-opportunity costs.

In contrast, current feed crop competition over land with food crops and land use change related to oilseed feed production play a significant role in the climate impact of non-ruminant livestock farming.

7.2 Impact of conventional feeds

Globally, pig farming contributes an estimated 668 million tonnes CO2eq of emissions, and poultry farming contribute 612 million tonnes CO2eq (Müller and Mottet 2017). Land used to grow pigfeed amounts to a total of 94 million hectares globally, of which 45.1 million hectares is cereal grains and 39 million hectares is oil seed and oil seed cakes (Müller and Mottet 2017).

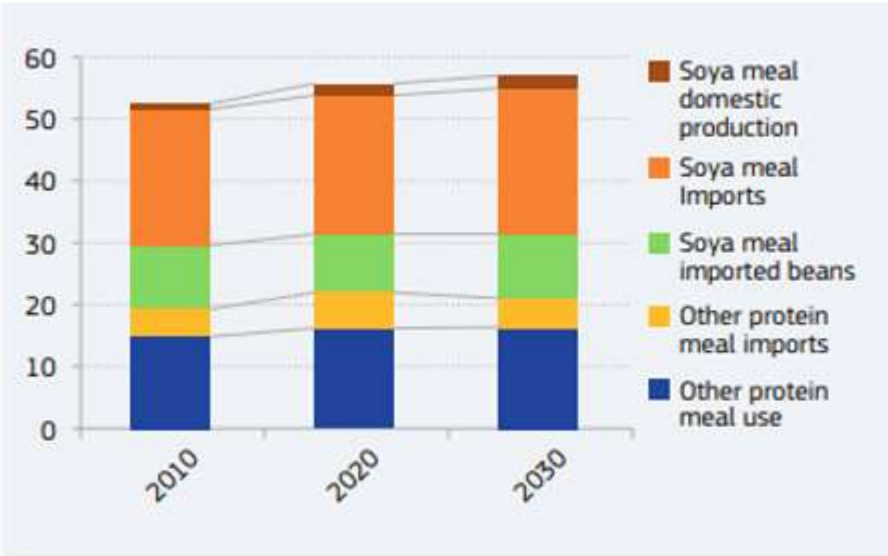
If every country in the world were to adopt the UK's 2011 average diet and meat consumption, 95% of global habitable land area would be needed for agriculture – up from 50% of land currently used (Ritchie and Roser 2017). Moreover, livestock production already occupies approximately 75% of agricultural land (Foley et al. 2011), and is growing rapidly. The meat industry is responsible for 14.5% of global emissions directly (Gerber and FAO 2013, 14), and if dramatic action is not taken, GHGs from the food system are projected to constitute more than half of the total global greenhouse gas emissions associated with human activities by 2050 (Bajželj 2014).

Feed is responsible for a substantial proportion of non-ruminant meat's environmental impact – for instance, in the UK feed contributes 78% of the total carbon footprint of pork production (Fry and Kingston 2009, 1–2). It is essential to both reduce the scale of meat production and consumption, and to reduce the environmental impact of the meat that is produced.

7.2.1 Soya: an ongoing environmental challenge for the feed industry

Over the past 50 years, production of soy has increased faster than any other crop from 27 million tonnes to 269 million tonnes, and the UN Food and Agriculture Organization predicts that global soy production may reach 515 million tonnes by 2050 (WWF 2017, 10). The average European consumes approximately 61kg of soy per year (WWF 2014), mostly indirectly through meat and dairy consumption. EU citizens consumed 12,851,000mt of pigs and pork in 2013, equivalent to 5,342,000mt of soybean and 2,002,000 hectares to produce this (Kroes and Kuepper 2015, 16). Of meat produced in EU countries, broiler chickens have the highest soy content at 1,089g per kg, pork contains 508g/kg and beef contains 456g/kg (Kroes and Kuepper 2015, 12) – this high consumption of soy in omnivorous non-ruminants shows the high potential for displacing soy with surplus food feeds. Figure 30 illustrates that most of the feed protein for the EU currently comes from soya products, and this is currently projected to continue under a "business as usual" scenario.

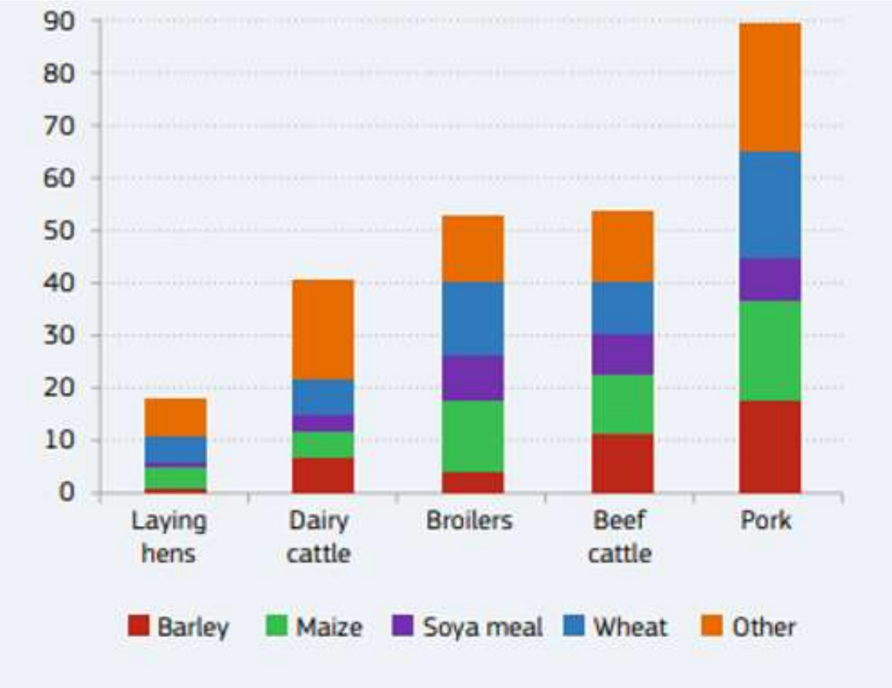
Figure 30: EU protein meal sources (million t)



Source: (European Union 2017, 34)

Figure 31 shows that pig production currently uses a high proportion of EU feed:

Figure 31: EU feed use per animal type in 2015/2016 (million t)



Source: (European Union 2017, 36)

As a result of the bans on feeding processed animal protein and catering food waste to livestock in 2001 and 2002 respectively, a deficiency in animal feed protein was created equivalent to 2.9 million tonnes of soymeal – as a result, EU imports of soymeal increased by 3 million tonnes between 2001 and 2003 (Steinfeld et al. 2006, 50). Table 12 shows that more than half of EU soy imports come from South America.

Table 12: Soy imports to EU28 from largest suppliers (1000 tonnes).

	2015	2016	2017
Argentina	144	196	78
Brazil	5,694	5,562	5,066
Canada	1,125	1,131	1,039
Paraguay	1,133	967	1,525
US	4,794	5,512	4,783
Uruguay	815	747	156

Source: Derived from (European Commission 2018c)

Argentina and Paraguay contain the highly biodiverse Gran Chaco region. Argentina has lost 22 percent of its forests between 1990 and 2015, primarily for soybean farming and cattle ranching (Mighty Earth, FERN, and Regnskogfondet 2018, 5). Conversion of the Chaco forest and grasslands to croplands and pasture is estimate to have released 3,024 million metric tons of carbon dioxide between 1985 and 2015 (Mighty Earth, FERN, and Regnskogfondet 2018, 5).

Efforts to tackle deforestation like the Brazilian Soy Moratorium and "Cerrado Manifesto" currently focus on the Amazon and Cerrado in Brazil, and provide perverse incentives for companies like Bunge and Cargill to just shift deforestation to frontiers like Argentina and Paraguay (Mighty Earth, FERN, and Regnskogfondet 2018, 14). Even so, in May 2018, five traders and multiple soy farmers were fined a total of US $29 million by the Brazilian government for soybean cultivation and purchasing that is connected to illegal deforestation (Byrne 2018b). Two of the five companies fined – Cargill and Bunge - are among the top five soy exporters from Brazil, and some of the few companies that have adopted zero deforestation commitments.

The fine demonstrates the vulnerability of the companies' systems for monitoring and tracking their supplies and the fact that they cannot guarantee that their sources are deforestation free (Vasconcelos and Burley 2018). The Trase tool shows the continued risk faced by soy traders regarding supply chain deforestation risk (TRASE 2018). The European Feed Manufacturers Association FEFAC acknowledges that soy is a strategically important raw material for the feed industry in Europe, and that for the foreseeable future, they will rely on imports, which is why responsible sourcing is incorporated into FEFAC's 2030 vision" (Byrne 2018a). But as shown, such efforts by the industry to increase responsible sourcing are extremely challenging.

Reducing soya content in feed

The pig industry has been working to reduce the percentage of soya used in feed. The British pig industry, for example, has brought soy down to less than 10% of compound feed by replacing it with rapeseed meal (BPEX 2014). Rapeseed meal is a by-product of rapeseed oil which has seen a startling rise in production across Europe in the past decade, mainly driven by its use in biofuel. However, rapeseed oil is not without its own environmental problems. A consequential LCA by Styles et al. (2015) shows that the displacement of animal feed by biofuel coproducts, leads to biofuel Global Warming Potential burdens because avoided soy bean production leads to avoided soy oil production which leads to more GHG-intensive palm oil production. Rapeseed in itself is less land efficient than palm oil (May-Tobin et al. 2012, 12) – meaning that it raises pressures on global agricultural land use, and therefore indirectly contributes to deforestation.

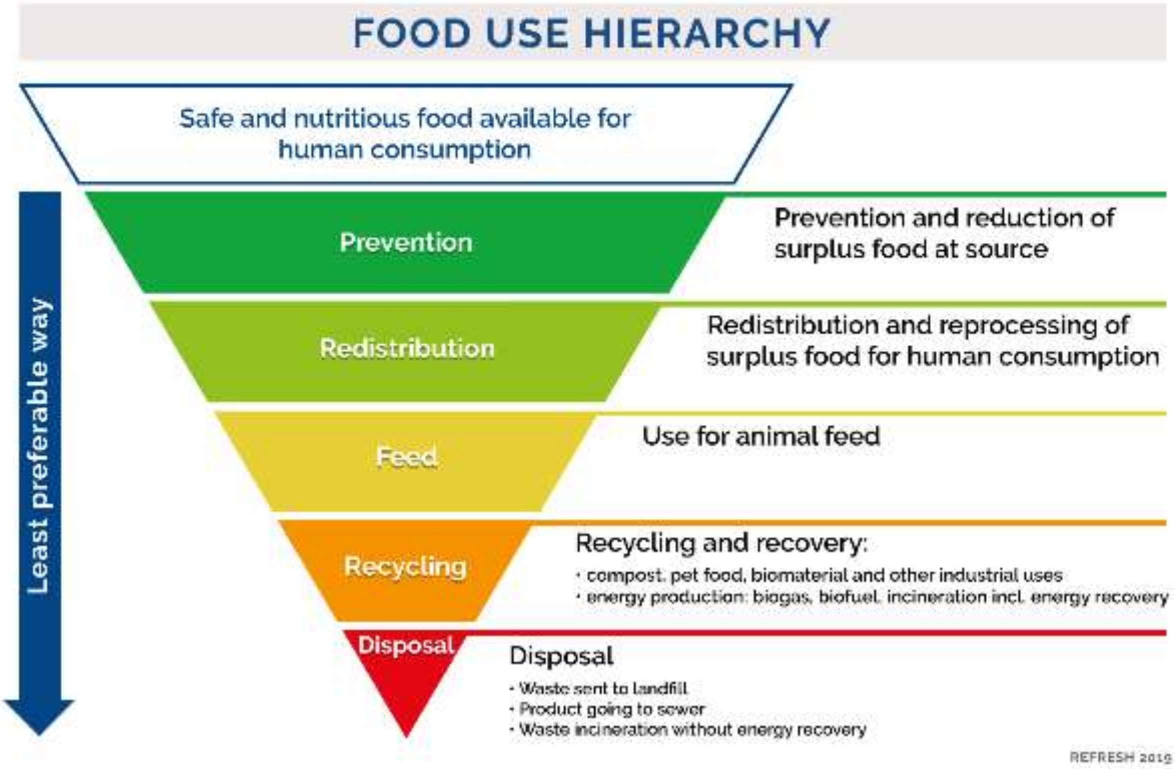
Another study found that biodiesel made from rapeseed emits roughly 20 percent more CO2 than diesel or petrol (Herman and Mayrhofer 2016), whilst simultaneously encroaching on land which was previously used to grow food or graze livestock, putting upwards pressure on food prices. Finally, rapeseed feeds have been found to be less digestible than soy feeds (Gonzalez-Vega and Stein 2012), making it a less efficient feed.

When replacing soy with other plant protein sources, it is important that full consequential life cycle analysis is carried out, including an analysis of global oil seed commodity markets, to ensure that the problem is not simply displaced elsewhere. In addition, as discussed in section 7.1, a climate and land use perspective suggests that feeding livestock with human-edible crops will not be an option in the future.

7.3 Food Waste Hierarchy

There has been a growing international consensus that a "food use hierarchy" is needed to prioritise the most environmentally preferable destinations for food that is currently wasted.

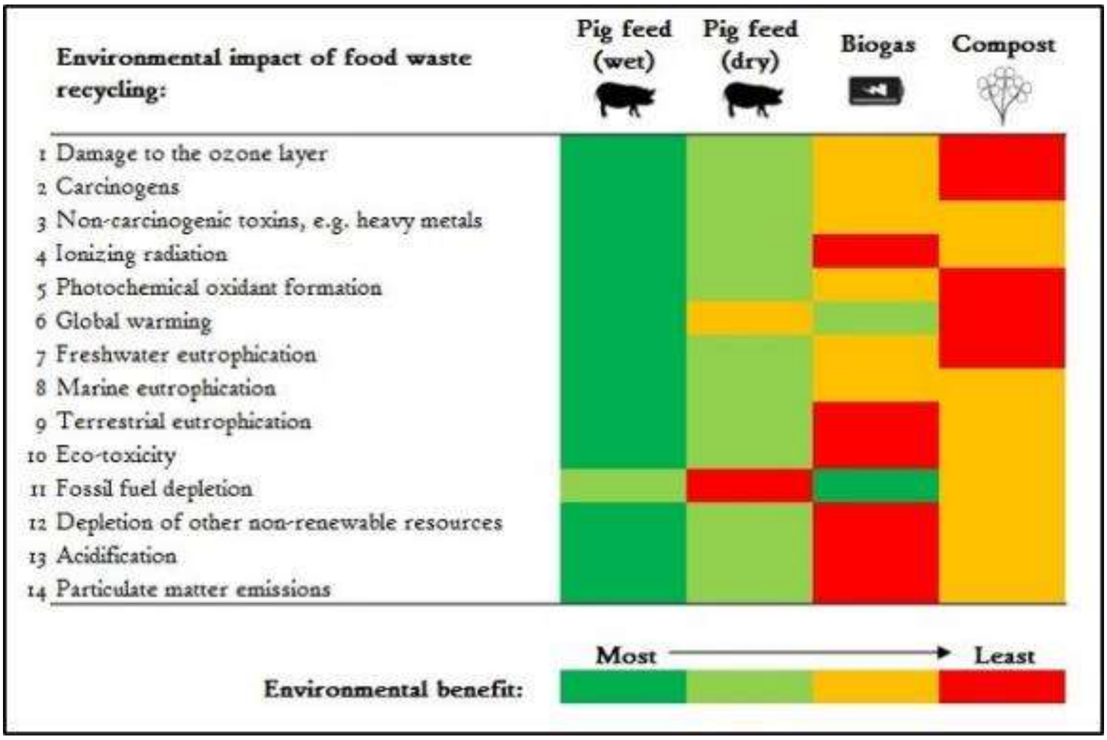
Figure 32: Food Use Hierarchy



A more comprehensive list of food waste destinations is provided in the Food Loss and Waste Standard (Hanson et al. 2017, 37). All use of surplus food as animal feed should occur within the framework of this food use hierarchy, so only food that is no longer edible for humans or is difficult to prevent from occurring in the first place, should be sent to animal feed.

At the same time, as a rule, any food still fit for animal feed should go there and not anaerobic digestion, compost and other uses. A hybrid, consequential LCA found that using food waste as animal feed scores better on 12 out of 14 environmental and health indicators for dry pigfeed compared to anaerobic digestion or composting – and better on 13 out of 14 indicators for wet pigfeed, including impact on global warming (Salemdeeb et al. 2017) (see Figure 33). The calculations in the study were based on the current UK energy mix for the energy needed to render the food waste safe. If renewable energy was used, feed could potentially beat biogas and compost on all indicators.

Figure 33: Environmental Impact of food waste recycling



Source: Developed from Salemdeeb et al. (2017)

The food use hierarchy is only a general rule of thumb – regional specifics may render the environmental impacts of higher stages of the hierarchy less environmentally friendly in some cases (Evans 2013, 53). Policy makers need to be sensitive to these regional variations, whilst still incentivising the hierarchy as a general guide.

7.3.1 Incentivising the food use hierarchy

Governments could analyse which combination of fiscal incentives and legislation would be most effective at moving food up the food use hierarchy. For example, the charges for food waste disposal introduced by the Japanese Food Recycling Law have played an important role in encouraging the food industry to send its leftovers to animal feed. South Korea banned the landfilling of food waste in 2005, and now 45% of all food waste is treated for animal feeding, another 45% by composting, and the remaining 10% by other alternatives such as anaerobic digestion (Kim et al. 2011). However, it is important that incentives do not have perverse effects. In the case of Europe, food waste that is avoidable or suitable for redistribution to people or animals has been drawn down the food use hierarchy to anaerobic digestion (AD) due to the incentives to this sector (Wunder et al. 2018). For example, the latest food waste data of the UK's largest retailer Tesco show that 19,898 tonnes of food fit for human consumption went to AD in 2017/18. While we do not want to remove incentives to prevent food waste going to landfill or incineration, additional incentives may be required to ensure surplus food that is suitable for human consumption stays in the food supply chain, and surplus food that is no longer fit for human consumption but still fit for feed, goes to feed.

7.4 Available volumes of surplus food

Certain by-products from agriculture and manufacturing such as brewers' grains, wheat grain unsuitable for bread flour and whey are already routinely used in animal feed. The former foodstuff processing industry in Europe transforms an estimated 5 million tonnes of leftover bread and other cereal and confectionary goods into feed ingredients (EFFPA 2018). EFFPA estimates that this figure could rise to 7 million. However, if legislation was changed for non-ruminant livestock, there would be significant additional potential for keeping surplus food in the supply chain as animal feed.

A realistic estimate of this potential can be calculated by taking the food waste figures from FUSIONS and applying the percentage of use in animal feed currently achieved in Japan (table 13). These calculations show us that at least fourteen million tonnes of food currently wasted from the manufacturing, retail and catering sectors in the European Union could be kept in the food supply chain as animal feed.

Table 13: Calculating the realistic volumes of food waste that could become available for non-ruminant feed as a result of legislative change

All volumes in x1,000 tonnes	
Total EU Food Waste	88,000
Total EU Food Waste from manufacturing, retail and catering	31,680
Current former foodstuffs (such as bakery goods) already used in livestock feed	5,000
Total EU surplus food flows from catering, manufacturing and retail (of which 5 million tonnes go to animal feed, and the rest goes to AD, incineration, landfill etc)	36,680
52% of this total surplus – which is the percentage currently achieved in Japan	19,074
Total volume of food leaving the supply chain which would be immediately suitable for animal feed (this figure is arrived at by subtracting the volume currently used as former foodstuffs from the 52% of the total from catering, manufacturing and retail)	14,074

Sources: (Stenmarck et al. 2016; EFFPA 2018; Japan Ministry of Agriculture, Forestry and Fisheries 2018)

More detailed calculations by REFRESH of food wastes found that in France 4.4 million tonnes of surplus food that are theoretically suitable for pig feed, are currently leaving the food supply chain from catering, manufacturing and retail. For the UK, this figure is 2.5 million (De Menna et al. 2018). Based on current Japanese surplus food to feed recycling rates, about half of this surplus can very realistically be turned into feed as soon as we legislate to do this safely and build the treatment plants.

Preventing the production of food that will not be eaten by humans must be our absolute priority. This is reflected in the prioritisation of resources within REFRESH to prevent food waste in households and the food supply chain. As progress is made in such prevention, total volumes of surplus food theoretically available for animal feed will reduce. This is only right. However, it may be possible to maintain practical volumes of surplus available for animal feed by increasing the proportion of unavoidable surplus food used as non-ruminant feed.

Household food waste

We have decided to not include household leftovers in our estimates because of the challenges involved in keeping leftovers fresh and free from contaminants such as packaging. However, we would propose that when cities, regions or member states implement more sophisticated household food waste recycling methods, this option should become available too. As part of this step it would be important to research the South Korean system of food waste collections and recycling. We have not considered South Korea in too much detail because of the ongoing presence of Foot and Mouth Disease amongst other diseases of concern. However, disease outbreaks in South Korea are linked to its geographical proximity with China.

Figure 34: Household food waste collection from a South Korean appartment block

Source: https://e360.yale.edu/features/in_south_korea_an_innovative_push_to_cut_back_on_food_waste?utm_content=buffer90dc6&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

Box 8: High tech food waste reduction in South Korea

Between 2013 and 2014, the South Korean government implemented a Radio Frequency Identification (RFID) food waste management system. This system requires residents to go to a Recycle Zone housing numerous high-tech food waste bins and scan their RFID card that contains their personal details before their waste disposal. When the residents dispose of their waste, the weight is automatically calculated and recorded under the user's account to be eventually billed accordingly at the end of each month. The collected food waste is also no longer sent to landfill but instead processed into animal feed, compost, or used to generate electricity. This system has had excellent results, reducing household food waste by 30%, restaurant food waste by 40%, and increasing the recycling rate of food waste to almost 100%.

Source: (Au 2018)

7.5 Life Cycle Analysis (LCA) of food surplus in pigfeed

7.5.1 Previous LCA studies

Even replacing small percentages of compound feed mix with currently permissible treated food surplus, such as pumpkins, mushrooms and yoghurt, could lead to significant carbon savings. For example, switching 10% of total broiler chicken feed to the food waste mix developed by the NOSHAN project could lead to a total avoidance of 6.2 million tons of CO_2 emissions to the atmosphere each year (Gillman 2018). A similar adoption of treated food surplus as part of livestock feed globally could lead to a "reduction of natural land transformation by 30% and agricultural land occupation by 12%, which would protect carbon sinks and prevent greenhouse gas emissions from the additional intensive agriculture." (Gillman 2018).

Zu Ermgassen et al (2016) calculated that using 39.2% of food waste from retail, catering, manufacturing and households at EU level, could reduce the land requirement for EU pork by 1.8 million ha which represents a 21.5% reduction in the current land use of industrial EU pork production. This calculation used EU food waste figures from 2010 and applied a food waste recycling rate averaged between Japan and South Korea. The land use reduction figure includes an estimated reduction of land required to grow soybean of 268,000 ha.

Differences between treatment systems and plant location

Results from an LCA by Ogino et al. (2007) in table 14 show that liquid feed treatment produces significantly less greenhouse gas emissions compared to the production of dry feed, but it also confirms REFRESH findings in the importance of transport fuel costs. Interestingly, **the worst performing liquid feed plant emits nearly as much as the best performing dry feed plant thanks to this plant using waste heat from an adjacent industrial waste incinerator,** but also because the worst performing liquid feed plant has the **highest transport**

costs of all five plants. It is therefore possible that if truly **renewable sources of heat are available, dry feed production could be an acceptable option from an environmental perspective. Dry feed production would then allow treatment plants to be located as close as possible to the sources of surplus food and then cut emissions from the onward transport of dry feed to farm.** Case-by-case consequential LCAs and the use of the REFRESH Forklift tool may help to determine whether dry feed production has the potential to be low-impact.

Table 14: g of CO2 equivalent emissions to produce 1kg of feed (dry matter) with fixed metabolizable energy content, in different treatment plants in Japan.

	Liquid feed treatment plants		Dry feed treatment plants		
Process	Plant A	Plant B	Plant C	Plant D	Plant E
Residue collection	95.8	171.4	120.5	51.3	26.6
Electricity	16.0	17.1	313.0	197.5	83.6
Fuel	100.9	134.5	1135.6	1042.1	247.8
Total	212.7	332.9	1569.1	1290.9	357.9

Source: (Ogino et al. 2007) Plant A uses kitchen and food-factory surplus to produce liquid feed, Plant B produces liquid feed using solid and liquid food factory wastes. Plant C produces dehydrated feed by steam heating. Plant D produces dehydrated feed by frying and drying food residues under reduced pressure; then, surplus edible oil derived from the food residues are recycled as fuel oil. Plant E uses the waste heat of an adjacent incinerator of industrial waste for dehydrating food residues.

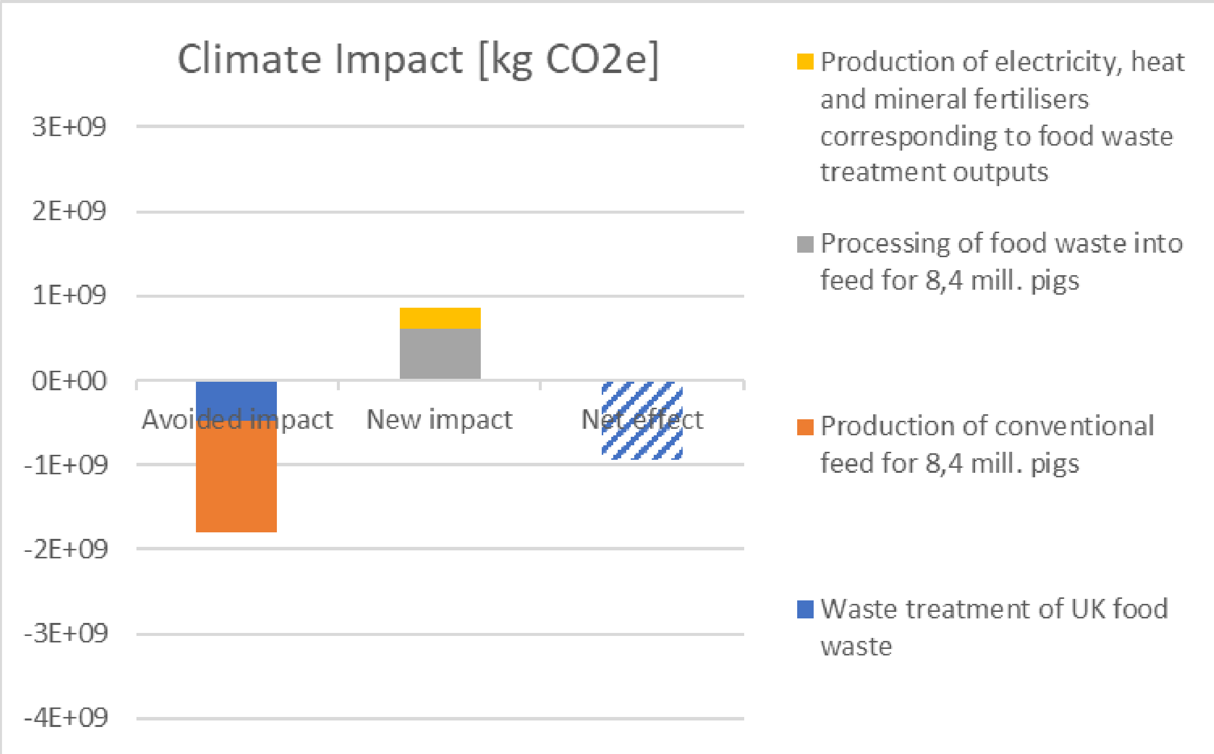
7.5.2 REFRESH Consequential Life Cycle Assessment

REFRESH calculated more detailed estimates for volumes of surplus food currently leaving the food supply chain from manufacturing, retail and catering sources in the UK and France. REFRESH also obtained detailed operational costs from a Japanese treatment plant which Kitani (2018) converted to UK and French equivalents through various relevant cost and price indices. REFRESH further refined these cost data through advice from food processing experts. Based on these data, a consequential LCA was then performed (de Menna et al. 2018) with results showing an important GHG reduction potential.

Figure 35 shows the net climate impact of utilising identified food waste as pig feed in the **UK** instead of sending it to current waste treatments. The **resulting savings in greenhouse gas emissions are about 1 million tonnes of carbon dioxide equivalents**. The main benefit comes from reduction of conventional feed components used in pig production in the UK (avoided emissions). Figure 36 shows the net climate impact of utilising identified food waste in **France** as pig feed instead of sending it to current waste treatments. The resulting **savings in greenhouse gas emissions are about 1,9 million tonnes of carbon dioxide**

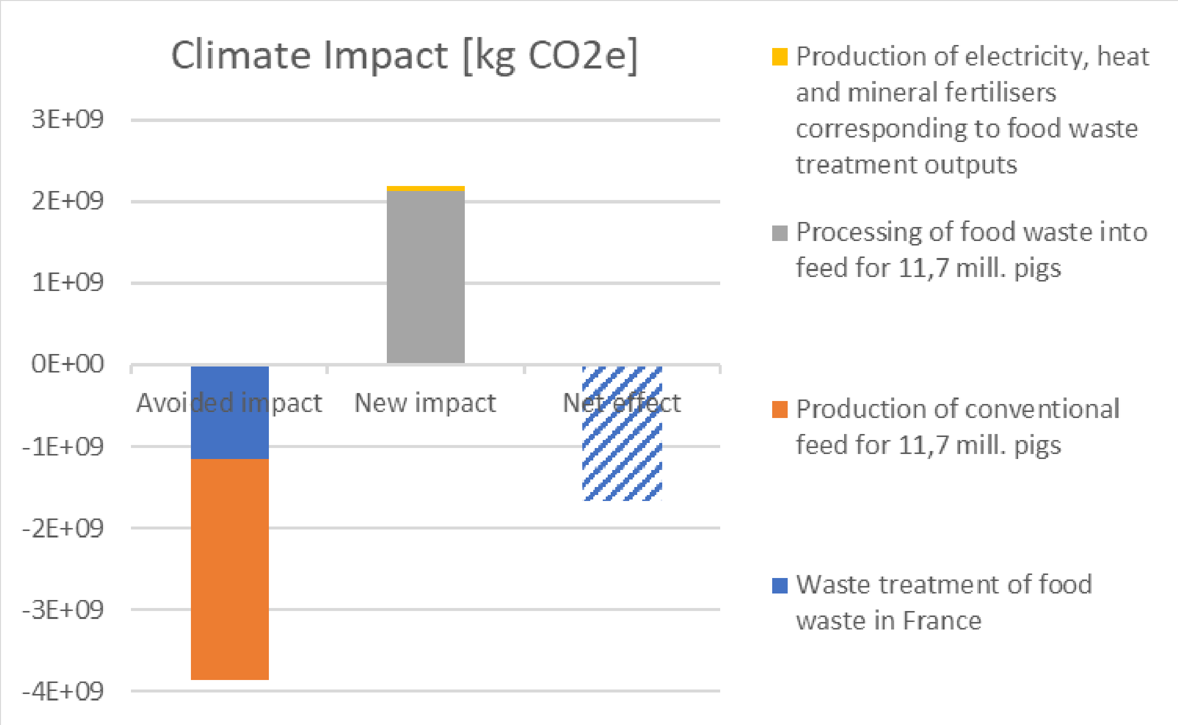
equivalents. The most important aspect to limit the additional climate impact of valorising the food waste into feed, is to decrease the impact of collecting the food waste, as well as transporting the liquid feed to the farms.

Figure 35: Net climate impact of using processed food waste as pig feed in UK



Source: De Menna et al. 2018

Figure 36: Net climate impact of using processed food waste as pig feed in France



Source: De Menna et al. (2018)

REFRESH findings highlight that the collection of the food waste and transporting it to the processing plant constitutes a significant proportion of the overall climate impact. The transport of the liquid feed to the farm is also an important contributor, even though it is proportionately smaller than the collection, mainly because a larger truck has been assumed in our model to be used for the transport to the farm; making it a more efficient mode of transport. Hence, **reducing the distance travelled and using non-fossil fuels in the collection of food waste and delivery of feed is important when aiming to reduce the climate impact of the food waste valorisation into feed.**

7.6 Comparison with insects as animal feed

Insects may be part of the solution, but they are currently only allowed to eat what farmed fish – and soon other omnivorous non-ruminants - are allowed to eat directly: vegetable food surplus, fish that is a different species and non-ruminant processed animal protein (insect amendment to the 999/2001 reg on TSE) (EU 2017). Thus, while insects may contribute to reducing the protein deficit, they would not at this stage help to prevent more surplus leaving the food chain. Moreover, according to a key Life Cycle Assessment (LCA) (Van Zanten et al. 2015), using larvae meal as animal feed results in "decreased land use" but "increased global warming potential and energy use", mostly because of the additional energy needed for growing and processing the larvae and the fact that you no longer use waste for bio-energy. Using renewable energy for insect farming may result in reduced global warming potential.

Another LCA of insects showed that a higher insect yield was achieved via the use of feed with good nutritional quality (e.g. rye meal, soybean meal), but then the final product was associated with high environmental impacts. On the other hand, low quality feeds for the insects, based on manure (currently illegal to feed manure to insects in the EU), had low efficiency for insect yields as it caused an increase in the use of resources at the insect growing stage, which overcame the benefits from manure utilization (Smetana et al. 2016). An EFSA scientific opinion also noted that viruses that affect humans and farm animals can survive in insects, and thus feeds for insects containing meat would need to be heat-treated to make them safe, in the same way as normal animal feed (EFSA Scientific Committee 2015). On balance, more research needs to be done to verify the environmental costs and benefits of using insects as animal feed.

7.7 Comparison with aquaculture

REFRESH has not been able to research the potential of using treated surplus food for fish feed in aquaculture, though it seems unlikely that liquid feeding is possible in aquaculture. Given the environmental impact of aquaculture and the use of fishmeal as feed, this topic merits further research. Globally, 90% of the fish turned into fishmeal for fish farms is classed as food-grade or prime food-grade (i.e. fine to eat, e.g. herring, anchoveta, mackerel) (Cashion et al. 2017). The industry has been turning to the use of soya to replace fishmeal which is not a satisfactory solution if the global impact of soya is born in mind (see section 7.2.1).

Moreover, over 50 percent of the world's fish oil production is fed to farmed salmon (FAO 2009, 146 Figure 50), and farmed salmon requires the use of Antarctic krill for astaxanthin, to colour its flesh. Krill harvesting in Antarctica is now having knock-on effects on the last pristine marine ecosystem on Earth. Since the 1970s, the krill population has dropped by 80%; in turn, research shows that Antarctic penguin populations, which depend on krill, have collapsed by 50% in studied colonies over the last 50 years. Fishing for krill for aquaculture threatens the integrity of the whole of the Antarctic ecosystem (Trivelpiece et al. 2011). Tilapia fish farming shows some promise because it has excellent feed conversion rates and does not depend on fishmeal as Tilapia is herbivorous. However, species like Tilapia are farmed in freshwater pond systems which currently emit significant amounts of methane (Poore and Nemecek 2018b).

8 Stakeholders

8.1 Consumer acceptance

8.1.1 Meat quality

Existing research indicates that feeding food waste to pigs may have neutral or positive effects on meat quality for consumers. For instance, Westendorf et al (1998) convened a consumer panel of 65 people, including faculty, staff, and students at Rutgers, the State University of New Jersey, who were fed samples of pork, and asked to rate the samples for intensity and preference. The samples of pork originated from pigs fed either food waste or corn soybean/meal. The consumer panel on average voted the pork taste of pigs fed on food waste as more intense in flavour, less chewy and juicier than the pigs fed corn soybean/meal. Overall, the consumer panel reported a significant preference for the texture of the pigs fed on food waste, and they reported an almost equal preference for the flavour of the two samples with a very slight preference for the pork from pigs fed on food waste (Westendorf, Dong, and Schoknecht 1998).

A wider review of 18 studies on the effect of surplus food feeds on the quality and nutrition of pork, including blinded taste trials, found that increasing the proportion of surplus food in pig diets had no overall effect on overall palatability, flavour, colour and fat composition, among other traits (zu Ermgassen et al. 2016). Another study found that liquid feeding resulted in no differences in meat quality compared to pigs raised on dry feed (BPEX, Defra, and MLC 2004).

Often, pork in Japan is consumed as sliced pork known as “shabu-shabu”. Higher fat content in feed tends to lower the firmness of pork (Nishioka and Irie 2006), meaning it is more difficult to slice and therefore less popular in Japanese meat shops. Eco-feed tends to contain relatively high fat in Japan, mainly as a result of vegetable oil, containing unsaturated fatty acid, which lowers the melting point of pork.

However, a study of consumer reactions to pork from pigs raised on either commercial formula feed or high-fat liquid feed, found that consumers mainly thought the pork from liquid feed was more tender and meltable. About half the subjects preferred the pork given the liquid feed and half preferred the pork fed the conventional feed (Sasaki et al. 2007). This shows that liking such pork is a matter of taste, and there is a definite market in Japan who prefer this type of pork. It would be necessary to conduct market research in Europe to discover European preferences. Whatever the desired fat content, this illustrates the importance for eco-feed producers to aim to balance fat content in food waste feeds to cater to the tastes of their target consumer. Chapter 5 discusses learning from the Japanese experience with regard to controlling fat content in feed made from surplus food.

8.1.2 Cost for consumers

There are two approaches to the consumer cost aspect: one is the premium product, the other is affordable pork.

Premium product

Historically in Japan, pork from pigs raised on food waste used to be informally called "garbage pork" by many of the public, and buyers of pork looked down on these types of pork. However, these prejudices have been eroded since the introduction of the Food Recycling Law and the renewed popularity of the *Mottainai* value, which conveys a sense of regret regarding waste. Pork fed on food waste is now sold at a premium price to consumers as "eco-pork" and marketed as a luxury product (see figure 37). In the next section we discuss research showing that Japanese consumers are willing to pay extra for ecofeed labelled pork, which is labelled as better for the environment but also healthier, as "yoghurt-pork" which refers to the fermentation of the feed with lactic acid bacteria. For the EU, a similar premium market potentially exists (see next section). The premium product approach would need to be linked to minimum percentages of surplus food ingredients in feed (see Chapter 5) and be verified and certified as such.

Figure 37: Marketing of Japanese eco-pork by the Kurao and Odakyu brands

Source: Kuraopork.com and Kawashima (2018)

Affordable pork

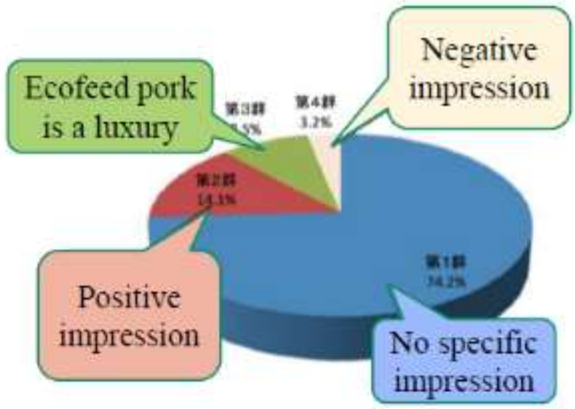
At the same time, predicted cost savings as discussed in Chapter 6 could partially be passed on to consumers. **An attempt could be made to break the current trend of environmentally friendly and high-welfare meat products being perceived as luxury products.** We need to further research feed treatment plant ownership models to ensure savings can be passed along the supply chain, so that farmer livelihoods can be improved alongside investment in animal welfare, reducing the use of anti-biotics, and more environmental farming leading to more ethical produce with a lower environmental impact for a similar price as traditionally fed pork.

8.1.3 Acceptance and interest in pork fed on treated surplus food

Japan

In Japan, a survey of consumers found that those most knowledgeable about the pig industry showed the strongest approval of recycling surplus food as feed (Sasaki et al. 2011), indicating that public education of food waste feeds may be beneficial in improving public acceptance. Most survey respondents had no specific impression of eco-pork, but those who were aware generally had a positive impression or even viewed ecofeed pork as a luxury.

Figure 38: Japanese consumer views on pork fed on surplus food



Source: Sasaki et al. (2011)

Another consumer study found that “the willingness to pay for the pork produced with feed from food residuals was approximately an additional 19.3 Japanese Yen per 100g of pork in comparison with to ordinary Japanese pork” and that the willingness to pay for reduced GHG emission pork was an additional 0.4 yen / g-CO_2. The study concluded that labels with information on resource recycling and CO_2 reduction encourage consumers to purchase the pork produced with feed from food residuals (Kurishima, Hishinuma, and Genchi 2011). The strongly held Japanese value of *Mottainai* – conveying a sense of regret of waste – may well play a role in the Japanese consumer acceptance of this pork.

Japan uses certification schemes to inspire greater consumer trust in eco-feed products**. Certification of feed itself** began in 2009 and is administered by the Japan Scientific Feeds Association – certifying that safety standards have been met, that the feed contains a certain percentage of food waste and that it has sufficient nutrient content. **Certification of pork produced with eco-feed** started in May 2011, is administered by the Japan Livestock Industry Association, and requires standards to be met around planned eco-feed feeding and specifying the routes until sale, for instance (Kawashima 2018).

In 2018, 46 companies were certified as eco-feed suppliers, but only 8 companies were certified to sell eco-pork products (Kawashima 2018). Currently, farmers don't get much profit from certification of eco-pork but there are efforts to get more farmers behind the scheme because it is beneficial for consumer education and uptake of the product.

Europe

The recent report by the European Commission (2018b) on the development of plant proteins in the EU shows that:

> *Consumers in the EU have become increasingly conscious about the way animal products are produced. They demand higher standards as regards animal welfare, environmental impact (climate change/deforestation), type of production (based on organic or non-genetically modified (non-GM) feed, regional supply chains). In response, different premium market segments for feed have emerged in the EU.*

This creates economic opportunities for EU-sourced feed. Regarding the demand for organic and non-GM feed, consumer motivation falls into two broad categories: one is environmental sustainability and the other is health and product quality (Monier-Dilhan and Bergès 2016). Animal welfare would be a third motivating factor. The growing popularity of flexitarian diet points to a group of people who like eating meat but want to reduce consumption for health and/ or environmental reasons. **Pork made from surplus food would primarily be of interest to consumers changing or reducing their meat consumption due to environmental considerations**. See section 8.5 for a discussion of the welfare and consumer acceptance in relation to the appearance of traces of pork in pig feed.

The European Commission report on EU plant proteins (2018b) also discusses the role that can be played by voluntary labelling, which increases the transparency related to origin and production method. Feedback's survey with 3500 UK consumers (next section) confirms the importance of certification for consumers to accept safety and environmental claims regarding pork from pigs fed on surplus food. We would emphasize the importance of independent verification of certification schemes, and strongly recommend that such verification is linked to the official licencing of treatment plants.

Meat availability in the ecological leftover scenario

REFRESH calculations show that in an ecological leftover scenario (see Chapter 5), there would be 21 grams of pork per person per day in the UK, based on the lower value which is limited by the energy available in surplus food streams currently leaving the food supply chain. If we take a more realistic recycling rate based on the Japanese experience, we need to divide this figure by half. Therefore, if we were to limit UK pork production to that which does not compete with food crops for feed, we would be able to eat one 100g pork steak every ten days. For France, due to higher volumes of food currently being wasted, there would be 100g of pork per person per week (see Figure 39). Calculations were based on the feed needed for grower/finishing pigs and exclude feed needed for piglet production. Detailes of calculations available in Supplementary Materials Part 8.

Figure 39: 400 grams of pork spare rib steaks: a person in France could eat one of these steaks once a week without feed for finishing pigs competing with human food crops

Image source: Riverford Organics

8.2 REFRESH consumer survey and citizens' understanding workshop

8.2.1 Valorisation of food surpluses and side-flows and citizens' understanding

This section is based on the report by Rahmani and Gil Roig (2018) which presents the results from a social experiment which was carried out in collaboration with the Regional Council of Vallès Oriental (Barcelona) in the context of parents' choices of their children's school meals. A group of 24 parents were tested to determine whether they would be open to the Council favouring catering companies that integrate valorised foods from food surpluses or side-flows when hiring school catering services. Parents were presented with 4 hypothetical school menu options using valorised foods:

i) a pumpkin cream made with gleaning pumpkins from leftover production;
ii) a pork steak from a pig fed with food-industry by-products;
iii) a pork steak from a pig fed with liquid feed (ecofeed) from catering food surplus (currently banned in the EU);
iv) a yoghurt fortified with vitamin C extracted from food surpluses and side-flows.

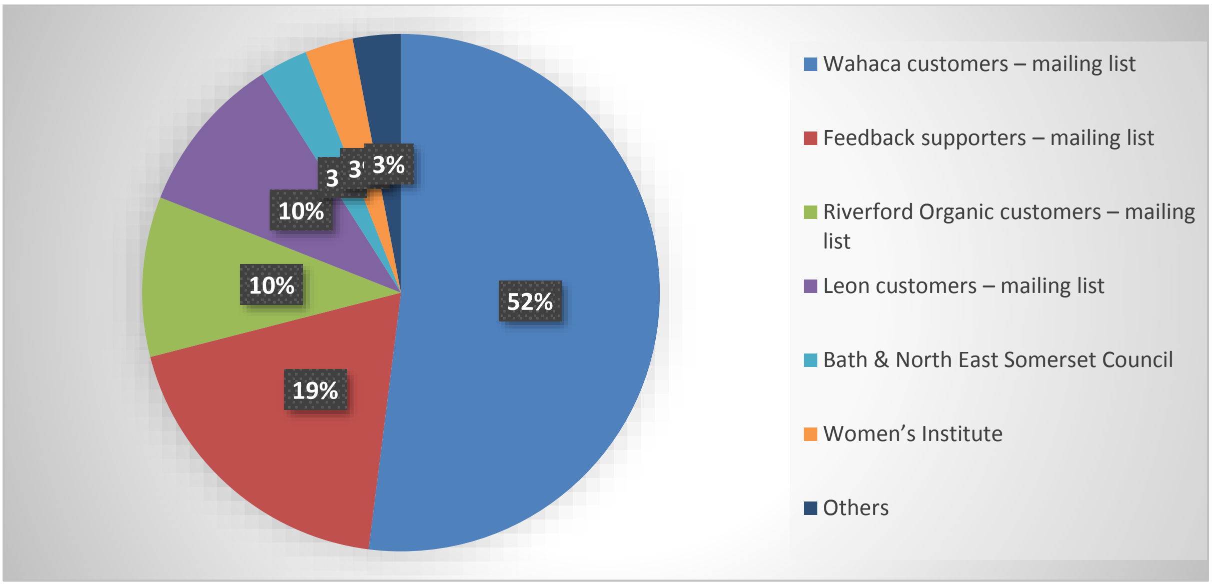
Parents felt only the pumpkin cream was acceptable on the school menu and rejected the other three options as unsuitable for their children. However, they did perceive all the valorisation options as suitable for adults. An interesting finding was that participants had very similar misgivings regarding the use of former foodstuffs in feed, as currently permitted in the EU, and the use of heat-treated surplus food from catering sources, which are currently not permitted. While participants valued the environmental and cost benefits, they were concerned about the lack of information, transparency and felt they could not trust the food industry to meet all the requirements of the Japanese model.

The study concluded that informational strategies are needed to increase the acceptance of valorised products by consumers. The provision of information has a larger likelihood for success, if it is continued until these kinds of food become familiar to the public. The outcomes of the experiments suggest that the acceptance of the studied valorisation methods is complex and needs time because it requires removing any existing negative perceptions towards such methods. The findings suggest that a focus on framing the message in a positive way, pointing out the potential benefits for the consumer (such as taste, naturalness, local origin, environmental friendliness, animal welfare, social inclusion, etc.), creates more positive motivations towards acceptance.

8.2.2 Consumer Survey – Attitude to pork from pigs reared on food waste feeds

REFRESH carried out a survey to study the attitudes of UK consumers to eating and buying “eco-pork” from pigs reared on food surplus – including issues of perceived safety and environmental impact. The bulk of the 3,491 respondents are Wahaca and Leon restaurant customers, Feedback supporters and Riverford Organics customers.

Figure 40: Survey respondent recruitment sources



Possible biases

It is possible that this survey was vulnerable to self-selection biases – people more likely to have a pre-formed opinion on the issue may have been more likely to fill out the survey. Based on self-reported buying behaviour, buyers of higher welfare pork (organic and free-range) over-represented in the study, so results for buyers of different types of pork have been disaggregated for key question results. Feedback supporters may have been exposed to Feedback's Pig Idea campaign. The same is possible for Wahaca customers, but Wahaca has not communicated on the issue since 2014. However, excluding Feedback and Wahaca respondents did not significantly affect the results. Supporters of environmental groups like Feedback, and customers of environmentally conscious businesses like Riverford Organic, Wahaca and Leon may also be more likely than most to care about environmental issues than the general population.

Further analysis of the possible biases can be found in the Supplementary Materials Part 5.

Demographics

- 33% of respondents were aged 30-45, 21% were aged 18-30, 27% were aged 45-60, 17% were over 60, and only 1% were under 18.
- 71% of respondents lived in urban regions, and 29% lived in rural regions.
- 34% of the respondents usually buy mid-price range pork, 25% buy free-range pork, 14% buy organic pork and 4% buy value-range pork.
- 17% of respondents don't buy meat because they are vegetarian or vegan, and 5% don't buy meat for other reasons, like religion or cost.

Key results:

- **Perceived environmental impact: 88% of respondents thought pork raised on food waste was more environmentally friendly than pork raised on conventional feed**
- **Legal reform: 93% of respondents would "support the law being changed to allow more food waste to be fed to pigs, if this could be proved to be done safely"**,
- Buying "eco-pork": When asked whether they would "buy pork which comes from pigs fed on food waste (after it's been heat-treated to make it safe)", 83% said yes (47% said they'd buy it in preference to other types of pork, and 36% said they'd give it a try), with 5% saying "maybe" and 12% saying "no".
- When counting only meat-eaters – i.e. when those who do not eat meat because they are vegan/vegetarian, or don't eat meat for other reasons (e.g. religion, cost) are filtered out – the proportion saying "no" falls to 2%, with 94% saying "yes" (52% said they'd buy it in preference to other types of pork, and 42% said they'd give it a try) and 5% saying maybe.
- Within the meat-eaters category, consumers of organic and free-range pork were more likely to say that they'd buy eco-pork in preference to other types of pork (58% of free-range pork buyers and 56% of organic pork buyers chose this option), whereas a slightly lower percentage of mid-price and value-range pork chose this option (48% and 39% respectively).
- Price willing to pay for eco-pork: When asked "How much would you be willing to pay for "eco-pork" from pigs fed on food waste?", 51% of respondents said they'd be willing to pay extra as long as the pigs are guaranteed to have been reared to organic welfare standards, an additional 8% said they'd pay extra, 29% said they'd pay the same price as for average pork, but no more, 11% said they wouldn't buy it whatever the price, and only 1% said it would have to be cheaper than other pork for them to buy it. This question was very sensitive to what types of pork customers currently bought – for instance, the answer "I'd pay extra as long as the pigs are guaranteed to have been reared to organic welfare standards" was selected by 79% of respondents for organic pork buyers. 49% of buyers of mid-range pork would pay the same price as for average pork, but no more, increasing to 56% for buyers of value-range pork

Table 15: Responses to the question "How comfortable would you feel about the inclusion of the following in pig feed?"

Foodstuff	Weighted average +2 : Very comfortable +1 : Quite comfortable 0 : Indifferent/unsure -1 : Quite uncomfortable -2 : Very uncomfortable	Standard Deviation
Mixed restaurant leftovers (may contain meat, heat-treated)	0.83	1.27
Confectionery like biscuit crumbs from factories	1.23	1.14
Unsold bread from supermarkets	1.56	0.88
Unsold egg sandwiches from supermarkets (heat-treated if risk come into contact with meat)	1.15	1.14
Unsold bacon sandwiches from supermarkets (heat-treated)	-0.45	1.54
Unsold chicken sandwiches from supermarkets (heat-treated)	0.58	1.39
Mixed household food leftovers (may contain meat, heat-treated)	0.72	1.28

Discussion

Respondents feel quite to very comfortable with food surplus not containing meat being fed to pigs. Respondents feel generally quite comfortable with heat-treated mixed restaurant leftovers which may contain meat being fed to pigs. **They are slightly more uncertain about heat-treated mixed household food leftovers which may contain meat, and unsold chicken sandwiches from supermarkets (heat-treated), but are still on average closer to being "quite comfortable" with these being fed to pigs than "indifferent/unsure".** There is a larger standard deviation for these categories of food surplus, indicating some variety of opinion – for instance, 12% of respondents felt very uncomfortable with unsold chicken sandwiches being fed to pigs, and 12% felt quite uncomfortable. We examined the level of comfort with heat-treated mixed restaurant leftovers disaggregated by which types of meat consumer current buy and found broadly positive reactions across the spectrum amongst the meat-eaters. The overall average is skewed downwards by vegetarian/vegans.

The only surplus food which respondents were on average uncomfortable about was "Unsold bacon sandwiches from supermarkets (heat-treated)" – they were on average between indifferent/unsure and quite uncomfortable (-0.45). This is also the category with the largest standard deviation of responses. **When non-meat eaters are excluded from the results, the level of discomfort slightly falls to -0.36. Feeding heat-treated bacon sandwiches is** divisive issue. E**ven with minimal public information assuring the public that feeding pork to pigs is safe, 31% of meat-eating respondents are already comfortable with this**, and on average the respondents were closer to indifferent/unsure than quite uncomfortable.

The level of discomfort with pigs eating pork tends to rise in consumers who buy higher animal welfare pork. This becomes particularly relevant if eco-pork is sold at a premium price, since as Q5 indicates, organic and free-range customers are the most enthusiastic about paying extra for eco-pork, mainly on the condition that it is raised according to organic welfare standards**.** Although those who do not buy pork, either because they are vegan/vegetarian or for other reasons, are not the target market for eco-pork, it is important to factor in their opinions in public discourse. This category had higher than average discomfort with feeding bacon sandwiches to pigs

We then asked the respondents to read some educational text (see Supplementary Materials Section 5.9), and they were then asked "After reading the above statement, would you feel more or less comfortable about eating pork from pigs fed on food waste?". 43% said they felt a lot more comfortable, 28% said they felt slightly more comfortable, 26% said they felt as comfortable/uncomfortable as before, and only 2% said they felt either slightly less or a lot less comfortable. Of the people who in Q6 said they were either quite uncomfortable or very uncomfortable with pigs eating bacon from supermarkets, 34% said they felt a lot more comfortable, 34% said they felt slightly more comfortable, and 28% said they felt as comfortable/uncomfortable as before after reading the statement – although the question was not specifically about bacon, so it is possible this reflects their general feelings about other food waste feeds more than it does their views on feeing bacon to pigs. However, this indicates that generally consumers respond well to additional information assuring them feeding surplus food to pigs is safe – showing good potential for reservations about feeding pork to pigs to be alleviated.

In Question 8, "Are there particular types of food waste which you still feel uncomfortable being fed to pigs, and if so why?", the most common response was concern about feeding pigs pork on the grounds of moral opposition to cannibalism, so this is clearly a potential barrier in public perception. There were 171 mentions of "cannibal/cannibalism" and 889 mentions of "pork" raised as concerns out of 2,679 responses to this question. Although some of these 889 mentions of pork and cannibalism were arguing against the idea that this was a problem, the vast majority of mentions express concern over pigs eating pork, usually on moral grounds. 106 responses also mention "processed" foods as a concern, and 85 mention high sugar foods – indicating a concern for pig nutritional health.

Table 16: Responses to the question "What measures would assure you that eating pork fed on food waste is safe?"

% of (meat-eating) respondents who were assured by each measure (multiple options could be chosen by each respondent)	
Certification mark introduced to show eco-pork sourced from licensed farm and pigfeed processor	59%
Academics and experts publicly back the safety of pork fed on food surplus	56%
Food waste feeds are only legally obtainable through licensed, off-farm processors	46%
Pig farmers publicly back the safety of pork fed on food surplus	40%
I am already convinced	37%
The government making it legal would be enough to convince me	22%
It is available through organic shops/schemes	15%
It is widely available in supermarkets and shops	15%
My friends had tried it and recommended it	2%
Celebrities publicly back the safety of pork fed on food surplus	2%

Notable differences based on demographics

- **Age: Respondents over 60 years old were far more comfortable than the average with pigs eating heat-treated bacon sandwiches from supermarkets** – the only age group to have an average positive impression (+0.10). This could be partially because they are more likely to remember the "pig clubs" and where food waste was fed to pigs during the Second World War and its aftermath. There was a large overlap between the over 60s category and Riverford customers, so this may also be a factor. Within this age group too, though, there was considerable variation, with 23% feeling very uncomfortable with it, and 17% feeling quite uncomfortable compared to 29% feeling very comfortable and 15% feeling quite comfortable. Other age groups were quite similar in their attitude to pigs eating heat-treated bacon sandwiches from supermarkets – all ranging from -0.5 to -0.6, i.e. slightly uncomfortable.
- **Source: Feedback supporters were less likely to be uncomfortable with pigs eating heat-treated bacon sandwiches from supermarkets** (with 23% very comfortable with its inclusion in pig feed) – although they were still on average opposed to this (-0.23).
- **Rural/urban: People living in rural regions were slightly less uncomfortable (-0.35) than people living in urban regions (-0.47) about pigs eating heat-treated bacon sandwiches from supermarkets.**

To check that Feedback and Wahaca's involvement with the Pig Idea has not biased the survey, the results for the survey without Feedback supporters and Wahaca customers was tested for some of the most significant questions. There was no significant difference observed in results – for instance, 86% of respondents still viewed pork raised on food waste as more environmentally friendly than that raised on conventional feeds, and 91% were still supported the law being changed to allow more food waste to be fed to pigs, if this could be proved to be done safely (only 2% lower in both cases). Respondents were slightly less comfortable with different food surpluses being fed to pigs when Feedback and Wahaca responses were excluded, but this difference only ranged from 0-0.2 in difference – in most cases only 0-0.1 lower, and in the most controversial case of heat-treated bacon sandwiches from supermarkets, only 0.02 lower.

Respondents who buy organic pork were asked "Would you buy eco-pork from pigs which were reared on organic welfare principles, but fed on food which may not have been grown organically?". 51% responded "Yes, definitely", 31% said "Maybe", 10% said "I'd need more convincing" and 8% said "Definitely not".

8.3 Pig farming industry acceptance

Zu Ermgassen et al found strong support (>75%) for the relegalisation of surplus food feeding among both pig farmers and other stakeholders in the UK, if procedures were put in place to ensure swill was heat-treated. The sample for this study was 82 pig farmers and 81 other agricultural stakeholders interviewed at a UK agricultural trade fair (zu Ermgassen et al. 2018, 2). Of the 82 farmers surveyed, 60 owned farms with more than 1000 animals, "making up approximately 4% of the 1,410 large pig farms in the UK" (zu Ermgassen et al. 2018, 19). Larger pig farmers are often assumed to be less in favour of lifting a ban than smaller farmers, so this is a significant finding.

Those most supportive of relegalisation in the study were more concerned with farm financial performance and efficiency, benefit to the environment and reduction of trade-deficits (zu Ermgassen et al. 2018, 2). The study found that 84% of respondents "reported swill would lead to "lower" or "much lower" feed costs" for farmers (zu Ermgassen et al. 2018, 13). There was greater uncertainly among the sample group about the effect of pig swill diets on "pig growth rates and their feed conversion (i.e. how many kilograms of feed are required per kilogram of growth)" (zu Ermgassen et al. 2018, 13). In Chapter 5 we have shown how existing Japanese know-how on feed formulation with surplus food ingredients can overcome these challenges.

The biggest industry concerns by those who were less supportive were about disease control and consumer acceptance of swill-fed pork (zu Ermgassen et al. 2018, 2), which suggests that if these barriers can be overcome, an even broader range of industry would be supportive. The paper concludes that "Any new system for the use of swill will therefore require careful design of regulation and operating procedures to reduce the risk of uncooked animal by-products entering feed to a negligible level. Our results suggest, however, that if such a system for safe swill feeding can be established, there would be widespread support amongst UK pig farmers and other agricultural stakeholders for its relegalisation." (zu Ermgassen et al. 2018, 21).

The mainstream pig industry is increasingly considering the proposal in a wider concern with the environmental impact of the sector, even in a current context of caution regarding African Swine Fever. For example, a recent opinion piece by Pig Progress editor Vincent ter Beek discusses the need for the sector to keep looking forward to the safe use of leftovers in the context of a circular economy framework and suggests this discussion should not be halted due to concerns around African Swine Fever (ter Beek 2018). The UK National Pig Association (Driver n.d.) has stated that:

> *"The National Pig Association would not be completely opposed to centrally managed and tightly controlled food waste treatment plants, but would question who would pay for them, how the quality of the product as a nutritional supplement would be assured and whether the consumer would be content to buy pork from pigs fed on such a product. An independent risk assessment would need to be undertaken to assess the viability of this feed source. We would not however support the feeding of pork products to pigs."*

The UK NPA has also expressed a strong concern on how a change in legislation would lead to mixed messages resulting in small-scale farmers believing it is acceptable to feed untreated food waste to their pigs. REFRESH agrees that a well-designed awareness raising campaign would be essential. Given that the lifting of the ban on feeding treated surplus food to pigs is still seen as controversial by many, we believe that the ensuing media attention both during the legislative process and when legislation is actually changed, would support the key messaging that only feed sourced from licenced treatment plants is permitted.

8.4 Food industry acceptance

In the UK, Feedback's Pig Idea campaign has gathered support to lift the ban on feeding catering leftovers and food surplus containing meat to pigs from 12 celebrity chefs and 18 food businesses. The celebrity chefs include campaign co-founder Thomasina Miers, Hugh Fearnley-Whittingstall, Yotam Ottolenghi, and Michel Roux Jr – who collectively have a large influence on the UK restaurant industry. **Further dialogue is needed with the food industry throughout the EU to understand their views**.

"Food waste has risen … up the list of priorities for restaurants and the wider foodservice sector, with thousands of operators separating their waste and taking giant steps to reduce it in the first place. Armed with the latest scientific evidence and surveys, Feedback makes a very compelling case for, at the very least, a review of the current legislation which prohibits catering waste being fed to pigs. The economic, ethical and environmental case is strong, and the Sustainable Restaurant Association believes that with clear communication and the suggested safety measures in place, chefs and diners would give this their wholehearted support as it is good for pigs, good for farmers and good for the planet."

Andrew Stephen, Chief Executive of the UK Sustainable Restaurant Association.

8.5 Animal welfare

Reducing feed costs may support farmers wishing to invest in animal welfare. In addition, feeding surplus food to pigs may improve animal welfare directly. Deficiencies of essential amino acids may exacerbate tail biting in fattening pigs and deprivation of feeding behaviour, even when nutritional needs are met, may contribute to tail biting in pigs (Manteca et al. 2008, 230). While tail biting is triggered by a large number of variables, in certain situations it may be possible to contribute to a reduction in tail biting by replacing conventional feed with heat-treated leftovers that contain meat, allowing pigs to return to the type of diet they have evolved to eat as omnivores. Adding a diversity of food surplus food based feeds, so long as these give optimal nutrition balanced out over time may maintain homeostasis and reduce levels of stress (Manteca et al. 2008). If provided alongside conditions that allow rooting behaviour, feeds made from surplus food could provide the additional food types required for a high welfare score in the foraging category for welfare outcome assessments in UK pig-farm assurance schemes (Mullan et al. 2011). A roller mechanism in liquid feed helps to encourage rooting behaviour (Linden 2010). From a welfare perspective, it may be important to complement a homogeneous liquid or dry feed with unprocessed low-risk surplus food such as bread, fruit or vegetables to provide variation, reduce boredom and encourage chewing.

8.5.1 Intraspecies recycling: an ethical perspective.

In sections 3.4 and 5.1.1 we demonstrated that there are no safety reasons for preventing the presence of pork in pig diets. We pointed to the science on the issue which suggests that intraspecifies predation is not an aberrant behaviour limited to confined or highly stressed populations, but is a normal response to many environmental factors (Schutt 2017; Fox 1975) and which can be found in about 1,300 animal species (Polis 1981). The European Commission's Scientific Steering Committee (EC Scientific Steering Committee 1999) acknowledges that intra-species recycling used to be common practice in farm animals, especially pigs, poultry and fish. It is known that opportunistic cannibalism of deceased animals is commonplace in wild boar.

Ethically, stress-induced forms of cannibalism such as the savaging of piglets by first litter gilts (young female pigs) which may account for up to 3% in piglet mortality (The Pig Site 2018; NADIS 2018) and tail- and ear-biting should be prevented. The feeding of meat-containing surplus food could contribute to a reduction in these stress-induced behaviours.

In section 5.1.1 we show that the presence of pork products in pigfeed is not an issue in Asia or the United States. In Japan, any ethical concerns are superseded by strong feeling around the value of *Mottainai* – the sense of regret regarding waste (Kawashima 2018). In one sense, intraspecies recycling is already permitted in the EU in that blood products of non-ruminant origin can be used in feed for non-ruminant animals.

Having said all this, we acknowledge that one of the biggest hurdles to public acceptance of "eco-pork" in Europe is likely to be the issue of intra-species recycling. See section 3.4 for a description of how the volume of pork in pig feed could be reduced to a minimal level if this is deemed necessary in response to consumer demand.

9 Relevant EU policies and reports

In addition to the direct references to the use of surplus food in feed in the EU Circular Economy Action Plan and the European Parliament own-initiative report (Borzan 2017) (see Chapter 2), there are other relevant EU reports and policies:

The **Commission Report on the Development of Plant Proteins** in the (European Commission 2018b) notes the continued lack of self-sufficiency in plant protein and the need for the EU to increase the sustainability of its protein production and consumption as a contribution to its various sustainability commitments (e.g. halting tropical deforestation, to contribute to the Paris climate agreement, the UN's Sustainable Development Goals, the Renewable Energy Directive and the European sustainability and bioeconomy strategy)

Legislating for the safe use of surplus food in feed would also help the EU to meet **Sustainable Development Goal 12.3 of halving EU food waste by 2030** (United Nations 2017 SDG 12.3) as recognised in EC Communication (2016) 739 final (European Commission 2014, 18) and embedded as an aspirational target by the updated Waste Framework Directive (European Parliament and Council 2018). We recommend that *if food is inedible to humans*, it be counted as "reduced" towards this target if it is diverted for use as livestock feed, but *not* if it is used at lower levels of the food waste hierarchy such as anaerobic digestion. The priority should always be preventing the waste from occurring in the first place. This is in line with the World Resources Institute's recommendations (Hanson 2017, 4) - WRI are the secretariat of the internationally respected Food Loss and Waste Protocol ('Food Loss and Waste Protocol' 2018). Lifting the current ban on using commercial kitchen leftovers and food surplus containing meat from retail and manufacturing as feed for omnivorous non-ruminant livestock will therefore assist EU member states in achieving 50% reductions in food waste by 2030.

The **European Commission's low-carbon economy roadmap** sets the aims for the EU to cut greenhouse gas emissions to 80% below 1990 levels by 2050, with intermediary targets of a 40% emissions cut by 2030 and 60% by 2040 (European Commission 2016). This should be based on "domestic reductions alone (i.e. rather than relying on international credits)" (European Commission 2016). As demonstrated in section 7.5, this proposal would contribute to domestic emission reductions. Reducing the environmental impact of the EU pig industry and food waste can contribute to meeting obligations under the Paris Agreement.

The new **EU BioEconomy Strategy** refers to the potential land use savings that could result from applying new technologies for turning food waste into animal feed (European Commission 2018a).

Finally, the recent **Strategic and Economic Partnership Agreements between the European Union and Japan** state that the EU and Japan should cooperate "with a view to improving farm management, productivity and competitiveness, including the exchange of best practices regarding sustainable agriculture, as well as the use of technology and innovation" (EU 2018). It would be of significant benefit to the EU and global climate targets to include in such an exchange on best practices, the sharing of the Japanese experience on using treated surplus food in pig feed, particularly regarding the nutritional and system design aspects.

10 Conclusions and recommendations

The European Commission and European Parliament have both noted the need to prevent food leaving the supply chain when it could be used as livestock feed, as follows:

- **The EC's Circular Economy Action Plan** sets out to increase the use of surplus from the food chain in livestock feed without compromising feed and food safety
- **The European Parliament's Committee on the Environment, Public Health and Food Safety own-initiative report** (Borzan 2017) calls on the Commission "to analyse legal barriers to the use of former foodstuffs in feed production and to promote research in this area" while also bringing "food safety risk down to zero". It notes "the potential for optimisation of use of food unavoidably lost or discarded and by-products from the food chain, *in particular those of animal origin*, in feed production".

The central premise of the risk management system proposed in these guidelines is that only non-ruminant omnivorous livestock can be fed on feed made from surplus food, sourced exclusively from specialist licensed treatment plants that are located off-farm.

10.1 Safety and official controls

Chapter 3 of this report demonstrates how adequate heat treatment, acidification and biosecurity can deliver safe feed for non-ruminants made from surplus food.

10.1.1 Heat treatment and acidification

The appropriate level of health protection and desired pathogen inactivation objectives will need to be more stringent than those applied for common food pathogens such as *Clostridium Botilinum*, because of the severity of the impact and cost of a disease outbreak, such as African Swine Fever or Foot and Mouth Disease (FMD). Microbiologists set inactivation objectives in log reductions which express the percentage of disease pathogens that are destroyed. The inactivation objective for *Clostridium Botilinum* is a 12-log reduction, in other words, a destruction of 99.9999999999% of the *C.Botilinum* organisms present in the food that is being heat-treated. For most other food-borne pathogens a 6-log reduction is accepted as standard in the food industry.

Inactivation objectives are set for the most heat-resistant diseases of concern: in this case Foot and Mouth Disease, because inactivating FMD will automatically achieve inactivation for the more heat-sensitive pathogens such as African Swine Fever. Lowering the pH (acidification) results in further pathogen inactivation and extends the shelf life through the prevention of germination and outgrowth of toxin-forming spores.

Box 9: Next steps for setting treatment criteria for pathogen inactivation

- Feed microbiologists and competent authorities to agree desired levels of inactivation for the most heat-resistant pathogens: FMD and Porcine Reproductive and Respiratory Syndrome (PRRS) in the case of pig feed, and Newcastle's Disease and Avian Influenza in the case of poultry feed, bearing in mind the additional effect of acidification. PRRS inactivation data are scarce and some further laboratory testing on this pathogen may be required.

- Food microbiologists and competent authorities to set desired levels of inactivation for heat-resistant food pathogens, Clostridium and Bacillus spores, bearing in mind:
  - expected low initial contamination levels after food was processed for human consumption prior to being repurposed as feed and,
  - that outgrowth can be controlled with acidification.

- Use the models provided by Hayrapetyan, Nierop Groot and Zwietering (2018), and Van Asselt and Zwietering (2006), or similar, to determine different time – temperature combinations to achieve the desired inactivation objective. For example, in the case of Foot and Mouth Disease,
  - a 17 log reduction (99.999999999999999% of virus destroyed) can be achieved by a heat treatment of 80°C for 30 minutes
  - a 60 log reduction is achieved by heating to 100°C for 10 minutes

  Table 4 on page 18 gives further examples for higher temperatures and other diseases. The results of such modelling (ie lower temperatures for a longer time or higher temperatures for a shorter time) should then be analysed from a cost, energy and nutritional/ digestibility perspective to find the most desirable combination.

- Further finetune temperature – time combinations bearing in mind particle size (as per existing animal by-product legislation) and existing technology to continuously monitor and record actual temperatures.

Outcomes of this further testing and research should result in processing method recommendations with can be set following the existing legal template as set out in EC Regulation 142 / 2011. Please see Chapter 3 for more detailed recommendations.

10.1.2 Biosecurity

The technical requirements for biosecurity in the treatment of surplus food can be adapted from those applicable to the animal by-product industry. Commission Regulation 142/2011, Annex IV, Chapter 1 sets out the Requirements for Processing Plants and Certain Other Plants and Establishments, as applicable to Category 3 (low-risk) animal by-product materials. Some examples of these requirements are one directional process flows, zoning, measuring equipment to monitor temperature against time, etc. The know-how of the rendering industry can be applied to achieve adequate biosecurity.

10.1.3 Traceability

The heat treatment, acidification and biosecurity measures should be designed to deliver safe feed even in the case that infected meat makes its way into the surplus food prior to treatment. In other words, given the uncertainty regarding initial volumes of contaminated meat and viral loads, we propose a conservative approach which assumes high levels of contamination. However, traceability measures can provide an additional safeguard and we recommend a risk-based approach to traceability for surplus food that may contain or may have been in contact with meat:

- For pig feed treatment plants, any pig meat ingredients should be traceable to source. A similar principle should be applied to poultry feed.
- For all other ingredients, the "one-step-up, one-step-down" traceability approach, which is standard in most of the food and feed sectors, should be applied by all operators in the supply chain.

The above traceability requirements will need to be stipulated in the contractual arrangements between the feed treatment plant and surplus food suppliers. See Section 3.5 for further guidance on traceability and the option of a closed-loop system.

10.1.4 Official controls

Preventing the accidental or deliberate breaking of the law is as important as effective pathogen inactivation and biosecurity. Chapter 4 explores the way in which the risk-based approach of official controls can be extended to provide the enforcement regime needed to ensure safety.

Farm-level controls

TSE legislation and controls for ruminant feed need to remain as they are. Controls also need to remain the same for non-ruminant feed *on unlicensed farms*. For controlling feed on farms licensed to use surplus-food-based feed, control tools will need to differentiate between surplus food found in feed from licenced treatment plants and that introduced illegally or accidentally.

Therefore, for premises licenced to use treated surplus food, existing tests for mammalian muscle fibre will not apply, but a mix of the following control approaches could be developed:

- detailed documentation on animal production volumes and feed volumes, investigating the possibilities to develop closed pipelines and feeding infrastructure,
- testing for the presence of unprocessed meat proteins. Possible options to be researched for this testing could include immunoassay approaches, vibrational or infrared spectroscopy or chemical markers.

Treatment plant controls

We recommend that the same controls apply to surplus-food treatment plants as currently apply to the animal by-product processing (rendering) and feed manufacturing sectors. Businesses could pay for an initial application to obtain the permit, followed by annual subsistence charges to pay for ongoing inspections. Inspectors would monitor Hygiene and Processing Requirements such as one directional process flows, zoning, complaints and recall, labelling, traceability and HACCP procedures. The biosecurity and processing aspects of relevant regulations on Animal By-Products (EC Regulation 142/2011), Feed Hygiene, TSEs, Placing on the Market and Use of Feed and other relevant regulations, as well as monitoring of mycotoxin, dioxin and nickel levels would all apply. It may be of interest to a new surplus-food-to-feed industry to develop its own industry standards as a way of supporting the industry to uphold the highest standards and protecting against rogue operators, through a government approved assurance or certification scheme.

10.2 Nutrition

We have framed our discussion of the nutritional aspect of this proposal in terms of two scenarios. The more ambitious scenario considers a new surplus-food-to-feed industry within a framework of an environmentally sustainable human diet. In this scenario meat consumption is decreased and we only feed livestock with unavoidable by-products and surplus food (Van Zanten et al. 2018). The Japanese ecofeed sector has demonstrated that it is possible to breed pigs on a diet sourced almost entirely from unavoidable by-products and surplus food. However, given the ongoing developments in the modern pig industry regarding precision feeding and related high-performing breeds, a 100% surplus-food-to-feed approach may only be possible with more robust, traditional pig breeds.

We have demonstrated that there is significant nutritional value in surplus food. In our detailed compositional analysis of surplus food streams in France and the UK, we even found a surplus of lysine relative to energy content. However, this balance may change with the effect of heat treatment on lysine.

Box 10: Achieving nutritionally adequate feed for the modern pig

A range of strategies can be adapted from the Japanese ecofeed industry to achieve nutritionally balanced feed:

- Sourcing surplus food from a wide variety of food businesses to dilute variation
- Blending with conventional feed ingredients, co-products such as wheat middlings or spent brewers' grains, and conventional feed additives as standard in the industry
- Separating surplus food into nutritional categories. In Japan this is often done at source (ie retailer). Whilst this may appear challenging and costly, European retailers such as Colruyt, Tesco and Sainsbury already manage strict segregation for their bakery surplus so that it meets existing legal requirements for former foodstuffs. In the system proposed here, surplus food would only be fed to non-ruminants and separation would be for nutritional, not safety purposes, and be therefore less stringent.
- Computerised mixing of surplus food feeds with conventional ingredients can be deployed to achieve the required nutritional profile, using the same feed formulation tools that are routinely used by the industry. The Japan Livestock Technology Association (2011) manual notes that high carbohydrate foods can be used without problem from early stage to late stage of fattening. However, high protein, high fat surplus foods should only be used in the early stage of fattening.
- The minimum requirement from a nutritional perspective would be to separate low-fat from high-fat foods, but further separation into broad food categories (carbohydrates, meat, fish, vegetables, etc) supports the computerised input of surplus food in the treatment plant to allow for a nutritionally consistent product.
- Selective sourcing of surplus food that is relatively consistent in composition is also an option though we need to balance this with our aim to maximise the use of unavoidable surplus in feed
- It may also be helpful to adapt the specialist eco-feed formulation program of the Japan National Institute of Livestock and Grassland Science (JLTA 2011) for use in the EU.

Section 5.3 discusses the trade-offs between liquid and dry feed and summarises the ample evidence supporting the nutritional and health advantages of fermented liquid feed.

10.3 Economic feasibility

Given the environmental and nutritional advantages of fermented liquid feed, REFRESH economic feasibility research has focussed on liquid feed production. National level REFRESH life cycle costing (LCC) analyses show a net financial saving of €278 million per year in the UK, but an additional cost of €413 million per year in France (De Menna et al. 2018). This difference can mainly be attributed to the transport costs resulting from the larger distances in France between surplus food suppliers in the most important population centres, such as Paris, and the main pig farming region in Brittany. Overall the LCC calculations show that transport is by far the most significant cost. This means that potential cost savings could be achieved if surplus food generated in the most populated areas of France was taken to be processed near the pig farming areas of Belgium, the Netherlands and Italy. Research on the most transport efficient locations of treatment plants, perhaps by using Geographical Information Systems software (GIS), and research on increasing efficiencies in the collection of surplus food may deliver additional savings.

The LCC analysis was done for a plant with assumed processing capacity of 260,000 tonnes of surplus food per year. A further techno-economic scaling evaluation at treatment plant level was carried out by REFRESH and concluded that a processing capacity of 100,000 tonnes per year is more economically attractive. At this capacity, the scaling advantages for production at larger size are balanced against the transport costs which decrease if more plants at smaller capacity are considered.

Current incentives and gate fees for food waste disposal will also influence the feasibility even at the local level. Different sectorial policies (waste management and renewable energy) at different government levels will need to address this issue. We will develop this recommendation further in the broader REFRESH policy recommendations report.

Further research is needed to determine which treatment plant ownership and business models would allow for savings to be passed onto consumers, farmers and pigs in the shape of investment in increased welfare.

10.4 Environmental case

A consequential life cycle assessment carried (CLCA) out by REFRESH shows that using 14 million tonnes of surplus food – equivalent to 52% of food that currently goes to waste from the retail, catering and manufacturing sectors - to replace pigfeed could lead to an estimated annual reduction of greenhouse gas emissions of 5.8 million tonnes of CO_2 eq. See supplementary materials Part 9 for the calculations. This calculation is only a rough estimate because it was extrapolated from results for the UK and France where the CLCA was based on data from the current feed, pig farming, energy and waste handling sectors.

We have considered the environmental cost of the heat treatment necessary to render the feed safe, as well as the need to turn to other sources of energy and fertilizer with reduced use of food waste in anaerobic digestion. The key reason that using unavoidable surplus in pigfeed results in GHG emission savings is a reduced reliance on conventional feed crops particularly soya which is connected with deforestation in the Amazon. Findings by REFRESH on the environmental benefits echo those of other studies (zu Ermgassen et al. 2016; Salemdeeb et al. 2017; Ogino et al. 2007).

Given that the rate of 52% of catering, retail and manufacturing surplus is currently achieved in Japan, we posit that the GHG emission savings in the range of 5.8 million CO_2 eq would become available as the treatment and collection infrastructure is established. As the EU begins to prevent food waste from occurring in the first place, the total volume of surplus food theoretically available for feed will decrease. However, while total volumes of food waste are reduced, increased experience in using surplus food in feed will help to increase the proportion used in feed. There are two further ways in which the environmental benefits could be enhanced:

- increased efficiencies in household food waste collection resulting in this surplus becoming suitable for use in feed
- increased efficiencies in the transport of surplus food to treatment plants and feed to farms, compared to the model REFRESH used in its calculations

In other words, transport is a big issue, economically but mostly environmentally. If policy makers were to consider legislating the feeding of treated surplus food to non-ruminant livestock, they may also wish to ensure related policy measures include specific requirements on short supply chains. The Japanese ecofeed experience demonstrates the possibilities in terms of closed loop systems. Corresponding EU policy could aim at closing local loops, linking urban and rural food economies, and supporting local farming.

From a circular economy perspective, current processing pathways for wasted foods, specifically landfilling and incineration, interrupt the natural circles for carbon and nutrients such as nitrogen. Through composting, the organic matter - bound carbon and nutrients like nitrogen - can largely be reused in agriculture. Through anaerobic digestion prior to composting, digestible compounds are valorised for energy. Nonetheless, a circle where food follows the steps of agricultural production, followed by processing to food and then to waste is short, and product use has not been maximised. Through valorisation in feed the product is functionally used, meanwhile extending the circle. The circle is still closed through utilisation of manure as AD feedstock or fertiliser in agriculture.

10.5 Stakeholder views and consumer acceptance

10.5.1 Pig Industry

The pig industry is cautious about the use of surplus food in feed, and points to the risk of further spreading disease such as African Swine Fever. However, given its concern with the environmental impact of the sector and the nearly prohibitive cost of pig feed, the industry appears increasingly interested in exploring the possibility of producing feed from surplus food in specialist licenced facilities. A survey of 82 pig farmers – of which 60 owned farms with more than 1000 animals - and 81 other agricultural stakeholders interviewed at a UK agricultural trade fair found strong support (>75%) for the relegalisation of surplus food feeding if procedures were put in place to ensure surplus food was heat-treated (zu Ermgassen et al. 2018).

10.5.2 Consumers

Regarding consumer acceptance in Japan, pork from pigs fed on surplus food evolved from "garbage pork" into a luxury product sold at a premium based on its environmental credentials. Japanese consumer research also found that those most knowledgeable about the pig industry are more likely to value pork from pigs fed on surplus. REFRESH research with consumers in Spain and the UK, shows that while information and awareness raising work will be important to build acceptance, there is already an important niche market with consumers whose choices are influenced by broader environmental concerns. This chimes with the findings of the recent report by the European Commission (2018b) on the development of plant proteins which notes that:

> *Consumers in the EU have become increasingly conscious about the way animal products are produced. They demand higher standards as regards animal welfare, environmental impact (climate change/deforestation), type of production (based on organic or non-genetically modified (non-GM) feed, regional supply chains). In response, different premium market segments for feed have emerged in the EU.*

Both the Japanese experience and the UK consumer survey show that the establishment of an independent, credible certification and labelling scheme will be paramount.

Intraspecies recycling

A review of the available literature and legislation in the US, Australia, New Zealand and Japan underpins REFRESH conclusions that outside the EU, TSE is not considered a hazard for non-ruminants. EFSA scientific opinions confirm that TSE has never naturally occurred in pigs, even when pigs were fed infected material and in situations where they were likely to have consumed feed with traces of pork. We therefore recommend a review of the application of the precautionary principle in the intraspecies recycling ban for non-ruminants, within a broader risk analysis that bears in mind climate change and food security. The issue of intraspecies recycling is further discussed in sections 3.4 (safety perspective), 5.1.1 (nutrition perspective) and 8.5.1 (welfare perspective).

10.6 Balance of Risks

In legislating for the use of treated meat-containing surplus food in omnivore non-ruminant feed, how can decision-makers balance existing animal disease risk with emerging risks of food security, climate change, and unknown disease? We propose a broad One Health approach - that bears in mind emerging risks such as climate change and food security - to the risk assessment of the legislative proposal that flows from these guidelines.

In Chapter 3 we have explained the disease risks and proposed risk management strategies. Knowing that there is no such thing as zero risk, we suggest that a well-developed disease risk management system consisting of heat treatment (section 3.1.4), acidification (3.1.5), biosecurity (3.2), traceability (3.5) and official control measures (Chapter 4) can provide an Appropriate Level of Protection (section 3.1.3) that allows us to maximise the surplus food that is kept in the food supply chain as animal feed.

Moreover, existing disease risks need to be considered against the need to mitigate climate change as a driver of other disease risks, for example through increased virus persistence during winter. For instance, the risk of Salmonella contamination increases by 10-15% for every one-degree increase in temperature (Beghian 2018).

In Chapter 7 we shared our findings on greenhouse gas emission reductions that can result from this proposal. It is paramount that these environmental benefits are put in the balance when risk managers decide whether to legislate for the tightly controlled use of surplus food in feed. While it is out of the scope of these guidelines to comprehensively discuss the climate risks threatening the global food system, we list a few risks relevant to this proposal:

10.6.1 Issues to put into the risk balance:

The mycotoxin load in staple food and feed crops is likely to increase due to combination of climate change factors including increasing temperatures and CO2 levels and extreme wet and drought conditions (European Food Safety Authority 2017). Preventing mycotoxin contamination of animal feed is an important part of overall food and feed safety strategies (Binder 2007). Therefore, mitigating climate change contributes to animal feed safety.

In Chapter 6 and 7, we discuss the impact of climate change on feed prices and volatility. We also discuss the EU's continued reliance on imports for conventional feed ingredients. From a land-use and climate perspective, a diet which only includes animal-source food from livestock fed on surplus food and by-products is the most effective option.

These findings have implications on Europe's food security and farmer livelihoods because a feed industry that increases its uptake of locally-sourced feed ingredients, can be both more secure and more predictable in terms of cost. The alleviation on land, water, fossil fuels and other resources created by resource efficiency, including food waste reduction, would lead to lower and less volatile food prices (Dobbs et al. 2011). What is important regarding price hikes and volatility in relation to this report is that, from a food security perspective, it makes sense to take any opportunity we can to decouple feed supply from global agricultural commodity prices. In interviews with REFRESH, Spanish stakeholders have reported an increased interest in using surplus food as pigfeed whenever feed crop prices increase.

Japanese farmers report using less antibiotics thanks to the probiotic advantages of fermented liquid feed discussed in section 5.3.1. Given the importance of reducing antibiotic use in pig farming, we suggest this benefit is added to the balance when analysing the risks related to liquid feed made from surplus food, and the additional investment needed to improve feeding and transport infrastructure for liquid feed systems.

10.6.2 Designing a prototype sourcing, treatment and feed production system

In addition to the additional research steps outlined in section 10.1.1 about safety and official controls, the next step to develop this proposal is to design and build a surplus-food-to-feed prototype sourcing, treatment and production system. Designing such prototype system in a specific geographical location would allow the recommendations set out in this report to be finetuned in response to available surplus food streams. The system design could also aim to find the ideal trade-offs between environmental, economic and nutritional considerations. GIS modelling would be an essential first step to deliver optimum location options in terms of transport efficiencies.

We recommend that a prototype project involves the following experts and stakeholders:

- Japanese academic and ecofeed industry experts
- European former foodstuff processing industry
- European rendering industry
- European pig industry and pig nutritionists
- European porcine health academic and other experts
- Food and feed microbiologists

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