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Exploring the Landscape of Innovative "from Food to Feed" Strategies: A Review

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ABSTRACT

The identification of new strategies to prevent or at least reduce the volume of food waste needs to consider a wide range of solutions and priorities that EU policy is recently implementing. Based on the principles of the circular economy, one of the most promising solutions is to prevent food losses turning into waste by working synergistically on different action points. Amongst them, the strategy of repurposing food waste through conversion in a safe and sustainable feed product is acquiring huge interest amongst scientists and policy makers. In this context, the aim of the work is to depict the landscape of the existent solutions for the valorisation of food waste for animal feeding, through a systematic review of the literature, to answer the following three research questions: 1) To what extent is the interest of the academic research increasing, in line with the priorities of the international political agenda? 2) Which kinds of approaches have been used to explore this issue? 3) What type of solutions is the scientific literature able to propose to support policy makers in setting the strategies for the re-use of food waste as animal feed? A set of keywords has been applied for the search in the "Topic" option of the Web of Science Core Collection resulting in 114 references. The application of filters for the identification of the relevant papers led to a final dataset composed of 31 scientific studies. Papers have been coded according to the nature of the study, namely theoretical or experimental, the source and the type of food waste considered, the type of technology used to process food waste (if any) and the destination of the final product. The literature suggests that the most positive aspect related to these practices is the low environmental impact, while the most critical issue regards compliance with the EU legal framework that is strictly dependent on the composition of the wasted food. The analysis revealed a growing interest in this field of research, with a great focus on the estimation of the environmental impact but few studies targeted on the assessment of the economic dimension.

Keywords: *Food waste; animal feed; food waste re-use*

1 Introduction

Food waste is a global problem whose importance is destined to grow because of the necessity to feed an increasing population (Alexandratos et al., 2012). At present, roughly one third of the food produced for human consumption gets lost or wasted: a study commissioned by the Food and Agriculture Organization (FAO, 2013) showed that the agricultural production is responsible for the greatest amount of total food wastage volumes at the global level (33 percent). In the European Union around 88 million tonnes of food are wasted annually, with associated costs estimated at 143 billion euros (Council of the European Union, 2016), 70 percent of which arises from the household, food service and retail sectors. This amount of waste has far-reaching impacts on food security, resource conservation and climate change, and the need to prevent and reduce food waste, while ensuring the safety of the food and feed chain is an aim of growing social, economic, environmental and political interest (Vandermeersch et al., 2014). Moreover, the management of food waste is an economic problem related to the generation of huge disposal costs at any level of the food chain, from the food industry to citizens (Eriksson et al., 2005; Aschemann-Witzel et al., 2015).

The magnitude of the related ethical and economic issues requires the involvement of all actors in the food chain to play a role in preventing and reducing food waste, and the scientific literature is increasingly focusing on the identification and the impact estimation of innovative waste valorisation strategies (Venkat, 2011; Takata et al., 2012; Arancon et al., 2013; Mirabella et al., 2014; Thyberg and Tonjes, 2016), as well as the identification of practical solutions to be applied on a small scale and subsequently spread on a global scale (Papargyropoulou et al., 2014). These innovative strategies are part of the European strategy described by food waste management hierarchy (Figure 1), which prioritises actions of food waste prevention and donation for charitable purposes (redistribution). The third level of the food waste hierarchy is the use of food waste in animal feeding, since food that is no longer reusable for humans can potentially still have a high nutritional value. Scholars are intensively investigating the identification of the causes of food waste, the methodologies for its quantification and the action to be taken to reduce it whereas most studies focused on household food waste reduction (Reynolds et al., 2019). In turn, food waste management for the subsequent levels of the food waste hierarchy have been scarcely investigated. Thus, the issue of the reuse of food for feed purposes needs to be more extensively explored and evaluated given its potential to reduce the environmental impact of feed production and provide a potential land/water saving by replacing the traditional raw materials for feed production. In a nutshell, “feed from food” strategies would seem to have a positive socio-economic impact and to successfully contribute to the improvement in the global sustainability of the agri-food system.

In this regard, the European Commission recently released a document of guidelines for the feed use of food no longer intended for human consumption (2018/C 133/02) with the purpose to clarify EU legislation on this issue, with the underlying assumption that the feed use of food prevents these materials from being composted, transformed into biogas or disposed of by incineration or landfilling, thus preserving their nutritional and economic value.

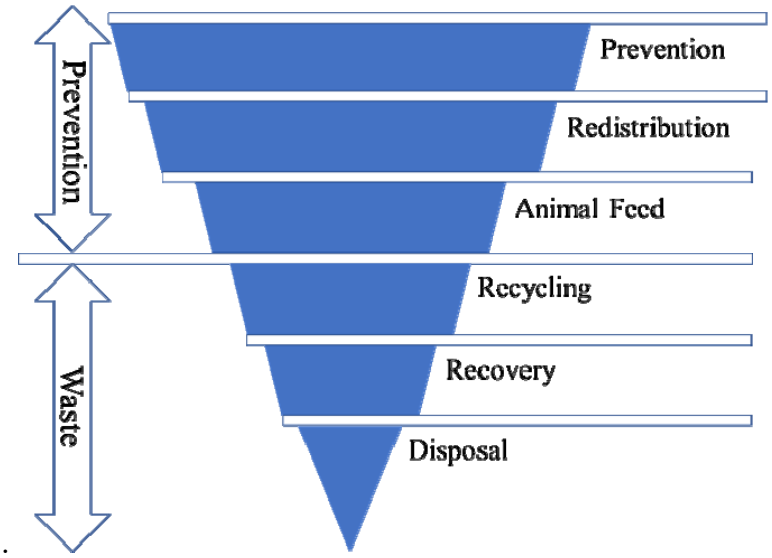

Figure 1. European food waste management hierarchy
Source: EU Platform on Food Losses and Food Waste.

In this context, the present contribution is focused on three main research questions as follows: 1) To what extent is the interest of the academic research increasing, in line with the priorities of the international political agenda? 2) Which kinds of approaches have been developed by the academic literature to explore this issue? 3) What type of solutions is the scientific literature able to propose to support policy makers in setting the strategies for the re-use of food waste as animal feed?

Consequently, the aim of this work is to conduct a deep literature research on different existing methods on the reuse of food waste as animal feed in order to review the range of solutions that academic research is analyzing with respect to this field of research and to summarize the main prospects and constraints connected to the implementation of the so-called “feed from food” approach.

2 Methodology

A systematic review (Greenhalgh and Peacock., 2005) was conducted in order to identify research papers regarding the use of food waste for feed production. To identify the relevant articles, the following search string was used:

1) ("FOOD WASTE" OR "FOOD SURPLUS" OR "FOOD LOSS")
2) AND ("FEED" OR "FEEDSTUFF")
3) AND ("ANIMAL" OR "LIVESTOCK" OR "PET")

The present combination of keywords has been applied for the search in the “Topic” option of the Web of Science Core Collection, which includes titles, abstracts, author keywords, and keywords plus fields of the articles. The search was performed on June 2018, obtaining 114 potentially relevant articles. For pragmatic reasons, language of publication was limited to English, and results have been filtered for articles and reviews only, excluding conference proceedings and book chapters, obtaining 108 unique references.

The second step of the selection process involved the evaluation of the titles and abstracts by two researchers independently. In this way the coding procedure is duplicated by independent coders and their coding outcomes are compared through the measure of inter-coder agreement, that provides an assurance of the validity of research results. In our study, the Inter-coder Agreement (Cohen’s Kappa) was 97.2%, and the remaining differences were resolved through personal consultation between by the two coders. The evaluation of titles resulted in the exclusion of 43 articles, mainly because they were off-topic. Abstract evaluation excluded papers concerning the use of food waste as feed for different living organisms (i.e. microorganisms, algae, fungi) not included in the scope of the analysis and resulted in 26 papers for the next phase of the review.

For the final step a search for the full text of all 26 papers was undertaken using the libraries accessible to the authors through their institutional affiliations. The full text of one paper was not immediately retrievable and the review team excluded it. The remaining 25 papers were then screened based on full paper content. During this final step, 6 studies retrieved from the reference list of the selected papers have been added, obtaining a final dataset composed of 31 scientific studies.

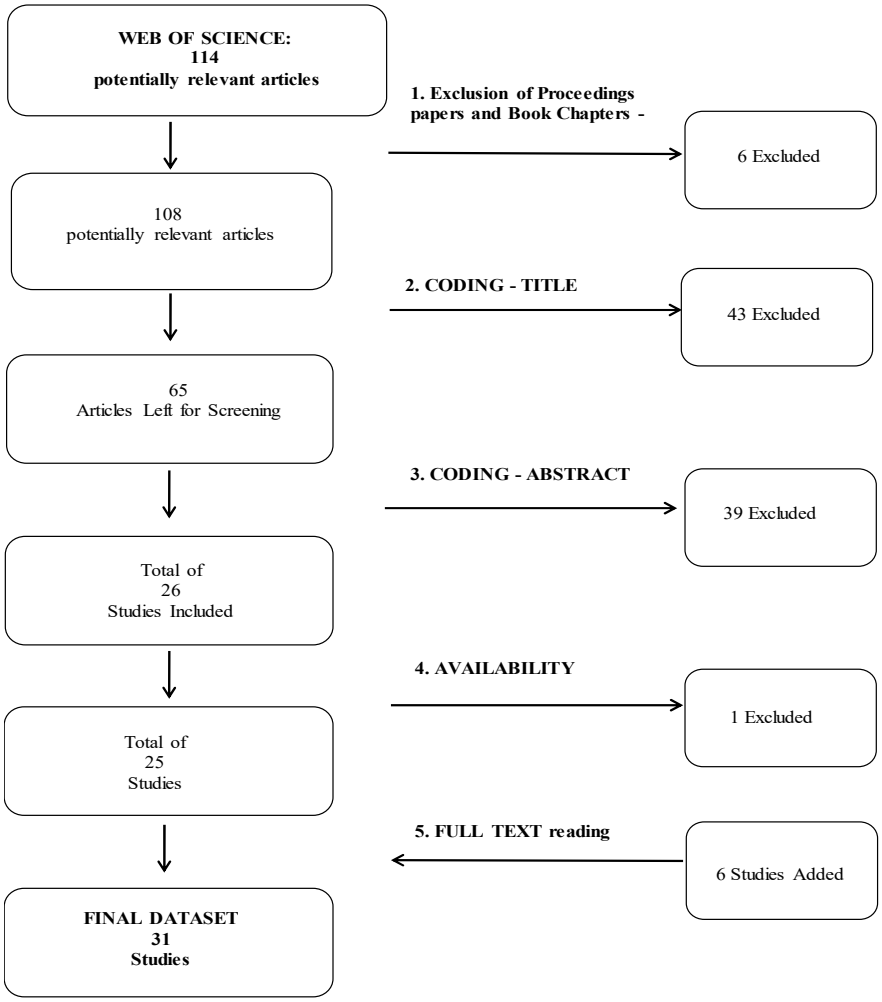

Figure 2. Flowchart of study selection process

The final set of academic papers has been coded according to different levels of classification, primarily the nature of the study, namely the theoretical or experimental approach used. More specifically, theoretical studies describe a more hypothetical assessment of different impacts (i.e. economic, environmental) related to the use of food waste as animal feed, including surveys amongst stakeholders. The experimental set of studies consists of papers in which food waste and deriving products have been tested for nutritional properties, palatability, chemical composition or ability to increase animal performances.

Secondly, papers have been categorised according to:

1) **Source of food waste:** this variable accounts for the different points in the food chain in which food waste can be potentially collected, i.e. household, school catering, restaurants.
2) **Type of food waste**: this variable describes the nature of the food waste collected, such as bakery by-products or plate leftovers. Where not explicitly specified, the classification used the general term "food waste".
3) **Type of technology used** to perform the food waste treatment and conversion into animal feed, if any.
4) **Animal destination** of the food waste-derived feed, namely the type of animal considered (i.e. farmed animals, aquarium fish, pets).

Since this branch of research is very recent and seminal, the inclusion of all types of papers, of both qualitative and quantitative research, has been considered a more proper strategy, in line with the aim of the work that comprised the provision of the first landscape of the research activity conducted on these issues.

3 Results and Discussions

The time trend of the scientific production on this topic outlines the growing interest of academic research on the re-use of food waste for animal feed (Figure 3). Nevertheless, this topic started to be analysed several years ago, with the first publication dated 1965, concerning the evaluation and the comparison of the nutritional value of garbage (municipal, institutional, military) as a feed for swine, but only in the last ten-year period did it acquire greater relevance, as the number of papers published from 2010 to 2018 doubled in value with respect to the 2000-2009 period. Moreover, Figure 3 outlines the shift from a first wave of research focused on what has been defined as the experimental set of papers, related to the practical evaluation of feed products derived by food waste, to a second wave of research activity started in 2010, dealing with the analysis of the economic, environmental or social impacts of different "feed from food" strategies.

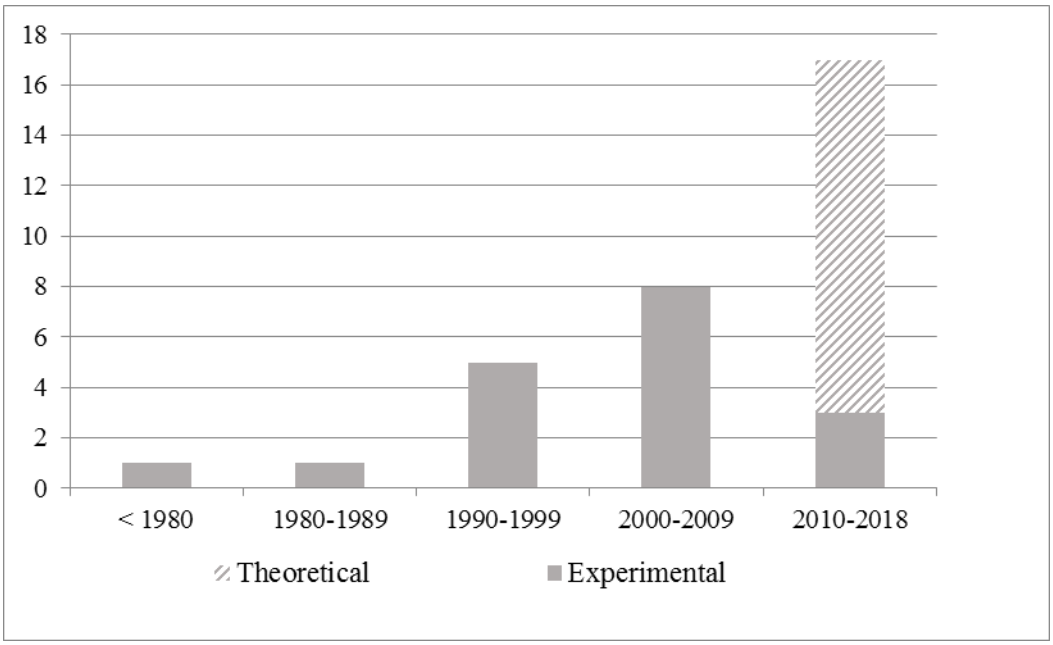

Figure 3. Time trend of scientific publications

Country analysis of papers, based on the affiliation of the first author, revealed that EU academic research shows the highest productivity in this field of research, followed by USA and, to a lower extent, by two Asian countries, namely China and Korea. Within the European Union, Spain is the Member State with the greatest number of scientific publications on this issue.

3.1 Experimental studies

From the analysis of the experimental studies (Table 1) it emerged that the characteristics of the final product, namely the output, greatly depend on the composition of the input material, and consequently, the analysis of the type and composition of waste is one of the most important steps in order to obtain an overall evaluation of the derived feed. As for the type of food waste collected, four papers analysed food waste from the municipal collection (Summers et al., 1980; Garcia et al., 2005; Pinacho et al., 2006; Chen et al., 2007), while other authors used fruit and vegetable waste, fish waste, restaurant and canteen waste and table plate waste derived from a separate collection. Regarding the source of food waste, several papers collected material from more than one location, while others focused on the collection phase of a specific food waste source (retail, restaurants or household level).

Table 1.
Summary of experimental studies

Authors	Journal	Year	Source of food waste	Type of food waste	Type of process	Animal destination
Brancoli et al.	*Resources Conservation And Recycling*	2017	Retail	Bread	n.a.	Animal feed
Kwak and Kang	*Bioresource Technology*	2006	Restaurant	Bakery by-products	Aerobically processed and vacuum dried	Pigs
Sancho et al.	*Waste Management*	2004	Retail	Food waste	Heat treatment	Animal feed
Tosun and Saygin	*Solar Energy*	1993	Restaurant		Solar dry and Heat Treatment	Chicken
Garcia et al.	*Waste Management*	2005	Butchers, fishmongers, fruit and vegetable shops	Food waste (municipal, fruit and vegetable, restaurant, household)	Heat treatment	Animal feed
Esteban et al.	*Waste Management*	2007	Biodegradable municipal waste	Fruit-vegetable and fish waste	Heat Treatment	Pigs
Pinacho et al.	*Waste Management*	2006	Biodegradable municipal waste	Fruit and vegetables	Drying	Animal feed
Myer et al.	*Journal Of Animal Science*	1999	Restaurants	Food waste	Drying	Pigs
Westendorf et al.	*Journal Of Animal Science*	1998	Restaurants	Food waste	n.a.	Pigs
Chen et al.	*Asian Australas. J. Anim. Sci.*	2007	Biodegradable municipal waste	Food waste	Fermentation and Drying	Chicken
Chen et al.	*Waste Management*	2015	Restaurant, hotel and canteens and leftovers	Food waste	Fermentation and Heat Treatment	Animal feed
Chae et al.	*Asian Australas. J. Anim. Sci.*	2000	n.a.	Food waste	Drying	Pigs
Kornegay et al.	*Journal Of Animal Science*	1965	n.a.	Municipal solid waste	n.a.	Pigs
Paek et al.	*Asian Australas. J. Anim. Sci.,*	2005	Households	Leftover food	Drying	Ruminants
Summers et al.	*Anim. Feed Sci. Technol.*	1980	Institutional, restaurants and households	Culinary waste	Chemical Treatment	Ruminants
Westendorf et al.	*Prof. Anim. Sci.*	1996	Municipal solid waste	Table plate waste, vegetable and food processing waste, bakery waste, and waste from dairy product and egg processing	n.a.	Farmed
Westendorf et al.	*The Professional Animal Scientist*	1999	Restaurants, casinos, military bases, hospitals, and nursing homes	n.a.	n.a.	Pigs
Bakshi et al.	*Animal Feed Science And Technology*	2018	n.a.	Vegetable wastes	Drying	Livestock

As for the technologies used, several studies showed that the most important step that allows the stabilization of the product from the hygienic point of view is the dry-heat treatment: indeed, only in few studies (Chen et al., 2007, Summers et al., 1980; Chen et al., 2015) are different treatments investigated: fermentation and chemical treatments. The studies focusing on the heat treatment have been conducted through pilot plants at different temperatures; Sancho et al. (2004) and Garcia et al. (2005) observed that after thermal treatment at a temperature of at least 65 C degrees for 20 min, the microbiological parameters remained suitable for their

possible use as animal feed, while Tosun and Saygin (1993) built a solar boiler-dryer working at 105 C and drying time was two days; Westendorf et al. (1998) applied a cooking process at boiling temperature (100 C) for 30 minutes prior to feeding.

As indicated by Esteban et al. (2007), waste digestibility decreased with high temperature. For this reason, more studies are needed to define the correct correlation between times and temperatures in order to reduce moisture content while preserving the nutritional quality of the final product.

A further aspect considered by the scientific literature is the nutritional characteristics of the various matrices, and more specifically to what extent the output product preserves the nutritional characteristics of the input (food waste). Kwak and Kang (2006) demonstrated that feeding finishing pigs with bakery waste mixture is similar to a corn-soy diet, in terms of carcass weight, dressing percentage, backfat thickness and carcass grade, meat fatty acid composition, and meat quality. Similar results have been obtained by Myer et al. (1999) and Westendorf et al. (1998) feeding pigs with dehydrated restaurant food wastes; moreover, the authors carried out a taste panel test (flavor, taste, tenderness, juiciness, and overall acceptance) and observed no significant differences in acceptability between the waste-based diet and a traditional diet. In conclusion, the studies showed that food waste is a sustainable and alternative solution that responds to the global need to reduce food waste and to find new protein resources to produce feedstuff.

3.2 Theoretical Studies

The second set of papers (n=14) have been classified as theoretical studies since they describe a more hypothetical assessment of different impacts (i.e. economic, environmental) related to the use of food waste as animal feed. It is composed of very recent studies, when compared with the papers belonging to the “empirical” set, and this aspect suggests that the academic interest towards the evaluation of the global impact of innovative “feed from food” solutions has increased in recent years. The emerging attention to this approach is confirmed by Makkar (2017), reporting a summary of a FAO conference on the use of food loss and waste as well as non-food parts as livestock feed. The most important topics emerged during the event regarding the needs to establish a clear legal framework to regulate the safe use of food loss and waste as animal feed, the strategies for its upscaling, and technical support to small-scale industries to start implementing similar solutions.

Some additional studies performed a simulation of different scenarios of food waste reduction due to its conversion to animal feed. Redlingshofer et al. (2017), though concluding that animal feed production can play an only moderate role in food waste reduction during primary production and processing, outlined a severe lack of data on food loss estimates.

Table 2.
Summary of theoretical studies

Authors	Year	Journal	Source of food waste	Type of food waste	Type of process	Animal destination
Castrica et al.	2018	*Sustainability*	Various sources	Food Waste	Heat and Dry Treatment	Farmed animals
Dou et al.	2018	*Global Food Security*	Food waste		n.a.	Livestock
Eriksson et al.	2015	*Journal Of Cleaner Production*	n.a.	Bananas, grilled chicken, lettuce, beef and bread	n.a.	Animal feed
Makkar	2017	*Animal*	n.a.	n.a.	n.a.	Animal feed
Mourad	2016	*Journal Of Cleaner Production*	n.a.	Surplus food and waste	n.a.	Animal feed
Ramirez et al.	2017	*Revista De Ciencias Agricolas*	Various sources	Food loss and waste	Silage	Pigs
Redlingshofer et al.	2017	*Journal Of Cleaner Production*	Primary production and processing	Fruit and vegetable and animal by-products	n.a.	Animal feed
Salemdeeb et al.	2017	*Journal Of Cleaner Production*	n.a.	Food waste	Drying	Pig
Thieme and Makkar	2017	*Animal Production Science*	Primary production	Food loss and non food parts	n.a.	Animal feed
Vandermeersch et al.	2014	*Resources Conservation And Recycling*	Retail	Bread	n.a.	Animal feed
Willersinn et al.	2016	*Agrarforschung Schweiz*	Various sources	Potatoes	n.a.	Animal feed
Willersinn et al.	2017	*Journal Of Cleaner Production*	n.a.	Potatoes	n.a.	Animal feed
zu Ermgassen et al.	2016	*Food Policy*	n.a.	Food waste	Swill	Pigs
zu Ermgassen et al.	2018	*Plos One*	n.a.	Food loss	Swill production	Pigs

Several other studies are based on experimental surveys aimed to collect information on the perception of different stakeholders of the food chain about the potential implementation of “feed from food” strategies. Zu Ermgassen et al. (2018) performed a survey amongst European pig industry stakeholders and consumers to evaluate their perception on the potential relegalisation of swill (traditional name for the feeding of food scraps to pigs) finding strong support by farmers and some concerns about disease control issues in consumers. Mourad (2016) evaluated stakeholders' interests and motives to implement solutions for food waste prevention and management, including feed production, evidencing that actors with different interests in food commodity chains can potentially develop competing solutions.

Ramirez et al. (2017) reviewed different alternatives for the re-use of dish residues, while Dou et al. (2018) analysed the feasibility, safety and sustainability implications of using animals as bio-processors able to convert human-inedible food materials into meat, eggs and milk, with positive implications on different levels including pollution and climate-change mitigation.

A growing branch of research regards the analysis of the sustainability implications of food waste-derived feed through a life cycle assessment (LCA) approach: Willersinn et al. (2017) investigated how potential loss reduction scenarios and various loss treatments (animal feed, biogas, incineration) might affect the total ecological performance of the supply chain, and found that food loss treatment solutions, in particular feeding and fermentation, could reduce the examined impacts.

Eriksson et al. (2015) evaluated the effect on greenhouse gas emissions of different food waste management scenarios (landfill, incineration, composting, anaerobic digestion, animal feed and donations). In the same line Vandermeersch et al. (2014) estimated the environmental performance of two food waste valorization scenarios, namely anaerobic digestion and animal feed production, concluding that the latter is more efficient and presents lower environmental impacts, especially for matrices with low water content (as bread waste).

Salemdeeb et al. (2017) analysed through LCA the environmental and health impacts of animal feed production, aerobic digestion and composting, finding that the best solution is the conversion of food waste into animal feed. Therefore, the authors called for the support from policy makers, the public and the pig industry to re-legalise the use of food waste as pig feed. This aspect, the regulatory framework of feed production in the European Union, is the focus of a further paper by Zu Emergassen et al. (2016), stating that despite the use of swill representing low-cost, low-impact animal feed, that could potentially save 1.8 million hectares of agricultural land, food waste-derived feed is currently banned in the EU because of disease control concerns due to the presence of animal proteins. He also points out that several East Asian states have already introduced innovative systems for safely recycling food wastes into animal feed, and consequently solicits its adoption in the European Union as well, addressing consumer and farmer concerns for the re-introduction of this new method of feed production. By contrast, Castrica et al. (2018) stated that given the current EU regulatory framework, pet food can be the most concrete strategy for re-using food waste and that the implementation of pet food production measures to reduce food waste in Europe is already possible and does not need to wait for further policy interventions.

4 Conclusions

The first relevant aspect derived from the analysis is that the nature of this topic is *per se* multidisciplinary, due to the huge complexity of the processes involved and the food matrices considered. The analysis outlined that the academic interest in the reduction of food waste is rapidly increasing, and the development of strategies that exploit the potential value of food waste as a resource in different fields is recognized as an opportunity to meet the objectives of the circular economy. Further evidence provided by the scientific literature is that "feed from food" strategies are feasible and highly sustainable when compared to its alternatives (landfill, incineration), and consequently more efforts are required to turn research into commercial products.

Secondly, the approach used by the academic literature towards the analysis of "feed from food" strategies includes experimental and theoretical activities, though in the most recent scientific production the latter is preferred to the former. This is probably due to the fact that experimental studies extensively demonstrated the fact that simple technologies of heat and dry treatment are sufficient to safely produce animal feed from food waste. In turn, the path for a real implementation of such innovative strategies requires huge research for the development of new production models and the contribution of all the stakeholders of the food chain.

With regard to the third research question - on the solutions the scientific literature is able to propose to support policy makers in setting the strategies for the re-use of food waste as animal feed - the analysis outlined that the determination of the variables that influence food waste have a fundamental role in the application of new actions aimed at the prevention of waste production; the analysis of the regulations in force can help in focusing on the points where it is possible to take actions with innovative solutions while protecting human and animal health. In this line, several authors pointed out that European legislation in force does not allow the use of food waste containing animal proteins for feeding farmed animals. As a consequence, several studies focused on the importance of selecting the waste matrices through controlled collection flows, in order to recover and use food waste derived from the specific food chain sector (i.e. fruit or vegetable waste). Other authors called for the modification of the existent legal framework, in order to relegalize the use of food waste as animal feed.

Nevertheless, the analysis outlined a lack in studies dealing with the evaluation of the economic impact of these innovative practices, both direct (i.e. disposal costs saving) and indirect economic impacts, as the reduced competition in the use of production factors and agricultural raw materials. The development of a more global framework including the evaluation of the economic and environmental aspects of the process could be crucial to support and promote the implementation of these solutions at the commercial level and/or facilitate potential policy changes. As a long-term goal, the analysis suggests to develop not only an efficient and effective management of waste, but also of models able to combine the social, environmental and economic aspects related to this issue.

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