Creeping Towards Sustainability

A Systematic Review of the Barriers to Establishing a Sustainable Insect Market for Feed and Food in the Global West

Master's Thesis

Obbe Annega

Aalborg University

Environmental Management and Sustainability Science

Department of Planning, Rendsburggade 14

9000 Aalborg, Denmark

Abstract

Background: The mounting pressure of the agri-food sector on the environment and food security is urging ways to rethink the production and consumption of food. In particular, the livestock industry is a significant contributor to these issues, yet the demand for meat is expected to continue to rise in the coming decades. The potential of insects as an alternative protein source, both as feed and food, has been extensively reviewed in recent years due to their environmental and nutritional advantages. Despite the presence of insects in many parts of the world, western countries have little to no involvement in insect production or consumption. However, that is changing, albeit slowly. For insects to successfully establish presence in western markets, many barriers need to be overcome.

Scope and approach: The purpose of this paper is to identify all the reported barriers to establishing an insect market in western countries through a systematic analysis of all relevant literature in the field. By compiling an overview of all barriers found within recent literature, this paper aims to illuminate all the areas which need to be addressed to successfully establish insect production and consumption.

Key findings and conclusion: A total of 44 individual barriers were identified, relating to societal, market and technical contexts. The findings suggest that successfully implementing insect production and consumption in western countries is likely to be challenging.

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Department: Sustainability Management in a Societal & Institutional Perspective, Department of Planning

Supervisors: Bo Weidema and Michele De Rosa

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1 Introduction

This section will serve as an introduction to the sustainability concerns of the livestock industry, the growing interest in insects as a potential alleviation to these concerns, and the current trends of insect production and consumption in Western countries. This will be followed by an assessment of the relevance of this paper in the context of the current state of research, laying the foundation for the research questions at the end of this section.

1.1 Background and Contextualization

The global food system is under critical pressure. As the availability of fertile land for agriculture declines, a growing population with rising incomes is creating a demand for food that is constricting supply, further exacerbated by frequent economic shocks and conflicts [1]. Combine this with escalating pressures from climate change—be it through intensified droughts, flooding, biodiversity loss, or prevalence of pests and diseases—and the failure to meet even the most basic nutritional requirements seems inevitable. In fact, this is already the case for roughly 767 million people who are chronically undernourished according to the Food and Agriculture Organization (FAO) [2]. Furthermore, recent estimates by the FAO suggest that 3.1 billion people are unable to afford a healthy diet [2]. And in recent years this trend has been worsening. Although the average rise in economic status and agricultural productivity allowed 216 million people to escape undernourishment between 1990-2015, an additional 179 million people have been added since [3], [4]. Among the United Nation's Sustainable Development Goals adopted in 2015, the goal to end world hunger by 2030 is an ambition that is becoming increasingly unrealistic.

Despite the dependency of agricultural productivity on climatic conditions, the agri-food sector is a major contributor to anthropogenic climate change. Here, the emphasis is on the animal industry. Fueled by a high demand for animal protein, the livestock sector alone is responsible for more than 18% of anthropogenic GHG emissions (CO_2-eq) and occupies 78% of global agricultural land [1], [5]. However, the livestock sector is responsible for only 18% and 37% of global calorie and protein supplies, respectively [4]. As the projected global population approaches 10 billion by 2050 and demand for food increases by 70-80% (compared to demand in 2012) [6]–[8], current production and consumption need to be revised. However, reducing the scale of the livestock industry to promote production towards crops intended for human consumption is unlikely due to the high demand for meat. Wealth, for example, is a determining factor of the demand for animal protein which makes any large reduction of livestock production unlikely as population and income rise [9].

1.2 Insect Protein

A promising alternative animal protein is already available, consumed globally, nutritionally diverse, and is orders of magnitude more sustainable across most environmental parameters [10]. Insects have received considerable attention in recent years as a potential solution to alleviating food insecurity and the environmental concerns of the livestock industry. This is possible through two mediums which are already utilized: production of insects (either processed or whole) as a feed additive for livestock, fisheries, and pets, or as a direct food supplement for human consumption [11]–[13]. Although the target use of insects, as feed or food, are inherently different in their impacts and technicalities, there also exist many overlapping similarities. The use of insects in both feed and food in Western societies are both a novel development, have significant environmental benefits, and face similar challenges. In this regard, both target uses of insects are relevant to explore. Particularly their environmental performance has made them a topic of high interest. Because insects are poikilotherms, or cold-blooded, they have a high feed conversion ratio (FCR) allowing them to convert organic matter into valuable protein very efficiently, as well as requiring low land and water inputs [14]. As a result, insects have recently been referred to as the missing link in the agri-food sector [15], with a potential to improve food security and circularity while reducing the environmental burdens of the sector.

Historically, entomophagy was prevalent in most parts of the world, and still is in large parts of Latin America, Southeast Asia, and Africa [14]. The exception to this are the Western societies, where implementation has been slow or non-existent [16]. In Europe, the United States, Canada, Australia, and New Zealand the consumption of insects, known as entomophagy, has practically no historical presence and is only a niche industry to this day [16][17]. Furthermore, the production of insects as a supplement for animal feed is gaining traction but is still in its infancy. In 2021, global production of insects as feed was 10 000 metric tons, with predictions towards 500 000 metric tons by 2030, an increase of 4 900%[18]. However, despite an abundance in the literature on the high potential of insects to emerge as a novel animal protein source, the prevalence of insect production is low [18].

Introducing insects onto the market is facing resistance from consumers, policy and regulation, and practitioners. For example, it was only in June 2021, almost a decade after the FAO published its first report on the potential of insect protein as feed and food, that the EU approved of the first insect as a novel food for humans [14][19]. Furthermore, the dominating theme among literature on insect production and consumption in Western societies involves the barriers of establishing an insect market, particularly regarding the issue of consumer acceptance of insects as food [20]. Similarly, many other barriers and challenges have been identified covering a wide range societal, economic, and technical matters. The majority of these challenges are the result of an existing food system that is not designed to

include insects [21]. Therefore, for insect protein production and consumption to gain presence, these barriers need to be identified and synthesized in a systematic way in order to provide an accurate overview of the barriers that need to be addressed in the coming years.

1.3 Relevance

Since insect production offers one of the most promising alternatives to meat production from a sustainability perspective, a detailed examination of the current state of insect production and consumption is of high interest. This paper intends to investigate the gap between (*1.*) the clear sustainability potential of insects as an alternative animal protein and (*2.*) the low prevalence of insect production and consumption in Western countries. This gap therefore represents a synthesis all the barriers that are described in existing literature. This will provide valuable insights into what current and prospective barriers exist within the insect industry.

Furthermore, this paper will focus exclusively on the barriers to establishing an insect market in Western countries, as opposed to addressing drivers or solutions. This has to do with the scope and goal of this review. Every region may experience different barriers, and different ways of working around or fixing these challenges, i.e. differences in policy/regulation in EU vs. US, or differences in climate that influence both the outlook on food security and direct insect production. By focusing on the barriers, all recent literature in the field can be synthesized to provide a clear overview of the approximate challenges wherever insect production is considered. Some of the results may be more applicable than others, depending on the context in which it is evaluated. Thus, synthesizing all challenges defined in the existing literature lays the groundwork for an enriched understanding of the obstacles.

Existing literature that provides an overview of insect production or consumption, including barriers, are limited in either their scope or relevance. The literature is predominantly focused on specific barriers that need to be overcome, as well as reviews of the recent developments and prospects in the insect industry. However, the lack of in-depth analysis using the latest literature on the main challenges and barriers that the insect industry is facing, how these have developed, and what barriers may lay ahead, gives way to the goal of this paper. This paper expands on this literature by synthesizing all challenges within the insect industry and across all Western countries. This will produce a holistic review of the main barriers that exist and are expected in the future with regards to implementing wide-scale insect production. Furthermore, the high interest in insect production and consumption has resulted in many recent publications, which makes a systematic review of these publications more relevant. Finally, to my knowledge, no such systematic literature review looking at all barriers of introducing insects into Western society exists.

Overall, by providing a comprehensive analysis of the challenges facing insect production, a better understanding of actions needed to overcome or avoid these challenges will hopefully become more transparent. Introducing a new industry at this scale is complex, and so laying out the main obstacles can act as valuable decision support for practitioners and policymakers.

1.4 Research Questions

Given the potential of insects to improve the sustainability of the Western agri-food sectors, the current arena of insect production and consumption warrants an in-depth systematic review of all the challenges that the upcoming industry is facing and will face for the years to come. It is in this light that this paper will attempt to answer the following main research question, sub-divided into three sub-questions:

RQ1: *What are the reported barriers to establishing insect protein as food and feed in Western societies, despite the strong evidence for the potential of insect as a sustainable alternative animal protein?*

- **RQ1.1**: *Why are insects perceived as a valuable opportunity for improving the sustainability of the agri-food industry?*
- **RQ1.2**: *What are the predominant themes underlying the barriers and how can these be categorized?*

2 Sustainability—Potential of Insects

One of the most promising aspects in favor of producing insect protein is its favorable sustainability over conventional animal protein [14], [22]. Therefore, an overview of the sustainability potential of insects will be provided in this section to contextualize the relevance of insect production and consumption. In particular, the FCR, environmental impact, and organic waste valorization are investigated.

2.1 Feed Conversion Ratio

Feed conversion ratio is defined as the amount of feed required per kg of body weight gain [23]. This is an important characteristic in animal husbandry because it determines how much feed input is required to yield a particular animal product. A low FCR is therefore an indication of higher production efficiency and lower environmental impact, since a significant portion of the environmental impact of animal production is due to the production of feed [22].

The FCR ratio of several edible insect species (used as food and feed) have been determined in various studies. One study comparing the four of the most commonly farmed insect species determined the most efficient FCRs (of four varying diets) for the Argentinean cockroach (1.5), black soldier fly (1.4), yellow mealworm (3.8), and house cricket (2.3) [22]. Comparing this with the FCR of poultry (2.3), pork (4.0), and beef (8.8) [24], it is evident that insects favor similarly to poultry and better than pork and beef. It should also be noted that conventional livestock feed has been tweaked to the highest efficiency due to the longstanding practice of rearing livestock, an indication that insects will also see improvements as production grows [22].

Although the FCR of insects is comparable to poultry, the ability of insects to convert low organic waste into body gives insects a significant advantage. The FCR of insects therefore becomes increasingly relevant when considering the other properties of insects.

2.2 Valorization of organic waste

Laboratory-scale experiments have indicated that many species of insects have the ability to convert low organic side streams into high value protein [25]. Considering that globally 1.3 billion tons of food is wasted per year [26], there is a significant opportunity for insects to provide circularity in the food industry. Sludge and manure have also been shown to be potential insect feed candidates, yet due to safety regulations it is more likely that insect production using such feedstuffs would be used for fuel production.

The research on the potential of insect feed and food derived from waste is still in its early stages, and more research is needed to understand the extent to which insects could play a role in waste upcycling. Safety regulations play a critical role here, as the risks involved with valorizing waste as a feedstuff for insects is likely to be an obstacle. The use of waste streams in insect production is therefore severely limited, but is expected to rise [25].

2.3 Environmental Impact

The environmental parameters that are favorable for insect production over conventional livestock production are GHG emissions, water use, and land use. The only parameter that is considered worse for insects is energy use (compared to poultry), which is due to the poikilothermic (cold-blooded) property of insects, requiring higher ambient temperatures than conventional livestock [14].

2.3.1 Greenhouse gas and ammonia emissions

The GHG and ammonia emissions favor the production of insects over conventional livestock products [27]. In a comparison between five commonly produced insect species and livestock, the CO_2-eq per kg of live weight averaged 5 and 57 grams per day, respectively [27]. This is largely due to the FCR ratio, as the metabolism of insects does not need to maintain body temperature [25]. Likewise, ammonia emissions averaged 3 mg/kg of body mass per day for insects, and 84 mg/kg of body mass per day for livestock [27]. Insects are therefore a promising alternative animal protein in terms of emissions.

2.3.2 Water use

Considering that water scarcity is a growing concern for almost 1.8 billion people, which is largely driven by agricultural practices [1], water use is of high importance to animal production. When comparing mealworms to pork, chicken, and beef, the water footprints are measured as 23, 57, 34, and 112 liters per gram of protein, respectively [28]. These measurements are based on the same feed inputs for all animals, indicating that insects could become even more efficient in terms of water use if reared on a feed of organic side streams. The potential to reduce water use by growing insects is therefore a significant advantage over conventional livestock.

2.3.3 Land use

The final environmental parameter that insects have an advantage in is land use. This is largely due to the fact that insects can be grown in confined spaces, require no sunlight, and have higher FCR, thus reducing the amount of feed crops required per unit of insect product [29]. A life cycle assessment on the land use

for mealworms in comparison to pork (3.23x as high), chicken (2.85x as high), and beef (14.12x as high) indicated that mealworms have a much more favorable land use footprint compared to conventional animal protein [30].

3 Methodology

This purpose of this section is to provide the methodological framework for conducting a systematic review. The methodology consists of the systematic review, as well as supplementary research.

3.1 Systematic Literature Review

A systematic review can be defined as a review of existing literature conforming to explicit methods [31]. Therefore, a systematic analysis of all relevant literature on the topic was sourced and screened. To do this, the choice of database(s) was crucial. Following a review of the most extensive and established databases in the scientific arena, the choice was made to use the *Scopus* database. *Scopus*, run by the *Elsevier* publishing company, is a database with a collection of literature from all major publishers, covering multidisciplinary literature from over 24 600 active journals [32]. The scope of literature available ensured that the sources in this review cover the vast majority of academic literature on the topic. Furthermore, the analytical tools available in the search engine allow for fine-tuning of search entries, ensuring that the potential for overlooking literature is limited.

Furthermore, for the literature review to be systematic in its analysis, a carefully selected search string was developed using the advanced search engine feature. The search input parameters ensured the coverage of all relevant research in the fields of Western insect production and consumption relating to feed and food production. To generate a representative collection of literature, the choice of search terms was crucial. A few search string variations preceded the final search configuration, as it became apparent that certain unintended search results were overlooked and relevant literature was underrepresented. For example, an initial search query generated a high proportion of literature on insecticides and pesticides, which prompted a refined search string. This was tweaked further until a brief scan of the generated literature verified that the search input was of satisfactory relevance and scope.

Table 1 presents the final search string terms based on their inclusion or exclusion in the literature. The operators “AND”, “AND NOT”, “OR”, and “*” indicate the inclusion, exclusion, alternative terms, and alternative variations of a word, respectively. Furthermore, the search string was restricted to filter through only the title, abstract, and key words of the literature using the “TITLE-ABS-KEY” operator preceding the search string.

Subject matter	Inclusion	Search parameter
Insects	AND	(insect* OR *larva* OR entomo*)
Production of insects	AND	(produc* OR 9esticide* OR rear*)
Utilization as feed and/or food	AND	(feed OR food)
Application of insects	AND	(human OR livestock OR consum* OR edible OR eat* OR diet* OR protein)
Focus on environmental potential	AND	(alternative OR environment* OR climate OR sustainab*)
Geographic regions of interest	AND	(europ* OR eu OR west* OR canada* OR "united states" OR australia OR "new zealand")
Insects in the context of insecticides or pesticides	AND NOT	(9esticide* OR insectic*)
Limitation of articles by year	AND	(PUBYEAR > 2002)
Subject area	AND	(LIMIT-TO(SUBJAREA, "agri" OR "envi" OR "ener" OR "soci" OR "eart"))

***Table 1**: Search string deconstructed into its constituent parameters*

The search string yielded 571 results from the database. A brief assessment of the generated literature indicated that it covered a wide selection of papers well within the scope of the research question. This sample of 571 papers was subsequently screened based on inclusion (include/exclude) criteria. *Figure 1* represents the screening process applied to the literature based on inclusion criteria at increasing levels of refinement.

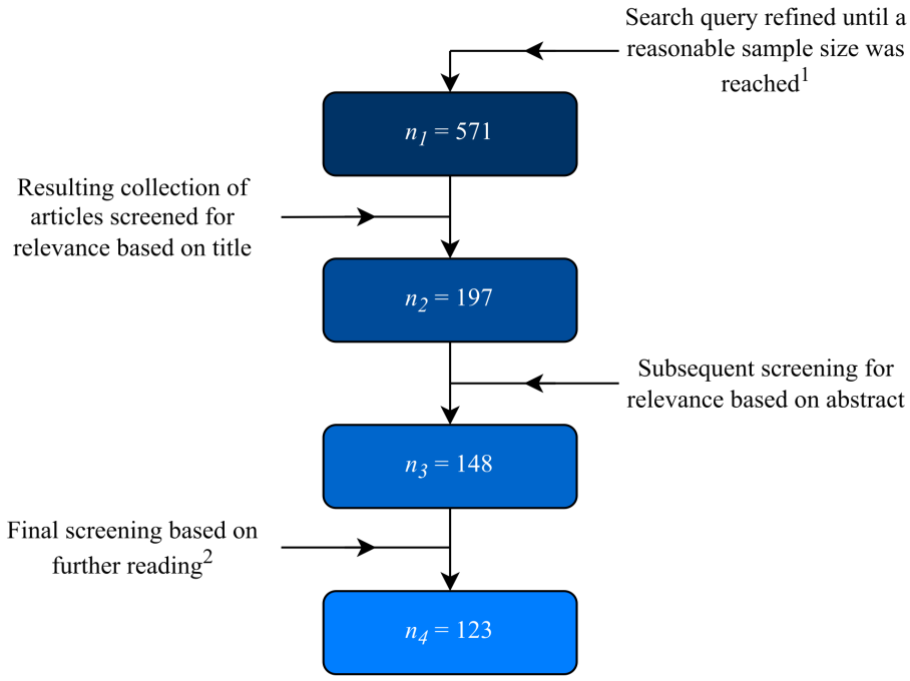

***Figure 1**: Visualization of the screening process to reach the final sample collection.*

[1]Previous search query alternatives were too specific or too broad
[2]A combination of in-depth reading and brief scanning

2

The screening of literature yielded a final sample size of 123 papers. The inclusion criteria were selected based on the scope and relevance of this review. At every screening stage the literature was re-evaluated based on the inclusion criteria. This ensured that only the literature relevant to this paper was included for use in the systematic review. *Table 2* represents the specific inclusion criteria used in the screening process.

Criteria		
1.	Any subject area within the general confines of insects as feed and food	Inclusion
2.	Focus on regions within global West	Inclusion
3.	Peer-reviewed and written in the English language	Inclusion
4.	The mention of a barrier or challenge facing the insect industry	Inclusion
5.	Insects in the context of insecticides or pesticides[1]	Exclusion
6.	Non-relevant or particularly niche subject areas[2]	Exclusion
7.	Duplicates or reviews of original papers	Exclusion

***Table 2**: Exclusion criteria between n_1 and n_4 in the literature review process*

[1]A small proportion of the literature focused on insects in this context, despite the exclusion operator for the terms "insecticide" and "pesticide" (and variants) in the search string.

[2]Papers that fit the initial search string but were of non-relevant subject areas, such as the pharmaceutical and cosmetic sciences.

3.2 Supplementary Research

Apart from the literature sourced in the systematic review, additional research was applied to supplement information when needed. This was necessary when a topic warranted more research that was not available in the literature generated from the search query. However, this literature was only used as supplementary information, and was not part of the literature review in ***Error! Reference source not found.***. For example, some articles that did not specify a particular geographic region, despite being relevant, were used for further research if deemed necessary. In these cases, the *Scopus* database was used to search for specific information.

4 General Findings

The final selection of 123 papers covered a multidisciplinary range of topics. A subsequent overview of this selection was put together to give additional insights into the literature. ***Error! Reference source not found.***, ***Error! Reference source not found.*** and ***Error! Reference source not found.*** represent the number of publications over time, the focus of its content (food and/or feed), and the geographic region of interest, respectively.

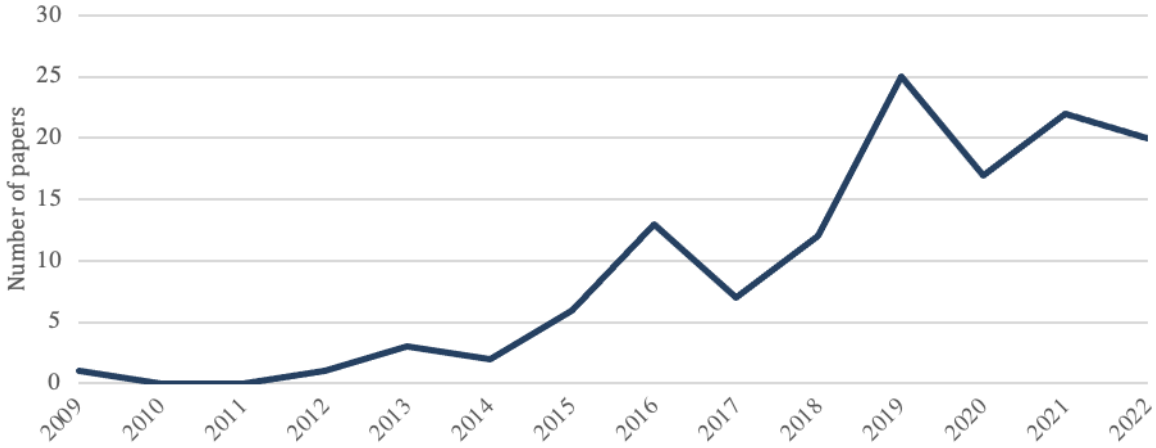

***Figure 5**: Number of publications per year from 2009-2022*

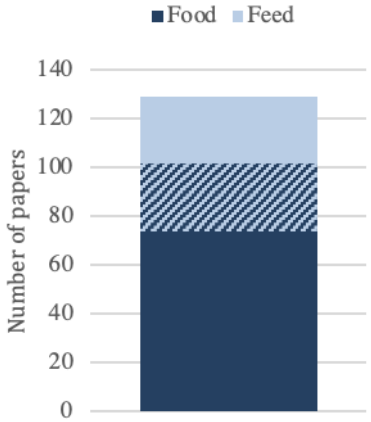

***Figure 3**: Representation of the focus of the paper: food, feed, or both*

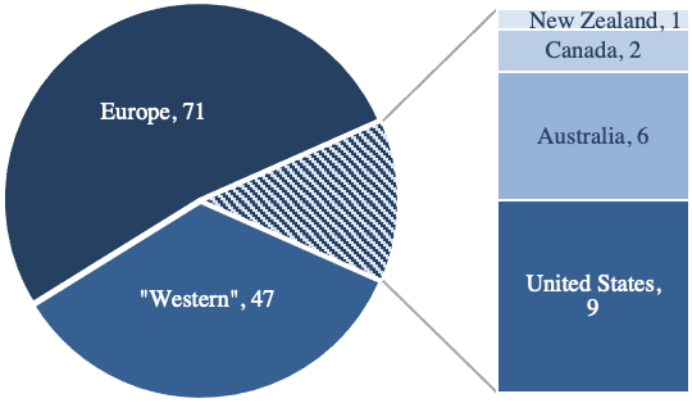

***Figure 4**: Representation of the geographic domain of the paper*

As represented in ***Error! Reference source not found.***, the interest in insects in the field of research has seen a rapid increase in recent years. Despite limiting the literature to publications after 2002, the first

paper included in the final sample of literature was published in 2009, with a peak of 25 publications in 2019. The sharp rise in publications since Furthermore, ***Error! Reference source not found.*** and ***Error! Reference source not found.*** indicate that the resulting literature adequately covers insects in the context of both feed and food, as well as a broad coverage of geographic areas, albeit heavily skewed towards research in Europe.

4.1 Key Themes

Key theme	Sub-theme (count)	Source
Sustainability **(Driver)**	Circularity (11)	[33]–[43]
	Environmental impact (36)	[11]–[13], [16], [21], [25], [28], [33], [34], [37], [38], [40], [44]–[67]
	Food security/nutrition (9)	[25], [33], [39], [46], [51], [63], [68]–[70]
Societal **Barriers**	Acceptance (69)	[12], [13], [16], [17], [20], [21], [25], [33], [36], [39]–[41], [47], [51], [62], [71]–[124]
	Food Safety (26)	[5], [13], [16], [21], [37]–[39], [51], [53], [54], [56], [57], [62], [64], [70], [90], [112], [125]–[133]
	Nutrition & health concerns (as food) (23)	[12], [13], [16], [17], [21], [39], [47], [51]–[54], [56], [61], [62], [64], [68], [70], [72], [90], [128], [134]–[136]
Market **Barriers**	Economic (27)	[17], [33], [35], [42], [50], [54], [134], [137], [21], [35]–[38], [40], [46], [63], [71], [94], [97], [104], [110], [116], [124], [126], [127], [138]
	Policy and regulatory (25)	[5], [21], [36], [38]–[40], [45], [47], [53], [55], [56], [60], [63], [64], [68], [86], [104], [112], [127], [129], [131], [139]–[142]
Technical **Barriers**	Production/technological (34)	[5], [11], [21], [25], [35], [39], [43], [47], [48], [50], [51], [55], [57], [58], [62], [63], [65], [66], [72], [90], [104], [112], [124], [129], [131], [137], [138], [140], [142]–[147]
	Nutrition & health concerns (as feed) (13)	[13], [21], [46], [52], [54], [56], [62], [64], [66], [70], [134], [140], [147]
	Animal welfare/ethics (5)	[34], [132], [148]–[150]

Table 3*: Overview of the themes, sub-themes, and associated literature covering those themes*

The 123 remaining articles were subsequently categorized according to themes. This categorization represented key themes, further divided into sub-themes. Since much of the literature covered more than one theme, many of the themes have overlapping sources. In ***Error! Reference source not found.***, the key themes and sub-themes are represented along with their respective article count. The subsequent graph in *Figure 6* represents the prevalence of research according to theme.

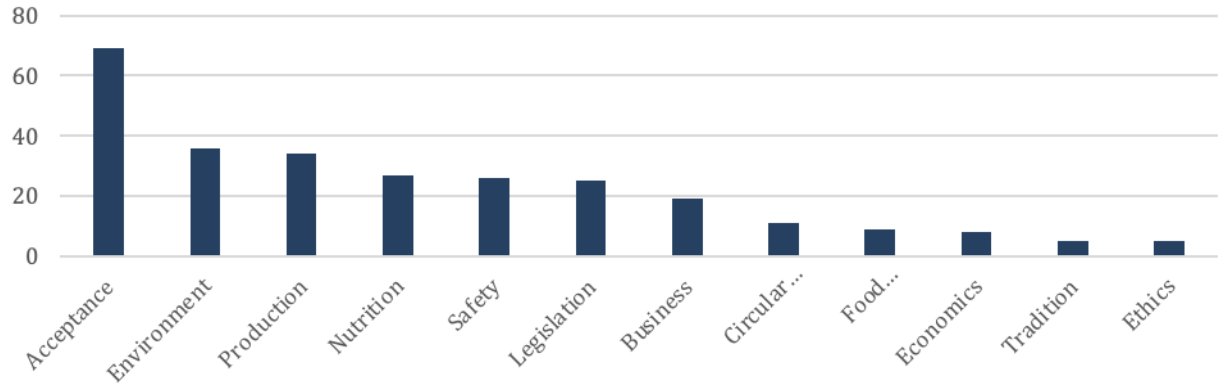

***Figure 6**: Prevalence of research by theme*

It is evident that the literature on insect production and consumption is focused heavily on consumer acceptance, representing 25% of the total research domain from the selected studies, followed by environmental impact representing 13%. However, the prevalence of a thematic focus does not strictly represent the prevalence of barriers i.e., in the context of insect consumption, consumer acceptance is portrayed as a barrier, whereas environmental impact is portrayed as an opportunity or driver. Nonetheless, the categorization of all extracted themes into key themes allows for the isolation of drivers and barriers. In ***Error! Reference source not found.*** the key theme of sustainability represents all the sub-themes that are represented as opportunities in the literature. Though, it should be reminded that all the literature was screened to include at least one barrier and was not screened to include drivers and opportunities. Despite this, the large number of sources that mention a driver or opportunity indicate that it is representative of the rest of the literature on the drivers of insect production and consumption. This also reflects the relevance of this paper, as sustainability is the underlying justification for assessing the barriers to insect production and consumption.

The goal of categorizing the literature into themes was to provide an overview of the scope of the barriers. In the results section, the barriers will be represented according to the key themes.

5 Results—Barriers to Introducing Insects

This section represents the synthesis of all the barriers extracted from the literature. All the barriers identified through the literature review are categorized into societal, market, and technical barriers. For each individual barrier, further delimitations are made to specify the exact nature of the barrier. Therefore, the individual barriers (e.g. disgust) are categorized into sub-themes (e.g. acceptance), which are further categorized into key themes (e.g. societal barrier). In this way, a coherent overview is given in which barriers are easily identified within their context.

5.1 Societal Barriers

5.1.1 Consumer Acceptance Barriers

The dominant theme in the literature deals with the acceptance of insect consumption from a consumer acceptance perspective. The majority of these articles analyze or measure either the cause of the disgust or fear (neophobia) of insect consumption, or discuss ways in which this acceptance can be improved. However, the complexity of consumers has resulted in a lot of resistance from consumers, for various reasons. These barriers are represented in *Table 4*, showing the classification of the barriers, and whether the barriers refers to insect in the context of food or feed.

		Source	
Classification of Barrier	**Description**	**Food**	**Feed**
Neophobia	The fear of new foods is a significant driver of the unwillingness to consume insect or their products, due to its novelty as a food in western societies.	[21], [78], [89], [98], [99], [107], [118]–[121]	
Disgust	Similar to neophobia, consumers often have a deep sense of disgust relating to insect consumption.	[21], [78], [99], [102], [107], [118], [121], [122], [151]–[154]	
Cultural/religious resistance	Certain cultures and religions are less accepting of insect consumption, hampering its acceptance.	[107], [122]	

High Price	Price is a major determinant of willingness to consume.	[20], [25], [74], [71] [124]
Unfamiliarity	Unfamiliarity refers to the unwillingness to consume insects, not necessarily out of fear, but because they may not know what it is.	[118], [120], [122], [155]
Attitudes/expectations	Attitudes and expectations, such as insect taste or texture affect the willingness to consume an insect.	[20]
Visible Insects	Consumers are more willing to try an insect products that do not show the insect in its entirety, but rather as a component of a dish.	[74], [99], [120]
Previous negative experience	A negative experience with insect consumption is a strong determinant of willingness to try insects again.	[93], [98], [122]
Poor understanding of sustainability implications	Many consumers are unaware of the environmental benefits of insect protein compared to conventional animal protein, which may affect levels of consumption.	[16], [25], [74], [78], [98], [107]
Bad taste	Taste is strongly correlated to the experience of consuming insects, and the willingness to try insects repeatedly.	[25], [74], [122]
Threat to masculinity	Men are more likely to refuse insects as some consider it to be more "masculine" to eat conventional animal meat.	[98]
Perceived safety risks	The food safety of insect consumption is poorly understood.	[16], [25], [133]
Lack of knowledge about nutrition	Nutritional benefits are poorly understood	[16], [122]
Insect species	Some insect species are considered more acceptable to eat than others.	[156]

***Table 4**: Barriers associated with consumer acceptance of insects in feed and food*

5.1.2 Food Safety

The food safety of insect consumption is defined by four individual barriers, which are predominantly due to the unknown risks of contamination and allergens. Table 5 represents the literature associated with each of these barriers.

		Source	
Classification of Barrier	**Description**	**Food**	**Feed**
Risk of food allergies	People allergic to certain crustaceans may experience allergenic reaction to the exoskeleton of insects	[21] [39][53][129] [64][54][16]	[39] [129] [64][54][16]
Potential release of pathogens and parasites	There is insufficient research available on the potential of insects to carry pathogens and parasites	[38][39] [53][112] [64][54][16][70]	[38] [39] [129] [64][54][16]
Chemical contamination	There is insufficient research available on the potential of insects to contain chemical contaminants	[39] [53] [64][54][16]	[39] [129] [64][54][16]

Lack of understanding of risks involved due to novelty	More research in needed on the safety of rearing insects for feed and food before they can be considered safe.	[39][127]	[39] [127]

Table 5: Barriers associated with food safety

5.1.3 Nutrition and Health (Food)

The barriers associated with the nutrition and health of insects as food is focused on the (anti)nutritional content of the insects and its properties. Here, the focus is on the human impact of these barriers. In total, five individual barriers were identified, represented in Table 6.

		Source	
Classification of Barrier	**Description**	**Food**	**Feed**
Large variation in nutritional profile between studies	Nutritional content varies between studies, due to the fact that feed is a significant determinant of nutritional content.	[21][16][64]	
Poor understanding of insect protein physiochemical and techno-functional properties	In order to produce insect products (either whole or from extracted protein) the functional properties need to be understood better.	[47][51] [128][54] [135] [70] [64][17]	
Large variation in nutritional profile depending on production/processing technique	The processing of insects (such as the manner in which they are dehydrated), affects the nutritional content and requires more research.	[90][52] [54][147] [135][136]	
Presence of antinutrients in insects	An antinutrient is a compound that inhibits the absorption of nutrients in the body. More research is needed to understand the level of antinutrients and their effects in insects.	[128][53] [64]	
Uncertain digestibility and bioavailability of nutrients	The nutrient content of insects is only valuable if it is effectively absorbed into the body. More research is needed on whether insect nutrients are effectively absorbed into the body.	[128] [54][135]	

Table 6: barriers associated with the health and nutrition of insects as food

5.2 Market Barriers

5.2.1 Economic barriers

The economic barriers that were identified in the literature covered six individual barriers. The majority of the barriers focused on insects as feed, likely due to the fact that the focus on western production of insects has been on feed and has therefore received more attention. Table 7 represents the literature associated with these barriers.

Classification of Barrier	Description	Source	
		Food	Feed
Cost of insect products	The cost of insects as a source for feed is a significant determinant of its economic viability as a feedstuff		[35][137][17][71]
Cost of insect growth substrate	The cost of feed for insects is a significant determinant of the economic viability of growing insects.		[35] [35] [17]
Lack of commercialization of insect by-products	Certain insect by products, such as frass, have no commercialization potential currently.	[35]	[35] [50]
Low incentives for production	Practitioners have a low incentive to switch to insect farming, or using insects as feed due to the small-scale (and thus costly) market size.	[50] [134]	[50] [134] [137]
Complexity of circular economy in food sector	Improving the circularity of the agri-food sector is complex, and cost-benefit analyses and lifecycle assessments are warranted to understand how resources such as waste can be used as insect feed.	[94], [97], [104], [110], [116]	[94], [97], [104], [110]

Table 7: Barriers associated with economic feasibility

5.2.2 Policy and Regulatory Barriers

The policy and regulatory barriers associated with insect production are represented in **Table 8**. The legislation involved with insect production and consumption has received a lot of attention in recent years as insects popularized, which explains why the focus on the policy and regulatory barriers is on slow and limiting policy.

Classification of Barrier	Description	Source	
		Food	Feed
Slow policy implementation	Due to the novelty of insect production and consumption, the new policy and legislation is slow moving	[21] [40] [53][56] [60]	[21] [40] [53]
Food safety regulations restricting use of available food waste for insect feed	Considering that the valorization of waste is an important potential of insects, restrictions on the use of waste for this purpose is a threat to the viability of insect production.	[38] [53][55][60]	[38] [53] [55]
Limited permitted application of insects	Only few insects are currently allowed to be sold or used as feed in western markets, limiting the potential of insects.	[40] [56]	[40]
Over-generalization of regulatory framework for insect production due to its novelty		[53][64]	[53] [64]

***Table 8**: Legislative barriers of insect use in feed and food*

5.3 Technical Barriers

5.3.1 Animal welfare and ethics

The barriers associated with animal welfare are related to two individual barriers; a poor understanding of the welfare of insects (due to novelty and thus insufficient research), and welfare of the livestock fed on insect feed. Most of the articles associated with these barriers also point out the welfare of insects is often overlooked simply because insects are not considered to have welfare concerns. Table 9 represents the barriers and associated literature.

		Source	
Classification of Barrier	**Description**	**Food**	**Feed**
Poor understanding of insect welfare	Insect welfare is either misunderstood, overlooked, or disregarded by practitioners, even though there is no indication that insects should not be subject to the same welfare standards as other livestock.	[34], [132], [148]–[150]	[34], [132], [148]–[150]
livestock welfare raised on insect feed	Replacing or supplementing livestock feed with insects may negatively affect the welfare of livestock, through potential health implications or because the diet is too far detached from their "natural" diet.	[148]	[148]

Table 9: barriers associated with animal welfare and ethics

5.3.2 Technological Barriers

The technological barriers associated with insect production arise from the production challenges of rearing insects due to their novelty. Insect farming is new and its production has therefore had insufficient time to become efficient. This is also due to the fact that most insect farming is currently being done at a small scale, not representative of large scale practices.

Classification of Barrier	Description	Source	
		Food	Feed
Inefficient processing techniques	Due to the novelty of insect farming, production techniques have not been optimized.	[5], [11], [21], [25], [35], [39], [43], [47], [55], [57], [58], [62], [63], [65], [66], [72], [90], [138], [140], [142]–[147]	[5], [11], [21], [25], [35], [39], [43], [47], [55], [57], [58], [62], [63], [65], [66], [72], [142]–[147]
Poor understanding of optimal growing conditions	Due to the novelty of insect farming, production techniques have not been optimized.	[66], [104], [112], [131], [137], [138], [140], [142]	[66], [104], [112], [131], [137], [138], [140], [142]
Techno-functional properties of insects poorly understood	Processing of insects into other products requires an understanding of the techno-functional properties of insects. More research is required.	[25], [55], [65]	[25], [55], [65], [138]
Unclear guide on how to upscale production	Due to its novelty there is no clear guide on how to produce insects efficiently at a large scale	[112]	
Insect farming techniques based on small scale farms		[72], [140]	[140]

Table 10: barriers associated with technological barriers of insect production

5.3.3 Nutrition and Health Concerns (Feed)

Nutrition and health concerns relating to insects as feed for livestock is related to the effect of insect nutritional content on the health of livestock. Table 11 represents the barriers and associated literature.

Classification of Barrier		Source	
		Food	Feed
Poor fermentation and digestibility in ruminants	There is an indication that some livestock have poor digestion of insects, making them unsuitable to those species.		[90] [128] [66]
Presence of antinutrients	An antinutrient is a compound that inhibits the absorption of nutrients in the body. More research is needed to understand the level of antinutrients and their effects.		[128]

Table 11: barriers associated with the nutrition and health concerns of insect feed

6 Discussion and Conclusion

The purpose of the paper was to compile all the reported barriers of insect production in western countries based on existing literature on the topic. By means of a systematic review, the following research question was formulated:

> "*What are the reported barriers to establishing insect protein as food and feed in Western societies, despite the strong evidence for the potential of insect as a sustainable alternative animal protein?"*

The results of this literature review indicate that establishing an insect market in western societies is currently—and is expected to be—met with a significant number of barriers. In total, 44 individual societal, market, and technological barriers were identified in the literature. It is therefore reasonable to assume that the implementation of insect production in western countries is likely to be challenging, despite the promising nature of insects in the agri-food context as a solution to environmental and food security related issues. By compiling all the reported barriers in the existing literature on insect production, this review offers a complete overview of the barriers that can be expected when introducing insect on western markets.

Although this paper attempted to conduct a holistic review of all the existing barriers of establishing an insect market, there are certain limitations that need to be addressed. First, the literature that was sourced through the Scopus database was highly determined by the scope of the search query. Although the methodology was carefully considered and revised multiple times, it is likely that not every single piece of relevant literature was included in the final literature sample. Therefore, it may be expected that there are other barriers to establishing an insect market. However, it may also be assumed that due to the scope of this literature review, an accurate representation of almost all barriers was considered.

Furthermore, this paper fails to consider the drivers and opportunities of establishing an insect market, focusing solely on the barriers that have been reported. Although this allows for a holistic overview of all challenges expected within the insect market, it simultaneously fails to indicate where the biggest opportunities are for developing such a market. Therefore, to get a comprehensive overview of where the barriers and opportunities may lay in terms of insect production and consumption, a similar analysis on the drivers and opportunities is warranted.

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