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Is ‘waste’ an appropriate concept in a sustainable bioeconomy?

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A R T I C L E I N F O

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A B S T R A C T

Valorisation of agri-food waste is an essential aspect of creating sustainable circular food systems. The European Research Area Network Cofund Food Systems and Climate (FOSC) and the SUSFOOD2 ERA-Net Cofund supported eight projects focusing on the valorisation of waste generated during primary production or food processing. The projects identified barriers related to the technological, socio-economic, legislative, and institutional challenges of developing a circular food system, and concluded that overcoming these barriers and promoting a circular bioeconomy requires a comprehensive approach involving multiple stakeholders, including fostering supportive policies, and addressing regulatory concerns. The collective experience of the eight projects demonstrates that it is essential to rethink the limitations imposed by the term ‘waste’, and instead to consider all agri-food residues as side streams which have the potential to be valorised as resources for food and feed production if they can be proven as safe to return to the food chain.

1. Introduction

The growing demand for food production is increasingly constrained by competition for land, water, and other natural resources, leading to overexploitation, degradation of ecosystems, and significant environmental consequences [25]. To sustainably meet future global nutritional needs, a shift toward circular food systems is imperative. Central to this transition is the development of a bioeconomy that prioritises sustainability by transforming biomass residues, side streams, and biowaste into valuable resources. The generation of organic residues and waste is an inherent aspect of the entire food supply chain, encompassing stages from primary agricultural production to processing, distribution, retail, and final consumption. In developed countries, household waste accounts for 42 % of food losses, while the food manufacturing industry is responsible for 39 %, followed by the food service sector (14 %), and retail and distribution (5 %) [16]. Importantly, these figures do not account for agricultural waste, which further adds to the resource challenge.

For a sustainable bioeconomy to thrive, it is essential to ‘close the loop’ by reintegrating these waste streams into productive cycles – a

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process known as valorisation or upcycling. Valorisation not only reduces waste but also enhances resource efficiency, aligning with key sustainability practices that are increasingly being recognised as pivotal to mitigating environmental impact and promoting circularity in food systems [14,27]. By reusing agricultural by-products and food industry side streams, these innovative strategies contribute to reducing the overall ecological footprint of food production, while simultaneously supporting long-term food security and resilience [10].

Usually three processes, namely composting, incineration, or anaerobic digestion, are used to deal with agri-food waste. However, it is argued here that these processes do not contribute to an adequate use of the potential of organic residues as a resource. This paper brings together perspectives on the valorisation of agri-food waste from eight projects conducted under the European Research Area Network (ERA-Net) Cofund Food Systems and Climate (FOSC). FOSC aims to initiate and push ahead transnational collaboration on the societal and systemic transition to sustainable and climate-resilient food systems. Six of the projects were funded by the 2019 FOSC call (BLUE-CYCLING, CHIAM, CLIMAQUA, PHEALING, THERMOK, TRUSTFARM) and two by the 2021 joint call of FOSC and the SUSFOOD2 ERA-Net Cofund (ALGAE-BREW, OLIVE3P). Each project conducted innovative research to explore solutions to the valorisation of waste produced at one of two points along the food supply chain – primary production or food processing – and examined the barriers to upscaling these solutions.

This paper further aims to clarify the resource potential of organic residues irrespective of their origin and characteristics. Starting with a definition of organic residues as either biowaste, by-product or side stream, it will be shown how the definition used influences policy and behaviour, and consequently valorisation approaches. Based on the experiences and lesson learned (particularly relating to technological, socio-economic, legislative as well as institutional barriers) from the eight projects, recommendations are made for an integrated approach which encourages multi-actored dialogues between stakeholders, and advocates for supportive policies that promote sustainable and circular practices and the valorisation of agri-food waste for food and feed production.

2. Definition of biowaste, by-product and side stream

The EU Waste Framework Directive entered into force in 2008 [6] and was revised in 2018 [7]. The legislation establishes the basic concepts related to waste management, including definitions of waste, by-product and biowaste (Table 1). Waste is defined as 'any substance or object which the holder discards or intends or is required to discard', while by-product means 'a substance or object resulting from a production process, the primary aim of which is not the production of that substance or object'. A by-product is not considered waste if it meets specific conditions: its further use is certain; it can be used directly without any further processing other than normal industrial practice; it is produced as an integral part of a production process; and it fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts. When a by-product does not meet all the conditions of the standard, it must be classified as waste and disposed of. However, if it is subjected to specific recovery operations and a market or demand exists for such a substance or object, it loses its status as waste and so it is possible to use it as a raw material for a new production process (so-called 'end-of-waste status'). The difference between the by-product and the end-of-waste status is that the former is never classified as waste, while the latter is initially categorized as waste and later, if there is the intention to requalify it, it can be put back into a production cycle as a resource [31].

Table 1
Definitions of food waste, food by-product and food side streams.

	Food waste	Food by-product	Food side stream
Definition	Any substance intended to be eaten by humans and which is discarded	Residues generated during primary production or food processing that were not intended to be eaten, have value, and can be used directly without any further processing other than normal industrial practice	Residues generated during primary food production or food processing that were not intended to be eaten, have potential value, and can be re-purposed for other usage upon further processing
Example (from aquaculture)	Out-of-date fish fillets in a supermarket	Fish residues (e.g. trimmings, skins, heads, frames)	Sludge and discharge water

The definition of bio-waste was revised in 2018 as 'biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants' [7]. Food waste means all food as defined in Article 2 of Regulation (EC) No 178/2002 – 'any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans' – that has become waste [8]. Food waste therefore refers to edible produce that is discarded, while food by-product refers to the residues generated during primary production or food processing that were not intended to be eaten, such as peels, stems, seeds, or fruit and vegetable trimmings, which meet the qualification criteria of 'by-product' outlined above.

In Europe, around 88 million tons of food are wasted annually along the food supply chain, from primary production to consumption, with associated costs estimated at 143 billion euros [3]. 72 % of food waste is generated during processing (17 million tons) and by households (47 million tons) [26]. The Waste Framework Directive establishes the waste hierarchy which prioritises waste prevention, reuse, recycling, and recovery over disposal. In the context of the waste hierarchy, end-of-waste status occurs at the reuse level, since the waste ceases to be waste. According to the waste hierarchy framework, the most preferable food waste management options cascade downwards from reduction, through redistribution to people, feeding to animals, anaerobic digestion, composting, incineration, and finally, as a last resort, landfill. Food waste policy is mainly focused on reduction or prevention of food waste and proper waste management, rather than on valorisation of waste as a resource.

An important term that is missing from the Waste Framework Directive is 'side stream', which is generally understood to refer to materials that are produced as a secondary output during the main production process and which have potential value that may require further processing to be utilised effectively. The difference between by-product and side stream can be illustrated by an example: residues from the preparation of fish fillets have an established value as an input for pet food, fishmeal and fish oil production, and would therefore be considered as a by-product, while the water used in processing the fish fillets could be regarded as a side stream rather than automatically assumed to be waste, since it has the potential to be reused or recycled, thereby aligning with the principle of the end-of-waste status.

Agricultural waste, such as manure, slurry and crop residues, is excluded from the Waste Framework Directive, presumably due to its long history of in situ reuse as fertilisers [4]. Aside from applying these residues to the land, other common management options are composting and anaerobic digestion. Yet the potential for valorisation of these residues is a subject too important to ignore, bearing in mind their quantity, which Bedoić et al. [1] estimated to amount to 18.4 billion tonnes between 2010 and 2016, representing a mean 2.6 billion tons/-year in the EU alone. Much of the waste occurs during primary production, with large quantities of edible crop parts left in the field at harvest [5].

Land-based aquaculture also produces waste that is excluded from the Waste Framework Directive, and the absence of regulations promoting its use means that certain types of aquaculture side streams are not efficiently valorised. Adopting the cascading principles of the food waste hierarchy, Stevens et al. [28] proposed a food recovery hierarchy for fish by-products – the edible or inedible parts left over following the preparation of the main product, such as trimmings, skins, heads, frames (bones with attached flesh), viscera (guts) and blood – whereby food grade by-products should be processed for human use, downgraded by-products should be used for feed, fuel, fertiliser or compost, and waste products should be incinerated or sent to landfill as a last resort. Other aquaculture side streams, such as sludge – organic-rich matter made from faeces and uneaten feed – and discharge water, are typically disposed of. While uncontrolled discharge of these residues can lead to eutrophication due to the nitrogen and phosphorus content, these same nutrients also offer potential for their reuse and valorisation [2,24].

Biowaste and agri-food side streams offer significant potential for valorisation as inputs that can be recycled back into the food system, thereby contributing to the circular economy [17]. A paradigm shift is therefore needed to transition from thinking of these in terms of waste to thinking in terms of resources and opportunities.

3. Conversion of waste to resource

In the following the eight projects which focus on the valorisation of side streams from primary production or biowaste from food processing are introduced (Table 2). The projects have identified technological, socio-economic, legislative, and institutional barriers hindering the implementation of the outcomes of the eight projects presented (Table 3).

3.1. Side streams from primary production

3.1.1. CHIAM

The CHIAM project is developing a sustainable food value chain in Africa by integrating chia and oyster mushroom production. This climate-smart farming system uses lignocellulosic residues from chia plants to cultivate oyster mushrooms. The spent mushroom substrate (SMS) left after mushroom harvest is used as animal feed, and the resulting manure is processed to produce biogas. This biogas serves as a clean energy source, and the biogas digestate is used as a biofertiliser, enhancing soil quality. This integrated system promotes circularity, reduces waste, and supports food security and climate resilience.

Table 2
Overall summary of the eight valorisation projects funded by SUSFOOD2 and FOSC.

Project	Treated food waste/ side streams	Valorisation agent	Target products
CHIAM	Lignocellulosic residue from chia plant Spent mushroom substrate Manure	Oyster mushroom Anaerobic digestion	Food Feed Biogas and fertiliser
CLIMAQUA	Aquaculture wastewater Aquaculture sludge Seafood residues Fish by-products	Phototrophic microalgae Heterotrophic microalgae	Feed
TRUSTFARM	Agriculture side streams	Vermicompost	Feed
THERMOK	Poultry feathers (keratin as target substrate)	Anaerobic bacteria	Feed, biofertiliser, peptides and amino acids
ALGAEBREW	Brewery wastewater Brewer's spent grain	Phototrophic microalgae	Aquaculture feed Fertiliser
PHEALING	Cassava and potato peels (suberin as target substrate)	n/a	Food coating
OLIVE3P	Olive mill effluent (OME) Cheese processing effluent	Yeast / Biochar	Aquaculture feed Poultry feed Adsorbent for OME depollution
BLUE-CYCLING	Food processing waste	Black soldier fly larvae	Aquaculture feed

3.1.2. CLIMAQUA

The CLIMAQUA project aims to create a sustainable feed production method for the aquaculture industry to reduce its climate impact. The FAO reports that greenhouse gas (GHG) emissions from different aquaculture species range from 1.4 to 1.8 kg CO_2 per kg of live fish weight. When feed production is included, GHG emissions nearly double, amounting to 87 % of emissions [9]. To address this, the project proposes using side streams from aquaculture (e.g., wastewater, sludge, seafood residues) as feed substrates, thereby avoiding conventional waste disposal methods that contribute to carbon and nitrogen emissions. In Europe, efficient use of fish by-products is already a widespread practice, but managing sludge and wastewater remains a challenge [21]. Optimising microalgae cultivation based on regional environmental conditions can reduce emissions and links waste management with feed production, necessitating careful consideration of current legislation.

3.1.3. TRUSTFARM

The TRUSTFARM project aims to create resilient and sustainable agri-ecosystems through climate-smart farming practices based on circular economy principles, specifically the RRR (Reduce, Reuse, Recycle) approach. Key activities include producing vermicompost from organic agricultural side streams, conducting field trials using vermicompost [30,29], and optimising manure management in dairy sheep farms in Roquefort, France.

3.1.4. THERMOK

The THERMOK project focuses on utilising selected thermophilic anaerobic bacterial cultures and consortia to degrade keratin-laden waste, such as poultry feathers. Keratin, a highly recalcitrant polymer found in feathers, hair, nails, and hooves, poses a significant challenge for the animal rendering industry due to its resilient structure composed of disulfide bonds, hydrogen bonds, and hydrophobic interactions. The project aims to harness the natural degradation processes involving extracellular and cell-bond enzymes from thermophilic anaerobic bacteria to efficiently break down keratin waste, thereby addressing the significant environmental impact of disposing of such waste and producing feed, biofertiliser, peptides and amino acids [12].

3.2. Biowaste from food processing

3.2.1. ALGAEBREW

The ALGAEBREW project aims to create a sustainable and circular food process by using microalgae to valorise brewery biowaste into omega-3 rich aquaculture feed and fertilisers. Traditional waste treatment methods for brewery side streams are costly and environmentally harmful, whereas growing microalgae on biowaste can recover nutrients and convert them into valuable biomass. This biomass can be used directly in animal feed or processed further to extract high-value compounds. The project focuses on identifying microalgal species that can thrive on different types of biowaste and integrating these processes into existing wastewater treatment systems [13]. Results from the project to-date have shown that phototrophic microalgae can be successfully grown at lab scale on brewery wastewater with minimal pre-treatment and prior adjustment of the wastewater characteristics, thus minimising cost. The microalgal bioremediation process developed in the project recovered almost all of the available nutrients in the wastewater, demonstrating its effectiveness as a wastewater treatment method. However, commercial and legislative barriers need to be addressed for widespread adoption of this technology in Europe. The high cost

Table 3
Identified technological, socio-economic, legislative, and institutional barriers hindering the implementation of the outcomes of the eight projects.

Project	Technological	Socio-economic	Legislative	Institutional
CHIAM	- Process development in oyster mushroom growing in Africa: Testing the appropriateness of side streams of chia production and other locally available materials as feedstock for oyster mushroom growing. - Cascade usage of spent mushroom substrate: Examining the possibility of closing the loop of the value chain through pig feeding, biogas and biofertiliser production.	- Market acceptance: Establishing market acceptance of oyster mushroom and novel food products fortified by oyster mushroom. - Support of local farmers: Teaching local farmers how to use their available side streams to grow mushrooms, and then how to utilise the spent mushroom substrate. - Economic viability: Addressing the cost-effectiveness of the circular model of oyster mushroom production.	- Legislative barrier: Using waste as substrate for food production is not always accepted. - Environmental compliance: Ensuring compliance with environmental regulations related to waste management. - Food safety standards: Adhering to food safety regulations and certifications for oyster mushroom and novel food fortified by oyster mushroom in Africa.	- Research collaboration: Collaborating with farmers, research institutions, and academia to fine-tune the technologies to local needs. - Policy support: Advocating for policies that promote circular economy practices, sustainable biowaste management, and the use of bio-based materials.
CLIMAQUA	- System integration: Developing efficient and scalable integrated algae cultivation systems that optimise resource use (water, nutrients, space). - Technological innovation: Developing new technologies for nutrient recovery, waste management, and energy efficiency within integrated systems.	- Market acceptance: Generating market demand and consumer acceptance. - Economic viability: Addressing the cost-effectiveness of aquaculture. - Skill development: Training and capacity building for farmers and stakeholders to manage integrated algae biomass production systems. - Access to finance: Securing funding and investment for infrastructure development, technology adoption, and operational scaling.	- Regulatory frameworks: Navigating diverse regulations for aquaculture and integrated systems that may vary across regions and countries. - Environmental permits: Obtaining permits related to water use, waste discharge, and potential ecological impacts of aquaculture operations. - Food safety standards: Adhering to food safety regulations and certifications for products from aquaculture systems.	- Collaboration and partnerships: Establishing partnerships between aquaculture and algae cultivation sectors, research institutions, and government bodies to support knowledge exchange and technology transfer. - Policy support: Advocating for policies that promote sustainable aquaculture practices, resource efficiency, and circular economy principles. - Public awareness: Increasing awareness and understanding among stakeholders, policymakers, and the public about the benefits and potential of integrated aquaculture systems.
TRUSTFARM	- Technology adoption: Adoption of vermicomposting techniques may require training and capacity building among farmers. - Infrastructure for scaling up: Establishing and maintaining earthworm farms and composting facilities might require initial investment and technical know-how.	- Awareness and acceptance: Farmers may need to be convinced of the benefits of vermicomposting over traditional waste disposal methods. - Economic viability: Initial costs and time investment in setting up vermicomposting operations might deter some farmers.	- Regulatory compliance: Compliance with environmental regulations related to waste management and organic farming practices.	- Policy support: Lack of policies that incentivise or support farmers in adopting sustainable farming practices like vermicomposting.
THERMOK	- Bioprocess optimisation: Optimising conditions for thermophilic bacterial degradation of keratin-rich waste materials. - Scale-up: Scaling up thermophilic biodegradation processes from lab-scale to industrial applications.	- Waste disposal practices: Overcoming inertia in traditional waste disposal methods (e.g., landfilling or incineration) for keratin-rich waste.	- Regulatory compliance: Compliance with environmental regulations for waste treatment and biodegradation processes.	- Research collaboration: Collaboration with industries and waste management sectors for technology transfer and adoption.
ALGAEBREW	- Bioprocess optimisation: Optimising the growth conditions and nutrient management for microalgae cultivation on brewery waste streams. - Scale-up: Scaling up microalgae cultivation processes from lab-scale to industrial-scale may pose technical challenges.	- Cost-effectiveness: Economic viability of microalgae-based systems compared to traditional waste treatment methods. - Market acceptance: Establishing a market for microalgae-based products in animal feed industries.	- Regulatory approval: Regulatory hurdles related to the use of microalgae in food and feed products, especially for novel applications using biomass derived on wastewater.	- Research funding: Dependence on public or private funding for research and development in novel biotechnological applications.
PHEALING	- Biopolymer development: Scaling up production of suberin-based coatings for commercial applications. - Bioprospecting: Identifying and utilising microbial antagonists effectively for post-harvest disease management.	- Market acceptance: Acceptance of new technologies like suberin coatings in the food industry. - Cost-effectiveness: Cost of production and application of suberin-based coatings compared to conventional methods.	- Regulatory compliance: Regulatory approval for novel food coatings and microbial biocontrol agents.	- Industry collaboration: Collaboration with food processing and packaging industries for technology adoption and market penetration.
OLIVE3P	- Bioprocess integration: Integrating biowaste streams (olive mill solid waste) for efficient adsorbent production. - Bioprocess integration: Integrating biowaste streams (OME and CPE) for efficient yeast production. - Nutrient optimisation: Optimising nutrient composition and conditions for yeast growth on diverse biowaste substrates.	- Market penetration: Developing markets for edible yeast and biopesticides derived from biowaste streams. - Economic viability: Cost-effectiveness of biowaste valorisation compared to conventional waste management practices.	- Regulatory approval: Regulatory challenges related to the use of biowaste-derived products in food and agriculture.	- Policy support: Need for policies that promote and incentivise circular economy practices and biowaste valorisation.

(continued on next page)

Table 3 (*continued*)

Project	Technological	Socio-economic	Legislative	Institutional
BLUE-CYCLING	- Bioprocess efficiency: Ensuring efficient conversion of biowaste into high-quality insect protein. - Nutrient optimisation: Optimising insect larvae nutrient composition tailored for aquaponic fish feeds.	- Market integration: Integrating insect protein into existing fish feed markets. - Economic viability: Cost-effectiveness of insect-based feeds compared to traditional fish feeds containing fishmeal protein (economies of scale).	- Regulatory approval: Regulatory constraints on permitted biowaste feedstocks for insects, which limit the scalability and cost-effectiveness of insect farming and thus affect the economic viability of insect-based fish feeds.	- Policy support: Lack of supportive policies for the development of insect-based fish feeds.

associated with microalgal growth and biomass processing at scale, as well as the difficulty encountered in maintaining culture performance and biomass quality across seasonal variations in wastewater compositions, stifles commercial deployment of large-scale microalgal wastewater treatment. Additionally, stringent regulatory barriers on the use of biomass derived from waste nutrients have precluded potential application of microalgal biomass obtained from wastewater treatment in the animal feed and food sectors, adding an extra layer of complexity in the development of a viable business model for microalgal-based wastewater treatment.

3.2.2. PHEALING

The PHEALING project explores natural plant healing mechanisms and microbial antagonists to reduce post-harvest losses and food waste. Key findings include the potential of suberin polymer as a food coating material to extend crop shelf life by reducing water loss and its application in enhancing non-isocyanate polyurethane foams [15]. Suberin, derived from biowaste such as potato and cassava peels, supports recycling within food value chains and offers an alternative to restricted microplastics. Optimisation of suberin extraction processes and understanding suberin biosynthesis in plants are essential for further applications. Additionally, the project investigates lytic bacteriophages to combat bacterial pathogens, enhancing food safety and shelf life.

3.2.3. OLIVE3P

The OLIVE3P project aims to transform the traditional linear food production model into a more sustainable and resilient circular system by converting olive mill solid waste into biochar, which serves as an effective adsorbent for the depollution of olive mill effluent. Initial results indicate that biochar achieved a maximum polyphenol adsorption of 23.2 mg/g, removing 92.2 % of polyphenols, 65.5 % of total organic carbon (TOC), and 80.8 % of chemical oxygen demand (COD). These findings highlight biochar's efficiency in maximising polyphenol recovery [22,23]. Additionally, the project focuses on converting olive mill effluent (OME) and cheese processing effluent (CPE) into valuable products. By leveraging the rich organic compounds present in these biowastes, OLIVE3P seeks to produce non-conventional edible biomass, specifically oleaginous yeast strains like *Rhodotorula*. These yeast strains can metabolise the nutrients from OME and CPE into protein-rich biomass, suitable for use in fish and poultry feed. The project's goals include reducing environmental pollution, improving biowaste management, promoting the circular economy, and decreasing reliance on non-renewable resources.

3.2.4. BLUE-CYCLING

The BLUE-CYCLING project explored replacing fishmeal in Nile tilapia diets in aquaponics with meal made from black soldier fly larvae reared on food processing biowaste [20]. This approach addresses environmental and economic concerns about commercial fishmeal, which is unsustainable and costly due to overfishing and high demand [11]. Insects, especially black soldier fly larvae, are a sustainable alternative, converting waste into high-protein feed efficiently. In aquaponics tailored feeds are needed that incorporate the necessary minerals to balance the nutrient needs of fish, plants, and bacteria. Since the feedstock used to rear insects affects their nutritional composition, this raises the possibility of designing insect feedstocks using components which are high in the minerals commonly lacking in aquaponic systems. However, regulatory barriers limit the feedstocks permitted for insect farming in the EU, unlike in Africa and Asia where a wider range of biowaste is used. The diversification of the inputs authorised as insect substrates, such as the approval of catering waste or former foodstuffs containing meat and fish, is seen as a catalyst to upscale insect farming, and would play a key role in accelerating the growth of the sector by significantly decreasing input costs for operators. Deregulation and approval of diverse substrates could therefore enhance the nascent insect farming industry, reduce costs for consumers, and promote local circular agri-food systems.

4. Outcomes

All eight projects resulted in significant technological advancements aimed at the future valorisation of biowaste and side streams within the food production sector. However, several critical barriers were also identified across technological, socio-economic, legislative, and institutional dimensions (Table 3). Common technological challenges include scaling up processes from laboratory to industrial levels, optimising process efficiencies, and integrating diverse waste streams into a cohesive system. Socio-economic concerns often revolved around the economic viability of the developed solutions, market acceptance, and consumer perception, particularly with respect to food and feed ingredients derived from organic residues. Legislative and institutional challenges centred on regulatory hurdles, compliance with environmental standards, and the need for enhanced policy support and research funding at national and EU levels.

Addressing these legislative barriers requires a multi-stakeholder approach that aligns with the EU Waste Framework Directive and its principles of waste hierarchy, which prioritises waste prevention, reuse, and recycling over disposal. The two key strategies for overcoming these barriers involve, first, advocating for policies that incentivise sustainable and circular bioeconomy practices, such as the valorisation of agri-food waste through tax incentives and market-based mechanisms. Secondly, establishing a dialogue with regulatory bodies is crucial to ensure they understand the unique challenges posed by circular bioeconomy practices and to help design regulations that facilitate the integration of side streams into food and feed production. An important aspect of this regulatory conversation is the careful and consistent use of the term 'waste', promoting the redefinition of waste streams as valuable by-products or side streams where appropriate, to support the valorisation process [18].

The outcomes of the eight projects clearly demonstrate that agri-food waste can serve as suitable feedstocks for food and feed production. Despite variations in the bioconversion methods employed across the projects, all produced viable products that can be safely integrated into food and feed systems, with no detectable microbial or chemical contaminants. Notably, these approaches represent a departure from conventional waste treatments such as anaerobic digestion, incineration, and composting, and pave the way for more efficient resource use in a circular bioeconomy [19]. The projects collectively highlight the potential for transforming biowaste into valuable resources, emphasising the need for continued innovation and supportive legislative frameworks to fully realise the benefits of these circular bioeconomy practices within the EU and beyond.

5. Conclusions

In conclusion, the valorisation of organic residues plays a crucial role in transitioning towards circular food systems. The results of the eight presented projects demonstrate the potential for organic residues from agri-food sectors to be valorised beyond their traditional use in energy production. However, the projects also identify technological, socio-economic, legislative, and institutional barriers that need to be addressed to scale up the utilisation of these resources. From the lessons learned it can be concluded that an integrated approach is needed to overcome these barriers, one which encourages multi-actored dialogues between stakeholders in academia, industry and policy making, and advocating for supportive policies that promote sustainable and circular practices and the valorisation of agri-food waste for food and feed production.

CRediT authorship contribution statement

Imene Chentir: Investigation. **Osama Ahmed:** Investigation. **Waâd Nasri:** Investigation. **Samah Mohamed:** Investigation. **Nils-Kåre Birkeland:** Investigation. **Ronald Halim:** Investigation. **Hervé Vanderschuren:** Investigation. **Ajay Iyer:** Investigation. **Ima Zainuddin:** Investigation. **Sara Esteves:** Investigation. **Monica Mburu:** Investigation. **Sarah Milliken:** Investigation. **Katalin Kalai:** Investigation. **Daniel Pleissner:** Investigation. **Loreena Stephan:** Investigation.

Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Data availability

Data will be made available on request.

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