EXTERNAL SCIENTIFIC REPORT

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Food and feed safety vulnerabilities in the circular economy

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Abstract

Circular economy (CE) is an approach that decouples economic activity from the consumption of finite resources, designs out waste, and instead promotes an economic model based on sharing, leasing, reuse, repair, refurbishment and recycling, in an (almost) closed loop. This extensive literature review identified and categorised CE practices within all stages of the food and feed production chain in Europe to provide an overview of current and envisaged practices. Four broad macro areas were identified within which CE practices are envisaged or currently used in Europe: primary production of food and feed; reducing industrial/manufacturing/processing waste; reducing food and feed waste in wholesale, food retail, catering and households; and reducing food and feed packaging waste. In each macro area, there were a variety of practices of interest regarding emerging risk to plant, animal, human health and the environment.

Following consultation with EFSA and wider stakeholders, a focused literature search was carried out to identify emerging risks to plant, animal, human health and the environment from 'novel foods and feeds within the framework of CE'. The literature showed a bias towards research investigating the suitability of novel feeds in terms of animal productivity parameters rather than on emerging risks of novel food/feed for animal, human, plant health and the environment. Those studies that investigated risk were almost entirely focused on the biological and chemical hazards, risks to health, and environmental impacts of insects as food or feed and the substrates that they are reared on. Emerging risks are characterised and recommendations made for future research. We recommend that future primary research in novel food and feed in the CE focuses on areas other than insect farming, and that there are further investigations into the potential risks associated with importation into the EU of livestock/goods that may have been subject to different restrictions/legislation.

Key words: novel food, novel feed, emerging risk, biological hazards, chemical hazards, food waste

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Summary

Background

Circular economy (CE) is an approach that decouples economic activity from the consumption of finite resources, designs out waste, opposes the take-make-consume-waste linear economic model and replaces it with an economic model based on sharing, leasing, reuse, repair, refurbishment and recycling, in an (almost) closed loop.

In March 2020, the European Commission adopted the new CE action plan. The aim of the European Union's (EU) transition to a CE is to reduce pressure on natural resources and create sustainable growth and jobs. It is also fundamental to achieving the EU's 2050 climate neutrality target, halting biodiversity loss, and is a prerequisite to the EU's is commitment to achieving the global Sustainable Development Goal (SDG) Target 12.3 to halve per capita food waste at the retail and consumer level by 2030, and reduce food losses along the food production and supply chains. The Commission will propose legally binding targets for food waste reduction by 2023, as called for by the Farm to Fork Strategy.

The European Food Safety Authority (EFSA) is undertaking a 2-year project on "Food and feed safety vulnerabilities in circular economy" (2021-2022). As part of this project EFSA requested an extensive literature review to gather and evaluate the evidence for vulnerabilities in the CE approach for food and feed safety, plant, animal and human health and the environment.

Three specific objectives were requested:

Objective 1: To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe.

Objective 2: to identify emerging risks for plant, animal and human health and the environment related to CE, resulting from new hazards and new exposure pathways leading to increased exposure, by conducting an extensive literature search of the scientific literature and monitoring on-going research projects.

Objective 3: to characterise the identified emerging risks by providing the available information justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities. Specific objectives for each of the three main objectives were agreed with EFSA at each stage of the project.

Methods

Objective 1 To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe.

Current and envisaged practices relevant to CE for food and feed in Europe were identified from:

- Published and grey literature
- Completed and on-going scientific Horizon 2020 research projects

Information from the evidence collated was extracted to:

- Categorise CE practices identified within the food and feed supply chain
- Identify examples of potential emerging risks from CE practices for plant, animal and human health and the environment

Stakeholder consultation via a survey was carried out to:

- Compare and rate each CE practice identified in terms of importance to the CE
- Rate the likely ease of implementation of each CE practice
- Rate the likelihood of risk from implementation of each CE practice
- Rate the ease of overcoming the risk from implementation of each CE practice
- Rate the current state of knowledge regarding the risks from each of the CE practices

The results from the consultation were used to inform the choice of topic, novel foods and feeds within the CE framework, for the extensive literature search (Objective 2).

Objective 2. to identify emerging risks for plant, animal and human health and the environment related to CE, resulting from new hazards and new exposure pathways leading to increased exposure

An extensive literature search was conducted and on-going research projects were monitored to:

- Create a comprehensive list of novel foods and feeds investigated in the articles and projects captured
- Identify emerging risks for plant, animal and human health and the environment from novel foods and feeds within the CE framework reported in the studies captured

Stakeholder consultation in collaboration with EFSA was carried out to:

- Validate risks identified through the literature search related to novel food and feed
- Identify additional emerging risks related to novel food and feed
- Collect first inputs on future emerging risk characterisation methodology (to be conducted in Objective 3)

Evidence collated in Objective 2 was carried forward to Objective 3 for characterisation of emerging risks.

Objective 3. to characterise the identified emerging risks by providing the available information justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities.

Meta-data was extracted from the full text of studies about novel food and feed within the CE framework where there are associated risks to human, animal, plant health and the environment and where possible used to answer the following questions:

- What type of emerging risk has been identified (new hazard, increased exposure)?
- What are the biological, physical and chemical hazards in food, feed or in the environment?
- What type, amount and frequency of application of products are applied in/on environmental matrices?
- Which food/feed products could pose a risk, and which plants or animals species are at risk?
- Which locations within a supply chain are where new and emerging risks are most likely to emerge?
- Identify which scientific areas (E.g. Plant Health, Animal Health, Biological Hazards, Chemical contaminants (including biotoxins, etc.) within EFSA's remit that this might relate to.
- What is the availability of data underpinning the definition of emerging risk:
    - (eco)toxicological, bioaccumulation and environmental accumulation, epidemiological, biomonitoring, consumption and occurrence data in line with EFSAs environmental risk assessments remit
    - severity, duration and frequency of the expected effects on human, plant and animal health
    - descriptions of exposure pathways
    - interactions with other contaminants and possible additive effects
- What evidence is there for risk management and reduction measures:
    - monitoring systems/programs, practices to lower or eliminate the contamination risks,
    - possible solutions to achieve a safe CE practice/technology etc.
    - existing international/national regulations/guidelines,
- What are the impacts on economy, environment, social aspects, and food and feed security?
- At what scale (local, national, regional, European, global) is the available evidence?
- What is the availability of detection methods?
- What is the strength of the association with CE?
- What is the imminence of these impacts? (How quickly might the risk materialise? How urgent is the response?)

- What are the parallels and interactions with other areas and emerging issues?
- What are the data gaps and research needs, including needs for new analytical approaches?

In addition, a comprehensive list of novel foods and feeds, from studies both inside and outside of Europe, was created for EFSA to use in horizon scanning exercises with stakeholders to identify potential emerging risks.

Results

Objective 1 To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe.

Four broad macro areas were identified within which CE practices are envisaged or currently used in Europe:

1. Primary production of food and feed:
    - Use of organic waste streams
    - Novel sources of food and feed (i.e. primary production of novel foods and feeds (e.g. farming insects, growing algae or in vitro production of meat). Any novel food and feeds (materials or additives) derived from industrial/manufacturing/processing waste or food waste are discussed under macro areas 2 & 3 respectively)
    - Crop protection and breeding
    - Livestock health and breeding
    - Locally produced food and feed

2. Reducing industrial/manufacturing/processing waste:
    - Use of livestock (excluding fish/crustacea) waste – waste generated in the processing or manufacturing of products from dairy/eggs/meat
    - Use of food crop waste – waste generated in the processing or manufacturing of products from crops grown for food
    - Use of fish/crustacea waste – waste from processing and manufacturing of products containing fish and crustacea

3. Reducing food and feed waste in wholesale, food retail, catering and households
    - Change or removal of date labels (e.g. best before dates) or selling food beyond its best before date
    - Using food contact materials to extend shelf life
    - Reducing food waste in the supply chain
    - Redistribution of edible surplus food for human consumption
    - Food waste for animal feed
    - Changing marketing and operation management
    - Repurposing surplus food for human consumption
    - Food waste for energy recovery
    - Nutrient recovery from food waste
    - Biorefinery of food waste (excluding energy, animal feed & nutrient recovery)
    - Knowledge transfer and training to reduce food waste

4. Reducing food and feed packaging waste
    - Development and recycling of biobased materials
    - Recycling of petrochemical based plastics and paper/card packaging materials
    - Source reduction
    - Reuse of packaging

- Education for reducing use and recycling of packaging

For each CE practice, we provided specific examples. We also identified examples of associated risks with these practices to plant, animal and human health and the environment.

Following the stakeholder consultation survey, it was decided with EFSA that, 'novel sources of foods and feeds' within the CE framework, would be the focus area for Objective 2.

Objective 2. to identify emerging risks for plant, animal and human health and the environment from novel foods and feeds within the framework of the CE, resulting from new hazards and new exposure pathways leading to increased exposure

A total of 51,235 articles were retrieved in the bibliographic database searches. Following duplicate removal, 26,669 articles remained for screening on title and abstract against the inclusion criteria. DistillerSR Artificial Intelligence algorithm was used to identify potentially relevant documents.

Over 1000 articles investigated novel foods and feeds within the CE but did not investigate emerging risk. These articles were categorised separately to create a list of foods and feeds with unknown risk.

Twenty-six primary research articles reporting 26 unique studies were identified that investigated emerging risk to plant, animal, human health or the environment.

Twenty-nine relevant reviews and reports, and one PhD thesis were captured. Relevant primary research was included in the 26 studies reported above. Useful inferences from authors of reviews and reports were noted in the report.

Relevant evidence was carried forward to Objective 3 for meta-data extraction and characterisation of the identified emerging risks.

Objective 3. to characterise the identified emerging risks by providing the available information justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities.

All but two of the 26 retrieved studies investigated invertebrates reared on side streams, waste or former food products (FFP). The remaining 2 studies investigated poultry by product (poultry fat, poultry by-product meal and steam hydrolysed feather meal) for animal feed and scallop by-products for fish feed.

A total of 14 studies measured endpoints for biological or chemical hazards to human or animal health from novel foods or feeds within the CE framework. One study reported a potential allergenic hazard.

No studies reported physical hazards or risk to plant health.

Seven of the studies reported the presence of potential biological hazards in invertebrates and/or insect frass. All seven studies investigated invertebrates rearing on sidestreams or food waste. Biological hazards reported were bacterial, fungal, yeasts and antibiotic resistance genes (ARGs).

Seven studies reported the presence of potential chemical hazards in food or feed. Chemical hazards included heavy metals, dioxins, polychlorinated biphenyls (PCBs), Polycyclic aromatic hydrocarbons (PAHs), mineral oil hydrocarbons, veterinary medicines and pesticides. One study reported on the chemical risk from plastic and paperboard carton contamination of FFP as substrate for insect larvae. With the exception of the study on fish fed on fermented soybean meal and scallop by-product blend the remainder investigated FFP, sidestreams and wastestreams novel feeds for insects.

Thirteen studies carried out an assessment of the environmental risks of producing food or feed from waste or side streams. The majority investigated the environmental impacts of rearing insects. The remaining studies investigated poultry by product (poultry fat, poultry by-product meal and steam hydrolysed feather meal) for animal feed and the rearing of the earthworms on a sidestream.

Over 200 types of novel food or feed were described in studies that did not investigate emerging risk. These studies were conducted both within and outside of Europe.

Conclusions

The topic 'CE practices within the food and feed supply chain in Europe' is very broad and is of increasing interest on a global scale. A substantial volume of relevant literature has been published, and published research is growing in volume year on year.

Circular economy practices envisaged or currently used in Europe can be divided into four macro areas: primary production of food and feed; reducing industrial/manufacturing/processing waste; reducing food and feed waste in wholesale, food retail, catering and households; and reducing food and feed packaging waste. In each macro area, there are various practices that may link to emerging risks to plant, animal, human health and the environment.

A large and growing volume of research and development is being carried out globally specifically on novel food and feeds in relation to the CE framework. The key findings from this literature indicate:

- The volume of research investigating emerging risks for animal, human, plant health and the environment is small when compared to the volume of research investigating the suitability of novel feeds in terms of animal productivity parameters.
- Primary research about risks is focused on invertebrates (primarily insects) as food or feed and the substrate that they are reared on. Primary research about the risks of other novel foods and feeds arising from the CE framework are limited.
- The focus of primary research is on biological and chemical hazards for human health and environmental impacts. One study investigated allergenic hazards. Potential physical hazards have only been discussed in reviews.
- Biological hazards reported were bacterial, fungal, yeasts and antibiotic resistance genes found in invertebrates reared on sidestreams or food waste. No primary research studies were captured investigating viruses or parasites.
- A wide range of chemical hazards were reported including heavy metals, dioxins, PCBs, PAHs, mineral oil hydrocarbons, veterinary medicines and pesticides. One study was on fish fed on fermented soybean meal and scallop by-product blend. The remaining studies investigated FFP, sidestreams and animal manure as novel feeds for insects.
- Emerging risks for animal and human health and environment regarding the production and consumption of invertebrates are correlated to the type of rearing substrate. Specific hazards identified by authors of primary research in this review include the presence of:
    - ARGs in substrates, larvae and insect frass
    - High levels of the heavy metals Cadmium (Cd) and Nickle (Ni) in prepupae
    - Uptake of allergens by insects from the substrate e.g. gluten

- Post-harvest invertebrate thermal or freeze-drying treatments may reduce or eliminate some microbiological hazards but authors indicate that not all treatments are effective for complete inactivation of microorganisms and their toxins.

- Authors also recommended the following mitigation measures for insect producers to avoid particular biological hazards:
    - Monitoring for and good hygiene practices to avoid contamination with pathogens (e.g. *Clostridium perfringens*)
    - Prudent use of antibiotics in rearing to reduce the risk from some pathogens and ARGs
    - Testing of insects for the presence of gluten when reared substrates containing gluten

- Many of the studies investigating invertebrates reared on side streams for food or feed in Europe reported the presence of biological or chemical hazards in substrate, larvae or frass, at levels below European recommended safety limits for food or feed. This is perhaps unsurprising considering the current strict food and feed safety legislation in Europe.

- A wide range of environmental hazards were considered, predominantly for rearing invertebrates on novel feed within the CE framework. The main risk reported was that insect production, when compared to conventional feed production, has a high global warming potential. This is because of the energy intensive processing requirements and use of non-renewable energy resources. This results in a trade-off between the benefit in the reduction of land use, with an increase in energy use for insect rearing.

- To minimise energy use and greenhouse gas emissions in insect rearing plants:
    - Insect rearing plants could be located next to waste incineration facilities, where heat generated could be used for drying the larvae
    - Renewable energy sources could be used such as solar or wind energy

- One author suggested that use of some organic waste streams (e.g. food waste) as a substrate for insect larvae production is in direct competition with bioenergy production, potentially leading to an increase in fossil fuels use, and subsequently resulting in a higher environmental impact.

- Should EU food and feed legislation change as a result of a transition towards CE to allow substrates that are currently not authorised for rearing substrate (e.g. animal manure, catering waste, slaughterhouse products, FFP containing meat and fish), future emerging hazards and risks in the EU may arise.

- Food and feed safety legislation varies around the world. It is therefore, prudent to be vigilant about the commercial use of novel substrates used as animal feeds outside of Europe and the implications for safety of food and feed imported into the EU.

Recommendations

The authors of this report make the following recommendations:

- That future research considers the wide range of potential emerging risks from a much broader spectrum of novel foods and feeds
    - Existing evidence largely focuses on the impact of novel feeds on animal production parameters. However, emerging risks arising from biological, chemical or physical hazards associated with these novel feeds are often not considered.
    - Large evidence gaps exist regarding the risks to plant, human and animal health and the environment from novel food and feeds within the CE framework. The emerging risks that have been considered almost exclusively focus on invertebrates reared for food or feed.
- That future research considers novel foods and feed research and development, and use of these foods or feeds in commercial practice, in countries outside of the EU
    - According to the food and feed regulation in the EU, some CE materials obtained in the circular economy framework cannot be used for food or feed. However, legislation is different elsewhere in the world. This may have implications for the safety of food and feed imports into the EU.
    - Scientific evidence from countries outside of the EU may help inform decision-making in the EU's transition towards CE.
- That researchers and commercial practitioners consider the recommendations made by authors of the included studies in this report, specifically:
    - Mitigation of risk
    - Knowledge gaps to be addressed by primary research
- That authors use consistent CE terminology
    - No singular definition of CE exists and the concept is interpreted differently by different societal actors, seeking to influence its meaning and understanding, resulting in a diversity of conflicting approaches
    - The definition of 'waste' has different meanings in different contexts
- That future research considers further development and testing of artificial intelligence (AI) for literature review, specifically in the searching and screening stages where evidence is likely to be highly heterogenous
    - The volume of literature for some CE topics is very large and often highly heterogenous
- That other tools are used in combination with literature reviews to explore emerging risk related to CE
    - Although literature reviews provide an evidence base onto which to build a greater understanding, they inherently look backwards.
- That expert elicitation is used to:
    - Help identify additional emerging risks to human, animal or plant health and the environment, for the wider range of novel foods and feeds.
    - Identify upcoming novel foods and feeds that do not appear in published literature and any associated emerging risks.
    - Help to address the following questions set by EFSA that could not be answered using the evidence captured in this report:
        - What is the availability of data underpinning the definition of emerging risk:

        - (eco)toxicological, bioaccumulation and environmental accumulation, epidemiological, biomonitoring, consumption and occurrence data in line with EFSAs environmental risk assessments remit
        - severity, duration and frequency of the expected effects on human, plant and animal health
        - descriptions of exposure pathways
        - interactions with other contaminants and possible additive effects

    - What evidence is there for risk management and reduction measures:
        - monitoring systems/programs
        - What type, amount and frequency of application of products are applied in/on environmental matrices?
        - What are the impacts on economy, environment, social aspects, and food and feed security?
        - What is the imminence of these impacts? (How quickly might the risk materialise? How urgent is the response?)
        - What are the parallels and interactions with other areas and emerging issues?

- We suggest further research to investigate the emerging risk of using insects to decontaminate animal manure to reduce environmental risk from hazards such as heavy metals, and if the residual insects and frass can be safely used as animal feed or fertiliser
    - During the literature screening stage of the review, a number of recently published studies were excluded that investigated the role of insects in the biotransformation of livestock manures, to reduce environmental contamination (e.g. heavy metals). The aim of these studies was to provide a preliminary understanding of the biotranformation process (e.g. Wang et al., 2021), although authors noted that residual insect bodies and frass in theory could be valuable source of animal feed and fertiliser. Further research is required to fully understand the implications for emerging risk of these transformed products.
- That future reviews focus on emerging risk from other areas of the circular economy
    - Use of organic waste streams other than feed or food:
        - Animal manures, (including insect frass), and municipal sewage as fertilisers
        - Wastewaters for irrigation
        - Livestock, crop and non-crop by-products for fertiliser
    - Food contact materials relevant to the CE framework to extend shelf life of food and feeds e.g. bio-based materials
    - Recycling and reuse (e.g. refillable containers) of existing food and feed packaging (e.g. plastic and cardboard) and new bio-based packaging

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Table of contents

Figures

Tables

1. Introduction

1.1. Background and Terms of Reference as provided by EFSA

Circular economy (CE) is an approach that decouples economic activity from the consumption of finite resources, designs out waste, opposes the take-make-consume-waste linear economic model and replaces it with an economic model based on sharing, leasing, reuse, repair, refurbishment and recycling, in an (almost) closed loop. Such change from a linear economy to a circular one is expected to significantly support the attainment of the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible consumption and production). However, the design and implementation of circular economy requires a careful consideration of the trade-offs that may emerge. This is a pre-requisite for the attainment of the SDG 3 (Good health and well-being).

During the transition to a CE, it will be crucial to identify potential emerging risks for the environment and food and feed safety in a holistic and integrated fashion in order to achieve an optimal balance between opportunities, benefits and risks. It is necessary to ensure that food and feed safety and environmental health considerations are incorporated at an early stage of research or policy initiatives linked to recycling and the circular economy.

In the framework of enabling regulatory and policy drivers (e.g. Circular Economy Action Plan, Integrated Nutrient Management Plan, Farm to Fork strategy, new Water Reuse Regulation, the European Bioeconomy Strategy, Single Use Plastics Directive etc), EFSA is undertaking a 2-year project on "Food and feed safety vulnerabilities in circular economy" (2021-2022).

As part of the 2-year project, EFSA requested an extensive literature review to gather and evaluate the evidence for vulnerabilities in the CE approach for food and feed safety, plant, animal and human health and the environment. As a new driver, implementation of CE approaches might bring about a set of emerging risks, understood as risks resulting from a newly identified hazard to which significant exposure may occur, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard. This information will be integrated with that derived from *ad-hoc* stakeholder consultations organised by EFSA.

Three specific objectives were requested:

Objective 1: To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe.

Objective 2: To identify emerging risks for plant, animal and human health and the environment related to CE, resulting from new hazards and new exposure pathways leading to increased exposure, by conducting an extensive literature search of the scientific literature and monitoring on-going research projects.

Objective 3: To characterise the identified emerging risks by providing the available information justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities.

The review and analysis covered all stages of food/feed production chains, as defined in the Food Law[1] and related food and feed EU regulatory frameworks. In terms of geographical scope, the focus was on Europe. However, relevant studies from outside Europe were included when they relate to CE practices which may be up taken in Europe in the near future.

The methodology, results and discussion sections of this report are structured according to the three objectives.

[1] Regulation (EC) No 178/2002, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002R0178

1.2. Interpretation of the Terms of Reference

1.2.1. Scope and definitions

Circular economy

In recent years, the CE concept has gained significant momentum, but no singular definition of CE exists, and the concept has been widely reported to be interpreted differently by different societal actors, seeking to influence its meaning and understanding, resulting in a diversity of conflicting approaches (e.g. Kirchherr, Reike and Hekkert, 2017; Friant, Vermeulen and Salomone, 2021). CE is most frequently depicted as reducing waste to a minimum through a combination of reduce, reuse and recycle activities (e.g. Kirchherr, Reike and Hekkert, 2017).

The geographical focus of this review was Europe and therefore for the purposes of this review we have used the European Commission's definition of CE, which concurs with the most frequently used definitions of CE.

'where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised' (EC, 2015).

In March 2020, the European Commission adopted the new CE action plan (EC, 2020). This action plan is one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The aim of the EU's transition to a CE is to reduce pressure on natural resources and create sustainable growth and jobs. It is also fundamental to achieving the EU's 2050 climate neutrality target and halting biodiversity loss.

Transition to the CE is also a prerequisite to the EU's is commitment to achieving the global Sustainable Development Goal Target 12.3 to halve per capita food waste at the retail and consumer level by 2030, and reduce food losses along the food production and supply chains. To accelerate the EU's progress, the Commission will propose legally binding targets for food waste reduction by 2023, as called for by the Farm to Fork Strategy (EC, 2020). Innovative strategies for food within the CE framework will contribute to reaching this target.

The review considered emerging risks to *plant, animal and human health and the environment.* In the context of this review, 'animal' refers to farmed animals (food producing and non-food producing animals) and companion animals (including pets, working or service animals). All animal species were considered for inclusion (i.e. all vertebrates and invertebrates).

Wild plants and animals were regarded to be part of the environment. The environment was defined as the 'natural environment' encompassing all living (i.e. wild animals, plants, algae and fungi) organisms and non-living natural resources (i.e. soil, air and water).

Emerging risks are defined by EFSA[2] as 'a risk resulting from a newly identified *hazard* to which a significant *exposure* may occur, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard.'

The review considered risks arising in all stages of the food and feed production and supply chain, from production/manufacture (e.g. environmental pollution arising from primary or secondary production) to consumption of foods and feeds, as illustrated in Figure 1.

[2] https://www.efsa.europa.eu/en/topics/topic/emerging-risks

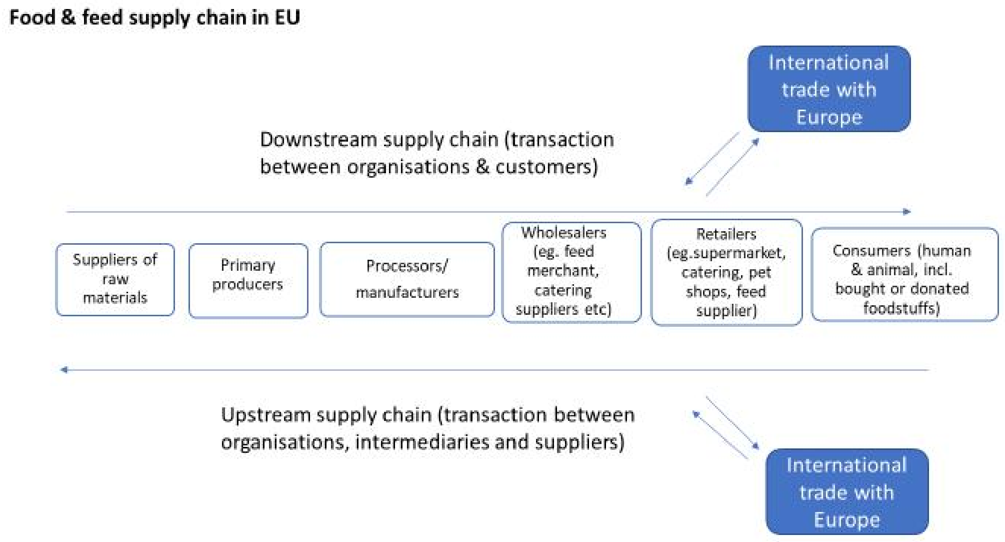

Figure 1 - Food and feed production and supply chains from which risk may arise

1.2.2. Specific objectives

The main objectives (1-3) were carried out successively. Specific objectives for each of the three main objectives were agreed with EFSA at each stage of the project as follows:

1.2.2.1. Specific objectives for Objective 1. To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe.

To identify current and envisaged practices relevant to CE for food and feed in Europe from:

- Published and grey literature
- Completed and on-going scientific Horizon 2020 research projects

B. To record and extract information from the evidence collated to:

- Categorise CE practices identified within the food and feed supply chain
- Identify examples of potential emerging risks from CE practices for plant, animal and human health and the environment

C. To carry out a stakeholder consultation to compare and rate each CE practice identified in terms of:

- importance to the CE
- likely ease of implementation of each CE practice
- likelihood of risk from implementation of each CE practice
- ease of overcoming the risk from implementation of each CE practice
- current state of knowledge regarding the risks from each of the CE practices

The results from the consultation were used to inform the choice of topic for the extensive literature search (Objective 2).

1.2.2.2. Specific objectives for Objective 2. To identify emerging risks for plant, animal and human health and the environment related to CE, resulting from new hazards or new exposure pathways leading to increased exposure.

A. To conduct an extensive literature search (following EFSA Systematic Review Guidance, EFSA, 2010) and monitor on-going research projects to:

- Create a comprehensive list of novel foods and feeds investigated in the articles and projects captured
- Identify emerging risks for plant, animal and human health and the environment from novel foods and feeds within the CE framework reported in the studies captured

B. To carry out stakeholder consultation in collaboration with EFSA to:

- Validate risks identified through the literature search related to novel food and feed
- Identify additional emerging risks related to novel food and feed
- Collect first inputs on future emerging risk characterisation methodology (to be conducted in Objective 3)

The evidence collated in Objective 2 was carried forward to Objective 3 for characterisation of emerging risks.

1.2.2.3. Specific objectives for Objective 3. To characterise the identified emerging risks by providing the available information justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities.

A. To extract meta-data from the full text of studies about novel food and feed within the CE framework where there are associated risks to human, animal, plant health and the environment and where possible address the following questions:

- What are the emerging risks, new hazards, increased exposures?
- What are the biological, physical and chemical hazards in food, feed or in the environment?
- What type, amount and frequency of application of products are applied in/on environmental matrices?
- Which food/feed products could pose a risk and which plants or animals species are at risk?
- Which locations within a supply chain are where new and emerging risks are most likely to emerge?
- Identify which scientific areas (E.g. Plant Health, Animal Health, Biological Hazards, Chemical contaminants (including biotoxins, etc.) within EFSA's remit that this might relate to.
- What is the availability of data underpinning the definition of emerging risk:
    - (eco)toxicological, bioaccumulation and environmental accumulation, epidemiological, biomonitoring, consumption and occurrence data in line with EFSAs environmental risk assessments remit
    - severity, duration and frequency of the expected effects on human, plant and animal health
    - descriptions of exposure pathways
    - interactions with other contaminants and possible additive effects
- What evidence is there for risk management and reduction measures:
    - monitoring systems/programs, practices to lower or eliminate the contamination risks,
    - possible solutions to achieve a safe CE practice/technology etc.
    - existing international/national regulations/guidelines,
- What are the impacts on economy, environment, social aspects, and food and feed security?
- At what scale (local, national, regional, European, global) is the available evidence?
- What is the availability of detection methods?
- What is the strength of the association with CE?
- What is the imminence of these impacts? (How quickly might the risk materialise? How urgent is the response?)

• What are the parallels and interactions with other areas and emerging issues?
• What are the data gaps and research needs, including needs for new analytical approaches?

B. To enable identification of potential emerging risk, where risk has not been investigated or reported in the literature captured: Categorise and list novel foods and feeds within the CE framework where no risk to human, animal, plant health has been reported or investigated, and provide an indication about the geographical location of where the novel food or feed research or practice originates from if outside of the EU.

2. Methodologies

2.1. Objective 1. To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe

2.1.1. Objective 1A. To identify current and envisaged practices relevant to CE for food and feed in Europe from:

- Published and grey literature
- Completed and on-going scientific Horizon 2020 research projects

Due to the breadth of the topic, it was not feasible to identify all possible practices and potential associated risks, instead the aim was to provide an overview of the topic as follows:

- Identify broad 'macro' areas within the food and feed supply chain where CE practices are envisaged or currently used
- Provide a list of current or envisaged CE practices for each macro area (meso-level description)
- Provide specific examples (micro-level description) from the literature for each practice
- Where possible, provide an example article reporting risks associated with the specific (micro-level) practice

Figure 2. illustrates a food and feed supply chain macro areas with two CE practices at the 'meso' level and two specific examples of 'micro-level' CE practices, with examples of associated risks from the literature.

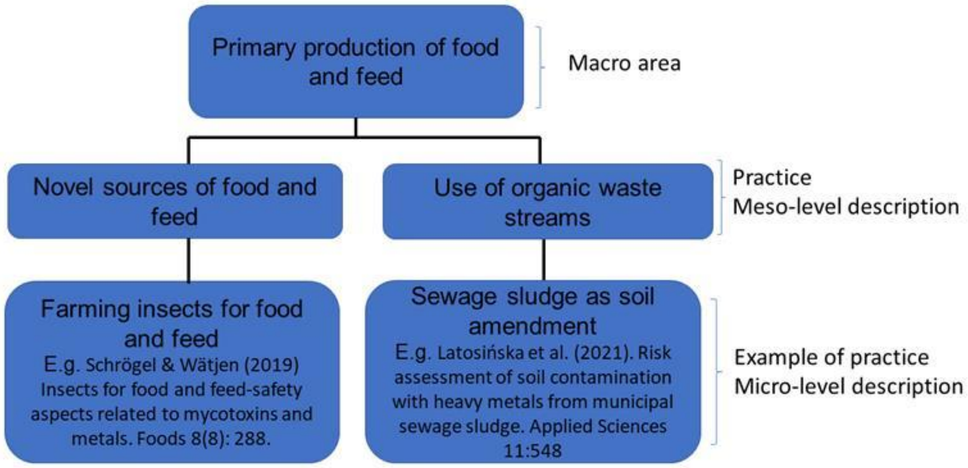

Figure 2 - Illustration of a food and feed supply chain macro area, with two example circular economy practices at the 'meso level' and two specific examples of 'micro-level' CE practices, with examples of associated risks from the literature

Macro areas and relevant practices were identified using a 4-stage process (including one in Section 2.1.2):

Stage 1. Initial identification of macro areas and practices: A combination of expert knowledge and background literature (provided by EFSA and articles published by the project team) were used to identify potential macro areas and practices for circular economy in the food and feed supply chain.

Stage 2. Refinement and identification of additional macro areas & practices using grey literature and completed and ongoing research: Macro areas were refined and added to by examining:

- Grey literature provided by EFSA or sourced from searches of thirty-eight websites of organisations, institutions and research platforms (see Appendix A. Worksheet 1. for a list of the 38 websites searched). The list of websites was developed through consultation with EFSA and the 'stakeholder network' as well as recommendations from the project team.
- An up-to-date list of completed and on-going Horizon 2020 research projects (provided by EFSA).

Stage 3. Topic modelling of published literature to identify any further macro areas and practices: Published literature was searched for in Scopus bibliographic database. Eight search strings were developed, one for each of the 7 initial macro area identified in stages 1 & 2 (above), and one with general circular economy key words and qualifiers for food and feed (see Appendix A. Worksheet 2 for a record of the search strings used). Keywords for search string development were identified through a combination of expert consultation (EFSA project team, the 'stakeholder network' and the project team experts), and literature relevant to the topic (sourced by the contractor or recommended by the stakeholder network). Scoping searches were used to test and refine the search strings to ensure return of relevant results.

All articles returned by Scopus for each search string were imported separately into Sciome SWIFT-Review software for topic modelling to identify any additional macro areas and example practices. Topic modelling parameters were set to 50 topics per search string. Sciome SWIFT-Review uses Latent Dirichlet Allocation to automatically compute topic models from literature imported from searches in bibliographic databases. This statistical method discovers themes and concepts in a large set of documents, and enabled practices at macro, meso and micro level to be identified and defined. Topic modelling was used to:

- Confirm and identify any further macro areas (using search string containing circular economy terminology)
- Confirm and identify practices and specific examples relevant to macro areas identified in stages 1 & 2.

2.1.2. Objective 1B. To record and extract information from the evidence collated to enable:

- Categorisation of CE practices identified within the food and feed supply chain
- Identification of examples of potential emerging risks from CE practices for plant, animal and human health and the environment.

Stage 4. Final categorisation of macro areas and practices: The 7 macro areas identified in stages 1-3 were simplified and combined to reflect different stages of the food/feed supply chain. Circular economy practices to minimise waste or produce food sustainably were categorised into macro areas according to where they occur in the food and feed supply chain. Where possible examples of practices (at the micro-descriptive level) in the literature that identified potential risks were gathered from the evidence captured in stages 1-3. Because the primary aim of stages 1-3 was to identify envisaged and current practices, risks associated with these practices were not searched for specifically e.g. using terminology for risk in the search strings. Therefore, where suitable examples of risk were not found using the above methods described in stages 1-3, additional examples were sourced by searching for risk of each practice in google scholar. The outputs were tabulated and the supporting evidence recorded in an Excel file for transparency. Due to the time constraints, information was extracted from evidence mainly by using abstracts, executive summaries and project summaries.

Criteria used for the inclusion of evidence

The criteria for searching for and including evidence to identify macro areas and practices from all sources and at all stages (1-3) were as follows:

- Any current or envisaged practice in the food and feed supply chain that is relevant to circular economy for food for human consumption or feed for animal (farmed and non-farmed animals) consumption could be included.
- There were no geographical restrictions for the inclusion of evidence but the practice must be of current or future relevance to food or feed consumption in the EU.
- There were no date restrictions for the inclusion of evidence.
- Literature was searched for in English language and records captured only included those published in English language.

Any articles about associated risks with CE practices had to be relevant to for crops, animals (food producing and non-food producing animals) and human health and the environment (i.e. soils, plants, water and air).

Recording searches for literature

To ensure transparency and repeatability a record was made of all searches for evidence used to identify macro areas, and practices.

- For grey literature searches (conducted in stage 2) this included: date of the search; how the site was searched (e.g. publication pages using inbuilt search function, search term used); number of records returned in the website; number of records retrieved from the website (See Appendix A. Worksheet 1. for record detail).
- For the Scopus searches (conducted in stage 3) this included: the date of the search; search string used; where the search string searched within articles (e.g. title, abstract, keyword);

number of records returned in Scopus; restrictions used in the searches for literature (see Appendix A. Worksheet 2. for record of detail).

Recording the evidence used to identify macro areas and provide examples of practices

An Excel spreadsheet was used to:

- Record the full reference of the literature used to initially identify macro areas (stage 1) and where it was sourced from (Appendix A. Worksheet 3.).
- Record the full reference of the literature used for example practices, where the literature was sourced from and any potential risks that the literature cited (Appendix A. Worksheets 4-7).

The following stakeholders/topic experts were were asked to complete a survey *'Priority checklist: The current degree of uptake of circular economy within all stages of food/feed production chains in Europe'* (Appendix B.):

- AINIA
- CNR-ISPA, Consiglio Nazionale delle Ricerche, Istituto do Scienze delle Produzioni Alimentari
- EU Association of Specialty Feed Ingredients and their Mixtures (FEFANA)
- European Commission
- European Economic and Social Committee (EESC)
- European Environment Agency (EEA)
- European Feed Manufacturers' Federation (FEFAC)
- European Food Safety Authority (EFSA)
- European Former Foodstuff Processors Association (EFFPA)
- FAMI-QS The Quality and Safety System for Specialty Feed
- Federation of Veterinarians of Europe (FVE)
- German Federal Institute for Risk Assessment (BfR)
- Harper Adams University
- International Platform of Insects for Food and Feed (IPIFF)
- Istituto Superiore di Sanità (ISS)
- Joint Research Centre (JRC) - European Commission
- National Institute for Public Health and the Environment (RIVM)
- Nederlandse Voedsel- en Warenautoriteit (NVWA)
- Prospex BVL
- Swedish University of Agricultural Sciences (SLU)
- Wageningen University and Research (WUR)

Respondents were asked to compare the CE practices (identified in specific objective 1 and 2) and rate their importance to the CE (high, medium or low). For those respondents who felt that they did not have sufficient knowledge to comment on a particular question there was an option to select 'Do not know'. The second part of the survey asked respondents to rate each of the CE practices (high, medium or low) in response to:

- The likely ease of implementation of practice (where high = most easy to implement)
- The likelihood of risk from implementation of the practice (where high = highest risk)
- The ease of overcoming the risk from implementation of the practice (where high= most easy to overcome risk)
- The current state of knowledge regarding the risks from these circular economy practices (where high = high state of knowledge)

Additional comments were welcomed at the end of the questionnaire.

To enable to the data to be weighted in order to inform the next steps for Objective 2, a comparative score for the practices was calculated. For each question, responses were weighted as follows:

- High = 10

- Medium = 5
- Low = 0

Where two options had been selected, they were weighted as follows:

- High;Medium = 7.5
- Medium;Low = 2.5

The number of responses (for High, Medium Low) was multiplied by the corresponding weightings to give a total weighting. The mean value for each question was calculated by dividing the total weighting by the number of responses (i.e. the number of question responders minus the number of 'Do not know' responses).

The results of the survey were used to inform the identification of the topic area for Objective 2 the extensive literature search. The topic identification exercise was carried out in consultation with EFSA.

Identification of the topic area was carried out in two stages:

Stage 1. The EFSA team proposed a higher weighting (x 1.5) for the stakeholder scores for each CE practice for the following criteria combined:

- The likelihood of risk from implementation of the CE practice
- Ease of overcoming the risk from implementation of the CE practice
- The current state of knowledge regarding the risks from the CE practice

The remaining criteria were not weighted.

Stage 2. The top 10 highest scoring CE practices from Stage 1 were discussed against 4 further criteria with EFSA to identify the final topic area for the literature search in Objective 2. The criteria were:

- Time constraints of the project and the likely volume of evidence for each CE practice
- Expertise of the contractor project team
- Policy needs
- Expert evaluation i.e. the results of the survey

2.2. Objective 2. To identify emerging risks for plant, animal and human health and the environment related to CE, resulting from new hazards and new exposure pathways leading to increased exposure.

2.2.1. Objective 2A. To conduct an extensive literature search and monitor on-going research projects to:

- Create a comprehensive list of novel foods and feeds investigated in the articles and projects captured
- Identify emerging risks for plant, animal and human health and the environment from novel foods and feeds within the CE framework reported in the studies captured

2.2.1.1. Topic identification, scope and definitions for extensive literature search

Following the stakeholder consultation (outline in Objective 1C), it was agreed with EFSA that the topic the extensive literature review would be:

What are the emerging risks for plant, animal and human health and the environment resulting from new hazards and new exposure pathways leading to increased exposure, from novel food and feeds of relevance to circular economy?

The scope of the literature search focused on using waste, former food products (FFP), and side streams (by-products and co-products) as a resource to develop novel foods and feeds, so contributing to CE. All novel foods and feeds arising from waste, FFP and side streams (i.e. by-product and co-products) from all stages of food/feed production and supply chains and the emerging risks to plant, animal and human health and the environment were considered. In this objective, there were no geographical restrictions on inclusion of literature, in order to better understand potential emerging risks on a global scale that may have ramifications for food and feed safety in the EU.

Novel foods for humans are defined in EU regulations as: 'any food that was not consumed "significantly" in the EU prior to May 15 1997 (Regulation (EU) 2015/2283)'. 'Novel Food' can be newly developed, innovative food, food produced using new technologies and production processes, as well as food which is or has been traditionally eaten outside of the EU.

To our knowledge 'novel feed' for animals has yet to be defined in EU regulation. For the purposes of this literature search we considered 'novel feeds' to be new sources of feed from the food industries, biofuel industries and industrial processes and new types of ingredients such as processed animal proteins (PAPs) derived from farmed insects, and ingredients from marine resources and aquatic plants (FAO/WHO 2019). In addition to 'novel' sources of PAPs, we also considered the EU's re-introduction of the use of PAPs from poultry for pigs that was previously banned in 2001 in the wake of the bovine spongiform encephalopathy crisis (EC 2021/1372). The drivers for re-introduction of these previously banned specific PAPs includes: the growing demand for protein sources, and their potentially valuable contribution to creating a CE, the European Green Deal and farming's net zero goals for greenhouse gas (GHG) emissions (Driver, 2021). Although these previously banned PAPs may not technically be classed as 'novel' feed because historically they have been fed to animals, there is concern about the health risks of their re-introduction (e.g. Moran, 2021) and the ban will not, for example, be lifted in the United Kingdom (Boffey, 2021). For this reason, we decided to include literature about these previously banned PAPs (from poultry for pigs and from pigs for poultry).

European Commission regulations (EC 999/2001; EC 1774/2002; EC 767/2009; EC 1069/2009) prohibits the use of some materials for animal feed. For example, wastes including faeces, and catering and household waste, and 'intra-species recycling' (the systematic re-feeding of feedstuffs derived from the tissues of one species of animal back to the same species). We included studies that investigated these prohibited materials as feeds within the CE framework. The rationale for including these studies is that there may be changes in regulation in the future in the transition to CE in Europe.

Whilst EU regulation for novel food is specific to food only, we have taken a broader approach and also include for example, food (and feed) additives and flavourings that aim to minimise waste and contribute towards CE.

Examples of novel foods and feeds that fit with the CE approach include: utilisation of biorefinery sidestreams to create novel food and feed (e.g. Lange and Meyer, 2019); alternative primary production of sources of animal protein such as insects reared on bio-waste substrate (e.g. EEA 2020, SAPEA 2020).

Novel foods and feeds that are not related to minimising waste or utilising sidestreams or FFP but that have wider sustainability benefits were not included e.g. foods grown in laboratories (and not using waste, former food stuffs or side streams as a substrate).

Emerging risks, resulting from allergens, biological (e.g. microbial), chemical (e.g. heavy metals) and physical (e.g. glass, plastic fragments) hazards were included. Hazards to the environment reported in studies were included on an iterative basis (e.g. greenhouse warming, acidification, eutrophication).

Studies about novel foods and feeds within the CE framework where the author did not investigate or report risk were collated and categorised separately. This expanded list of novel foods and feeds, may provide an indication about the geographical location of where the novel food or feed research or practice originates from if outside of the EU. The rationale for this is to understand what substrates are being considered globally and the potential implications for food, feed and environmental safety in future horizon scanning exercises.

2.2.1.2. Inclusion criteria for the extensive literature search

Two levels of inclusion criteria (what a study must contain to be included in the report) were developed:

- Inclusion criteria to identify studies investigating the risk from novel food and feed to human, animal, plant health and the environment
- Inclusion criteria to identify literature reporting novel foods and feeds within the CE framework but where no risk was reported or investigated

2.2.1.3. Inclusion criteria to identify studies investigating the risk from novel food and feed to human, animal, plant health and the environment

Population at risk: Humans, animals, plants and the environment as defined in Section 1.2.1

Exposure route: Novel foods and feeds (as defined in Section 2.2.1.1) arising from all stages of food/feed production and supply chains (as defined in Section 1.2.1).

Study comparators: Use of novel foods and feeds compared to their counterparts used currently or no comparator.

Study outcomes: Any allergenic, biological (e.g. microbes, antibiotic resistance genes (ARGs)) chemical (e.g. heavy metals, dioxins, pesticides, pharmaceuticals, mycotoxins) and physical (e.g. plastic, card, glass packaging) hazards that constitute emerging risks for plant, animal and human health and the environment originating from production or consumption of novel foods and feeds. Hazards to the environment reported in studies were included (e.g. greenhouse warming, acidification, eutrophication).

Primary research studies about the risk of animal feeds derived from waste, FFP, and side streams on biological animal production parameters (e.g. live weight, digestibility of product, organ development) were excluded, where the authors reported no risk if the product was included in the diet within the recommendations of the study findings.

Primary research studies about invertebrates and potential risk for plant, animal, human health and the environment but where there was no clear relationship to the CE framework were excluded.

Study designs: Primary research and reviews and on-going research projects were captured but only primary research was considered for inclusion for meta-data extraction/study characterisation. Reviews and on-going research were categorised separately and screened for relevant primary research to ensure that no primary research was missed in the searches. Useful inferences made by the authors of reviews about hazards and emerging risks were noted. Books, book chapters and MSc theses were excluded.

Geographical limitations for inclusion of evidence: No geographical restrictions. The rationale for including worldwide evidence was to highlight potential emerging risks for food and feed safety arising from imports into the European Union.

Date restrictions: Literature was included from 1997 onwards following the European Union Regulation (EU) 2015/2283 definition for novel food (not eaten before May 15 1997).

Languages: Only literature in English language was searched for and included due to limited resources for translating non-English language texts.

2.2.1.4. Inclusion criteria to identify studies investigating novel food and feeds within the CE framework but where no risk was reported or investigated

Population at risk: Humans, animals, plants and the environment as defined in Section 1.2.1.

Exposure route: Novel foods and feeds (as defined in Section 2.2.1.1) arising from all stages of food/feed production and supply chains (as defined in Section 1.2.1).

Study outcomes: Any article about novel food or feed within the CE framework. Research about the risk of novel animal feeds on biological animal production parameters (e.g. live weight, digestibility of product) where the authors reported no risk if the product was included in the diet within the recommendations of the study findings, were included. Primary research studies about invertebrates and potential risk for plant, animal, human health and the environment but where there was no clear relationship to the CE framework were excluded.

Study designs: All literature and study designs were considered for inclusion with the exception of books, book chapters and MSc theses which were excluded.

Geographical limitations for inclusion of evidence: No geographical restrictions. The rationale for including worldwide evidence was to highlight potential emerging risks for food and feed safety arising from imports into the European Union, possible policy evolution and future implementation in Europe.

Date restrictions: Literature was included from 1997 onwards following the European Union Regulation (EU) 2015/2283 definition for novel food (not eaten before May 15 1997).

Languages: Only literature in English language was searched for and included due to limited resources for translating non-English language texts.

2.2.1.5. Search string development

Scoping searches were conducted to test the specificity and sensitivity of keywords relevant to the scope of the literature search (Appendix C, Worksheet 1. & 2.). The scoping searches were used to develop the search string that was used to search for literature in bibliographic databases (and where appropriate other online sources of literature).

The search string below was used to collate relevant evidence. Exposure (blue) keywords, qualifiers (green) and limiters (orange) were used to ensure relevance to food and feed and prevent the capture of irrelevant literature (e.g. experiments about how animals behave towards novel feed, people's attitudes towards novel food). The search string was applied to title and abstract in bibliographic database searches for literature.

"lab-grown meat" OR "test tube meat" OR "artificial meat*" OR "cultured meat*" OR "in vitro meat*" OR "synthetic meat*" OR "novel food*" OR "novel feed*" OR "alternative food*" OR "alternative feed*" OR "edible insect*" OR "insect food*" OR "insects as food" OR "insect feed*" OR "alternative protein*" OR "cell-based meat*" OR "insect protein*" OR "novel plant protein*" OR "cell-based protein*" OR "innovative food*" OR "innovative feed*" OR "sustainable protein*" OR "recycled protein*" OR "novel by-product*" OR "agri-food side stream*" OR "processed animal protein*" OR "mycoprotein*" OR upcycle* OR "new dietary ingredient*" OR "former food*" AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR "*nutrient*" NOT psychology OR accept* OR attitud* OR behav*

Note: *Following the searches for literature using the search string above, it was decided with the EFSA team that cultured meats (i.e. "lab-grown meat", "test tube meat", "artificial meat*", "cultured meat*", "in vitro meat*", "synthetic meat*") would not be included. This is because the production of these meats is not related to reutilisation of waste in a circular context 'waste' but instead may have wider* *sustainability benefits compared to conventional farming. These articles picked up by the search string above were subsequently screened out at the title and abstract screening stage.*

The scoping searches showed that it was not possible to include some keywords for specific novel foods or feeds or sources of novel foods and feeds, without returning very large volumes of evidence. Given the time and resources allocated to this project it was not feasible to screen all these additional articles for relevance. We therefore developed shorter limited search strings for these specific keywords, applied at title only in bibliographic database searches. The shorter search strings are shown below:

- "by-catch" AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR nutrient*
- algae AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR nutrient*
- "aquatic plant*" OR "aquatic protist*" AND Food* OR Feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR nutrient*
  algae OR microalgae OR macroalgae OR seaweed AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR nutrient*
- ❖ "recycling plant waste*" OR "plant waste*" OR "crop residue*" OR "forestry residue*" OR "crop waste*" OR "forestry waste*" AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR nutrient*
- ❖ "fermentation of waste*" OR "waste fermentation" OR "fermented waste*" OR "fermentation of sidestream*" OR "sidestream fermentation" OR "fermented sidestream" OR "fermentation of by-product*" OR "by-product fermentation" OR "fermented by-product" AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin OR nutrient*
- biorefiner* OR bioprocess OR biowaste* OR "by-product*" and "novel food*" OR "novel feed*" OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR *nutrient*
- biofuel OR biodiesel OR bioethanol AND "co-product*" AND food* OR feed* OR ingredient* OR additive* OR supplement* OR mineral* OR vitamin* OR "*nutrient*"

❖ Denotes the additional searches recommended in the stakeholder consultation see Section 2.2.2. These searches were applied at title in the bibliographic database Scopus.

2.2.1.6. Searching for literature

A comprehensive search that aimed to capture an un-biased sample of published and grey literature was undertaken in July 2021 using multiple information sources including: bibliographic databases, websites of relevant organisations and research funding platforms. Table 1 documents the sources searched.

The searches endeavoured to be as thorough as possible within the timescale of this project. The search string was adapted to the syntax of each source searched and a record of each search was made: date the search was conducted; database name; search term; number of hits; and notes. Database and repository searches were conducted in the English language:

- Appendix C, Worksheet 3. for searches of bibliographic databases using the main search string
- Appendix C, Worksheet 4. for searches of bibliographic databases for the short search strings
- Appendix C, Worksheet 5. searches for literature from organisational websites

Any publications provided by team experts and the wider stakeholder network were considered for inclusion. Literature collated in Objective 1 that was relevant to Objective 2 was also included. Historical and ongoing research project pages (Horizon 2020, SUSFOOD, UKRI) were also searched for relevant literature.

Table 1 - Sources searched for published and grey literature and on-going research projects.

Bibliographic databases	Pubmed
	Web of Science – including Web of Science TM Core collection
	Scopus
	DART E-Thesis
	EBSCO (CAB Abstracts, Food Science Source, GreenFILE, Business Source Complete, eBook Collection (EBSCOhost), Harper Adams Library Catalogue, Regional Business News, Teacher Reference Center, Library, Information Science & Technology Abstracts)
Organisation Websites	Food Navigator https://www.foodnavigator.com/ SAPEA
	Fédération Européenne des Fabricants d'Adjuvants pour la Nutrition Animal
	World Health Organisation
	Food and Agriculture Organisation of the United Nations
	International Platform of Insects for Food and Feed
	PROteINSECT
	European Feed Manufacturer's Federation
	Joint Research Centre EU Science Hub
	Pet Food Manufacturers Association
	Nordic Council of Ministers
	Susinchain - Sustainable Insect Chain
	Luonnonvarakeskus
	National Institute for Public Health and the Environment Ministry of Health Welfare and Sport Netherlands
	Netherlands Food and Consumer Product Safety Authority. Ministry of Agriculture, Nature and Food Quality
	Health and Environment Alliance
	Department for Environment Food and Rural Affairs
	EFSA
	PBL Netherlands Environmental Assessment Agency
	Joint Research Centre Publication Repository
	United Nations Environment Programme
	European Centre for Disease Prevention and Control
	EC Europa
	EFFPA (European Former Foodstuff Processors Association)
	Ellen MacArthur Foundation
	ETP food for life
	EU Platform on Food Losses and Food Waste
	Interreg Europe
	OECD i Library
	The European Aquaculture Technology and Innovation Platform
	Waseabi
Research funding platforms	Horizon 2020

	SUSFOOD
	UKRI

2.2.1.7. Screening literature for inclusion

Articles retrieved from grey literature searches (i.e. from organisational web site searches and research funding platforms) were screened on a case by case basis for inclusion (against the inclusion criteria detailed in Section 2.2.1.2) during the searching of websites.

All articles retrieved from the bibliographic database searches (see list of databases in Table 1), were first collated in a reference management program (EndNoteTM) and duplicate articles removed using the automated duplicate removal function. The remaining articles, were exported from EndNoteTM into EPPI-Reviewer4 a specialised systematic reviewing software. A second round of duplicate removal was conducted using EPPI-Reviewer4 automated duplicate removal function.

A total of 51,235 articles were retrieved in the bibliographic database searches. Following duplicate removal using EndNoteTM and EPPI-Reviewer4, a total of 26,669 articles remained for screening on title and abstract against the inclusion criteria.

DistillerSR Artificial Intelligence (AI) algorithm was used to automatise the identification of relevant documents.

2.2.1.8. Training the DistillerSR AI algorithm

A set of 1334 articles (5%) of the total corpus (26,669 articles) was randomly selected for manual screening at title and abstract against pre-defined inclusion criteria by two independent reviewers. A Cohens Kappa result of 0.58 indicated moderate agreement (Landis and Koch, 1973) between reviewers in screening at title and abstract of this 5%. After resolving possible conflict between reviewers' judgment, the human-labelled set was used to train DistillerSR AI screening (a SVM classifier). DistillerAI was trained using a percentage (80%) of manually reviewed references and then the trained algorithm was applied to unreviewed references to automatically determine if references should be included or excluded, providing a measure of the probability of relevance. The remaining 20% of manually screened articles was used to calculate performance measures of DistillerAI, namely accuracy (number of all correct predictions divided by the total number of references), sensitivity/recall (the number of correct positive predictions divided by the total number of relevant references) and specificity (number of correct negative predictions divided by the total number of irrelevant references). Those measures were calculated for different values of threshold, the cut-off value of predicted probability of relevance. When setting the threshold, there is a trade-off between recall and specificity, that is the ability of the classifier to identify all the relevant papers and the ability to identify irrelevant paper. Setting a threshold with low value, leads to inclusion of many irrelevant articles (high false positive) with consequent low value of specificity, but leads to inclusion of many relevant articles with consequent high value of sensitivity. Setting a threshold with high value, leads to exclusion of many irrelevant articles but also the potential exclusion of relevant articles, with consequent low value of sensitivity and high value of specificity.

To benefit from the workload reduction property of active learning, an additional 5% of the 26,669 articles, ranked according to predicted relevance, were again manually screened by the two independent reviewers. DistillerAI was trained again using (80%) of total manually reviewed references and performance measures were re-calculated on the remaining 20% (Figure 3). A value of threshold equal to 0.3 was selected, corresponding to sensitivity of 87% and specificity of 62%. The estimated percentage of relevant articles missed with the selected threshold is 13%.

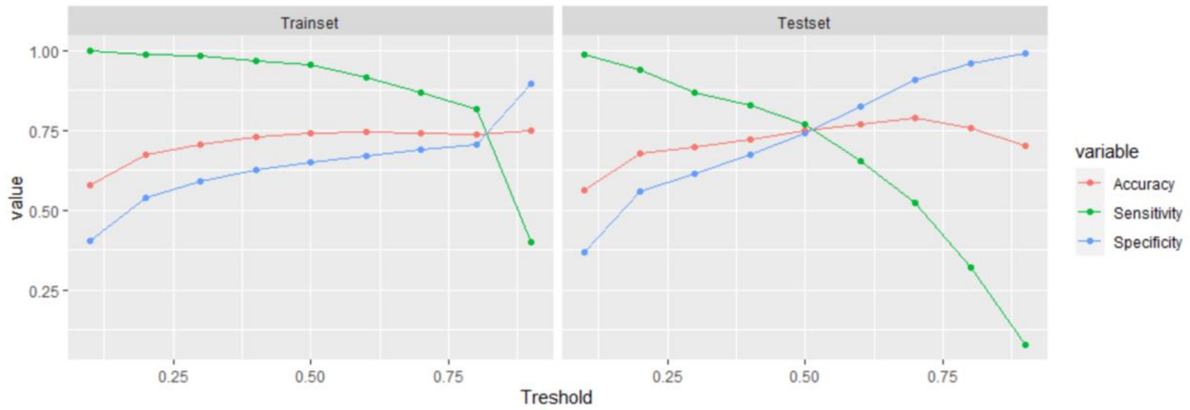

Figure 3 - Performance measures of trained classifier for training set and test set, based on 10% manually screened articles, (5% random selection and 5% active learning)

2.2.1.9. Screening the literature selected by the DistillerSR AI algorithm

Using the threshold of 0.3 two independent reviewers screened the 1,457 articles considered by the AI to be of relevance. Following screening of these articles using a threshold of 0.3, it was decided that to benefit again from the AI an additional 603 articles would be screened at title and abstract using the threshold of 0.5. A threshold of 0.5 was used this time due to time constraints to screen literature, as the threshold of 0.5 returned fewer articles.

Articles included following title and abstract screening stage were then screened against pre-defined inclusion criteria at full text.

2.2.2. Objective 2B. To carry out stakeholder consultation in collaboration with EFSA and Prospex bv to:

- Validate risks identified through the literature search related to novel food and feed
- Identify additional emerging risks related to novel food and feed
- Collect first inputs on future emerging risk characterisation methodology (to be conducted in Objective 3)

A stakeholder workshop was held to:

- Validate risks identified through the literature search related to novel food and feed
- Identify additional emerging risks related to novel food and feed
- Collect first inputs on future emerging risk characterisation methodology (to be conducted in Objective 3)

The workshop was hosted by Prospex bv as part of a parallel EFSA project '*stakeholder mapping and engagement*'. A summary of the methodology and results from Objective 1 and 2 of this project were presented, including a preliminary list of novel foods and feeds of relevance to the CE framework, and associated potential risks to human, animal, plant health and the environment. The proposed plan for the emerging risk characterisation methodology to be conducted in Objective 3 was also presented. Feedback from the workshop was collated by Prospex and disseminated back to the team working on this project.

In response to the feedback, some additional methodology was included in Objective 2:

- Two additional short search strings were developed for plant waste and fermentation of waste (see Section 2.2.1.5)
- Stakeholders considered it important in the characterisation of the evidence to: have a list of novel food and feeds related to the CE framework, even where no risk was reported in the literature and an indication as to whether the food or feed originated from within or outside of the EU. The rationale for this is to further understand what substrates are being considered globally and the potential implications for food, feed and environmental safety in future horizon scanning exercises.

2.3. Objective 3. To characterise the identified emerging risks by justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities.

2.3.1. Objective 3A. To extract meta-data from the full text of studies about novel food and feed within the CE framework where there are associated risks to human, animal, plant health and the environment and identify:

• What type of emerging risk is it (new hazard, increased exposure)?
• What are the biological, physical and chemical hazards in food, feed or in the environment?
• What type, amount and frequency of application of products are applied in/on environmental matrices?
• Which food/feed products could pose a risk and which plants or animals species are at risk?
• Which locations within a supply chain are where new and emerging risks are most likely to emerge?
• Identify which scientific areas (e.g. Plant Health, Animal Health, Biological Hazards, Chemical Contaminants (including biotoxins, etc.) within EFSA's remit that this might relate to.
• What is the availability of data underpinning the definition of emerging risk:
  - (eco)toxicological, bioaccumulation and environmental accumulation, epidemiological, biomonitoring, consumption and occurrence data in line with EFSAs environmental risk assessments remit
  - severity, duration and frequency of the expected effects on human, plant and animal health
  - descriptions of exposure pathways
  - interactions with other contaminants and possible additive effects
• What evidence is there for risk management and reduction measures:
  - monitoring systems/programs, practices to lower or eliminate the contamination risks,
  - possible solutions to achieve a safe CE practice/technology etc.
  - existing international/national regulations/guidelines,
• What are the impacts on economy, environment, social aspects, and food and feed security?
• At what scale (local, national, regional, European, global) is the available evidence?
• What is the availability of detection methods?
• What is the strength of the association with CE?
• What is the imminence of these impacts? (How quickly might the risk materialise? How urgent is the response?)
• What are the parallels and interactions with other areas and emerging issues?
• What are the data gaps and research needs, including needs for new analytical approaches?

Meta-data were extracted from the full text of the 26 articles that investigated risk associated with novel foods and feeds within the CE framework. This meta-data was used to address the questions set out in specific objective A. The coding table for meta-data extraction is provided in Appendix D, Worksheet 1.

Study designs were highly heterogenous making it difficult to carry out any formal critical appraisal of studies. However, we extracted study design quality indicators (e.g. use of control, replication, randomisation) to provide an indication of the reliability of the evidence base.

2.3.2. Objective 3 B. Categorise and list novel foods and feeds within the CE framework where no risk to human, animal, plant health has been reported or investigated, and provide an indication about the geographical location of where the novel food or feed research or practice originates from if outside of the EU.

Novel food and feeds were categorised and listed using information provided in the abstracts or summaries of articles. Using a combination of bibliographic information (title, abstracts, journal, authors) and general knowledge we attempted to provide an indication about the geographical location of where the novel food or feed research or practice originates from if outside of the EU.

3. Results

3.1. Objective 1. To identify and categorise current and envisaged CE practices within all stages of the food and feed production chain in Europe

These results relate to:

- Objective 1A. To identify current and envisaged practices relevant to CE for food and feed in Europe from:
  - Published and grey literature
  - Completed and on-going scientific Horizon 2020 research projects
- Objective 1B. To record and extract information from the evidence collated to enable:
  - Categorisation of CE practices identified within the food and feed supply chain
  - Identification of examples of potential emerging risks from CE practices for plant, animal and human health and the environment.

3.1.1. Literature used to identify and categorise current and envisaged CE practices

A total of 258 articles were retrieved in the grey literature searches of organisational websites (Appendix A, Worksheet 1). These articles were screened manually for current and envisaged CE practices and examples of associated risk with practices.

Nearly 50,000 articles were returned from the 8 search strings used to search for literature relevant to CE practices in the bibliographic database Scopus (Appendix A, Worksheet 2). Articles returned for each of the 8 search strings was run in topic modelling software separately, to identify current and envisaged CE practices and examples of risks associated with these practices.

3.1.2. Identification of 'macro' areas within the food and feed supply chain where CE practices are envisaged or currently used

The circular economy for food and feed within all stages of the supply chain is a highly complex and broad topic area, with many cross-cutting themes. Figure 4 illustrates how the macro areas were initially identified and then simplified, following the 4-stage process outlined in the methodology (Sections 2.1.1 and 2.1.2). A record of all the literature used to initially identify macro areas (Figure 4 – Stage 1) and where it was sourced from can be found in Appendix A, Worksheet 3.

Using this 4-stage process, we identified four broad macro areas within which CE practices are envisaged or currently used:

1. Primary production of food and feed
2. Reducing industrial/manufacturing/processing waste
3. Reducing food and feed waste in wholesale, food retail, catering and households
4. Reducing food and feed packaging waste

The definitions of each of the 4 macro areas are presented in the following sections along with examples of practices within that macro area, and examples of risks associated with the practices where highlighted by study authors.

A record (full reference) of the literature cited for each example practice and where literature was sourced from are available in Appendix A, Worksheets 4-7.

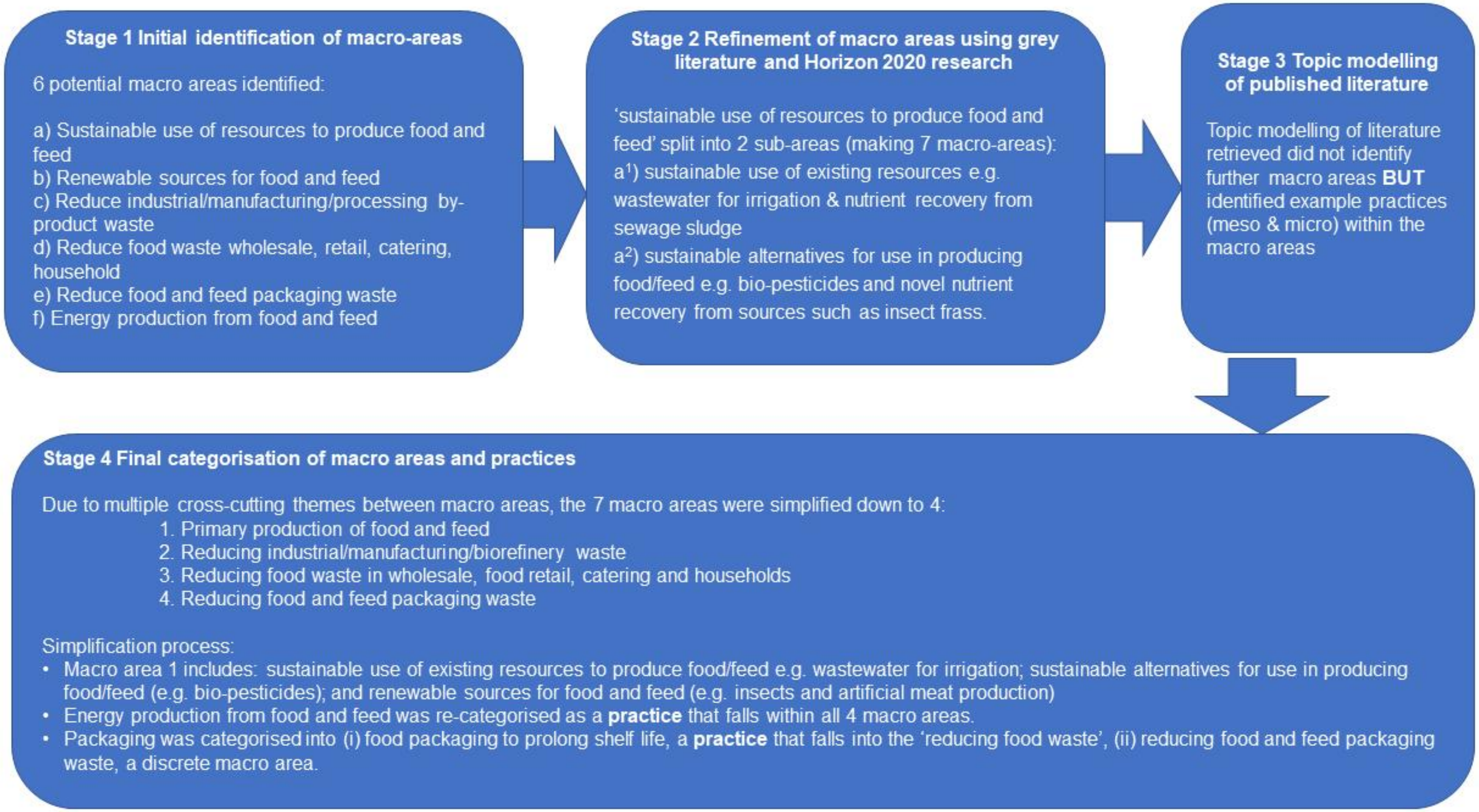

Figure 4 - Macro areas identification and simplification, following the 4-stage process outlined in the methodology

3.1.3. Examples of current or envisaged CE practices and associated risks within each of the 4 macro areas

The results presented in the following sections are intended to provide an overview of current and envisaged circular economy practices within all stages of the food and feed production chain in Europe and examples of potential risks associated with the practices.

For each circular economy practice, we did not set out to search for or identify every possible risk, but instead provide examples cited in the literature. It is important to note that:

- For some practices there may have been many more examples than those cited.
- Where no risk is reported for a particular practice this does not mean that no risk exists, but that we did not find one during our literature searches.
- No quality appraisal was conducted, so we do not condone (or disagree with) any of the risks associated with practices that authors may highlight.

3.1.3.1. Primary production of food and feed

This macro area covers producing food and feed using practices that aim to reduce, re-use and recycle resources and minimise waste, to increase the efficient use of resources rather than destroying or depleting them, whilst maintaining or improving yield/productivity and environmental services. This systemic approach relies on healthy crops, livestock, and agroecosystems, including soils.

A wide range of food and feed producing systems exist where circular economy practices are integral to the core principals of the system. For example, regenerative, organic, integrated, biological, conservation farming; permaculture; agroforestry; rotational grazing and mixed farming systems. These systems could all be considered agro-ecological approaches that incorporate specific CE practices and therefore these systems are not listed in the circular economy practices listed below.

Five broad circular economy practices were identified for food and feed production:

- Use of organic waste streams
- Novel sources of food and feed (i.e. primary production of novel foods and feeds (e.g. farming insects, growing algae or in vitro production of meat). Any novel food and feeds (materials or additives) derived from industrial/manufacturing/processing waste or food waste are discussed under macro areas 2 & 3 respectively)
- Crop protection and breeding
- Livestock health and breeding
- Locally produced food and feed

Under EU regulations, any food that was not consumed "significantly" prior to 1997 is considered to be a novel food (Regulation (EU) 2015/2283). 'Novel food' includes new foods, food from new sources, new substances used in food, as well as new ways and technologies for producing food (EFSA, n.d.). It is worth noting that this regulation is specific to food and not animal feed, and to our knowledge 'novel feed' has yet to be defined in EU regulation. For the purposes of this report we have relied upon the author of included articles to describe the feed under consideration as new or novel.

Table 2 shows examples of current and envisaged circular economy practices within the primary production of food and feed and associated potential risks with some of these practices.

Table 2 - Current and envisaged circular economy practices within primary production of food and feed, with specific examples (and risks where highlighted) from the literature.

CE Practice	Example of practice from the literature	Example(s) of potential risk(s) of practice where highlighted by article author
Use of organic waste streams	**Using manure as soil conditioner, soil amendment or fertiliser** Muola A, Fuchs B, Laihonen M, Rainio K, Heikkonen L, Ruuskanen S, Saikkonen, K, Helander, M, 2021. Risk in the circular food economy: Glyphosate-based herbicide residues in manure fertilizers decrease crop yield. Science of the Total Environment, 750, 141442.	Glyphosate excreted by poultry reduces crop yields
	Using municipal sewage sludge for soil amendment Latosińska J, Kowalik R, Gawdzik, J 2021. Risk assessment of soil contamination with heavy metals from municipal sewage sludge. Applied Sciences, 11(2), 548.	Contamination of soil with heavy metals from municipal sewage and emerging pollutants of concern
	Using insect frass as a biofertilizer Milanović, V, Roncolini A, Cardinali F, Garofalo C, Aquilanti L, Riolo P, Ruschioni S, Corsi L, Isidoro N, Zarantoniello M and Olivotto I, 2021. Occurrence of Antibiotic Resistance Genes in *Hermetia illucens* Larvae Fed Coffee Silverskin Enriched with Schizochytrium limacinum or Isochrysis galbana Microalgae. Genes, 12(2), 213.	Accumulation of antibiotic resistant genes in *H. illucens* frass indicates potential safety concerns in reusing frass in agriculture
	Using wastewater from sewage plants for irrigation Truchado P, Garre A, Gil MI, Simón-Andreu PJ, Sánchez G, Allende A, 2020. Monitoring of human enteric virus and coliphages throughout water reuse system of wastewater treatment plants to irrigation endpoint of leafy greens. Science of the Total Environment, 782, 146837.	Bacterial and viral contamination of food crops
	Using wastewater from industry for irrigation Shammi M, Kashem MA, Rahman MM, Hossain MD, Rahman R, Uddin MK, 2016. Health risk assessment of textile effluent reuses as irrigation water in leafy vegetable Basella alba.	Repeated applications of textile waste water increase salinity and heavy metals in agricultural soil

	International Journal of Recycling of Organic Waste in Agriculture, 5, 113-123.	
	Sewage used to grow microalgae for fish feed Sarvala J 1993. Utilization of eutrophication for fish production. Memorie - Istituto Italiano di Idrobiologia.	Toxic substances and disease from sewage loadings in fish feed
Novel sources of food and feed	**Farming insects for food and feed** Schrögel P, Wätjen W, 2019. Insects for food and feed-safety aspects related to mycotoxins and metals. Foods, 8(8), 288.	Accumulation of heavy metals and mycotoxins in insects used for food and feed
	***In vitro* production of meat** Hocquette JF 2016. Is in vitro meat the solution for the future? Meat science, 120, 167-176.	Hormones and endocrine disruptors might migrate into food from in vitro cultivation; cancerous cells may be present in artificial meat and risk for human health is unknown
	Production of novel proteins from algae Bleakley S and Hayes M, 2017. Algal proteins: extraction, application, and challenges concerning production. Foods, 6(5), 33. McClain S, Bowman C, Fernández-Rivas M, Ladics GS, Van Ree R, 2014. Allergic sensitization: Food-And protein-related factors. Clinical and Translational Allergy, 4, 11.	Novel proteins have an allergy potential
	Earthworms for human consumption Conti C, Castrica M, Balzaretti CM, Tedesco DEA, 2019. Edible earthworms in a food safety perspective: Preliminary data. Italian Journal of Food Safety, 8, 7695.	Potential for microbial contamination of earthworms fed on fruit and vegetable waste
Crop protection and breeding	**Genetically engineering crops to utilise resources more efficiently and minimise reliance on chemical pesticides** Bauer-Panskus A, Miyazaki J, Kawall K and Then C, 2020. Risk assessment of genetically engineered plants that can persist and propagate in the environment. Environmental Sciences Europe, 32(1), 1-15.	Genetically engineered organisms may be able to persist and spontaneously propagate in the environment

	Use of bio-pesticides as alternative to synthetic chemicals Zhang Y, Chen H, Fan Y, Yang Y, Gao J, Xu W, Xu Z, Li Z, Tao L, 2019. Cytotoxic effects of bio-pesticide spinosad on human lung A549 cells. Chemosphere, 230, 182-189.	Occupational exposure to bio-pesticide during agricultural production can induce cytotoxic effects
	Encouraging natural pest control and reducing reliance on synthetic chemicals Lynch LD, Ives AR, Waage JK, Hochberg ME and Thomas MB, 2002. The risks of biocontrol: transient impacts and minimum nontarget densities. Ecological Applications, 12(6), 1872-1882.	Biocontrol agents can cause a strong decline or local extirpation of the nontarget species
Livestock health and breeding	**Breeding livestock that can efficiently utilise biomass inedible for humans** Van Zanten HHE, 2019. The role of farm animals in a circular food system. Global Food Security 21, 18-22.	
	Curtailing antibiotic use to reduce antibiotic resistant genes in livestock waste used as manure Rauseo J, Caracciolo AB, Ademollo N, Cardoni M, Di Lenola M, Gaze W, Stanton I, Grenni P, Pescatore T, Spataro F and Patrolecco L, 2019. Dissipation of the antibiotic sulfamethoxazole in a soil amended with anaerobically digested cattle manure. Journal of hazardous materials 378, 120769.	Livestock waste can be a source of antibiotic resistant bacteria and genes in agroecosystems
	Occupying materials & bedding for livestock to improve welfare from by-product, re-cycled or re-used sources Woelk L, Luber P, Reckzeh C, 2020. Toys and occupying materials in animal husbandry ID0426. Briefing Note on Emerging Issues EFSA.	Potential microorganism, mycotoxin and chemical contamination of occupying materials and bedding that passes up the food chain
Locally produced food and feed to reduce food miles	**Urban hydroponic farming** Schnitzler WH 2013. Urban hydroponics for green and clean cities and for food security. Acta Horticulturae, 1004(1004), 13-26.	

3.1.3.2. Reducing industrial/manufacturing/processing waste

Different types of biorefineries aim to use processing of various biomass streams from agro-industry to create bio-based products, including novel food/feed, food/feed additives (e.g. prebiotics), food packaging/films and bioenergy. These biomass streams derive from processing (e.g. slaughterhouses), manufacturing (e.g. manufacture of food and feed products and nutritional supplements) and industrial processing of non-food crops (e.g. crops grown for energy). Using these previously unused biomass sources aims to reduce waste and ensure efficient use of resources within the circular economy for food and feed.

Four biomass streams were identified from which biobased products are produced:

- Livestock (excluding fish/crustacea) waste – waste generated in the processing or manufacturing of products from dairy/eggs/meat
- Food crop waste – waste generated in the processing or manufacturing of products from crops grown for food
- Fish/crustacea waste – waste from processing and manufacturing of products containing fish and crustacea
- Non-food crop waste – waste from crops grown for purposes other than food

Current EU legislation prohibits the use of some animal protein waste streams in food and feed. Regulation EC 1069/2009 prohibits 'intra-species recycling' due to concerns about the transmission of prions and pathogens. A recent (August 2021) change in legislation (EC 2021/1372) has re-authorised the use of some inter-species recycling that was previously prohibited, specifically:

- processed animal proteins (PAP) derived from pigs and insects in poultry feed;
- processed animal proteins derived from poultry and insect in pig feed;
- gelatine and collagen of ruminant origin in the feed of non-ruminant farmed animals.

The use of PAPs optimises the use of scarce resources and avoids waste and are fully in line with circular economy objectives. For this reason, we have included waste streams from animal origin, for use in animal feed as a circular economy practice for consideration.

Table 3 shows examples of current and envisaged practices to utilise biomass streams from industrial/manufacturing/processing and associated risks with practices. Biomass streams are not only used to create biobased products but are also used to create energy and this circular economy practice is also highlighted in the table.

Table 3 - Current and envisaged circular economy practices to utilise and reduce waste from industrial/manufacturing/processing, with specific examples (and risks where highlighted) from the literature.

CE Practice	Example of practice from the literature	Example(s) of potential risk(s) of practice where highlighted by article author
Livestock waste	**Valorization of lactose and whey protein into novel and functional foods products** Lappa IK, Papadaki A, Kachrimanidou V, Terpou A, Koulougliotis D, Eriotou E, Kopsahelis N, 2019. Cheese whey processing: Integrated biorefinery concepts and emerging food applications. Foods 8(8), 347.	
	Waste from slaughterhouses to produce methane and nutrients for animal feed Schwede S, Thorin E, Lindmark J, Klintenberg P, Jääskeläinen A, Suhonen A, Laatikainen R and Hakalehto E, 2017. Using slaughterhouse waste in a biochemical-based biorefinery–results from pilot scale tests. Environmental Technology, 38(10), 1275-1284.	
	Animal waste (e.g. meat and bone) to protein rich animal feed Lange L, Meyer AS 2019. Potentials and possible safety issues of using biorefinery products in food value chains. Trends in Food Science & Technology, 84, 7-11.	Pathogen and disease transfer in food chain
	Waste from egg for fertiliser, feed and food Caldeira C, Vlysidis A, Fiore G, De Laurentiis V, Vignali G, Sala S, 2020. Sustainability of food waste biorefinery: A review on valorisation pathways, techno-economic constraints, and environmental assessment. Bioresource Technology, 312, 123575.	
Food crop waste	**Brewery and vinification industry waste used to make food and feed products** Lavelli V, Torri L, Zeppa G, Fiori, L, Spigno G, 2016. Recovery of winemaking by-products for innovative food applications. Italian Journal of Food Science 28, 542-564. Świątkiewicz S, and Koreleski J, 2008. The use of distillers dried grains with solubles (DDGS) in poultry nutrition. World's Poultry Science Journal, 64(2), 257-266.	
	Wastes from olive industry used for production of food, pharmaceutical and nutraceutical compounds	

	Cláudio AFM, Cognigni A, de Faria ELP, Silvestre AJD, Zirbs R, Freire MG, Bica K, 2018. Valorization of olive tree leaves: Extraction of oleanolic acid using aqueous solutions of surface-active ionic liquids. Separation and Purification Technology, 204, 30-37. del Pozo C, Bartrolí J, Puy N and Fàbregas E, 2018. Separation of value-added chemical groups from bio-oil of olive mill waste. Industrial Crops and Products, 125, 160-167.	
	Bioplastic produced from rice straw for food packaging Bilo F, Pandini S, Sartore L, Depero LE, Gargiulo G, Bonassi A, Federici S, Bontempi E, 2018. A sustainable bioplastic obtained from rice straw. Journal of Cleaner Production, 200, 357-368.	
	Xylooligosaccharides from rye grass used as prebiotics for farm animals Lange L and Meyer AS, 2019. Potentials and possible safety issues of using biorefinery products in food value chains. Trends in Food Science & Technology, 84, 7-11.	
	Pectin and essential oils extracted from orange peel for use in foodstuffs Fidalgo A, Ciriminna R, Carnaroglio D, Tamburino A, Cravotto G, Grillo G, Ilharco LM, Pagliaro M, 2016. Eco-friendly extraction of pectin and essential oils from orange and lemon peels. ACS Sustainable Chemistry and Engineering, 4, 2243-2251.	
	Starch and bioactive compounds from waste potato and peelings for food (e.g. nutraceuticals) and non-food (e.g. biopolymer film) applications Torres, M.D.; Fradinho, P.; Rodríguez, P.; Falqué, E.; Santos, V.; Domínguez, H. (2020). Biorefinery concept for discarded potatoes: Recovery of starch and bioactive compounds Journal of Food Engineering 275:109886	
Fish/Crustacea waste	**Fish waste used to make food supplements** Alfio VG, Manzo C and Micillo R, 2021. From Fish Waste to Value: An overview of the sustainable recovery of omega-3 for food supplements. Molecules, 26(4), 1002.	
	Chitosan from seafood waste used to extend the shelf life of food Bonwick G, Bradley E, Lock L and Romero R, 2019. Bio-based materials for use in food contact applications. Fera project number FR/001658. Report to the Food Standards Agency June 2019.	Allergenicity of chitosan and potential toxicity of chitosan nanomaterials that migrate into food (e.g. resulting from incomplete purification)

	Santos VP, Marques N, Maia P, Lima M, Franco LO and Campos-Takaki GM, 2020. Seafood waste as attractive source of chitin and chitosan production and their applications. International Journal of Molecular Sciences, 21(12), 4290.	Environmental impact of their production and degradation unknown.
	Recovery of proteins from microalgal biomass grown in fish manure for use as fish feed Hernández D, Molinuevo-Salces B, Riaño B, Larrán-García AM, Tomás-Almenar C and García-González MC, 2018. Recovery of protein concentrates from microalgal biomass grown in manure for fish feed and valorization of the by-products through anaerobic digestion. Frontiers in Sustainable Food Systems, 2, 28.	
	Recovered Omega 3 lipids for use in food and feed Lange L and Meyer AS, 2019. Potentials and possible safety issues of using biorefinery products in food value chains. Trends in Food Science & Technology, 84, 7-11.	Oxidation to lipid peroxides and other secondary oxidation products that may be harmful
Non-food crop waste	**Antioxidant phenolic compounds for food and feed from miscanthus** Rivas S, Vila C, Alonso JL, Santos V, Parajó JC and Leahy JJ, 2019. Biorefinery processes for the valorization of Miscanthus polysaccharides: from constituent sugars to platform chemicals. Industrial Crops and Products, 134, 309-317.	
	Xylooligosaccharides from straw used as pre-biotics for pigs Lange L and Meyer AS, 2019. Potentials and possible safety issues of using biorefinery products in food value chains. Trends in Food Science & Technology, 84, 7-11.	Mycotoxins and toxicity of compounds produced in hydrothermal pre-treatment
	Microalgae used after remediation of wastewater to produce biodiesel and biofertilizers Khan SA, Sharma GK, Malla FA, Kumar A and Gupta N, 2019. Microalgae based biofertilizers: A biorefinery approach to phycoremediate wastewater and harvest biodiesel and manure. Journal of Cleaner Production, 211(11), 1412-1419.	
	Protein-rich microorganisms grown on wood waste used for fish food Alriksson B, Hörnberg A, Gudnason AE, Knobloch, S, Arnason J, Johannsson R, 2014. Fish feed from wood. Cellulose Chemistry and Technology 48 (9-10), 843-848.	

Energy Production	**Waste from cultivation and processing of olives used to produce energy** Ruiz E, Romero-García JM, Romero I, Manzanares P, Negro MJ, Castro E, 2017. Olive-derived biomass as a source of energy and chemicals. Biofuels, Bioproducts and Biorefining, 11 (6), 1077.	

3.1.3.3. Reducing food waste in wholesale, food retail, catering and households

In line with EU legislation, all food discarded from the food supply chain (post-harvest) is regarded and quantified as food waste. In this macro area we include food waste discarded by wholesalers (excluding manufacturers), food retailers, caterers and households:

- Wholesale - any business entity that sells food products to other businesses but excluding manufacturers that are covered in the macro area for Industrial/manufacturing/processing waste.
- Retail food - food, other than restaurant food, that is purchased by consumers and consumed off-premise. For example, supermarkets, farmers markets.
- Catering - businesses, institutions, and companies responsible for any meal prepared outside the home. For example, restaurants, school and hospital cafeterias and catering operations
- Households – food waste generated in the residential environment.

Food waste is generated in a multitude of ways, for example: being discarded due to color or appearance; inefficient store operations and replenishment policies; inadequate forecasting of consumer demand; food scraps from preparing meals; overpreparing food for meals; plate waste by consumers; over buying; not eating purchased food before it spoils; and date label confusion. A wide range of practices are currently being used or developed to mitigate food waste as illustrated in Table 3.

Eleven broad circular economy practices were identified to mitigate for food waste:

- Change or removal of date labels (e.g. best before dates) or selling food beyond its best before date
- Using food contact materials to extend shelf life
- Reducing food waste in the supply chain
- Redistribution of edible surplus food for human consumption
- Food waste for animal feed
- Changing marketing and operation management
- Repurposing surplus food for human consumption
- Food waste for energy recovery
- Nutrient recovery from food waste
- Biorefinery of food waste (excluding energy, animal feed & nutrient recovery)
- Knowledge transfer and training to reduce food waste

Current EU regulation (Regulation EC 1069\2009) prohibits food waste of animal-origin (e.g. from catering waste) as animal feed due to concerns about pathogen and prion transmission. In other parts of the world, for example Japan, South Korea and Taiwan, tightly regulated policies and the use of heat treatment, allow food waste of animal origin to be converted into animal feed (Zu Ermgassen et al., 2016). Allowing food waste of animal origin to be used as animal feed in the EU is a topic of current debate in the literature (e.g. Shurson, 2020) and is therefore included as a potential CE practice.

Table 4 provides specific examples of practices within these areas and associated risk.

Table 4 - Current and envisaged circular economy practices to reduce food waste in wholesale, food retail, catering and households, with specific examples (and risks where highlighted) from the literature.

CE practice	Example of practice from the literature	Example(s) of potential risk(s) of practice where highlighted by article author
Change or removal of date labels or selling food beyond best before date	**Change or removal of date labels and selling food beyond best before date** European Environment Agency, 2020. Bio-waste in Europe - turning challenges into opportunities. Report No. 04/2020. Huang IY, Manning L, James KL, Grigoriadis V, Millington A, Wood V, Ward S, 2021. Food waste management: A review of retailers business practices and their implications for sustainable value. Journal of Cleaner Production, 285, 125484. Koutsoumanis K, Allende A, Alvarez-Ordóñez A, Bolton D, Bover-Cid S, Chemaly M, Davies R, De Cesare A, Herman L and Nauta M, 2020. Guidance on date marking and related food information: part 1 (date marking). EFSA Journal, 18(12), 06306.	Contamination of food with pathogenic microorganisms
Food contact materials (FCM) to extend shelf life	**Nanoparticles in food packaging to extend shelf life of product** Primožič M, Knez Ž, Leitgeb M, 2021. (Bio)nanotechnology in food science-food packaging. Nanomaterials 11(2), 292. Bronwick G, Bradley E, Lock I, Romero R, 2019. Bio-based materials for use in food contact applications. Fera project number FR/001658. Report to the Food Standards Agency June 2019.	Immunogenicity and allergenicity of bio-based FCM, migration of nanomaterials into food and toxicity
Reducing food waste in supply chain	**Buying and selling 'whole crop' including cosmetically imperfect produce** de Hooge I, van Dulm E, van Trijp HCM, 2018. Cosmetic specifications in the food waste issue: supply chain considerations and practices concerning suboptimal food products. Journal of Cleaner Production, 183, 698e709.	
Redistribution of edible surplus food for human	**Redistribution of food to charity**	Contamination with bacterial, chemical,

	Science Advice for Policy by European Academies, 2020. A sustainable food system for the European Union. Berlin: SAPEA. Koutsoumanis K, Allende A, Alvarez-Ordóñez A, Bover-Cid S, Chemaly M, Davies R, Herman L, Hilbert F, Lindqvist R and Nauta M, 2018. Scientific Opinion on the hazard analysis approaches for certain small retail establishments and food donations: second scientific opinion. EFSA Journal, 16(11), 5432.	physical hazards or allergens
	Re-selling surplus food to specialist discount shops or Apps Huang IY, Manning L, James KL, Grigoriadis V, Millington A, Wood V, Ward S, 2021. Food waste management: A review of retailers business practices and their implications for sustainable value. Journal of Cleaner Production, 285, 125484.	
Food waste for animal feed	**Food waste for animal feed (including pets and zoo animals)** Salemdeeb R, zu Ermgassen EKHJ, Kim MH, Balmford A, Al-Tabbaa A, 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. Journal of Cleaner Production, 140(2), 871-880. Castrica M, Tedesco DE, Panseri S, Ferrazzi G, Ventura V, Frisio DG and Balzaretti CM, 2018. Pet food as the most concrete strategy for using food waste as feedstuff within the European context: A Feasibility Study. Sustainability, 10, 2035. Stroka J, Robouch P, Goncalves C, 2021. Aspects of food and feed safety regarding insects and the flow of commodities. JRC, Geel JRC124260. Shurson GC, 2020. What a waste - Can we improve sustainability of food animal production systems by recycling food waste streams into animal feed in an era of health, climate, and economic crises? Sustainability, 2(17), 7071.	Risk of heavy metal accumulation; allergens in feed Mycotoxin, algal and plant toxins in substrate contaminating insects Risk of transmission of prions, parasites, bacteria and viruses
Changing marketing and operations management	**Removal of buy one get one free offers** Aschemann-Witzel J, De Hooge IE, Rohm H, Normann A, Bossle MB, Grønhøj A and Oostindjer M, 2017. Key characteristics and success factors of supply chain initiatives tackling consumer-related food waste – A	

	multiple case study. Journal of Cleaner Production, 155(2), 33-45.	
	Improved forecasting to prevent food waste Kiil K, Dreyer HC, Hovlby H-H, Chabada L, 2018. Sustainable food supply chains: the impact of automatic replenishment in grocery stores. Production, Planning and Control, 29, 106e116.	
Repurposing surplus food for human consumption	**Retailers turn fresh produce nearing the end of its shelf life into other food products** Huang IY, Manning L, James KL, Grigoriadis V, Millington A, Wood V, Ward S, 2021. Food waste management: A review of retailers business practices and their implications for sustainable value. Journal of Cleaner Production, 285, 125484.	
Food waste for energy recovery	**Anaerobic digestion of food waste** Cecchi F and Cavinato C, 2019. Smart approaches to food waste final disposal. International Journal of Environmental Research and Public Health, 16(16), 2860.	
	Rendering of food waste Bedoić R, Špehar A, Puljko J, Čuček L, Ćosić B, Pukšec, T and Duić N, 2020. Opportunities and challenges: Experimental and kinetic analysis of anaerobic co-digestion of food waste and rendering industry streams for biogas production. Renewable and Sustainable Energy Reviews, 130, 109951.	
Nutrient recovery from food waste	**Composting of food waste** Murphy S, Gaffney MT, Fanning S, Burgess CM, 2016. Potential for transfer of Escherichia coli O157:H7, *Listeria monocytogenes* and *Salmonella Senftenberg* from contaminated food waste derived compost and anaerobic digestate liquid to lettuce plants. Food Microbiology, 59, 7-13.	Pathogenic bacteria contamination of food
	Liao H, Friman VP, Geisen S, Zhao Q, Cui P, Lu X, Chen Z, Yu Z, Zhou S, 2019. Horizontal gene transfer and shifts in linked bacterial community composition are associated with maintenance of antibiotic resistance genes during food waste composting. Science of the Total Environment, 660, 841-850.	Contamination of soils by bacteria carrying antibiotic resistant genes
	Anaerobic digestate from food waste used as biofertiliser SAPEA, Science Advice for Policy by European Academies, 2020. A sustainable food system for the European Union. Berlin: SAPEA.	

Biorefinery of food waste	**Biorefinery of food waste for platform chemicals and biomaterials** Dahiya S, Kumar AN, Shanthi Sravan J, Chatterjee S, Sarkar O, Mohan SV, 2018. Food waste biorefinery: Sustainable strategy for circular bioeconomy. Bioresources Technology, 248(Pt A), 2-12.	
Knowledge transfer and training to reduce food waste	**Retailers raising awareness of food waste with consumers** Huang I Y, Manning L, James KL, Grigoriadis V, Millington A, Wood V, Ward S, 2021. Food waste management: A review of retailers business practices and their implications for sustainable value. Journal of Cleaner Production, 285, 125484.	
	Staff training to reduce food waste Huang I Y, Manning L, James KL, Grigoriadis V, Millington A, Wood V, Ward S, 2021. Food waste management: A review of retailers business practices and their implications for sustainable value. Journal of Cleaner Production, 285, 125484.	
	Eco-labelling to motivate companies and raise awareness about food waste European Environment Agency (2020). Bio-waste in Europe - turning challenges into opportunities. Report No. 04/2020.	

3.1.3.4. Reducing food and feed packaging waste

The linear system of take, make and disposing of packaging is having a negative impact on our environment and natural resources. It is now widely recognised that a range of mitigation measures are required to tackle this issue. For example, through legislation. The EU's Single-Use Plastic Directive (EU) 2019/904) aims to reduce or completely phase out single-use plastics, which are commonly used for food packaging, tableware and cutlery. However, packaging also plays an important role in food/feed safety and prolongs shelf life, so a complete phase-out is neither realistic nor desirable (SAPEA 2020). Therefore, we need to be able to safely recycle and reuse existing packaging as well as develop new biodegradable packaging from renewable resources (bio-based packaging).

Five broad circular economy practices were identified:

- Development and recycling of biobased materials
- Recycling of petrochemical based plastics and paper/card packaging materials
- Source reduction
- Reuse of packaging
- Education for reducing use and recycling of packaging

Table 5 provides examples of current and envisaged circular economy practices to reduce food and feed packaging waste and associated risks within these 5 areas.

Table 5 - Current and envisaged circular economy practices to reduce food and feed packaging waste, with specific examples (and risks where highlighted) from the literature.

CE Practice	Example of practice from the literature	Example(s) of potential risk(s) of practice where highlighted by article author
Development and recycling of biobased materials	**Chitosan gel for biodegradable film** Hamil S, Baha M, Abdi A, Alili M, Bilican BK, Yilmaz BA, Cakmak YS, Bilican I, Kaya M, 2020. Use of sea urchin spines with chitosan gel for biodegradable film production. International Journal of Biological Macromolecules, 52, 102-108.	
	Composting nanocomposite food packaging Xia Y, Rubino M, Auras R, 2019. Interaction of nanoclay-reinforced packaging nanocomposites with food simulants and compost environments. Advances in Food Nutrition Research, 88, 275-298.	Mass transfer of nanocomposites into the environment and potential toxicity
	Biodegradable composite from sugar beet pulp for food packaging Li W, Coffin DR, Jin TZ, Latona N, Liu CK, Liu B, Zhang J, Liu L, 2012. Biodegradable composites from polyester and sugar beet pulp with antimicrobial coating for food packaging. Journal of Applied Polymer Science, 126(S1), E362-E373.	
Recycling of petrochemical based plastics and paper/card packaging materials	**Biodegradation of plastic by insects** Yang Y, Yang J, Wu WM, Zhao J, Song Y, Gao L, Yang R and Jiang L, 2015. Biodegradation and mineralization of polystyrene by plastic-eating mealworms: Part 1. Chemical and physical characterization and isotopic tests. Environmental Science & Technology, 49(20), 12080-12086.	
	Recycle post-consumer polyethylene terephthalate (PET) into food packaging materials Silano V, Barat Baviera JM, Bolognesi C, Chesson A, Cocconcelli PS, Crebelli R, Gott DM, Grob K, Lambré C, Mengelers M, 2020. Safety assessment of the process Veolia URRC used to recycle post- consumer PET into food contact materials. EFSA Journal, 18(5), 6125.	Chemical contamination that may pose a risk to human health

	Recycling paper/paperboard for food packaging Mohammadpour I, Ahmadkhaniha R, Jeddi MZ, and Rastkari N, 2016. Heavy Metals in Recycled Pastry Packages and Pastries. Acta Alimentaria, 45(4), 509-514. Vandermarken T, Boonen I, Gryspeirt C, Croes K, Van Den Houwe K, Denison MS, Gao Y, Van Hoeck E, Elskens M, 2019. Assessment of estrogenic compounds in paperboard for dry food packaging with the ERE-CALUX bioassay. Chemosphere, 221, 99-106. Hladíková Z, Kejlová K, Sosnovcová J, Jírová D, Vavrouš A, Janoušek A, Syčová M, Špelina V, 2015. Microbial contamination of paper-based food contact materials with different contents of recycled fiber. Czech Journal of Food Science, 33 (4), 308–312.	Heavy metal contamination of food Endocrine active chemicals migrate into dried food from recycled paperboard. Recycling rate of paperboard food packaging highly related to estrogenic activity. Microbial contamination of food
Source reduction	**Selling produce without packaging** Huang I Y, Manning L, James KL, Grigoriadis V, Millington A, Wood V, Ward S, 2021. Food waste management: A review of retailers business practices and their implications for sustainable value. Journal of Cleaner Production, 285, 125484.	
	'Lightweighting' or using less material to make the same packaging Sæter F, Alvarado IO, Pettersen IN, 2020. Reuse principle for primary packaging circularity in the food system. DS 101: Proceedings of NordDesign 2020, Lyngby, Denmark, 12th - 14th August 2020.	
Reuse of packaging	**Consumers using reusable and refillable containers to buy produce from refilling point or a physical store** Sæter F, Alvarado IO, Pettersen IN, 2020. Reuse principle for primary packaging circularity in the food system. DS 101: Proceedings of NordDesign 2020, Lyngby, Denmark, 12th - 14th August 2020 Ellen McArthur Foundation (2019). Reuse rethinking packaging.	Food safety highlighted as a challenge
	Returnable and reusable containers in retail or catering sector	Food safety highlighted as a challenge

	Ellen McArthur Foundation (2019). Reuse rethinking packaging.	
	Reusing containers, crates, pallets in food production, processing and retail Zhu Y, Wu F, Trmcic A, Wang S, Warriner K, 2020. Microbiological status of reusable plastic containers in commercial grower/packer operations and risk of Salmonella cross-contamination between containers and cucumbers. Food Control, 110, 107021. Ellen McArthur Foundation (2019). Reuse rethinking packaging	Microbial contamination of food Food safety highlighted as a challenge
Education	**Citizen education campaigns for reducing use and recycling of packaging** WRAP 'clear on plastics campaign' and 'recycle' campaign	

3.1.4. Stakeholder consultation

These results relate to: Objective 1C. To carry out a stakeholder consultation to compare and rate each CE practice identified.

The practices listed for the 4 macro areas in the previous section were grouped and simplified into a final list of 26 CE practices as listed in Table 6. These practices were presented to the stakeholders through an online questionnaire (see Section 2.1.2 and Appendix B). Fifty-one respondents completed the questionnaire in which they compared and rated each of the 26 CE practices in terms of:

- importance to the CE
- likely ease of implementation of each CE practice
- likelihood of risk from implementation of each CE practice
- ease of overcoming the risk from implementation of each CE practice
- current state of knowledge regarding the risks from each of the CE practices

Table 6 - Circular economy practices that were presented to stakeholders in the questionnaire.

ID	CE Practice
1	**Use of organic waste streams**
2	**Novel sources of food & feed**
3	**Crop protection & breeding**
4	**Livestock health & breeding**
5	**Locally produced food & feed**
6	**Livestock waste**
7	**Food crop waste**
8	**Fish/Crustacea waste**
9	**Non-food crop waste**
10	**Energy Production**
11	**Date labels or selling beyond best before date**
12	**Food contact materials (FCM) to extend shelf life**
13	**Reducing food waste in supply chain**
14	**Redistribution of edible surplus food**
15	**Food waste for animal feed**
16	**Changing marketing and operations management**
17	**Repurposing surplus food for human consumption**
18	**Food waste for energy recovery**
19	**Nutrient recovery from food waste**
20	**Biorefinery of food waste**
21	**Knowledge transfer & training to reduce food waste**
22	**Development & recycling of biobased materials**
23	**Recycling of plastics & paper/card packaging**
24	**Source reduction**
25	**Reuse of packaging**
26	**Education**

3.1.4.1. The importance of the CE practice to the circular economy

The values rating the importance of the different practices to the circular economy are shown in Table 7. They are ranked in descending order with the highest at the top. The top 7 practices identified as most important were:

- Use of organic waste streams

- Food crop waste
- Reducing food waste in supply chain
- Education
- Reuse of packaging
- Recycling of plastics & paper/card packaging
- Source reduction

Table 7 - Stakeholder opinion on the importance of named CE practices within all stages of food/feed chains in Europe to the circular economy, ranked by level of importance according to categories provided by questionnaire participants (n=51).

Circular Economy Practice	Score	
1. **Use of organic waste streams**	8.1	High
7. **Food crop waste**	8.0	
13.**Reducing food waste in supply chain**	7.9	
26. **Education**	7.3	
25. **Reuse of packaging**	7.3	
23. **Recycling of plastics & paper/card packaging**	7.1	
24. **Source reduction**	7.1	
6. **Livestock waste**	6.8	
21. **Knowledge transfer & training to reduce food waste**	6.5	
8. **Fish/Crustacea waste**	6.4	
3. **Crop protection & breeding**	6.4	
14. **Redistribution of edible surplus food**	6.2	
22. **Development & recycling of biobased materials**	6.2	
4. **Livestock health & breeding**	6.1	Mean
17. **Repurposing surplus food for human consumption**	5.9	
19. **Nutrient recovery from food waste**	5.9	
15. **Food waste for animal feed**	5.8	
12. **Food contact materials (FCM) to extend shelf life**	5.7	
2. **Novel sources of food & feed**	5.6	
5. **Locally produced food & feed to reduce food miles**	5.4	
11. D**ate labels or selling beyond best before date**	4.9	
16. **Changing marketing and operations management**	4.9	
20. **Biorefinery of food waste**	4.8	
9. **Non-food crop waste**	4.5	
10. **Energy Production**	4.1	
18. **Food waste for energy recovery**	4.1	Low

3.1.4.2. The likelihood of risk from implementation of the practice and the ease of overcoming the risk from implementation of the practice

The likelihood of risk from implementation of the circular economy practices compared to the ease of overcoming the risk from implementation is shown in Figure 5. The top 7 practices identified as most important (Table 7) are highlighted as red dots. Those practices considered to have the highest likelihood of risk are circled. These were:

- Use of organic waste streams
- Recycling of plastics & paper/card packaging
- Livestock waste
- Crop protection & breeding
- Development & recycling of biobased materials
- Food contact materials (FCM) to extend shelf life
- Novel sources of food & feed

The responses indicated that the ease of overcoming the risk from implementation was similar for most of the practices. Changing marketing and operations management (16) was considered the risk that was easiest to overcome and Novel sources of food & feed, Crop protection & breeding, Food contact materials (FCM) to extend shelf life and Recycling of plastics &paper/card packaging (2, 3, 12 and 23) had risks thought to be more difficult to overcome.

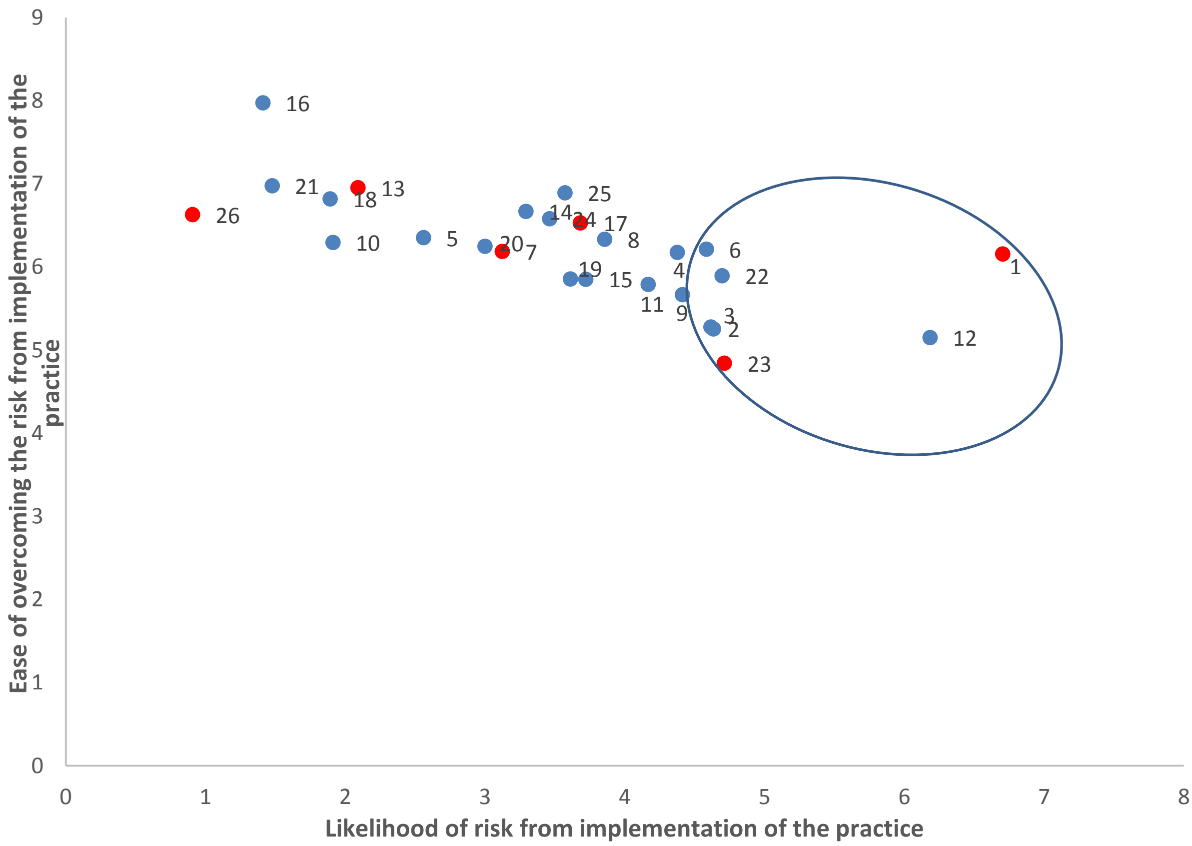

Figure 5 - The perceived likelihood of risk from implementation of a food/feed related practice versus the ease of overcoming the risk from implementation of the practice, based on stakeholder response to the questionnaire. Red dots are those practices that had the highest mean scores for importance to the circular economy within food/feed chains in Europe. The circle highlights the seven practices that have the highest perceived risk and are also perceived to be the least easy to overcome.

Table 8 shows the ranking of the importance of practice to the circular economy and the 7 practices considered to have the highest likelihood of risk. These practices are highlighted in red and orange (identified as the practices with the highest likelihood of risk from implementation in Figure 5), with red being considered higher risk than those marked orange.

Table 8 - Stakeholder opinion on the importance of named CE practices within all stages of food/feed chains in Europe to the circular economy, ranked by level of importance according to categories provided by questionnaire participants (n=51) with those rated as highest (highlighted red) and high (highlighted orange) risk shown.

Circular Economy Practice	Score for importance to circular economy	
1. Use of organic waste streams	8.1	High
7. Food crop waste	8.0	
13.Reducing food waste in supply chain	7.9	
26. Education	7.3	
25. Reuse of packaging	7.3	
23. Recycling of plastics & paper/card packaging	7.1	
24. Source reduction	7.1	
6. Livestock waste	6.8	
21. Knowledge transfer & training to reduce food waste	6.5	
8. Fish/Crustacea waste	6.4	
3. Crop protection & breeding	6.4	
14. Redistribution of edible surplus food	6.2	
22. Development & recycling of biobased materials	6.2	
4. Livestock health & breeding	6.1	Mean
17. Repurposing surplus food for human consumption	5.9	
19. Nutrient recovery from food waste	5.9	
15. Food waste for animal feed	5.8	
12. Food contact materials (FCM) to extend shelf life	5.7	
2. Novel sources of food & feed	5.6	
5. Locally produced food & feed to reduce food miles	5.4	
11. Date labels or selling beyond best before date	4.9	
16. Changing marketing and operations management	4.9	
20. Biorefinery of food waste	4.8	
9. Non-food crop waste	4.5	
10. Energy Production	4.1	
18. Food waste for energy recovery	4.1	Low

3.1.4.3. The importance of practices to the circular economy and the likely ease of implementation of practice

Combined stakeholder opinions on the importance of each practice to the circular economy was compared with the likely ease of implementation of practice and the results are shown in Figure 6. The seven practices considered most important to the circular economy whilst also having the greatest ease of implementation are circled. These were:

- Use of organic waste streams
- Livestock waste
- Food crop waste
- Reducing food waste in supply chain
- Knowledge transfer & training to reduce food waste
- Reuse of packaging
- Education

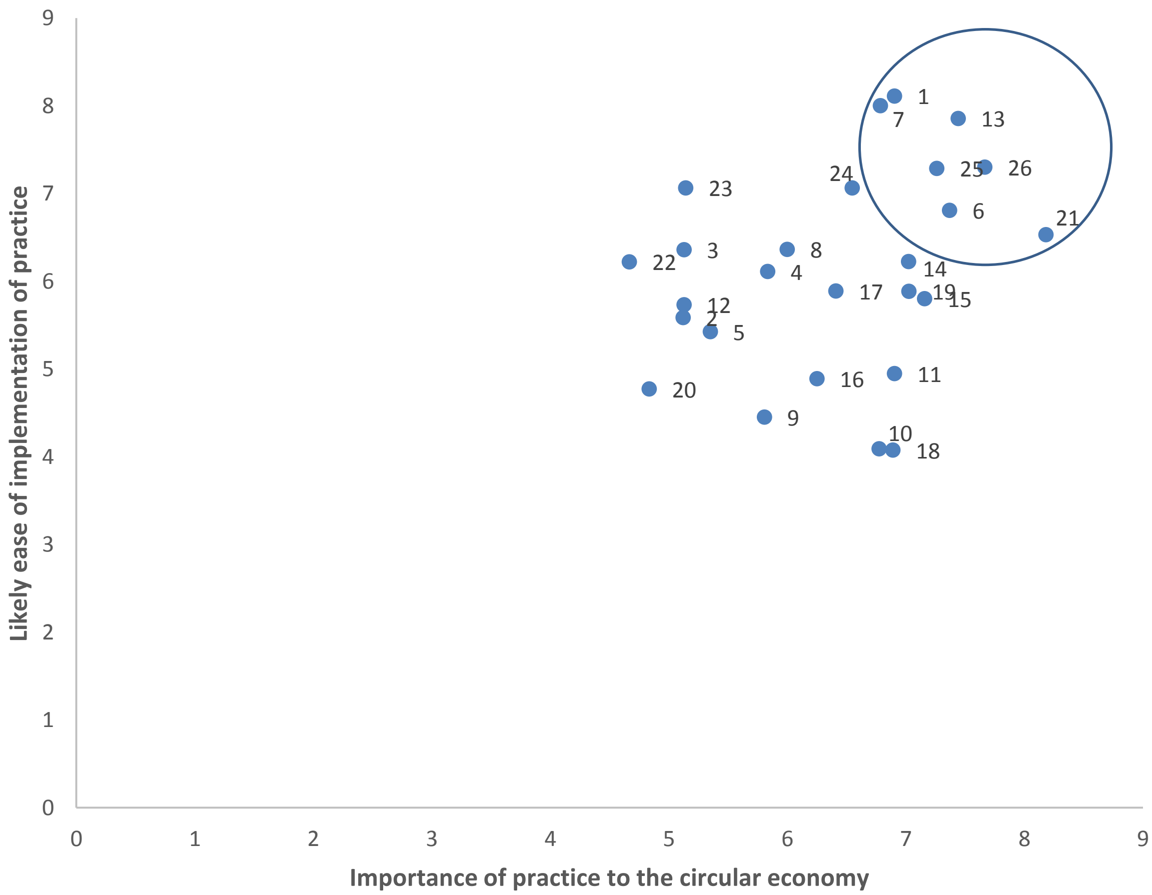

Figure 6 - The perceived importance of practice to the circular economy versus the likely ease of implementation of practice as based on stakeholder questionnaire responses. The circle highlights the seven practices that are perceived as both most important and most easy to implement.

3.1.4.4. The current state of knowledge regarding the risks from these circular economy practices

The identified current state of knowledge regarding the risks from the 26 circular economy practices is shown at Figure 7. Current knowledge was considered particularly low for:

- Biorefinery of food waste
- Novel sources of food & feed
- Development & recycling of biobased materials
- Food contact materials (FCM) to extend shelf life

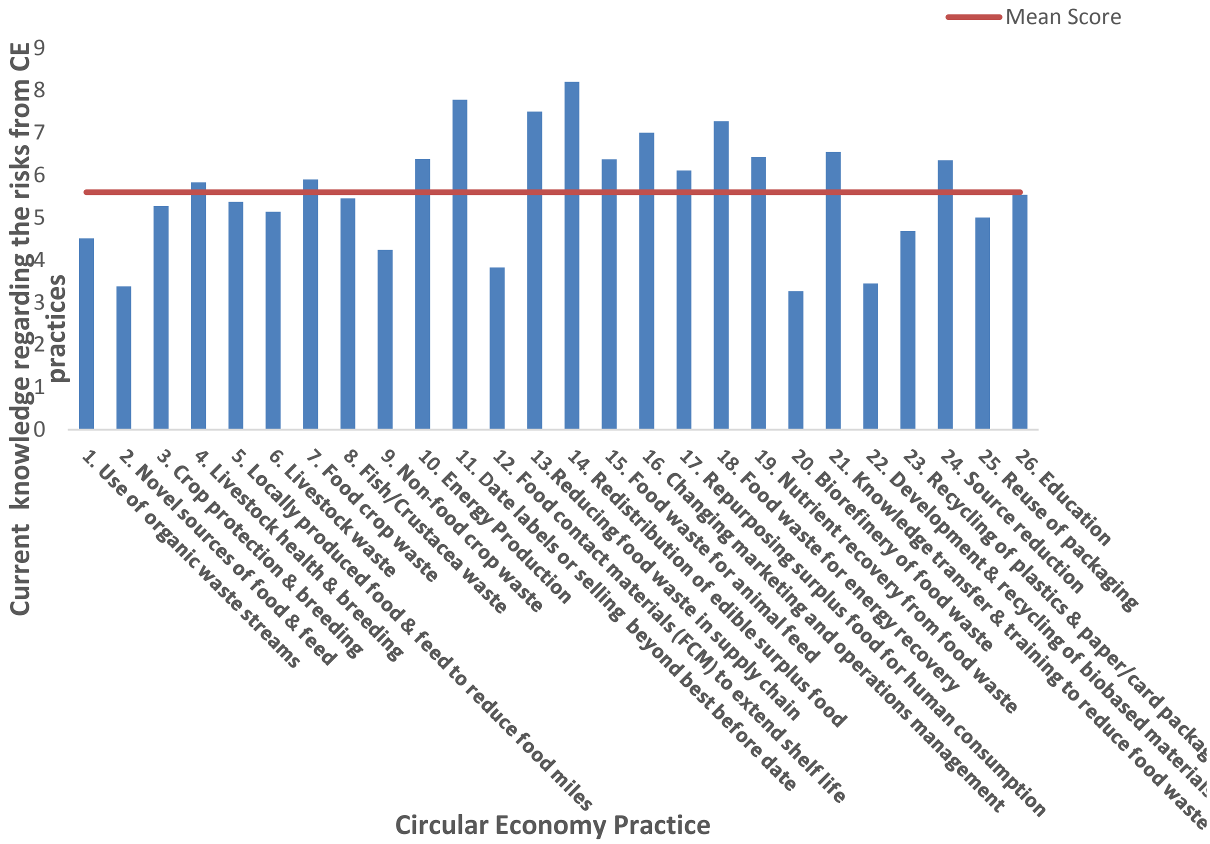

Figure 7 - The current state of knowledge regarding the risks from these circular economy practices

3.1.5. Identification of the topic area for the literature search in Objective 2, using the survey results to inform the decision-making

The results of the survey were used to inform the identification of the topic area for the literature search carried out in Objective 2. The topic identification exercise was carried out in consultation with the EFSA project team on the 8/07/2021.

Identification of the topic area was carried out in two stages:

Stage 1. The EFSA team proposed a higher weighting (x 1.5) for the stakeholder scores for each CE practice for the following criteria combined:

- The likelihood of risk from implementation of the CE practice
- Ease of overcoming the risk from implementation of the CE practice
- The current state of knowledge regarding the risks from the CE practice

The top 10 CE practices with the highest overall values for the criteria listed above were considered in stage 2 (Table 9.).

Stage 2. The top 10 CE practices from stage 1 were discussed against 4 further criteria with EFSA to identify the final topic area for the literature search in Objective 2. The criteria were:

- Time constraints of the project and the likely volume of evidence for each CE practice
- Expertise of the contractor project team
- Policy needs
- Expert evaluation

Table 9 - Combined scores (including 1.5 weighting) for stakeholder responses to likelihood of risk from implementation of the CE practice, ease of overcoming the risk from implementation of the CE practice and current state of knowledge regarding the risks from the CE practice. The top 10 practices with the highest scores are highlighted in bold.

Circular economy practice	Weighted combined criteria
1. Use of organic waste streams	**40.60**
2. Novel sources of food & feed	**34.90**
3. Crop protection & breeding	**32.79**
4. Livestock health & breeding	31.50
5. Locally produced food & feed to reduce food miles	27.88
6. Livestock waste	**35.82**
7. Food crop waste	**32.84**
8. Fish/Crustacea waste	31.63
9. **Non-food crop waste**	**32.75**
10. Energy Production	26.25
11. Date labels or selling beyond best before date	29.10
12. **Food contact materials (FCM) to extend shelf life**	**36.81**
13.Reducing food waste in supply chain	28.96
14. Redistribution of edible surplus food	27.72
15. Food waste for animal feed	31.70
16. Changing marketing and operations management	22.91
17. Repurposing surplus food for human consumption	30.34
18. Food waste for energy recovery	24.52
19. Nutrient recovery from food waste	31.34
20. Biorefinery of food waste	30.37
21. Knowledge transfer & training to reduce food waste	29.22
22. **Development & recycling of biobased materials**	**34.20**
23. **Recycling of plastics & paper/card packaging**	**34.98**
24. Source reduction	30.97
25. **Reuse of packaging**	**34.14**
26. Education	30.22

In discussion with EFSA, and using the criteria outlined in Stage 2, it was decided that 'novel sources of foods and feeds' within the CE framework, would be the focus area for Objective 2. The survey results indicated that current knowledge was considered particularly low for 'novel sources of food and feed' and potential likelihood of risk was high. Furthermore, this topic incorporates many of the other crosscutting CE practices including 'livestock wastes', 'food crop waste', 'non-food crop waste', 'biorefinery sidestreams' and 'food waste for animal feed'. It was decided that 'novel foods and feeds that are not related to minimising waste or utilising sidestreams or FFP but that have wider sustainability benefits would not be included in the extensive literature search e.g. foods grown in laboratories (and not using waste, former food stuffs or side streams as a substrate).

3.2. Objective 2. To identify emerging risks for plant, animal and human health and the environment related to CE, resulting from new hazards and new exposure pathways leading to increased exposure.

The focus area for Objective 2 was 'novel sources of foods and feeds' within the CE framework

A record of all the literature searches (source, date of search, search string used, number of hits etc) are provided in Appendix C, Worksheets 3-5.

3.2.1. Objective 2A Literature search descriptive statistics for articles about emerging risk to human, animal or plant health or the environment from novel food and feed within the CE framework

The screening process outlined in Section 2.2.1.7 resulted in the identification of 26 relevant primary research articles that investigated risk to human, animal or plant health or the environment from novel food or feed within the CE framework. Two of the 26 articles reported the same study. This study was first published in conference proceedings (van Zanten et al., 2014) and was subsequently published a year later in a peer reviewed journal (van Zanten et al., 2015). The study in the peer reviewed article was carried forward for characterisation of emerging risk because it reported the study in greater detail. Therefore, 25 primary research articles reporting 25 unique studies were carried forward to Objective 3 for meta-data extraction and characterisation of the identified emerging risks. Twenty-eight relevant reviews and reports, and one PhD thesis were captured and screened for relevant primary research studies, any found are included in the 25 studies above. Useful inferences from authors of reviews and reports were also noted and described in this report under Objective 3.

3.2.2. Objective 2B. Stakeholder consultation in collaboration with EFSA and Prospex

The stakeholder consultation in collaboration with EFSA and Prospex resulted in identification of an additional primary research study. Therefore, a total of 26 primary research studies were carried forward to Objective 3. An additional report was also identified by stakeholders (bringing the total number of reports/reviews to 29), and useful inferences from this report are discussed in Objective 3.

Discussions and feedback from the meeting highlighted the need for two additional literature search strings, for topics relating to recycling of plant waste/sidestreams and fermentation of waste/sidestreams (see Section 2.2.1.5). No additional relevant literature was captured using these search strings.

The stakeholder meeting also validated the characterisation methodology for Objective 3.

Figure 8 shows the literature capture and screening processes leading to the identification of the 26 primary research articles reporting 26 unique studies about risk to human, animal and plant health or the environment from novel foods and feeds within the circular economy framework.

3.2.3. Literature search description for articles about novel food and feed within the CE framework but that did not investigate or report risk to human, animal or plant health or the environment

Articles about novel food or feed within the CE framework but which did not investigate hazards or report risk, or that were about animal production performance parameters fell into 2 main categories:

(1) the impact of novel feeds on animal production performance parameters (e.g. growth, digestibility, development) where no risk was found so long as the feed was fed to animals within the guidelines recommended by the study author. These studies were categorised into studies conducted in European and non-European countries.

(2) research about novel foods and feeds within the CE framework but where risk to human, animal or plant health or the environment was not investigated or reported. For example, these studies often investigated industrial techniques for developing foods and feeds such as extrusion or fermentation processes and composition analysis.

Nearly 1000 research articles were captured that investigating the impact of novel feeds on animal production performance parameters. The volume of research reporting about novel foods and feeds, but where no risk was investigated or reported, was much lower with just over 100 articles captured.

It was often difficult to decipher the country a study originated from because full texts were not obtained. Therefore, categorisation of European and non-European studies comes with the caveat that some studies may have been categorised incorrectly.

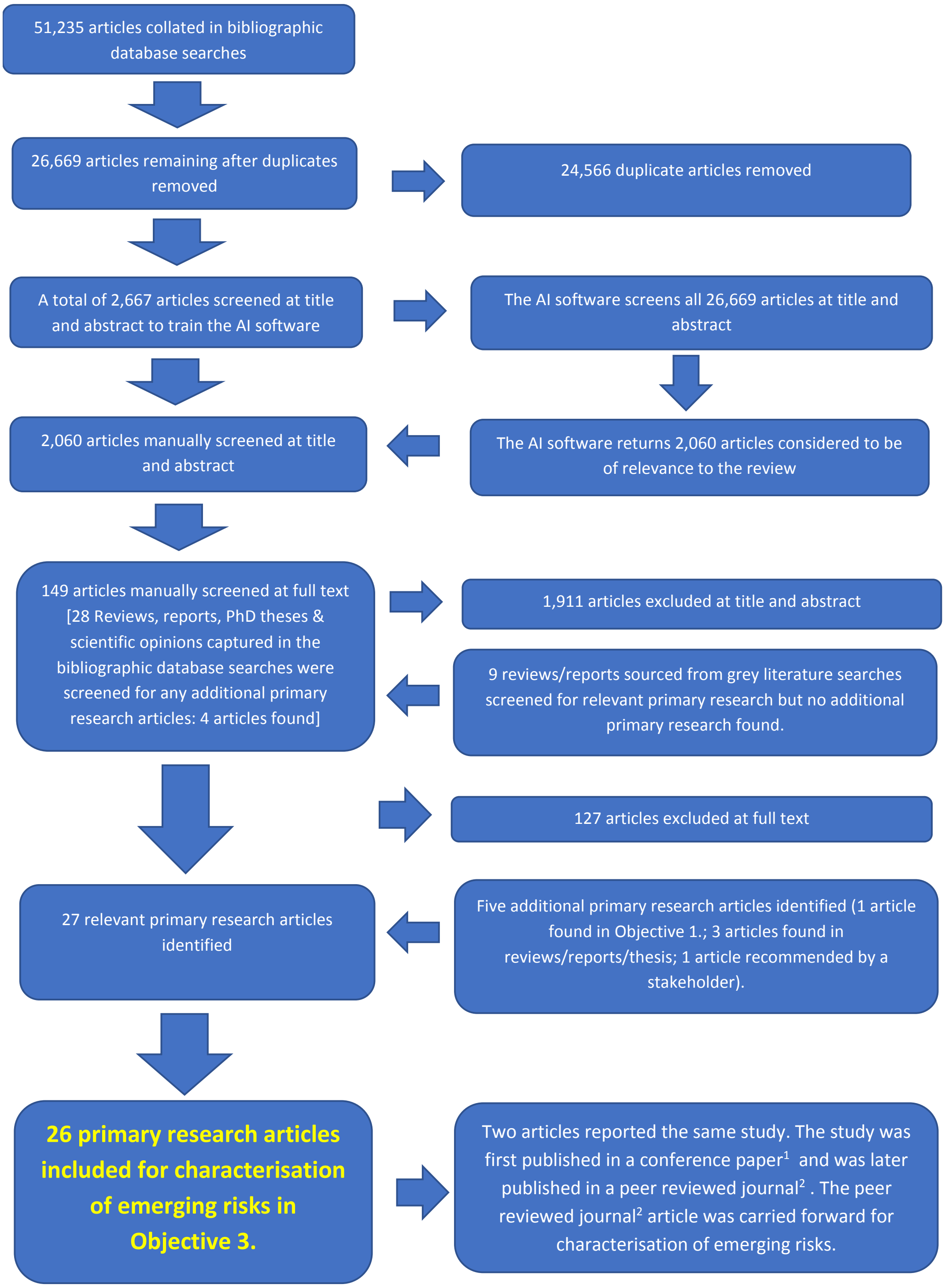

Figure 8 - Flow diagram depicting the literature capture and screening processes leading to the identification of the 26 primary research articles reporting 26 unique studies about risk to human, animal and plant health or the environment from novel foods and feeds within the CE framework

([1]van van Zanten HHE Oonincx DGAB, Mollenhorst H, Bikker P, Meerburg BG, de Boer IJM, 2014. Can environmental impact of livestock feed be reduced by using waste-fed housefly larvae? In: Proceedings of the 9th International Life Cycle Assessment of Foods Conference (LCA Food 2014), San Francisco, USA, 2014-10-08/2014-10-10 p. 1455 – 1461; [2] van Zanten HHE, Mollenhorst H, Oonincx DGAB, Bikker P, Meerburg BG, de Boer IJM, 2015. From environmental nuisance to environmental opportunity: housefly larvae convert waste to livestock feed, Journal of Cleaner Production:102:362-369).

3.2.4. Number of studies published per year investigating the risk for the human or animal health or the environment from novel food or feed within the CE

Twenty-six primary research studies investigated risk to the environment or human, or animal health from novel food or feed within the CE framework (Appendix D, Worksheet 2.). No studies were found that reported risk to plant health. The earliest study was published in 2011 and the latest in 2021 (Figure 9). With the exception of one study published as a conference proceeding all other studies were published in peer-reviewed journals.

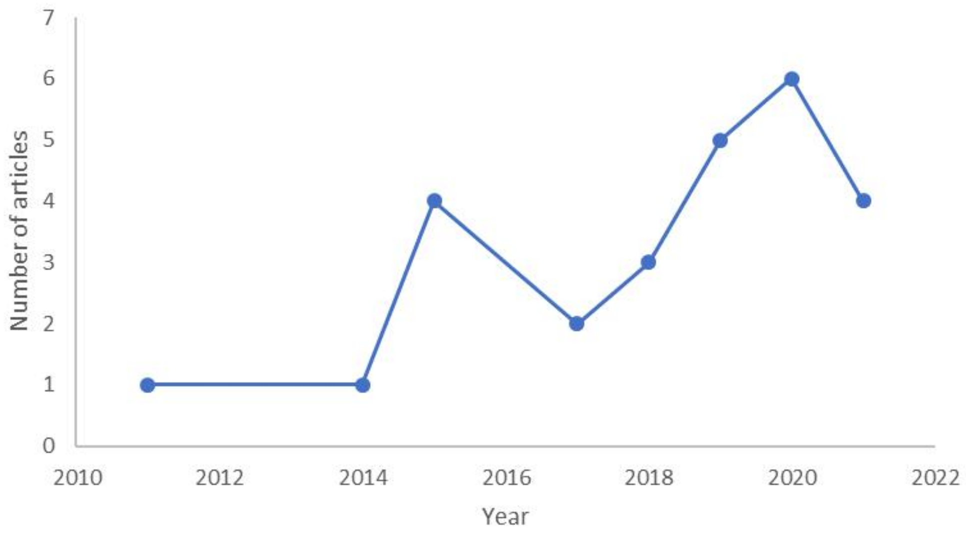

Figure 9 - Number of studies published per year investigating the risk for the human or animal health or the environment from novel food or feed within the CE

Nearly all of the studies were conducted in Europe with the exception of one study from Japan (Kader et al., 2011) and one study that reported experiments in China, Mali and Ghana and the United Kingdom (Charlton et al., 2015).

3.3. Objective 3. To characterise the identified emerging risks justifying the definition of emerging risk, relevant for EFSA's prioritisation and risk assessment activities.

These results relate to Objective 3A. To extract meta-data from the full text of studies about novel food and feed within the CE framework where there are associated risks to human, animal, plant health and the environment

3.3.1. Emerging risk to human, animal or plant health or the environment from novel foods and feeds within the CE framework

3.3.1.1. Overview of the novel food and feed investigated in each of the 26 primary research studies

Nearly all of the studies (n=24) investigated the rearing of invertebrates for food or feed on substrate arising from waste, side streams or FFP (Figure 10). The invertebrates studied were: *Hermetia illucens* (black soldier fly) n=14; *Musca domestica* (house fly) n=3; *Tenebrio molitor* (yellow mealworm) n=3; *Eisenia fetida* (earthworm) n=3; *Alphitobius diaperinus* (lesser mealworm) n=1; *Calliphora vomitoria* (bluebottle fly) n=2; *Chrysomya* spp (n=1) (some studies investigated more than one invertebrate species). One of these (24) studies investigated both *M. domestica* larvae reared on waste and rapeseed meal compared to traditional soybean meal feed for swine.

The remaining two studies investigated: (i) poultry by product (poultry fat, poultry by-product meal and steam hydrolysed feather meal) for animal feed and (ii) scallop by-product for fish feed.

Table 10. summarises the waste or side stream investigated in the 26 primary research studies that investigated risk to human, animal or plant health or the environment from novel foods and feeds within the CE framework, and the animal it was fed to.

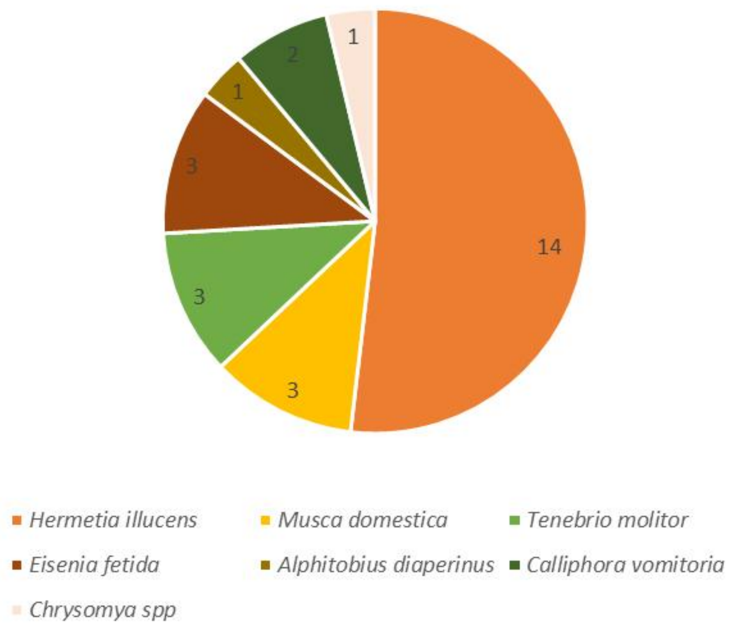

Figure 10 - Number of studies investigating different invertebrate species for food or feed reared on substrate arising from waste or side streams

No studies were found that investigated the risk of novel foods stemming from side streams or waste that are fed directly to humans (i.e. not indirect consumption, for example food insects fed on waste).

Nearly all of the studies aimed to be representative of real-world conditions i.e. substrates were not spiked with contaminants. However, in one study that investigated chemical food safety of using FFP for rearing *H. illucens* larvae for feed and food, packaging inclusion rate was higher than EU regulatory levels for animal feeds to provide a 'worst case' assessment of bioaccumulation of chemicals from substrate containing packaging materials (van der Fels-Klerx et al., 2021). Often the composition of the substrate was unspecified and instead was described as 'food waste', 'sidestream' or, meat or vegetarian FFP (e.g. Salomone et al., 2017; Wynants et al., 2018; van der Fels-Klerx et al., 2020). A range of substrate mixtures were reported, for example coffee silverskin combined with microalgae (Truzzi et al., 2020; Milanović et al., 2021; Osimani et al., 2021), food waste mixed with poultry manure (van Zanten et al., 2015); mixed fruit and vegetable wastes (e.g. Tedesco et al., 2019 & 2020). One author noted that vegetable waste alone is not enough to guarantee a fast insect growth and therefore other substrates containing all the nutrient required (e.g. poultry feed) need to be added to optimise commercial insect rearing (Varotto Boccazzi et al., 2017).

European Commission regulations (EC 999/2001; EC 1774/2002; EC 767/2009) prohibit the use of some materials for animal feed, for example, 'wastes' including faeces, and catering and household waste. However, legislation may differ elsewhere in the world. Eight of the studies captured investigated 'wastes' as substrate for insect rearing including animal manures (e.g. Nordentoft et al., 2014; Charlton et al., 2015; Oonincx et al., 2015) and restaurant and household food waste (e.g. Salomone et al., 2017; Varotto Boccazzi et al., 2017).

Table 10 - Waste or side stream investigated in the 26 primary research studies that investigated risk to human, animal or plant health or the environment from novel foods and feeds within the CE framework, and the animal it was fed to. The corresponding study reference is provided as a footnote at the bottom of the table for studies labelled 1-26.

Substrate/Animal fed	*Chrysomya* spp	*Hermetia illuncens*	*Calliphora vomitoria*	*Eisenia fetida*	Generic animal feed	*Musca domestica*	*Fish*	*Alphitobius diaperinus*	Pig	*Tenebrio molitor*
Cereal by-product		8								
Cereal flours (wheat, maize),										18
Coffee silverskin (roasting by-product)		10, 13,20								
Distillers' grain		2								
Brewers grains		1,2,9								
Brewery spent grain mixed with fish feed waste and yeast		4								
Feather meal					3					
Fish feed waste						4				
Food waste		2,15				23, 24				
Fruit waste		2		16,17						
Maize distiller		1								
Manure - bovine		2,12,14								
Manure - porcine		2,12				4				

Substrate/Animal fed	***Chrysomya* spp**	***Hermetia illuncens***	***Calliphora vomitoria***	***Eisenia fetida***	**Generic animal feed**	***Musca domestica***	***Fish***	***Alphitobius diaperinus***	**Pig**	***Tenebrio molitor***
Manure - poultry		2,12				4,11,23				
Manure – fermented poultry manure						4				
Manure – poultry manure mixed with fish feed waste	4					4				
Municipal organic waste		2								
Olive-pomace										19
Pig offal			4							
Potato starch		7								
Potato processing product		7								
Poultry by-product					3		8			
Rapeseed meal									24	18
Soybean by-product		1,2								18
Sugar beet by-product		2								
Sunflower meal										18
Unknown side stream								26		

Substrate/Animal fed	***Chrysomya* spp**	***Hermetia illuncens***	***Calliphora vomitoria***	***Eisenia fetida***	**Generic animal feed**	***Musca domestica***	***Fish***	***Alphitobius diaperinus***	**Pig**	***Tenebrio molitor***
Vegetable waste		2,25		5,16,17						
***M. domestica* larval meal fed on food waste**									24	
Wheat bran										18
Wheat flour										19
Wheat meal										19
Wheat middlings		2,21								
Wheat processing product		7								
Scallop by-product							6			
Meat and vegetable former food product contaminated with paperboard carton or plastic		22								

1. Bava et al. (2019); 2. Bosch et al. (2019); 3. Campos et al. (2020); 4. Charlton et al. (2015); 5. Conti et al. (2019); 6. Kader et al. (2011); 7. Looveren et al. (2021); 8. Maiolo et al. (2020); 9. Mancinia et al. (2020); 10. Milanović et al. (2021); 11. Nordentoft et al. (2014); 12. Oonincx et al. (2015); 13. Osimani et al. (2021); 14. Parodi et al. (2021); 15. Salomone et al. (2017); 16. Tedesco et al. (2019); 17. Tedesco et al. (2020); 18 Thévenot et al. (2018); 19. Truzzi et al. (2019); 20. Truzzi et al. (2020); 21. Tschirner and Simon (2015); 22. van der Fels-Klerx et al (2020); 23. van Zanten et al. (2015); 24. van Zanten et al. (2018); 25. Varotto Boccazzi et al. (2017); 26. Wynants et al. (2018)

3.3.1.2. Impact of novel feed within the CE framework on insect survival and development

Four studies recorded the impact of novel feed on insect survival and development, together with additional hazards (i.e. environmental, chemical or biological). The results for insect survival and development are presented separately because they may be of research and commercial interest but we believe they do not fit within the remit of EFSA's scientific areas.

All of the studies reported on *H. illucens* larval survival and development when reared on substrates within the CE framework, the results of these studies and author recommendations for mitigation of risk or future research are summarised in Table 11.

Table 11 - Studies reporting the impact of novel feed within the CE framework on insect survival and development and authors recommendations for mitigating risk and future research.

Invertebrate and rearing substrate and citing author	Insect survival and development	Mitigation of risk and Research gaps
Hermetia illucens reared on okara, maize distiller or brewer's grains mixed with trub (hop debris) (Bava et al., 2019)	Larvae fed on the control hen diet and the maize distiller diet had significantly higher final larval weight and required fewer days to reach the prepupal stage. These two diets were high in non-fiberous carbohydrate. Larvae were able to grow on all by-products but substrates with high neutral detergent fiber content, such as brewer's grains, resulted in a low growth rate and final larval weight, which can be a disadvantage for industrial scale production. All by-products allowed a high survival rate.	No mitigation measures reported for insect growth or development. Further studies are needed to evaluate the diet requirements of *H. illucens* larvae in relation to the quality of products.
H. illucens larvae reared on chicken, pig, or cow manure (Oonincx et al., 2015)	Survival rate of the larvae was higher on pig manure than on chicken manure and similar to that on cow manure; development time was similar for larvae on chicken and pig manure, but longer when fed on cow manure. The control feed (poultry feed) performed better than the manures for developmental time.	No mitigation measures reported for insect survival or development. Further research to investigate: (1) if drying manure reduces nutritional content (2) the impact on developmental times of larvae of: Larval age at transfer to manure and dietary quality during early development (e.g. using specialised starter diets), before transfer to manure; feeding fresh manure.
H. illucens larvae reared on dried distillers' grains with solubles or dried sugar beet	Larval survival and yield was lower on the two experimental substrates compared to the control (cereal middlings).	No mitigation measures reported for insect survival or yield.

pulp (Tschirner and Simon, 2015)	Lowest survival was on dried distillers' grains with solubles.	Further research on the nutritional requirements of *H. illucens* larvae.
H. illucens larvae reared on vegetarian or meat former food product (FFP) contaminated with paperboard carton or plastic (van der Fels-Klerx et al., 2020)	No significant difference in survival or total larval weight between FFP with either contaminant in the laboratory. Total weight of larvae was significantly lower in the pilot industrial plant experiment when larvae were reared on FFP contaminated with paperboard carton. Authors concluded that larvae can be reared on FFP containing traces of packaging materials, without negative effects on their growth or survival.	No mitigation measures reported for insect survival and growth. No research gaps highlighted for insect survival and growth.

3.3.1.3. Overview of biological, chemical and allergenic hazards to human and animal health from novel food and feeds within the CE framework

A total of 14 studies measured endpoints for biological or chemical hazards to human or animal health from novel foods or feeds within the CE framework. One study reported a potential allergenic hazard.

All but one of the studies investigated invertebrates reared on side streams, waste or FFP. The remaining study investigated the fish *Pagrus major* reared on scallop by-products (Kader et al., 2011)

The location within a supply chain where risks are most likely to emerge is in the consumption of the invertebrates or fish that have been reared on novel feeds within the framework of the CE.

The hazards reported related to three of EFSA's scientific areas namely 'Biological Hazards', 'Chemical Contaminants' and 'Dietetic Products, Nutrition and Allergies' (Table 12).

Table 12 - The scientific areas within EFSA that hazards reported by studies about novel feeds within the CE framework are related to: BH: 'Biological Hazards'; CC: 'Chemical Contaminants'; DPNA: 'Dietetic Products, Nutrition and Allergies'

Animal and rearing substrate	EFSA scientific area
Tenebrio molitor reared on brewers spent grain	DPNA
Tenebrio molitor reared on olive pomace	CC
Hermetia illucens reared on dried distillers' grains with solubles, dried sugar beet pulp or middlings	CC
Hermetia illucens reared on fruit and vegetable waste	BH
Hermetia illucens reared on coffee silverskin with or without addition of microalgae	BH & CC
Hermetia illucens reared on meat or vegetable FFP contaminated with paperboard carton or plastic packaging material	CC
Hermetia illucens reared on spent brewery grain mixed with fish feed waste and yeast	CC

Eisenia fetida reared on fruit and vegetable waste	BH
Alphitobius diaperinus reared on vegetables and unknown side stream source	BH
Musca domestica reared on poultry manure	CC
Musca domestica reared on poultry manure mixed with fish feed waste	CC
Musca domestica reared on fermented poultry manure	CC
Musca domestica reared on pig manure	CC
Calliphora vomitoria reared on pig offal	CC
Chrysomya sp. reared on poultry manure mixed with fish feed waste.	CC
Pagrus major reared on scallop by-product fermented with soybean meal	CC

3.3.1.3.1. Allergenic hazards to human health from novel foods and feeds within the CE framework as reported by authors and their recommendations for mitigating risk and future research

A single site in vivo controlled and replicated laboratory study in Italy by Mancinia et al. (2020), investigated whether *T. molitor* larvae reared on brewers spent grain contained gluten. Gluten was detected in the larvae. Washing and fasting decreased the quantity of gluten, with the authors concluding that gluten was present on the surface of the mealworms and in their gut. Washing and fasting the larvae resulted in a gluten content below 20 mg/kg and therefore was considered 'gluten free' under EU legislation (Regulation (EC) No 41/2009). However, the authors cautioned that the final risk of contamination is not zero, and testing of mealworms for the presence of gluten is advised (Table 13).

Detection methods are available for the hazard investigated and we are unsure if the substrate is used in current commercial practice for insect rearing.

Table 13 - Study reporting invertebrates reared on novel feeds within the CE framework and the presence of allergenic hazards in insects and study authors recommendations for mitigating risks and future research.

Invertebrate and rearing substrate and citing author	Biological hazard	Mitigation of risk and Research gaps
Tenebrio molitor larvae reared on brewers spent grain (Mancinia et al., 2020)	Larvae reared on brewers spent grain and wheat flour contained gluten above 20 mg/kg and therefore could not be deemed gluten free according to EU legislation (Regulation (EC) No 41/2009). Gluten was present in the gut and surface of the larvae.	Washing and fasting for 48 hrs reduced gluten in larvae fed brewers spent grain to below 20 mg/kg (considered gluten free according to EU legislation) but authors cautioned that the final risk of contamination is not zero, and testing of mealworms for the presence of gluten is advised. No research gaps identified.

3.3.1.3.2. Biological hazards to human and animal health from novel foods and feeds within the CE framework as reported by authors and their recommendations for mitigating risk

Seven studies reported the presence of potential biological hazards in invertebrates and/or insect frass. All seven studies investigated invertebrates reared on sidestreams or food waste. Biological hazards reported were bacterial, fungal, yeasts and antibiotic resistance genes (ARGs). No scientific studies were captured investigating other potential biological hazards such as viruses or parasites. Table 14 summarises the biological hazards identified and author recommendations for mitigating risk and future research. Detection methods for all hazards are available.

Food product: *A. diaperinus* reared on vegetables and unknown side stream source
Biological hazard: Mycotoxinogenic fungi, opportunistic pathogenic yeasts

Wynants et al. (2018), studied the microbial dynamics during production of *A. diaperinus* for human consumption at industrial scale (observational study of a single insect factory in Belgium). Mealworms were reared on dry feed (standard lesser mealworm feed) based on vegetable raw materials which are suitable and allowed for animal feed, and a moist product based on an unspecified side stream from food industry, also allowed for animal feed. *Fusarium spp*. were found in the substrates and *Aspergillus flavus* was detected in the larvae and substrate. These are mycotoxinogenic species. The study also recorded the presence of *Trichosporon asahi* in the larvae and *Diutina rugosa* and *Issatchenkia orientalis* in both the larvae and substrate. These are opportunistic pathogenic yeasts that are known causes of candidemia or trichosporonosis. The authors reported that generally, health hazards due to these species only apply to immunocompromised patients. A blanching treatment significantly reduced all bacterial counts, but a bacterial spore count of 4.0 log cfu/g remained.

The substrate is used in current commercial practice for insect rearing.

Food or feed product: *H. illucens* or *E. fetida* reared on fruit and vegetable waste
Biological hazards: Opportunistic pathogenic yeasts, pathogenic bacteria

Varotto Boccazzi et al. (2017), studied the fungal microbiota of *H. illucens* reared on vegetable waste for animal feed and the potential risks for food and feed safety, in a single site, in vivo, controlled laboratory study, in Italy. The vegetable waste was heat treated restaurant vegetable waste consisting of mashed potatoes, steam or oven cooked carrots and tomatoes. *T. asahii* was detected in the *H. illucens* larvae (as reported by Wynants et al., 2018, for *A. diaperinus* reared on vegetables and an unspecified sidestream). Varotto Boccazzi et al (2017), suggested that further investigations should be conducted to characterize this opportunistic yeast and its presence in insect-based feed or food. As Tedesco et al. (2019) highlighted, Varotto Boccazzi et al. (2017) also cautioned that the thermal treatments of insects as well as the choice of substrate have a great impact on the occurrence and levels of biological contaminants, and the type of thermal treatment is important because not all treatments are effective for complete inactivation of microorganisms and their toxins. The authors also highlighted that sidestreams are often not suitable as a feed source when fed alone to insect larvae, as they do not guarantee optimal production performance, and as such need to be fed in combination with other substrates to improve nutritional quality.

Conti et al. (2019) investigated the microbial food safety of fresh, drying at 50^0C or freeze-dried *E. fetida* reared on fruit and vegetable waste (mixed with straw), in a single site in vivo, field and laboratory experiment, in Italy. *Salmonella* spp. and *Listeria monocytogenes* were absent from the substrate and fresh, heat dried and freeze-dried worms. Fresh earthworm microbial contamination was considered acceptable for all parameters except for *Enterobacteriaceae* when compared to Center for Research and Documentation on Food Safety for minced meat (CeIRSA, 2013). Heat drying and freeze drying resulted in a reduction of all microbial parameters considered by CeIRSA, and were comparable to satisfying category reported for minced meat. The authors highlighted the importance of a heat drying or freeze-drying step in earthworm production for food to reduce microbial contamination to a level safe for food.

Tedesco et al. (2020) studied the risk of biological (bacteria, mycotoxins) [and chemical (pesticides, heavy metals, antibiotic residues, volatile organic compounds (VOCs))] contamination of *E. fetida* fed on fruit and vegetable waste from processing industries, in a single site in vivo, field and laboratory experiment, in Italy. The fruit and vegetable sidestream consisted of: pineapple skins (23%), pineapple tufts (12%), mango pulp and skins (16%), pomegranate skins (approximately 9%), grape including branches (approximately 12%), tomato skins (about 10%), kiwi skins (about 9%), and papaya skins (approximately 9%). The authors also investigated mitigating the risk of bacterial contamination through freeze drying and sterilisation (steam autoclave) of the larvae. Mesophilic aerobic bacteria, Enterobacteriaceae, *Bacillus cereus*, sulphite reducing clostridia and spores of sulphite reducing clostridia were found in fresh, freeze dried and sterilised worms. Overall, bacterial contamination was highest in fresh worms followed by freeze dried worms and all bacteria were <1 Log CFU/g for the sterilised worms. Specifically, *Escherichia coli* and coagulase-positive staphylococci were found in fresh, freeze dried and sterilised samples but at <1 Log CFU/g so were considered safe. The authors reported that whilst freeze drying reduced *B. cereus*, sulphite reducing clostridia and spores of reducing clostridia only sterilisation reduced risk completely. *Salmonella* spp. and *Listeria monocytogenes* were not present in any of the samples taken. This study highlights the industrial processes required to produce a microbiologically safe end-product. The author cautioned that some bacteria and emetic toxin of *B. cereus* can develop resistance to conventional heat treatments and that time and temperature variables should be carefully considered in order to obtain a safe product to include in human food. [In this study no residues of antibiotics, pesticides or mycotoxins were found and heavy metals were below detection levels. The authors concluded that the non-presence of these types of residue was probably due to the fact that the larvae had been fed food grade fruit and vegetables that have therefore undergone strict controls in order to ensure an adequate health and hygiene profile.]

Looveren et al (2021), investigated the occurrence of *Clostridium perfringens* vegetative cells and spores throughout an industrial production process of *H. illucens*, reared on a mixture of potato starch and wheat and potato processing product (plus protein kibble), (observational study in an insect factory in Belgium). *C. perfringens* was found at low numbers in both the (GMP+ certified) starter ingredients, the starter substrate mixture and the residual substrate containing frass. However, vegetative cells and spores of *C. perfringens* were below the detection limit in all larvae samples (starter, harvested, dried and stored larvae) suggesting that the pathogen did not colonise the larvae. Nevertheless, the authors suggested that insect producers monitor this pathogen and install good hygiene practices to avoid contamination. The authors also suggested further studies to verify these results, and testing of other substrates and insect species as horizontal transfer of pathogens from substrate to larvae can be substrate and/or species dependent. They also suggest further research is conducted to investigate the if pathogens in the frass pose a risk when used as fertiliser and how this can be mitigated (e.g. through heat treatment).

Insect factories are permitted to use vegetable raw materials which are suitable and allowed for animal feed in the EU. To our knowledge, earthworm rearing for food or feed on fruit and vegetable sidestreams is still in the experimental stage.

Feed product: *H. illucens* reared on coffee silverskin with or without addition of microalgae

Biological hazards: Antibiotic resistance genes, multidrug-resistant bacteria able to spread ARGs horizontally

Milanović et al. (2021) and Osimani et al. (2021) investigated the biological hazards of rearing *H. illucens* on a diet containing coffee silverskin (a coffee roasting by-product) fed alone or in combination with the microlagae (*Schizochytrium limacinum* or *Isochrysis galbana*). Both studies were single site, in vivo, controlled and replicated laboratory studies conducted in Italy. The rationale for adding microalgae to the diets was to increase the relative quantity of lipids and proteins in the larvae, to improve their nutritional value for animal feed. Both studies investigated contamination of the substrates, larvae and frass.

Milanović et al. (2021) examined the presence of 12 antibiotic resistance genes (ARGs) conferring resistance to the antibiotics erythromycin (erm), tetracycline (tet), vancomycin (vam), β-lactams (bla, mec), and aminoglycosides (aac-aph). The tet(M) and tet(S) genes were widely present in all analysed substrates, with the tet(K) gene also found in coffee silverskin. Larvae reared on the basal coffee silverskin substrate resulted positive for the erm (B) and tet (O) genes. However, no significant effect of rearing substrates (i.e. with and with microalgae added at different proportions to the coffee silverskin) on the distribution of the AR genes in the *H. illucens* larvae was found. In contrast, the authors observed that the frass samples were characterised by a significant accumulation of ARGs, and this was particularly evident for the frass after rearing larvae on substrates supplemented with high percentages (>20%) of *I. galbana*. The authors concluded that this raises concern since this waste can be used as a biofertilizer and that chitosan is used as a fish supplement posing risks to both the environment and humans. The authors highlighted that this is the first study to provide a baseline for future antibiotic resistance risk analysis in the edible insect production chain and until risk analyses are carried out they recommend the prudent use of antibiotics during rearing. They also suggested more research is needed to understand the correlation between the copy number of ARG's carried by microbial communities occurring in the rearing substrates and those contained in the insect gut and resulting frass using quantitative PCR assays (Milanović et al., 2021).

Osimani et al. (2021) investigated the microbial dynamics in rearing trials of *H. illucens* larvae fed coffee silverskin and microalgae. In this study the inclusion of *I. galbana* was characterised by the presence of bacteria from the Morganella genus in the larvae. Milanović et al. (2021) pointed out that multidrug-resistant species from the Morganella genus are able to spread ARGs horizontally among the same or different species. These studies highlight that careful consideration is required to assess the potential risks not only of side stream when used alone as substrate for rearing insects but also when combined with other ingredients that may further increase hazards. They also illustrate the importance of a holistic experimental approach to investigating hazards, in this case showing that not only are ARG present but bacteria with the potential to spread ARGs are also present.

We believe that this substrate is still in the experimental stage for insect rearing.

3.3.1.3.3. Chemical hazards to human and animal health from novel foods and feeds within the CE framework as reported by authors and their recommendations for mitigating risk

Seven studies reported the presence of potential chemical hazards in food or feed. A wide range of chemical hazards were reported including heavy metals, dioxins, PCBs, PAHs, mineral oil hydrocarbons, veterinary medicines and pesticides.

In some cases, although chemical contaminants were detected at levels below EU regulatory limits, the study results showed potential for bioaccumulation and so these studies have been included. One of the seven studies reported on the chemical risk of physical hazards, namely plastic and paperboard carton contamination of FFP as substrate for *H. illucens* larvae (van der Fels-Klerx et al., 2020). With the exception of one study on fish fed on fermented soybean meal and scallop by-product blend the remainder investigated FFP, sidestreams and wastestreams novel feeds for insects.

For all studies detection methods are available for the hazards reported.

Table 14 - Studies reporting invertebrates reared on novel feeds within the CE framework and the presence of biological hazards in insects and/or insect frass, or impact of the novel feed on invertebrate survival and study authors recommendations for mitigating risks and future research.

Invertebrate and rearing substrate and citing author	Biological hazard	Mitigation of risk and Research gaps
Eisenia fetida reared on fruit and vegetable sidestream (Conti et al., 2019)	Enterobacteriaceae levels were unacceptable in fresh earthworms when compared to guidelines from Center for Research and Documentation on Food Safety for minced meat (CeIRSA, 2013).	Heat drying (50^{0}C) and freeze drying of earthworms resulted in a reduction of all microbial parameters considered by CeIRSA, on Food Safety for minced meat. Further research about production, proper technological processing, packaging and storage conditions to prevent microbial contamination. Establishment of specific guidelines for the production and commercialization of earthworms for human consumption.
Hermetia illucens reared on a mixture of potato starch and wheat and potato processing product (plus protein kibble) (Looveren et al., 2021)	(Presumptive) *Clostridium perfringens* was found at low numbers in both the (separate) starter ingredients and in the starter substrate mixture, as well as the residual substrate that contained insect frass. Vegetative cells and spores of *C. perfringens* were below the detection limit in all larvae samples.	Insect producers to monitor for *C. perfringens* and install good hygiene practices to avoid contamination. Research to: (1) Test other substrates and insect species as horizontal transfer of pathogens from substrate to larvae can be substrate and/or species dependent (2) Investigate the if pathogens in the frass pose a risk when used as fertiliser and how this can be mitigated (e.g. through heat treatment).
H. illucens larvae reared on coffee silverskin mixed with microalgae (Milanović et al., 2021)	Antibiotic resistance genes (ARGs) present in all analysed substrates. Larvae were positive for ARGs and there was significant accumulation of ARGs in frass, and in particular in frass of insects reared on substrate supplemented with high percentages of the microalgae *Isochrysis galbana*.	Until risk analyses are carried the prudent use of antibiotics during rearing is recommended. To understand the correlation between the copy number of ARG's carried by microbial communities occurring in the rearing substrates and those contained in the insect gut and resulting frass using quantitative PCR assays.

Invertebrate and rearing substrate and citing author	Biological hazard	Mitigation of risk and Research gaps
H. illucens reared on coffee silverskin mixed with microalgae (Osimani et al., 2021)	Inclusion of microalgae (I. galbana) was characterised by the presence of bacteria from the Morganella genus in the larvae. Multi-drug resistant species from the Morganella genus are able to spread ARGs horizontally among the same or different species (as reported by Milanović et al. 2021).	None reported specifically for bacteria from the Morganella genus. None specifically for Morganella genus. Authors suggested that there may be an effect of algae nutrient bioactive substances may effect the abundance of some bacterial taxa in larvae and further research could investigate this potential control of entomopathogenic species and foodborne human pathogens potentially occurring in edible insects.
Earthworms reared on mixed fruit and vegetable sidestream Tedesco et al., 2020	Both fresh and freeze-dried earthworms contain the bacteria: Mesophilic aerobic bacteria, Enterobacteriaceae, *Bacillus cereus*, sulphite reducing clostridia and spores of sulphite reducing clostridia above >1 Log CFU/g. All bacteria were <1 Log CFU/g for the sterilised worms (so considered microbiologically safe). Whilst freeze drying reduced *B. cereus*, sulphite reducing clostridia and spores of reducing clostridia only sterilisation reduced risk completely.	Only sterilisation of defatted earthworms eradicates micro-organisms. Authors cautioned that some bacteria and emetic toxin of *B. cereus* can develop resistance to conventional heat treatments and that time and temperature variables should be carefully considered in order to obtain a safe product to include in human food. Research to investigate: (1) presence of allergens to indirect transmission routes (fresh earthworm–farmed animal–human) (2) nematodes for whom earthworms are intermediate hosts that could contaminate livestock such as poultry, and represent a public health risk for humans and (3) if sterilisation decreases the bioavailability of some amino acids which may affect nutritional content.
H. illucens reared on a combination of heat-treated restaurant vegetable waste and poultry feed (Varotto Boccazzi et al., 2017)	*Trichosporon asahi*, an opportunistic pathogenic yeast known to causes candidemia or trichosporonosis, (usually in immunocompromised persons) present in larvae.	None reported specifically for *T. asahi*. Authors suggested that heat treatment of larvae and/or treatment of substrate with antibiotics may be a mitigation measure for some pathogenic species. but the type of thermal treatment is important

Invertebrate and rearing substrate and citing author	Biological hazard	Mitigation of risk and Research gaps
		because not all treatments are effective for complete inactivation of all microorganisms and their toxins. To characterise the opportunistic yeast *T. asahii* and its presence in insect-based feed or food.
Alphitobius diaperinus larvae reared on unspecified sidestream from food industry (Wynants et al., 2018)	*Fusarium spp*. were found in the substrates and *Aspergillus flavus* was detected in the larvae and substrate. These are mycotoxinogenic species and therefore it cannot be excluded that mycotoxins were present. Presence of *T. asahi* in the larvae and *Diutina rugosa* and *Issatchenkia orientalis* in both the larvae and substrate. These are opportunistic pathogenic yeasts that are known causes of candidemia or trichosporonosis.	None reported specifically for *Fusarium spp*., *A. flavus, T. asahi, D. rugosa* and *Issatchenkia orientalis*. Authors found that blanching significantly reduced all bacterial counts, but a spore count of 4.0 log cfu/g remained. Possible hazards caused by the remaining bacterial spores, as well as on the possible presence of mycotoxins.

Table 15 summarises the biological hazards identified and author recommendations for mitigating risk and future research.

Feed product: *H. illucens* reared on dried distillers' grains with solubles, dried sugar beet pulp or middlings
Chemical hazard: heavy metals

Tschirner and Simon (2015) reared *H. illucens* larvae destined for animal feed on cereal middlings (control group), dried distillers' grains with solubles (protein group), and dried sugar beet pulp (fibre group). The study was a single site, in vivo, controlled and replicated laboratory study, conducted in Germany. The authors looked for the presence of heavy metals and reported considerable accumulation of Pb and Cd in the larvae from the substrates (including the control) but only larvae fed on dried sugar beet pulp had a Cd content (2.24mg/kg recorded in larvae) that exceeded the EC limit for Cd in animal feed by 12% (Directive 2002/32/EG (EC, 2002) the maximum levels for Cd 2 mg/kg). Larval survival and yield was also lower on the two experimental substrates compared to the control.

We are unsure if the by-products are currently used commercially in the EU for insect rearing.

Food product: *T. molitor* reared on olive pomace
Chemical hazard: heavy metals

Truzzi et al. (2019) investigated the presence of the heavy metals, cadmium (Cd), lead (Pb), nickel (Ni), arsenic (As) and mercury (Hg) in larvae of *T. molitor* fed on olive pomace (mixed with organic wheatmeal) and the risk for human consumption. The study was a single site, in vivo, controlled and replicated laboratory study, conducted in Italy. The authors reported that although toxic metals were present in the substrate they were below the legal limit of undesirable substances in animal feed (2002/32/EC). Toxic metals were also present in the larvae and a statistically significant correlation between metal content in feeding substrates and in larvae was evidenced for Hg, which bioaccumulates. Overall, the authors concluded that the risk of exposure to metals from consumption of the mealworm larvae is relatively low and in compliance with European Union regulations. This study however exemplifies that Hg can accumulate in larvae and that heavy metal accumulation is related to the substrate they are reared on. The bioaccumulation factor for Pb was also very high in all treatments but this was thought to be contamination from the carrot fed to larvae as a source of water.

We believe that the substrate is not used in commercial insect production in the EU and is still in the experimental stage.

Feed product: *H. illucens* reared on meat or vegetable FFP contaminated with paperboard carton or plastic packaging material
Chemical hazards: Heavy metals, dioxins, PCBs, PAHs and mineral oil hydrocarbons

van der Fels-Klerx et al. (2020) investigated the safety of meat and vegetable FFP contaminated with paperboard carton or plastic packaging material as a substrate for *H. illucens* larvae reared for food and feed. The experiment was conducted in the laboratory (controlled and replicated, in vivo experiment) and trialled at industrial scale in an insect factory, in the Netherlands. Packaging inclusion rates in the experiments were higher than EU regulatory levels for animal feeds to provide a 'worst case' assessment of bioaccumulation of chemicals from substrate. The substrates, larvae and residual material were tested for dioxins, PCBs, PAHs, mineral oil hydrocarbons and the heavy metals Cd, Pb, Hg and As.

None of the concentrations of the analysed contaminants in the substrate and the larvae exceeded the respective legal limits in the EU. However, the authors reported that bio-accumulation occurred for most of the tested contaminants, and in particular for mineral oils and cadmium. The authors suggested that mineral oil bio-accumulation may be independent of the substrate provided to the insects because hydrocarbons are important components of the cuticular lipids of many insects. They highlighted that more research is needed to investigate native content of mineral oil hydrocarbons in insect species reared for food and feed. A very high bio-accumulation factor was found for Cd in the vegetarian product with paperboard carton packaging. The authors reported that bio-accumulation of Cd from products contaminated with paperboard carton packaging material appeared to be higher than for plastic, but no such patterns could be found for other contaminants; nor for meat versus vegetable products.

To our knowledge the practice is still at the experimental stage and is not practiced commercially.

Feed product: *M. domestica* reared on poultry manure, poultry manure mixed with fish feed waste, fermented poultry manure or pig manure; C. vomitoria reared on pig offal; H. illucens reared on spent brewery grain mixed with fish feed waste and yeast; *Chrysomya* sp. reared on poultry manure mixed with fish feed waste.

Chemical hazards found: veterinary medicines, pesticides, PCBs, dioxins, heavy metals

Nordentoft et al. (2014) examined the accumulation of dioxins and polychlorinated biphenyls (PCBs) in *M. domestica* reared on poultry manure and used as feed for organic laying hens, compared to hens fed on conventional compound feed. The study was a single site, in vivo, controlled and replicated field (larvae reared under field conditions) and laboratory experiment, conducted in Denmark. Samples of fly larvae, poultry manure, compost and compound feed as well as egg samples were analysed for dioxin and PCB contamination.

The authors found that the larvae had a content of dioxins plus dioxin-like PCB four times higher than the poultry manure, suggesting accumulation in the larvae from the rearing substrate. However, the authors concluded that although the levels of dioxins and PCB in the larvae were four times the levels in the compound feed, the added exposure of the hens when feed with 15g larvae per day constitute only a minor amount compared to the exposure from the compound feed alone. No difference was found between the content of dioxins and dioxin-like PCB in the eggs from layers receiving larvae in the feed compared to chickens fed the conventional feed. Whilst this study indicates that the hazard of dioxins and PCB accumulation in larvae is no greater than conventional feed, it does illustrate that larvae are able to accumulate these chemicals.

Charlton et al. (2015), explored the chemical safety of *M. domestica*, *H. illucens* and *C. vomitoria* reared for animal feed, in an observational study using different production techniques and substrates in four geographical locations. The production methods were representative of the differences in size and scale of international maggot rearing, from small field-based operations in Africa to larger, industrial scale production in China. Local rearing substrates were investigated that represent low or zero value waste materials. Larvae were reared under field conditions. The authors examined the presence of veterinary pharmaceuticals, pesticides, heavy metals, dioxins, polychlorinated biphenyls and polyaromatic hydrocarbons (PAHs) and mycotoxins in the larvae.

The following species and substrates were examined in 4 locations worldwide:

Ghana: experiment 1 - poultry manure mixed with fish feed waste fed to *M. domestica* larvae; experiment 2 - spent grain (brewery solid waste) mixed with dry fish feed factory waste and yeast and water fed to *H. illucens* larva; experiment 3 - *Chrysomya* spp larvae reared on poultry manure mixed with fish feed waste; China Guangzhou: fermented chicken manure fed to *M. domestica* larvae; China Wuhan: pig manure fed to *M. domestica* larvae; United Kingdom: experiment 1- poultry manure fed to *M. domestica* larvae; experiment 2 - pig offal fed to *C. vomitoria* larvae; Mali: poultry manure fed to *M. domestica* larvae. The authors reported the following results:

Veterinary medicines: 4,4'-dinitrocarbanilide (nicarbazin) was detected in *M. domestica* larvae from Mali which the authors stated was possibly above the maximum concentration for animal feed (500 µg/kg) specified in Directive 2009/8/EC. All other veterinary medicines tested for were absent from the larvae or present at concentrations below the limit of detection. *Pesticides:* Chlorpyrifos was found in *M. domestica* larvae in the UK experiment but at a level the authors suggested does not pose a significant safety threat, furthermore, chlorpyrifos is no longer approved for use in the UK or EU. Piperonyl butoxide an insecticide synergist was found in *C. vomitoria* (200 µg/kg) in the UK. The authors reported that this chemical does not have a widely adopted recommended maximum concentration, but Codex advise that pea fodder should contain less than 2,000 µg/kg (Codex Alimentarius, 2014), suggesting that there is unlikely to be a significant safety concern. No other pesticide residues were detected in larvae samples at other locations. *Heavy metals:* Cadmium was present in all samples but in the samples from *M. domestica* larvae from Ghana, China (Wuhan) and the UK, levels were above the lowest EU limit for cadmium in animal feed (500 µg/kg) specified in directive 2002/32/EC. *Dioxins, polychlorinated biphenyls and polyaromatic hydrocarbons:* PCBs and WHO-TEF were below EU regulatory limits. PAH4 values were calculated for all samples analysed and these were between 0.28 and 9.82 µg/kg. No limits for PAHs in animal feed are specified in EU regulations. *Mycotoxins:* Beauvericin was present in *M. domestica* larvae from China (Guangdong). Enniatin A and Enniantin A1 were found in *M. domestica* larvae from Mali. These compounds were not present at levels that are believed to pose a safety risk.

Charlton et al. (2015), suggested that veterinary medicines in manure that are fed on by insects are a manageable risks which can be monitored through an understanding of the history of the feedstock or by analytical testing for potential risks prior to feeding. However, the authors stated that there is a significant and recurring risk of the potential bioaccumulation of metals in insects and in particular cadmium. They suggested that further research is required to determine if cadmium and other potential risks in insects used as feed are transferred into farm animals. The authors highlighted that each combination of insect and substrate they are reared on may present different risk potential and therefore routine monitoring is required to ensure the continued safety in the animal feed supply chain.

Manure is prohibited as a substrate for insect rearing in EU but maybe permissible in other regions of the world.

Feed product: *H. illucens* reared on coffee silverskin with or without addition of microalgae
Chemical hazards: Heavy metals

Truzzi et al. (2020), investigated the chemical hazards of rearing *H. illucens* on a diet containing coffee silverskin (a coffee roasting by-product) fed alone or in combination with the microlagae (*Schizochytrium limacinum* or *Isochrysis galbana*). The study was a single site, in vivo, controlled and replicated laboratory study, conducted in Italy. The rationale for adding microalgae to the diets was to increase the relative quantity of lipids and proteins in the larvae, to improve their nutritional value for animal feed. The study investigated contamination of the substrates, larvae and frass.

Truzzi et al. (2020) looked for the presence of Cd, Pb, As, Ni and Hg in the substrates, prepupae and frass. Prepupae accumulated Cd, Pb and Hg from all growth substrates: coffee silverskin alone or coffee silverskin plus 5, 10, 20, 25% of either *Schyzochytrium sp* or *Isochrysis sp*. The authors stated that this highlights the importance that safe production of the larvae as ingredient for feed or food needs a strict control of these undesirable contaminants both in the initial substrate as well as in the final product. In this study all heavy metals in all growth substrates, prepupae and frass were below EU legal limits for Cd, Pb, As and Hg, although Cd content of prepupae (Cd 0.077 mg kg^{-1} ww) was close to the legal limit for food (0.05 to 0.2 mg kg^{-1} ww Directive 1881/2006/EU and amending regulations 420/2011/EU respectively). The authors reported the concentration of Cd in the substrate feed was mainly influenced by its content in coffee silverskin.

Prepupae reared on substrates based on 100% coffee silverskin and 5 % of *Schizochytrium* sp. or *Isochrysis* sp. showed the high Ni concentration (0.76, 0.54 and 0.49 mg kg^{-1} ww). The authors suggested that considering the high level of Ni in the prepupae, its toxicity, and the limited number of studies for bioaccumulation in insects, that this potential risk requires more attention in future research.

The authors concluded that even if prepupae bioaccumulate Cd, Pb or Hg the risk is low to animals or humans consuming them and that levels are in compliance with EU regulation. In accordance with other studies cited in this review, the authors also stated that contamination depends on the growth substrate and that it would be useful in the future to create a specific list of tested growth substrates for safe edible-insect production.

To our knowledge the substrate is still in the experimental stage for insect rearing.

Feed product: *Pagrus major* (red seabream) reared on scallop by-product fermented with soybean meal

Chemical hazards: Heavy metals

Kader et al. (2011) investigated replacing traditional fishmeal feed with a mixture of fermented scallop by-product and soybean meal for juvenile *P. major*. The study was a single site, in vivo, randomised controlled laboratory trial, conducted in Japan. Five diets were formulated to replace 0%, 15%, 30%, 45%, and 60% of fishmeal protein with the fermented mixture. Dietary and whole-body analysis were carried out for heavy metal content. Dietary Cu and Cd increased significantly with increasing levels of the fermented mixture, whereas no differences were found in the dietary levels for Zn and Pb. Whole body analysis of the fish at the end of the trial showed that Cd increased significantly in fish fed 45% and 60% fermented mixture, and Pb significantly increased in the fish fed on all the replacement diets containing the fermented mixture. However, no significant differences were found in whole body analysis for Cu or Zn. The authors suggested that metabolism of heavy metals may vary depending on the metal and that further research is needed to understand the effects on element composition of fish tissues of long-term dietary exposure to recommended levels of feed containing scallop by-products.
Since this study was published, researchers have pioneered a new technique for Cd removal from squid viscera and scallop mid-gut glands to enable these by-products to be used as (fish) feed. The studies showed that this technique does not affect the quality of the feed and is safe in terms of Cd accumulation in fish (Satoh et al., 2013 & 2015). To our knowledge this practice is still at the experimental stage.

Table 15 - Studies reporting animals reared on novel feeds within the CE framework and the presence of chemical hazards in the animal and/or insect frass, and study authors recommendations for mitigating risks.

Animal and rearing substrate and citing author	Chemical hazard	Mitigation of risk and Research gaps
Animal manures (with and without fish feed waste) or brewery waste combined with fish feed waste or pig offal as a substrate for *Calliphora vomitoria; Musca domestica; Chrysomya* spp and *Hermetia illucens* larvae (Charlton et al., 2015)	4,4'-dinitrocarbanilide (nicarbazin) was detected in *M. domestica* larvae reared on poultry manure (in Mali) above the maximum concentration for animal feed (500 µg/kg) specified in Directive 2009/8/EC. Cadmium (Cd) detected above the lowest EU limit for cadmium in animal feed EC directive 2002/32/EC for *M. domestica* larvae reared on poultry manure and fish feed waste (in Ghana), pig manure (in China, Wuhan) and poultry manure (in UK). Authors reported a significant and recurring risk of the potential bioaccumulation of metals in insects and in particular Cd. The following were detected but at levels not considered to be of safety concern: Chlorpyrifos detected in *M. domestica* larvae reared on poultry manure and piperonyl butoxide detected in *C. vomitoria* reared on pig offal (in the UK). Dioxins, polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs): PCBs and WHO-TEF were below EU regulatory limits in all samples. PAH4 values for all samples ranged between 0.28 and 9.82 µg/kg. Beauvericin present in *M. domestica* larvae reared on fermented chicken manure (in China, Guangdong) and Enniatin A and Enniantin A1 present in *M. domestica* larvae reared on poultry manure and fish feed waste (in Mali).	Veterinary medicines in manure are a manageable risks which can be monitored through an understanding of the history of the feedstock or by analytical testing for potential risks prior to feeding. The authors highlighted that each combination of insect and substrate they are reared on may present different risk potential and therefore routine monitoring is required to ensure the continued safety in the animal feed supply chain. Further research to determine if cadmium and other potential risks in insects used as feed are transferred into farm animals.
Juvenile red sea bream *Pagrus major* fed with fermented soybean meal and scallop by-product blend (Kader et al., 2011)	Dietary Copper (Cu) and Cd increased significantly with increasing levels of the mixture replacing traditional fishmeal protein, whereas no differences were found in the dietary levels for Zn and Pb.	Kader et al. (2011) did not report any mitigation measures. However, since this study was published, researchers have pioneered a new technique for Cd removal from squid viscera and

Animal and rearing substrate and citing author	Chemical hazard	Mitigation of risk and Research gaps
	Whole body analysis of the fish at the end of the trial showed that Cd increased significantly in fish fed high levels of the alterative diet replacement, 45% and 60% of the fermented mixture, and Pb significantly increased in the fish fed on all the replacement diets containing the fermented mixture. However, no significant differences were found in whole body analysis for Cu or zinc (Zn).	scallop mid-gut glands to enable these by-products to be used as (fish) feed. The studies showed that this technique does not affect the quality of the feed and is safe in terms of Cd accumulation in fish[1,2] (this literature was captured in the searches for literature in this report). The authors suggested that metabolism of heavy metals may vary depending on the metal and that further research is needed to understand the effects on element composition of fish tissues of long-term dietary exposure to recommended levels of feed containing scallop by-products.
M. domestica reared in poultry manure (Nordentoft et al., 2014)	Larvae had a content of dioxins plus dioxin-like PCB four times higher than the poultry manure and the authors suggested accumulation in the larvae from the rearing substrate. However, the authors concluded that the hazard of dioxins and PCB accumulation in larvae is no greater than conventional feed, it does illustrate that larvae are able to accumulate these chemicals.	No mitigation measures reported. No research gaps reported.
Tenebrio molitor reared on olive pomace (Truzzi et al., 2019)	Heavy metals were present in the substrate but they were below the legal limit of undesirable substances in animal feed (2002/32/EC). Toxic metals were also present in the larvae and a statistically significant correlation between metal content in feeding substrates and in larvae was evidenced for mercury (Hg), which bioaccumulates. The authors concluded that the risk of exposure to metals from consumption of the mealworm larvae is relatively low and in compliance with European Union regulations.	Selinium (Se) protects from mercury toxicity. The authors concluded that the substrate had enough Se to protect the larvae against Hg toxicity. No research gaps reported.

Animal and rearing substrate and citing author	Chemical hazard	Mitigation of risk and Research gaps
H. illucens larvae reared on coffee silverskin mixed with microalgae (Truzzi et al., 2020)	Prepupae accumulated Cd, lead (Pb) and Hg from all growth substrates: coffee silverskin alone or coffee silverskin plus microalgae *Schyzochytrium sp* or *Isochrysis sp*. All heavy metals in all growth substrates, prepupae and frass were below EU legal limits for Cd, Pb, arsenic (As) and Hg, although Cd content of prepupae was close to the legal limit for food (Directive 1881/2006/EU and amending regulations 420/2011/EU respectively). The authors reported the concentration of Cd in the substrate feed was mainly influenced by its content in coffee silverskin. Prepupae reared on substrates based on 100% coffee silverskin and 5 % of *Schizochytrium* sp. or *Isochrysis* sp. showed the highest nickel (Ni) concentrations. The authors concluded that even if prepupae bioaccumulate Cd, Pb or Hg the risk is low to animals or humans consuming them and that levels are in compliance with EU regulation	No mitigation measures reported. Research to: (1) assess the potential risk of Ni contamination of prepupae (when considering the high level of Ni in the prepupae, its toxicity, and the limited number of studies for bioaccumulation in insects) (2) create a specific list of tested growth substrates for safe edible-insect production (when considering that contamination of prepupae depends on growth substrate).
H. illucens larvae reared on dried distillers' grains with solubles or dried sugar beet pulp (Tschirner and Simon, 2015)	Larvae fed on dried sugar beet pulp had a Cd content that exceeded the EC limit for Cd in animal feed (Directive 2002/32/EG (EC, 2002)	No mitigation measures reported. No research gaps reported.
H. illucens larvae reared on vegetarian or meat former food products contaminated with either paperboard carton or plastic (van der Fels-Klerx et al., 2020)	Bio-accumulation occurred for most of the tested contaminants (dioxins, PCBs, PAHs, mineral oil hydrocarbons and the heavy metals Cd, Pb, Hg and As), and in particular for mineral oils and Cd. A very high bio-accumulation factor was found for Cd in the vegetarian product with paperboard carton packaging. Bio-accumulation of Cd from products contaminated with paperboard carton packaging material appeared to be higher than for plastic. Overall, none of the analysed contaminants in the	No mitigation measures reported. Research to: (1) investigate native content of mineral oil hydrocarbons in insect species reared for food and feed (when considering that mineral oil bio-accumulation may be independent of the substrate provided to the insects because hydrocarbons are important components of the cuticular lipids of many insects) (2) investigate different FFP from different FFP classes and types and particle sizes of packaging materials (3)

Animal and rearing substrate and citing author	Chemical hazard	Mitigation of risk and Research gaps
	substrate and the larvae exceeded the respective legal limits in the EU.	assess the accumulation or transfer of other potential hazards that could be associated with FFP as substrate such as microbiological hazards.

[1]Satoh, N., Wakasugi, M., Nobuta, S (2015) Availability of fisheries by-product materials with cadmium removal treatment as a feed ingredient for fingerling black rockfish Sebastes schlegeli. Bulletin of Fisheries Research Agency 40:61-65; [2]Satoh, N., Nobuta, S., Wakasugi, M., Satoh, S., Takeuchi, T. (2013). Availability of squid viscera meal with cadmium removal treatment as a feed ingredient for fingerling black rockfish Sebastes schlegeli. Fisheries Science 79: 259-267

3.3.1.4. Overview of environmental hazards from novel food and feeds within the CE framework

Thirteen studies carried out an assessment of the environmental risks of producing food or feed from waste or side streams. The majority (n=11) of these studies investigated the environmental impacts of rearing insects (Oonincx et al., 2015; van Zanten et al., 2015; Salomone et al., 2017; Thévenot et al., 2018; van Zanten et al., 2018; Bava et al., 2019; Bosch et al., 2019; Maiolo et al., 2020; Milanović et al., 2021; Osimani et al., 2021; Parodi et al., 2021). One of these (11) studies investigated both *M. domestica* larvae reared on food waste and rapeseed meal compared to a traditional feed for swine (van Zanten et al., 2018). The remaining studies investigated poultry by product (poultry fat, poultry by-product meal and steam hydrolysed feather meal) for animal feed (Campos et al., 2020) and the rearing of the earthworm *E.fetida* (Tedesco et al., 2019).

Of the 13 studies that investigated potential risks to the environment, 9 used life cycle assessment (LCA) methodology to determine environmental impacts (van Zanten et al., 2015; Salomone et al., 2017; Thévenot et al., 2018; van Zanten et al., 2018; Bava et al., 2019; Bosch et al., 2019; Tedesco et al., 2019; Campos et al., 2020; Maiolo et al., 2020).

The remaining studies were single site, controlled and replicated laboratory experiments, investigating:

- the suitability of animal manures (chicken, pig, and cow manure) as feed for insect larvae which included assessments of nutrient loss, GHG and ammonia emissions (Oonincx et al., 2015; Parodi et al., 2021)
- the occurrence of ARGs (Milanović et al., 2021) and microbial dynamics (Osimani et al., 2021) in the rearing of *H. illucens* on coffee by-products (also see Section 3.3.1.3.2)

The location within a supply chain where new and emerging risks are most likely to emerge for the environmental hazards reported are in the primary production of novel foods and feed within the CE framework.

The scientific areas within EFSA's remit that environmental hazards reported apply to is: *Environmental risk assessment*

The following sections provide descriptive summaries of studies reporting environmental hazards to from novel food and feed within the CE framework authors recommendations for mitigation and future research and an indication of the availability of detection methods for hazards, scale of the available evidence and whether the novel food or feed is currently in commercial practice in Europe or just experimental.

3.3.1.4.1. Environmental risks arising from insects reared on waste

The majority of the LCA studies investigated the production of insects (n=8), reared on waste in comparison to conventional production systems for animal feed. A wide range of hazard endpoints were measured and reported in these studies including: GHG emissions (GHG), energy use, land use (LU), global warming potential (GWP), cumulative energy demand (CED), climate change, carbon dioxide emissions, acidification potential, eutrophication potential, ozone depletion, particulate matter, photochemical ozone formation, acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, water resource depletion, and mineral and fossil renewable resource depletion.

The overarching conclusion from these studies was that the main environmental risk arises from the high energy requirement of the system. For example, Thévenot et al. (2018) considered the environmental performance of *T. molitor* larvae meal reared on side streams (sugar beet pulp, wheat bran, sunflower meal, rapeseed meal) compared to feed production using soybean meal and fish meal. For both systems they assessed CED, (carbon dioxide) CO_2 equivalent for climate change, (sulphur dioxide) SO_2 equivalent for acidification potential, (phosphate) PO_4 equivalent for eutrophication potential and LU. The authors reported that *T. molitor* meal production had higher environmental impacts, especially the energy required, compared to the other animal feed protein production systems. Van Zanten et al. (2015) found similar results from the production of *M. domestica* larvae meal reared on food waste and poultry manure compared to compared to conventional fishmeal and soybean meal. The authors reported an increase in energy use and therefore an increase in GWP but also a reduction in LU. They concluded that insect production for animal feed to be trade-off between decreased LU and increased GWP and energy use. Van Zanten et al (2018), also investigated *M. domestica* larvae meal reared on food waste (using data from van Zanten et al., 2015) and rapeseed meal compared to traditional soybean meal for swine. Using consequential LCA the results indicated that using co-products and waste-fed larvae meal currently does not reduces the net environmental impact of pork production when compared to soybean meal. Rapeseed meal resulted in an increased GWP, energy use and LU whereas waste-fed larvae had an increased GWP and energy use, although LU was decreased (as per van Zanten et al., 2015 results for waste fed larvae), when compared to soybean meal.

Oonincx et al. (2015) and Parodi et al. (2021) studied the environmental risks of rearing *H. illucens* on animal manures. Ooincx et al. (2015) reported that a large proportion of the nitrogen (N) from the manure (23-78%) was lost in the production system. Parodi et al. (2021) quantified and compared nutrient balances, nutrient levels in residual materials and emissions of GHG and ammonia between manure incubated with and without *H. illucens*. The authors found that more carbon dioxide and ammonia-nitrogen were emitted from the system with *H. illucens* larvae compared to when larvae were absent. Oonincx et al. (2015) suggested that mitigation measures such as an air washer would be required to make the system ecologically sound.

Bava et al. (2019) proposed that it is the careful selection of rearing substrate that is important for optimising the growth and reducing the environmental impact of the production of insects for animal nutrition. Bosch et al. (2019), investigated the environmental impact of a wide variety of organic wastes, FFP and sidestreams for rearing *H. illucens*. The results showed that substrates currently not allowed in EU as animal feed have in general a lower impact in terms of global warming potential, energy use, and land use. Whereas, on a per kilogram protein basis, larvae reared on a resource that contains food (e.g. sorghum) and feed (e.g. dried distillers grains with solubles) products have higher environmental impacts when compared to conventional the protein sources fishmeal and soybean meal. The authors recommended that more studies are required to evaluate residual resources and the food safety risks before EU legislation changes can be considered to allow promising residual streams into the food chain via black soldier fly larvae. Bosch et al. (2019) reported that the study by van Zanten et al. (2015) using food waste as feeding substrate for housefly larvae is in direct competition with bioenergy production, leading to an increase in fossil fuels use, which subsequently resulted in a higher environmental impact. Bosch et al. (2019) suggest that using residual streams with a limited application (e.g. manure in The Netherlands due to the surplus) is recommended to avoid this competition. This competition can also be reduced by using residual streams as efficiently as possible, for example, using the remaining material as fertiliser or to produce bioenergy.

As reported in the Section 3.3.1.3.2. regarding biological health risks, insect larvae reared on side streams have been found to contain ARGs and bacteria that are able to spread ARGs horizontally among the same or different species. ARGs have also been shown to be present in insect frass (Milanović et al., 2021; Osimani et al., 2021). This presents an emerging risk for contamination of the environment by ARGs when the frass is used as biofertiliser or if ARGs are subsequently excreted into the environment when larvae are used as animal feed.

Hazards/Environmental Impact: High energy requirements and therefore an increase in GHG and global warming potential; Emissions of ammonia-nitrogen; ARGs in insect frass; using food waste as a substrate for larvae is in direct competition with bioenergy production which could lead to increased use of fossil fuels and associated environmental impacts
Mitigation measures: To minimise energy use and GHG emissions insect rearing plants could be located next to waste incineration facilities, where heat generated could be used for drying the larvae. Furthermore, alternative energy sources could be used such as solar or wind energy (van Zanten et al., 2015); Air washers to remove ammonia-nitrogen (Oonicx et al., 2015); Until risk analyses are carried out the prudent use of antibiotics during rearing is recommended to reduce occurrence of ARGs (Milanović et al., 2021)
Research gaps: Future work could investigate increasing processing speed to decrease N volatisation. (Oonicx et al., 2015); 'By increasing competition for raw materials and by-products (e.g. for biofuels), the emergence of a new insect supply chain might indirectly worsen environmental impacts of other types of agriculture production' and this needs investigating further (Thévenot et al., 2018); Improvements in rearing and extraction are required to reduce energy requirements ((Thévenot et al., 2018); Risk analysis for ARGs in insect rearing and research to understand the correlation between the copy number of ARG's carried by microbial communities occurring in the rearing substrates and those contained in the insect gut and resulting frass using quantitative PCR assays (Milanović et al., 2021); More research required to evaluate residual resources and the food safety risks of using residual resources for rearing substrate for *H.illucens* (Bosch et al., 2019)
Availability of detection methods for hazard: Available
Scale of available evidence: Single site studies
Is the practice present or envisaged?: To our knowledge the substrates describe are still in the experimental stage for insect rearing. Animal manures and food waste are prohibited for insect rearing in the EU.

3.3.1.4.2. Environmental risks arising from poultry by-products as animal feed

Campos et al. (2020) conducted an LCA for poultry fat, poultry by-product meal and steam hydrolyzed feather meal, compared to traditional fishmeal or fish oil as fish feed. The authors assessed global warming (CO_2), abiotic depletion, acidification (SO_2) and eutrophication potential of the systems. The authors highlighted points in the life cycle where the main hazards occur: the rendering process of poultry by-products is mainly responsible for global warming and abiotic depletion (mainly due to process heat), while the poultry production is the main contributor for acidification and eutrophication. However, overall the LCA indicated that poultry by product has a lower environmental impact compared to tradition fish feeds based on fishmeal/oil.

Hazards/Environmental Impact: Global warming; Abiotic depletion; Acidification; Eutrophication
Mitigation measures: None reported
Research gaps: None reported

Availability of detection methods for hazard: Available
Scale of available evidence: Secondary data analysis
Is the practice present or envisaged?: Envisaged?

3.3.1.4.3. Environmental risks arising from earthworms reared on vegetable waste

Food waste is a sustainability issue of the modern food chain due to the associated waste of natural resources and the production of GHG. The valorisation of fruit and vegetable waste (FVW) by vermicomposting can be seen as a method to reduce food waste. Tedesco et al. (2019) evaluate the environmental impact of the bioconversion of FVW into earthworm meal to be used as a food/feed source. The main areas of environmental concern were the emissions of methane, dinitrogen monoxide and ammonia from the vermicomposting and the energy requirements of FVW transport and fresh earthworm processing (freeze drying for food and oven drying for feed, the latter is more energy consuming). Tedesco et al. (2019) suggested that a move to renewable energy sources to improve the sustainability of the production of earthworm meal.

Hazards/Environmental Impact: Methane, dinitrogen monoxide and ammonia emissions from vermicomposting; Energy requirements for transportation of FVW and drying of earthworms.
Mitigation measures: To reduce the impacts of transport activities, vermicomposting could take place at the FVW production site. Switching to a photovoltaic system or other renewable energy sources could reduce energy use.
Research gaps: Further research is required to enhance productivity and reduce energy consumption to improve the sustainability of earthworm meal as food/feed source
Availability of detection methods for hazard: Available
Scale of available evidence: Analysis of secondary data
Is the practice present or envisaged?: Envisaged

3.3.2. Additional information: Key findings and research gaps from authors of reviews and reports about potential hazards and emerging risks

Twenty-nine reviews/reports and one PhD thesis (listed in Appendix D, Worksheet 3.) were found in the searches of: bibliographic databases; grey literature searches (including searching websites of relevant Horizon 2020), SUSFOOD and UKRI funded research projects (see Appendix D, Worksheet 4. for list of projects searched) and literature captured in Objective 1. Useful inferences from the authors of the reviews and reports about potential hazards and emerging risks are presented below:

- Physical hazards resulting from the use of FFP in animal feed were highlighted by Pinotti et al. (2019) and Luciano et al. (2020) but Pinotti et al. (2019) concluded that safety standards for producing feed from FFP in the EU means that the risk of contamination with packaging material is low.
- Authors of a recent report by the FAO (2021) investigating edible insects from a food safety perspective concluded:
  - While the risk of transmitting zoonotic infections to humans through edible insects appears to be low the topic requires further investigation.
  - Slaughterhouse by-products are a source of substrate that needs detailed safety investigation
- Lange and Meyer (2019) reviewed the potentials and possible safety issues of using biorefinery products in food value chains. The authors suggested that:

- The safety of thermally generated carbohydrate degradation products from biomass pre-treatment should be investigated in relation to using yellow and green biomass biorefinery products in food or feed.
- Markou et al. (2018) reviewed the contamination and safety of using agro-industrial wastes and wastewater (WaW) for the cultivation of microalgae and duckweeds. The authors reported that anaerobic digestion and post-treatment of WaW can lower the risks associated with heavy metals and pathogens, but that it is unclear for certain persistent xenobiotics.
- Vandeweyer et al. (2021) highlighted that pre-treatments (e.g. mixing, concentration by a heat or alternative treatment, milling, acidification) of side streams substrates for insects can potentially have both positive and negative effects on substrate microbial load. They concluded that the impact on food pathogens that can occur in (mixtures of) organic side streams of the currently used preparation technologies is not yet thoroughly investigated.
- A risk assessment 'Advice on animal and public health risks of insects reared on former foodstuffs as raw material for animal feed' (Anon, 2019) highlighted that there are many uncertainties and data gaps when considering chemical and microbiological risks associated with FFP including such as the lack of epidemiological data on incidents and outbreaks of disease caused by the use of insect larvae as animal feed.
- Varelas (2019) reviewed food wastes as a substrate for insect mass production for food and feed. The author highlighted that: many trials are applied with simple food mixtures of wastes and safety aspects such as microbial stability are usually not referred to; compilation of a standardised artificial diet for mass insect production based on household waste that contains highly heterogenous substrate will be highly complicated compared to simpler food industry mixtures of wastes; clinical trials of insects reared

on food materials and wastes have not been performed in humans and animals and are lacking.

- Spruijt et al. (2016), reported on the opportunities for micro algae grown on by-product or waste as ingredient in animal diets. Two operational cases studies were presented from the Netherlands (1) algae grown on bio-gas by-product which is GMP+ certified, allowing the application of the algae in a feed factory (2) algae grown on the liquid fraction of veal calve manure digestate. Spruijt et al. (2016), reported that the pumping of algal water in the production process and drying of algae for feed is energy demanding. Furthermore, depending on the cultivation circumstances there is potential for accumulation of heavy metals in algae, and potential levels of nucleic acid and ash content are also areas of concern. The authors stated that it was unclear to what extent nucleic acids should be considered as a harmful substance for animals. In the EU algae biomass may only be used as an ingredient in animal feed if a risk assessment has been carried out on the production method, and if the sellable products are analysed, to ensure that they contain a minimum level of potentially harmful substances and are not contaminated with pathogens. (Van der Weide et al., 2014).

In addition to the reviews and reports captured in literature searches, an article in an American emerging technology magazine (WIRED) was identified by one of the authors of this report. The article reported potential biological and chemical hazards associated with rearing insects on poultry manure (Filou, 2021). Dennis Oonincx a scientist at Wageningen University and Research in the Netherlands, researching insects as food and Jason Drew co-founder and CEO of the Insect Technology Group were interviewed. Oonincx said that 'some pathogens, such as the coccidia parasite, which is commonly found in chicken manure, are not digested by some species of insects. In such cases, insects would need to be processed before they can be used as animal feed'. Jason Drew said that the company had been experimenting with pig and poultry manures as insect substrates. He recounted an experience whereby poultry manure from a particular farm contaminated with insecticide (fed to chickens to avoid fly contamination on the poultry farm) killed the insect larvae, highlighting the need for careful sourcing of manures.

3.3.2.1. Articles that investigated risk to animal production performance parameters but did not find any risks for food or feed safety

These following results relate to Objective 3B. Categorise and list novel foods and feeds within the CE framework where no risk to human, animal, plant health has been reported or investigated, and provide an indication about the geographical location of where the novel food or feed research or practice originates from if outside of the EU.

A large volume of literature (nearly 1000 articles) was captured investigating the risks to animal production performance (e.g. growth, digestibility, development) from the direct feeding of waste, former food products and side streams to animals. The focus of these studies was predominantly farmed livestock, although a limited number of articles were relevant to companion animals. Many of these studies concluded that waste, FFP or side streams can only be fed to animals when combined with traditional feeds or with additives because these feeds alone do not provide the full nutritional requirements of the animal under investigation. The authors of the studies provided recommendations for the proportion of the diet the feedstuff should constitute to ameliorate negative impacts on performance parameters. These studies did not investigate potential biological, chemical or physical contamination of waste, FFP and side streams for animal feed or their environmental impact.

It was often difficult to decipher what country the study originated from because full texts were not obtained. We have attempted to categorise studies into those conducted in Europe and those conducted outside of Europe, however the results come with the caveat that some studies may have been categorised incorrectly.

Appendix D, Worksheet 5. shows a list of novel feeds from studies that investigated risk to animal performance parameters conducted both in Europe and non-European countries. The list includes an example article and a list of animals that the novel feed was fed to.

Over 200 different types of novel feeds were identified. Most of the novel feeds reported originated from plant by-products. Examples of novel feeds are shown below together with the animal it was fed to and an indication of where the research was carried out:

- Algae
  - Microalgae by-product from biofuel production for fish and pig feed (Europe and Non-European)
  - Algal biomass from manure treatment for fish feed (Europe)
  - Algal meal by-product from agar production for fish feed (Non-European)
- Fungi
  - Candida utilis from lignocellulosic biomass from underutilized wood co-products for pig feed (Europe)
  - Fungal biomass cultivated on vinasse for fish feed (Non-European)
  - Neurospora intermedia obtained from bioethanol production for chicken feed (Europe)
- Bacteria
  - Bacterial by-product meal from lysine industry for chicken and pig feed (Non-European)
  - Single cell proteins cultivated on different residual streams from wood-based biorefineries for fish feed (European)
- Plants
  - Almond hulls for chicken feed (Non-European)
  - Bilberry pomace for rabbit feed (Europe)

  - Cottonseed by-product for crab, fish, insect, chicken, ostrich, goose, quail, cattle, sheep and pig feed (Non-European)
- Molluscs
  - Asian rapa whelk non-edible parts or small whelk discarded for fish feed (Europe)
  - Squid by-product (e.g. liver, viscera) for shrimp and fish feed (Non-European)
- Animal manures
  - Poultry manure/litter fed to insects, chickens, ruminants and pigs (Non-European)
  - Sheep manure fed to insects (Non-European)
- Poultry by-products
  - Hatchery waste fed to chickens and insects (Non-European)
  - Feather meal to ruminants, crayfish, fish and chicken (Non-European)
  - Poultry by-product fed to ducks, chickens, fish, crayfish, shrimp, dog, cattle, pig (Non-European)
- Mammalian by-products
  - Pig blood by-product for fish, chicken, pig feed (Non-European)
  - Pig placenta for pig feed (Non-European)
  - Rumen content for rabbit feed (Non-European)
- Insects
  - Silkworm pupae by product of silk industry for fish, chicken, duck, turkey feed (European, Non-European)
  - Honey Bee slum gum for rabbit feed (Non-European)
- Fish
  - Tilapia processing by-product silage for shrimp (Non-European)
  - Salmon protein hydrolysate from salmon by-products for pig feed (Non-European)
- Crustacea
  - Krill by-product fed to fish (Non-European)
- Food processing by-products
  - corn taffy residue a by-product from taffy candy for sheep (Non-European)
  - spent mushroom substrate for sheep (Non-European)
  - monosodium glutamate by-product for cattle (Non-European)
- Food waste
  - Restaurant fat fed to sheep (Non-European)
  - Fried chicken restaurant waste to ducks (Non-European)
- Former food products
  - Chocolate confectionary for pig feed (Non-European)

Most notably the list of feed contains examples of practices that are currently prohibited in Europe, such as intra-species recycling and feeding of wastes.

The evidence provided in Appendix D, Worksheet 5 is from research studies and we do not know to what extent some/any of the feeds listed are used in commercial practice particularly outside of Europe. As previously discussed, strict regulation exists for animal feed in the EU but animal feed regulations are different elsewhere in the world. It is therefore prudent to be vigilant about the commercial use novel substrates used as animal feeds outside of Europe and the implications for food safety, of foods imported into the EU.

3.3.2.2. Articles about novel food and feed within the CE framework but that did not investigate or report risk to human, animal or plant health or the environment

Just over 100 articles investigated novel food and feed within the CE but where risk to human, animal or plant health or the environment was not investigated or reported. For example, these studies often investigated industrial techniques for developing foods and feeds such as extrusion or fermentation processes and composition analysis.

Appendix D, Worksheet 6 provides a list of the novel foods and feeds investigated. It was not possible from abstracts alone to decipher the country the study was conducted in or the type of animal that the feed was intended for. Many of the examples were for animal feeds, some of which have already been identified in Section 3.3.2.1. reporting the list of novel feeds from studies investigating risk for animal production performance parameters. Examples of novel foods in the list included:

- citrus by-product as fat Replacer ingredient for bakery confectionery products
- kimchi by-products as a source of functional ingredients
- dried squid head by-products for novel peptides
- vanilla flavouring from recycled plastic using bacteria

3.3.3. Limitations of the literature search and characterisation of the evidence base

Limitations of the literature search and characterisation of the evidence base include:

- DistillerSR AI algorithm was used to automatise the identification of relevant documents. A higher sensitivity threshold may have identified a greater number of relevant studies but the thresholds chosen were a compromise due to time constraints.
- Searches and selection of studies were carried out in English language. Relevant literature published in other languages will have been missed and literature captured will be geographically biased.
- Articles about risks to animal production performance or novel food or feed but where hazards were not assessed were categorised using abstracts only. It was not always possible to confirm the study locations, and so some studies may have been incorrectly categorised.
- Nearly all of the literature captured investigated risk of consuming or producing invertebrates (mainly insects) for feed and food reared on substrate within the CE framework. This appears to be a genuine bias in the literature, and is probably because invertebrates, such as insects and earthworms, are able to efficiently bioconvert and valorise a wide variety of sidestreams, wastes or FFP, and are considered to be a sustainable source of animal protein.
- The majority of the evidence captured investigated novel feeds within the CE framework rather than novel foods.
- The evidence was biased towards gathering academic research, but there is growing commercial research and development (R&D) regards novel foods and feeds within the CE framework. Much of this R&D will be unobtainable due to commercial confidentiality.
- Literature reviews inherently look backwards at existing evidence and the evidence gathered does not always 'look forward' and into the future for emerging risks.
- Literature reviews are only one tool for identifying emerging risks and other tools such as stakeholder elicitation and monitoring of upcoming research projects, for example, the H2020 project 'Demonstrable and replicable cluster implementing systemic solutions through multilevel circular value chains for eco-efficient valorization of fishing and fish industries side-streams', will help to inform this topic area.

The majority of the questions to characterise the evidence base outlined in Objective 3 could be addressed but a couple could only be partially addressed, and four questions could not be addressed by evidence captured from the extensive literature search (Table 16).

Table 16 - Questions to characterise the evidence base in Objective 3 that could be fully or partially addressed, or that could not be addressed by evidence captured from the extensive literature search.

Addressed	Partially addressed parts of question highlighted in red with remainder of question not addressed	Not addressed
What is the type of emerging risk (new hazard, increased exposure)?	What is the availability of data underpinning the definition of emerging risk: • (eco)toxicological, bioaccumulation and environmental accumulation, epidemiological, biomonitoring, consumption and occurrence data in line with EFSAs environmental risk assessments remit • severity, duration and frequency of the expected effects on human, plant and animal health • descriptions of exposure pathways • interactions with other contaminants and possible additive effects	What type, amount and frequency of application of products are applied in/on environmental matrices?
What are the biological, physical and chemical hazards in food, feed or in the environment?	What evidence is there for risk management and reduction measures: some evidence provided • monitoring systems/programs, practices to lower or eliminate the contamination risks • possible solutions to achieve a safe CE practice/technology etc. • existing international/national regulations/guidelines	What are the impacts on economy, environment, social aspects, and food and feed security?
Which food/feed products could pose a risk and which plants or animals species are at risk?		What is the imminence of these impacts? (How quickly might the risk materialise? How urgent is the response?)
Which locations within a supply chain are where new and emerging risks are most likely to emerge?		What are the parallels and interactions with other areas and emerging issues?
Identify which scientific areas (E.g. Plant Health, Animal Health, Biological Hazards, Chemical contaminants (including biotoxins, etc.) within EFSA's remit that this might relate to		
At what scale (local, national, regional, European, global) is the available evidence?		
What is the availability of detection methods?		
What is the strength of the association with CE?		
What are the data gaps and research needs, including needs for new analytical approaches?		

3.3.4. Limitations of the evidence base

- Specific detail of the constituents of substrates used in insect rearing were sometimes lacking. Reasons for this were:
    - Commercial confidence
    - Substrate consisted of mixed municipal organic waste

- Mixing rearing substrates was a confounding factor in some studies. For example, Truzzi et al. (2019), reported a high bioaccumulation factor for Pb in *T. molitor* reared on olive pomace but the Pb contamination was thought to be from the carrot fed to larvae as a source of water, rather than the olive pomace.
- In many studies it was not clear if the invertebrate (usually insects) had been reared on substrate within the CE framework. Again, this was either due to information being withheld due to commercial confidentiality or because the author did not provide information about the rearing substrate. These articles which were excluded from the report covered a wide range of risks of producing and consuming insects including: risk of allergy from consuming insects for food or feed (e.g. pet food) and risk of chemical or biological contamination of larvae via substrates (spiking of substrates or natural).

4. Conclusions

4.1. Objective 1. Current and envisaged circular economy practices within the food and feed supply chain in Europe

The topic 'CE practices within the food and feed supply chain in Europe' is very broad and is of increasing interest not only in Europe but on a global scale. A substantial volume of relevant literature has been published spanning a considerable timeframe, and published research is growing in volume year on year.

Circular economy practices envisaged or currently used in Europe can be divided into four macro areas: primary production of food and feed; reducing industrial/manufacturing/processing waste; reducing food and feed waste in wholesale, food retail, catering and households; and reducing food and feed packaging waste. In each macro area, there are various practices that may link to emerging risks to plant, animal, human health and the environment.

Although we did not specifically search for risk associated with CE whilst identifying current and envisaged CE practices within the food and feed supply chain in Europe, the process allowed us to identify specific examples of associated risks within these practices to plant, animal and human health and the environment. For example, bacterial and viral contamination of food crops from using wastewater for irrigation (Truchado et al., 2020) and the allergenic potential of chitosan (sidestream) in bio-based food contact materials (Bonwick et al., 2019).

4.2. Objective 2 & 3 Literature search and characterisation of emerging risks for human, animal, plant health and the environment from novel foods and feeds within the framework of the CE

A large and growing volume of research and development is being carried out on a global scale on novel food and feeds in relation to the CE framework. The key findings from this report suggest:

- The volume of research investigating emerging risks for animal, human, plant health and the environment is small, particularly when compared to the volume of research investigating the suitability of novel feeds in terms of animal productivity parameters.
- Primary research about risks is focused on invertebrates (primarily insects) as food or feed and the substrate that they are reared on. Primary research about the risks of other novel foods and feeds arising from the CE framework are limited.
- The focus of primary research is on biological and chemical hazards and environmental impacts. One study investigated allergenic hazards and potential physical hazards have only been discussed in reviews.
- Biological hazards reported were bacterial, fungal, yeasts and antibiotic resistance genes found in invertebrates reared on sidestreams or food waste. No primary research studies were captured investigating other biological hazards such as viruses or parasites. However, Dennis Oonincx, a scientist, reported in a magazine article that some pathogens, such as parasites in poultry manure used as a rearing substrate, are not digested by some species of insects, and therefore insects would need to be processed before they can be used as animal feed ((Filou, 2021).
- A wide range of chemical hazards were reported including heavy metals, dioxins, PCBs, PAHs, mineral oil hydrocarbons, veterinary medicines and pesticides. With the exception of one study on a fish fed on fermented soybean meal and scallop by-product blend, the remaining studies investigated FFP, sidestreams and animal manure as novel feeds for insects.
- Emerging risks for animal and human health and environment regarding the production and consumption of invertebrates are correlated to the type of rearing substrate. Specific hazards identified in primary research in this review include the presence of:
    - ARGs in substrates, larvae and insect frass (Milanović et al., 2021)
    - High levels of the heavy metals Cd and Ni in prepupae (e.g. Charlton et al., 2015; Tschiner and Simon, 2015; Truzzi et al., 2020);
    - Uptake of allergens by insects from the substrate e.g. gluten (Mancinia et al., 2020).
- Post-harvest invertebrate thermal or freeze-drying treatments can reduce or eliminate some microbiological hazards (e.g. Conti et al., 2019; Tedesco et al., 2020). However, Varotto Boccazzi et al. (2017), highlighted that the choice of treatment is important because not all treatments are effective for complete inactivation of microorganisms and their toxins.
- Authors recommended the following mitigation measures for insect producers to avoid particular biological hazards:
    - Monitoring for and good hygiene practices to avoid contamination with pathogens (e.g. *C. perfringens*) (Looveren et al., 2021)

- Prudent use of antibiotics in rearing to reduce the risk from some pathogens and ARGs (e.g. Varotto Boccazzi et al., 2017; Milanović et al., 2021)
- Testing of insects for the presence of gluten when reared substrates containing gluten (Mancinia et al., 2020

- Many of the studies investigating invertebrates reared on side streams for food or feed in Europe reported the presence of biological or chemical hazards in substrate, larvae or frass, at levels below European recommended safety limits for food or feed. This is perhaps unsurprising considering the current strict food and feed safety legislation in Europe

- A wide range of environmental hazards were considered, predominantly for rearing invertebrates on novel feed within the CE framework. The main impact reported (e.g. van Zanten et al., 2015; Thévenot et al., 2018) was that that insect production when compared to conventional feed production, has a higher global warming potential. This is because of the energy intensive processing requirements and use of non-renewable energy resources. This results in a trade-off between the benefit in the reduction of land use with insect production with an increase in energy use.

- To minimise energy use and GHG emissions in insect rearing plants:
    - Insect rearing plants could be located next to waste incineration facilities, where heat generated could be used for drying the larvae (van Zanten et al., 2015)
    - Renewable energy sources could be used such as solar or wind energy (van Zanten et al., 2015)

- One author suggested that use of some organic waste streams (e.g. food waste) as a substrate for insect larvae production is in direct competition with bioenergy production, potentially leading to an increase in fossil fuels use, and subsequently resulting in a higher environmental impact (Bosch et al., 2019).

- Should EU food and feed legislation change as a result of a transition towards CE to allow substrates that are currently not authorised for rearing substrate (e.g. animal manure, catering waste, slaughterhouse products, FFP containing meat and fish), future emerging hazards and risks in the EU may arise.

- Food and feed safety legislation varies around the world. It is therefore, prudent to be vigilant about the commercial use of novel substrates used as animal feeds outside of Europe and the implications for safety of food and feed imported into the EU.

5. Recommendations

The authors of this report make the following recommendations:

- That future research considers the wide range of potential emerging risks from a much broader spectrum of novel foods and feeds
  - Existing evidence largely focuses on the impact of novel feeds on animal production parameters. However, emerging risks arising from biological, chemical or physical hazards associated with the novel feed are not considered.
  - Evidence gaps exist regarding the risks to plant, human and animal health and the environment from novel food and feeds within the CE framework. Where emerging risks have been considered, this has been almost exclusively for invertebrates reared for food or feed.
- That future research considers novel foods and feed research and development, and use of these foods or feeds in commercial practice, in countries outside of the EU
  - Novel foods and feeds within the CE is a topic of interest worldwide. To date strict food and feed regulation in the EU, means that some CE materials cannot be used for food or feed. However, legislation is different elsewhere in the world. This may have implications for the safety of food and feed imports into the EU.
  - Scientific evidence from countries outside of the EU may help inform decision-making in the EU's transition towards CE.
- That researchers and commercial practitioners consider the recommendations made by authors of the included studies in this report, specifically:
  - Mitigation of risk
  - Knowledge gaps to be addressed by primary research
- That authors use consistent CE terminology
  - No singular definition of CE exists and the concept is interpreted differently by different societal actors, seeking to influence its meaning and understanding, resulting in a diversity of conflicting approaches
  - The definition of 'waste' has different meanings in different contexts
- That future research considers further development and testing of artificial intelligence (AI) for literature review, specifically in the searching and screening stages where evidence is likely to be highly heterogenous
  - The volume of literature for some CE topics is very large and often highly heterogenous
- That other tools are used in combination with literature review to explore emerging risk related to CE
  - Literature reviews inherently look backwards but provide an evidence base onto which to build a greater understanding, using other tools, e.g. expert elicitation
- That expert elicitation is used to:
  - Help identify additional emerging risks to human, animal or plant health and the environment, for the wider range of novel foods and feeds. The lists of foods and feeds provided in Appendix D, Worksheets 5. and 6. provide an indication of what is being researched globally and could be used in a horizon scanning exercise with expert stakeholders, to identify potential emerging risks.
  - Identify upcoming novel foods and feeds that do not appear in published literature and any associated emerging risks.

- Help to address the following questions set by EFSA that could not be answered using the evidence captured in this report:
  - What is the availability of data underpinning the definition of emerging risk:
    - (eco)toxicological, bioaccumulation and environmental accumulation, epidemiological, biomonitoring, consumption and occurrence data in line with EFSAs environmental risk assessments remit
    - severity, duration and frequency of the expected effects on human, plant and animal health
    - descriptions of exposure pathways
    - interactions with other contaminants and possible additive effects
  - What evidence is there for risk management and reduction measures:
    - monitoring systems/programs
    - What type, amount and frequency of application of products are applied in/on environmental matrices?
    - What are the impacts on economy, environment, social aspects, and food and feed security?
    - What is the imminence of these impacts? (How quickly might the risk materialise? How urgent is the response?)
    - What are the parallels and interactions with other areas and emerging issues?

- We suggest further research to investigate the emerging risk of using insects to decontaminate animal manure to reduce environmental risk from hazards such as heavy metals, and if the residual insects and frass can be safely used as animal feed or fertiliser
  - During the literature screening stage of the review, a number of recently published studies were excluded that investigated the role of insects in the biotransformation of livestock manures, to reduce environmental contamination (e.g. heavy metals). The aim of these studies was to provide a preliminary understanding of the biotranformation process (e.g. Wang et al., 2021), although authors noted that residual insect bodies and frass in theory could be valuable source of animal feed and fertiliser. Further research is required to fully understand the implications for emerging risk of these transformed products.
- That future reviews focus on emerging risk from other areas of the circular economy
  - Use of organic waste streams other than feed or food:
    - Animal manures, (including insect frass), and municipal sewage as fertilisers
    - Wastewaters for irrigation
    - Livestock, crop and non-crop by-products for fertiliser
  - Food contact materials relevant to the CE framework to extend shelf life of food and feeds e.g. bio-based materials
  - Recycling and reuse (e.g. refillable containers) of existing food and feed packaging (e.g. plastic and cardboard) and new biobased packaging

Recommendations for primary research by authors of studies included in this report:

Biological hazards

- Further research about production, technological processing, packaging and storage conditions to prevent microbial contamination of earthworms for food (Conti et al., 2019).

- Establishment of specific guidelines for the production and commercialisation of earthworms for human consumption (Conti et al., 2019).
- To investigate the presence of allergens to indirect transmission routes: fresh earthworm–farmed animal–human (Tedesco et al., 2020).
- To understand if nematodes for whom earthworms are intermediate hosts can contaminate livestock such as poultry, and represent a public health risk for humans (Tedesco et al., 2020).
- To investigate if sterilisation of earthworms to reduce biological hazards decreases the bioavailability of some amino acids which may affect nutritional content (Tedesco et al., 2020).
- To characterise the opportunistic yeast *T. asahii* and its presence in insect-based feed or food (Varotto Boccazzi et al., 2017).
- To investigate possible hazards caused by the remaining bacterial spores, as well as on the possible presence of mycotoxins in *A. diaperinus* larvae reared on sidestream from food industry (Wynants et al., 2018)
- Research to test substrates and insect species other than, potato starch and wheat and potato processing product, plus protein kibble for *H. illucens* larvae, as horizontal transfer of the pathogen *C. perfringens* from substrate to larvae can be substrate and/or species dependent (Looveren et al., 2021).
- To investigate the if pathogens such as *C. perfringens* in the frass pose a risk when used as fertiliser and how this can be mitigated (Looveren et al., 2021).
- To understand the correlation between the copy number of ARG's carried by microbial communities occurring in the rearing substrates and those contained in the insect gut and resulting frass using quantitative PCR assays (Milanović et al., 2021).
- To investigate the biological hazards associated with pre-treatments of side streams substrates for insects (Vandeweyer et al., 2021).
- Further investigation of the risk of transmitting zoonotic infections to humans through edible insects and slaughterhouse by-products are a source of substrate for insects (FAO, 2021).

Chemical hazards:

- Further research to determine if cadmium and other potential risks in insects used as feed are transferred into farm animals (Charlton et al., 2015).
- To understand:
    - How metabolism of heavy metals by fish may vary depending on the metal (Kader et al., 2011).
    - The effects on heavy metal element composition of fish tissues of long-term dietary exposure to recommended levels of feed containing scallop by-products (Kader et al., 2011).
- Research to:
    - Assess the potential risk of Ni contamination of prepupae (van der Fels-Klerx et al., 2020).
    - Create a specific list of tested growth substrates for safe edible-insect production (van der Fels-Klerx et al., 2020).
- Investigate the safety of thermally generated carbohydrate degradation products from biomass pretreatment in relation to using yellow and green biomass biorefinery products in food or feed (Lange and Meyer, 2019).

- Investigate the risk of persistent xenobiotics following anaerobic digestion of agro-industrial wastes and post-treatment of wastewater for the cultivation of microalgae and duckweeds (Markou et al., 2018).
- Investigate to what extent nucleic acids should be considered as a harmful substance for animals resulting from micro algae grown on by-product or waste as ingredient in animal diets (Spruijt et al., 2016).

Environmental hazards:

- To investigate increasing processing speed to decrease N volatisation (Oonicx et al., 2015).
- To investigate to what extent insect rearing increases competition for raw materials and by-products (e.g. for biofuels), and whether the emergence of a new insect supply chain might indirectly worsen environmental impacts of other types of agriculture production (Thévenot et al., 2018).
- Further research to improve rearing and extraction techniques to reduce energy requirements (Thévenot et al., 2018).
- To conduct risk analysis for ARGs in insect rearing and research to understand the correlation between the copy number of ARG's carried by microbial communities occurring in the rearing substrates and those contained in the insect gut and resulting frass using quantitative PCR assays (Milanović et al., 2021).

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Glossary and Abbreviations

Glossary

Term	Description
Allergenic hazard	Allergenic hazards are 'allergens' (a type of antigen) that cause allergic reactions (abnormal immune response to specific allergens).
Animal	'Animal' refers to farmed animals (food producing and non-food producing animals) and companion animals (including pets, working or service animals). All animal species were considered for inclusion in this report (i.e. all vertebrates and invertebrates).
Biological hazard	Biological substances that pose a risk to plant, human, animal health or the environment e.g. bacteria, viruses, yeasts, moulds and parasites.
Chemical hazard	Chemical substance (natural and man-made) that pose a risk to plant, human, animal health or the environment e.g. heavy metals, mycotoxins, pesticides, polychlorinated biphenyls
Circular economy	'where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised' (EC, 2015)
Emerging risks	'a risk resulting from a newly identified hazard to which a significant exposure may occur, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard.' (https://www.efsa.europa.eu/en/topics/topic/emerging-risks)
Environment	The 'natural environment' encompassing all living (i.e. wild animals, plants, algae and fungi) organisms and non-living natural resources (i.e. soil, air and water). Wild plants and animals were regarded to be part of the environment.
Environmental hazards	Any biological or non-biological hazards that are harmful to the health of the environment e.g. greenhouse gases, management and modification of natural environment or wilderness into arable fields or pastures, substances causing eutrophication or acidification of natural habitats.
Former food product	'foodstuffs, other than catering reflux, which were manufactured for human consumption in full compliance with the EU food law but which are no longer intended for human consumption for practical or logistical reasons or due to problems of manufacturing or packaging defects or other defects and which do not present any health risks when used as feed' (Regulation (EU) No 2017/1017)
Intra-species recycling	Systematic re-feeding of feedstuffs derived from the tissues of one species of animal back to the same species.

Novel food	'any food that was not consumed "significantly" in the EU prior to May 15 1997 (Regulation (EU) 2015/2283)'. 'Novel Food' can be newly developed, innovative food, food produced using new technologies and production processes, as well as food which is or has been traditionally eaten outside of the EU.
Novel feed	new sources of feed from the food industries, biofuel industries and industrial processes and new types of ingredients such as processed animal proteins (PAPs) derived from farmed insects, and ingredients from marine resources and aquatic plants (FAO/WHO 2019)
Physical hazard	Foreign materials unintentionally introduced to food or feed products that are hazardous to the consumer e.g. glass, plastic fragments
Plants	'Plants' in this report refers to crops grown for commercial use. Wild plants were considered to be part of the 'environment'.
Sidestream	'Sidestream' in this report refers to by-products secondary products that result incidentally from the manufacturing of a main product

Abbreviations

aac-aph	Aminoglycosides
ARGs	Antibiotic resistance genes
AS	Arsenic
AI	Artificial Intelligence
bla mec	β-lactams
BH	Biological hazards
Cd	Cadmium
CeIRSA	Centro Interdipartimentale di Ricerca e Documentazione sulla Sicurezza Alimentare
CC	Chemical Contaminants
CE	Circular economy
Cu	Copper
CED	Cumulative energy demand
DPNA	Dietetic Products, Nutrition and Allergies'
erm	Erythromycin
EC	European Commission
EEA	European Environment Agency
FEFAC	European Feed Manufacturers' Federation
EFSA	European Food Safety Authority
EFFPA	European Former Foodstuff Processors Association
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FFP	Former food product
FVW	Fruit and vegetable waste
GWP	Global warming potential
GHG	Greenhouse gas
IPIFF	International Platform of Insects for Food and Feed
LU	Land use
Pb	Lead
LCA	Life Cycle Assessment
Hg	Mercury
NVWA	Nederlandse Voedsel- en Warenautoriteit
Ni	Nickel
N	Nitrogen
OECD	Organisation for Economic Co-operation and Development
PCBs	Polychlorinated biphenyls

PAHs	Polycyclic aromatic hydrocarbons
PCR	Polymerase chain reaction
PAPs	Processed animal proteins
SAPEA	Science Advice for Policy · by European Academies
SDG	Sustainable Development Goal
tet	Tetracycline
UKRI	United Kingdom Research and Innovation
vam	Vancomycin
VOCs	Volatile organic compounds
WaW	Wastewater (WaW)
WUR	Wageningen University and Research
Zn	Zinc

Annex A - Additional files for Objective 1.

Annex A, Worksheet 1: Organisational websites searched for literature in Objective 1: Name of organisation; Web address; Date of search; Number of documents retrieved; How the site was searched

Annex A, Worksheet 2: Search strings used to retrieve published articles from Scopus for topic modelling (using Sciome SWIFT-Review software) Objective 1.

Annex A, Worksheet 3: Articles used to initially identify macro areas in stage 1.

Annex A, Worksheet 4: Articles used to identify meso and micro CE practices in the macro area, primary production of food and feed, and any examples of associated risks

Annex A, Worksheet 5: Articles used to identify meso and micro CE practices in the macro area, reducing industrial/manufacturing/processing waste, and any examples of associated risks

Annex A, Worksheet 6: Articles used to identify meso and micro CE practices in the macro area, reducing food waste in retail, catering and consumer sector, and any examples of associated risks

Annex A, Worksheet 7: Articles used to identify meso and micro CE practices within the macro area, Reducing packaging waste, and any examples of associated risks

Annex A can be found in the online version of this output ('Supporting information' section):

https://efsa.onlinelibrary.wiley.com/doi/10.2903/sp.efsa.2022.EN-7226

Annex B - Survey form, Objective 1. Priority checklist: The current degree of uptake of circular economy within all stages of the food/feed production chains in Europe

Annex B can be found in the online version of this output ('Supporting information' section):

https://efsa.onlinelibrary.wiley.com/doi/10.2903/sp.efsa.2022.EN-7226

Annex C - Additional files for Objective 2

Annex C, Worksheet 1: Scoping searches main search string

Annex C, Worksheet 2: Scoping searches and examples of short search strings for specific foods or feeds

Annex C, Worksheet 3: Search results from bibliographic databases using main search string: Database searched; Date searched; Search term; How the site was searched; Number of results returned; Notes; Number of articles imported into Endnote software

Annex C, Worksheet 4: Results of bibliographic searches using short specific search strings; Database searched; Date searched; Search term; How the site was searched; Number of results; Notes; Total imported into Endnote software

Annex C, Worksheet 5: Results for searches for literature from organisation websites: Organisation; Web address; Date of search; Number of articles retrieved; Comments; Search terms used to search site

Annex C can be found in the online version of this output ('Supporting information' section):

https://efsa.onlinelibrary.wiley.com/doi/10.2903/sp.efsa.2022.EN-7226

Annex D - Additional files for Objective 3

Appendix D, Worksheet 1: Coding template for meta-data extraction

Appendix D, Worksheet 2: Meta-data extracted from the 26 studies that investigated risk to animal and human health and the environment, from novel food and feed within the CE

Appendix D, Worksheet 3: References for the 29 reviews and reports and one PhD thesis captured in literature search

Appendix D, Worksheet 4: Historical and ongoing research (Horizon 2020, SUSFOOD2, UKRI) projects investigating novel food and feed in relation to the CE framework, captured in searches for research

Appendix D, Worksheet 5: List of novel feeds within the CE framework that investigated risk to animal performance parameters

Appendix D, Worksheet 6: List of novel foods and feed within the CE where no risk has been investigated

Annex D can be found in the online version of this output ('Supporting information' section):

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