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Faculty of Economics

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Dissertation thesis

Waste as a source of business opportunities for circular economy and bioeconomy

author: Ing. Anna Maroušková

supervisor: doc. Ing. Eva Cudlínová, CSc.

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Declaration

I declare that I have prepared my dissertation thesis independently only using the sources and literature listed in the cited literature.

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Ing. AnnaAroušková

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Content

1. Introduction

The continuously growing amount of various types of biowaste represents one of the most frequently mentioned untapped economic opportunities in academic literature. Especially, food waste represents a challenge that needs an immediate solution, since a significant part of this biowaste is still being landfilled even in the EU (Di Maria et al., 2018) which causes many environmental and economic issues. Environmental concerns include (but are not limited to) release of greenhouse gases due to the organic matter decay in the landfill and landfills' bodies collapse (Huang and Fan, 2016). Economic negatives can be interpreted as increasing the production costs of agricultural commodities, which are unnecessarily burdened by operations related to waste management (Agovino et al., 2020). On the other hand, the global population growth increases the need for food and feed which not only worsens the issue of food waste but also causes food insecurity and malnutrition in a significant part of the world (FAO, 2021). Therefore, the transformation towards more sustainable food systems is crucial. Ensuring less waste and making sustainable products the norm while promoting the circular economy (CE) concept - are priorities of the EU Circular Economy Action Plan, which is one of the main building blocks of the European Green Deal (EC, 2020). Implementation of innovative food waste management technologies that are in accordance with the circular bioeconomy economy principles is essential for mitigating negative environmental and economic impacts (Vea et al., 2018). One such method is food waste reduction via its utilization using insects. Moreover, this method allows turning biowaste into various value-added products such as protein for animal feed, fertilizers, oil, and many others (Cappellozza et al., 2019).

It's important to note, that developing alternative protein sources, including insect-based protein, is a keystone of the EU's Farm to Fork strategy which aims to enhance the transition to more sustainable food production and consumption (Jensen et al., 2021). According to various studies (Cortes et al., 2016; van Huis and Oonincx, 2017; Madau et al., 2020) insect-based protein has a great potential to substitute conventional protein sources like soybean meal or fish meal, and contribute to the transition to environmentally more sustainable food systems. Moreover, insects are considered as an important component for enhancing the circularity of the bioeconomy since industrialized insect rearing can transform food waste into valuable food and feed products (Jensen et al., 2021). According to the Updated Bioeconomy Strategy (2018), a significant reduction of food waste by 2030 and its transformation into valuable sources represents the key challenge of the European Bioeconomy Strategy and its Action Plan. Thus, this work, inter alia, deals with an overview of existing Bioeconomy Strategies on different levels and their possible influence on the development of the insect industry in the EU and EFTA (European Free Trade Association) Member states. Business development in general is affected by the state of knowledge in particular field, therefore a correlation analysis on the number of published publications, patents, and established companies in the field of one selected insect species namely Black Soldier Fly (BSF, *Hermetia Illucens*) rearing is conducted in the EU and EFTA Member states. Last but not the least, a competitiveness analysis of selected BSF product available on the EU market was carried out to learn the potential of this product to substitute products such as soybean meal and fish meal, and therefore the potential to promote the transition to a more sustainable business models and circular bioeconomy concept.

2. Aim of the work and research hypotheses

The first objective of this work is to investigate if there is a correlation between the achievements of the academic sector and the business sector in the field of Black Soldier Fly rearing in the EU and EFTA Member states. Any business development is also highly dependent on the state of the knowledge in a particular field Thus, the correlation analysis between the number of companies and patents (representing the business sector), and scientific publications (representing the academic sector) in the field of BSF rearing is conducted across the EU and EFTA Member states. The following hypothesis resulted from this objective:

H1: There is a significant correlation between business development and the scientific achievements of the academic sectors in the BSF rearing in the EU and EFTA Member states.

The second objective is to review Bioeconomy strategies in the world and find out if countries with Bioeconomy strategies adopted on the national level have better achievements both in the academic and business sectors in the field of BSF rearing with the focus on the EU and EFTA Member states. The following hypothesis resulted from this objective:

H2: Established Bioeconomy strategies on the national level positively affect the development of the business and academic achievements in the field of BSF rearing in the EU and EFTA Member states.

The third objective is to analyze the competitiveness of BSF biorefining products and their potential to transform the current waste management practices towards a more sustainable business model. The following hypothesis resulted from this objective:

H3: BSF products are competitive substitutes for products such as fish meal and soybean meal, and therefore BSF business concept has the potential to promote the transition to a more sustainable business model and support the development of circular bioeconomy concept.

3. Methodology

Firstly, assessment of the current state of the academic and business development in the field of BSF rearing was performed in the EU and EFTA Member states. Obtained data were statistically analyzed. For purpose of this study Poisson regression model was chosen to analyze the relation between number of publications, patents, and companies in the field of BSF rearing. Secondly, current Bioeconomy strategies in the EU Member states and the rest of the world were reviewed. In the next step numbers of publications and companies were compared in countries with Bioeconomy strategies at the different levels. Thirdly, a survey was conducted to analyze the competitiveness of BSF products and their potential to promote the transition to more sustainable economic model.

3.1. Academic and business development assessment (H1)

First, the number of published publications, published patents and established companies in the EU and EFTA Member states were quantified according to the procedure described in 3.2.1. Data from the United Kingdom were also incorporated since all companies included in the research were established before 31. 12. 2020, therefore before Brexit, and a significant number of publications and patents were published before that date as well. Obtained data were statistically analyzed via the Statistica® (version 13.6.0) analytics software (TIBCO Software Inc., CA, USA). In order to evaluate the relationship between the number of publications, patents and companies based on pairwise combinations, a nonparametric correlation estimator, namely Spearman correlation (Croux and Dehon, 2010) was used. Then, the relation between the number of publications and patents was analyzed via the Poisson regression model, which is a type of generalized linear model, where the dependent variable is not continuous and is far from being normally distributed. Poisson regression assumes the response variable has a Poisson distribution which is often used to model count data (Dobson and Barnett, 2008). According to Haight (1967), the Poisson distribution is a discrete probability distribution with a random variable that expresses the number of events occurring in a certain interval (time, space, volume, etc.) independently of each other and regardless of the time since the last event. In the Poisson distribution the probability of the occurring event does not remain constant and changes with time and previous occurrences, resulting in unequal mean and variance in the data. Considering that count data are often extremely skewed, using Poisson regression for analyzing those count variables is more appropriate since it has higher statistical power than traditional methods in case the distribution is skewed and approximates the Poisson distribution (Nussbaum et al., 2011).

As an independent variable was selected the number of publications and the number of patents was selected as the response variable. The relation between the number of publications and the number of companies was analyzed in the same manner, picking the latter as a response variable.

3.1.1. Quantification of publications, patents, and companies

The quantification of publications was conducted via the Web of Science research database (Clarivate, USA) according to the following parameters: 1/topic: "Hermetia Illucens" OR "Black Soldier Fly"; 2/publication years: 2010 – 2022; countries: EU + EFTA Member states that contributed to the research (Italy, Netherlands, Germany, Belgium, Spain, United Kingdom (England, Scotland, Wales, and Northern Ireland), Switzerland, Poland, Norway, Portugal, France, Sweden, Denmark, Czech Republic, Greece, Austria, Finland, Bulgaria, Romania, Slovakia, Slovenia, Ireland, Hungary, Iceland, Croatia, Lithuania, Estonia, Latvia, Luxembourg)

The quantification of patents was conducted via the Google patents database (Alphabet, Inc., USA) according to following parameters: 1/ search terms: "*Hermetia Illucens*" OR "Black Soldier Fly"; 2/ search fields: publication date from 01.01.2010 to 31.12.2022 (each year during this period was evaluated separately); and patent office: EP (The European Patent Office), BE, BG, CZ, DE, DK, EE, IE, FR, GB, IT, LT, LU, LV, HU, MT, NL, AT, PL, PT, RO, SI, SK, SE, FI, GR, CY, NO, CH, IS, LI, WO (World Intellectual Property Organization). The WO patent office affiliation was added due to the fact that in the majority of cases patents with WO affiliation at the same time had affiliation in one of the EU or EFTA member states, but the EP affiliation was not indicated. Moreover, mostly those patents were assigned to one of the companies based in the EU (Ynsect, Protix B. V, InnovaFeed).

The quantification of companies was conducted via: 1/ Google search engine (Alphabet, Inc., USA); 2/ LinkedIn a social media platform for business; 3/ literature (Wang and Shelomi, 2017; Skyquest, 2022; Grossule et al., 2023) and 4/ International Platform of Insects for Food and Feed (IPIFF). The year of establishment of each company was searched via Amadeus database of comparable financial information for public and private companies across Europe (Bureau van Dijk – A Moody's Analytics Company, Belgium).

3.2. Bioeconomy strategies comparison (H2)

A review of existing Bioeconomy strategies around the world was performed based on the data from the Web of Science research database (Clarivate, USA) and published Bioeconomy strategies of different EU Member states as well as other countries around the world. Subsequently, numbers of publications and companies in the field of BSF rearing were compared in the EU and EFTA Member states with Bioeconomy strategies at the different levels. The quantification of companies and publications included in the comparison is explained in the subsection 3.1.1.

3.3. Competitiveness analysis (H3)

Competitiveness analysis was conducted through a survey specially designed for this study, followed by a thorough evaluation of the outcomes in line with the recent scientific advancements. The main objective of the survey was to explore the degree of importance of the key parameters that influence decision-making in the selection of feed components. The questionnaire aimed mainly at feed manufacturers or sellers and farm animal producers, but also at the academic staff and experts with the focus on animal nutrition.

3.3.1. Identification of the products for the competitiveness analysis

The keywords “poultry feed”, “fish feed”, “pig feed”, “petfood”, and “protein” were entered into the search fields of scientific databases (Web of Science, Scopus and Google Scholar), with the time span set to last 10 years. The most cited publications from each database were scanned for the Abstract to assess relevance (possible substitutes for BSF products in the feed industry). Also, colleagues within the University of South Bohemia in České Budějovice, as well as independent experts working in feed science, were approached personally. Key players in the local feed market were contacted. Those who agreed to participate in the research were interviewed in a controlled manner to independently ascertain what the current state of the feed market is and what the main sources of protein are in the most traded pig, poultry, fish feed and petfood. Based on the results of literature research and consultation with experts, from a wide range of BSF products (Table 9) for the purpose of this survey defatted BSF meal (hereinafter BSF meal) was picked as a potential substitute for soybean meal and fish meal. Therefore, the survey compares those three main protein sources and analyses the possible replacement of soybean meal and fish meal with a BSF meal for feed purposes.

3.3.2. Questionnaire design

The paid version of the Survio® online survey service was purchased, which allows to create advanced questionnaires and subject them subsequently to a number of complex analyses. The online questionnaire was designed in the Survio® system based on the knowledge obtained through literature research, market research and a controlled discussion with experts and key players on the feed market. The questionnaire started with a very short survey introduction (a brief welcome, a cursory introduction to the research mission, and the contact information (in case technical support or help with interpretation was needed). The questionnaire was anonymous. The core of the questionnaire was 14 questions, between which it was possible to return. There was no time limit for completing the questionnaire. However, after the final submission, it was no longer possible to change the answers. Each of the 14 questions of the questionnaire was designed with respect to different groups of stakeholders in order to gain a deeper awareness of the opinions of the professional public and to obtain supporting arguments to confirm or refute H3. Description of each question is given below:

1. You are:

• Feed manufacturer or seller
• Animal producer
• Academic staff or expert with a focus on animal nutrition
• Other

2. What kinds of animals are the subject of your activities? Choose one or more answers.

• Fish
• Poultry
• Pigs
• Pets
• Other

3. According to the currently valid legislation, your activities fall into the category of:

- Microenterprise
- Small enterprise
- Medium enterprise
- Large enterprise
- Self-employed
- Non-business entity

4. Indicate which of the following ingredients do you use as a main nutritional source (either alone or in a mixture). Choose one or more answers.

- Soybean
- Fish meal
- Insect meal
- Cereals
- Pea
- Other

5. Please rate the degree of importance of each nutritional property of the feed (or main nutritional component).

- Protein content
- Amino acids
- Fatty acids
- Carbohydrates
- Minerals
- Vitamins
- Fiber
- Energy MJ/kg
- Digestibility
- Palatability

6. Please rate the degree of importance of ecological aspects (how important is it to you that feed production has the least possible impact on the environment).

• Energy consumption
• Water consumption
• Land use
• Carbon footprint (GHG emissions)
• Use of agrochemicals
• Load on water bodies
• Deforestation

7. Please rate the degree of importance of logistical aspects.
• Delivery time
• Storage time
• Local availability

8. Please rate the degree of importance of price.
• Price per protein content (%)
• Price per unit of weight (kg)

9. Are you aware of the possibility of using Black Soldier Fly (Hermetia Illucens) larvae as a source of protein in feed?
• Yes, and I use it or recommend it to my customers
• Yes, but I don't use it
• No

10. What requirements do insect products have to meet for you to be willing to use them (or recommend them to your customers) as a source of protein for animals?

11. If insect products met your requirements, would you be willing to use them (or recommend them to your customers) as a source of protein for animals?
• Yes
• No
• I'm not sure

12. Whatever your previous answer was, please describe the main reasons.

13. What price range would you be willing to accept for an insect protein source?

• Lower than current protein source

• Comparable to currently used

• Higher if it is of better quality

• Price is not a relevant criterion

14. Here please write any comments on the possibility of using insects in feed or on the questionnaire itself.

Question 1 served to divide the respondents into manufacturers, sellers, farm animal producers, academic staff, or expert with a focus on animal nutrition, or other stakeholders. It was a semi-closed question. Question 2 was set in such a way as to make it possible to identify what kinds of animals are subject of stakeholders' activities, and therefore to verify whether BSF products are relevant feed for a given type of animal. It was a semi-closed question. Question 3 was related to the segmentation of the respondents from the legal point of view, which was a closed question. Question 4 inquired about currently used or recommended sources of protein in feed. It was a semi-closed question. In Questions 5 to 8 the respondents were asked to assign the degree of importance to each of the key parameters related to feed. There were five types of the degree of importance: "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure". The key parameters were divided into four groups: Question 5 included nutritional parameters, Question 6 included environmental aspects, Question 7 included logistical aspects, and Question 8 was about the price.

In Question 9 respondents were asked about their awareness of BSF as a possible source of protein. It was a closed question. Question 10 was open-ended and inquired about the requirements that insect feed products would have to meet for the respondents to be willing to use or recommend them in their activities. Question 11 follows on from Question 10 and asks if the respondents would be willing to use (or recommend) insect feed products if the requirements they stated in Question 10 were met. Question 12 requires a description of the reasons that led to the answer on Question 11. Question 13 is a closed question were respondents have to choose a preferred price range. The last Question 14 is open and allows the respondents to freely comment on the questionnaire, or add any clarifying comments or opinions related to the use of insects in feed.

3.3.3. Survey results evaluation

The initial statistical evaluation with visual output was performed in the Survio® package, which offers this option proprietary in the paid version. Subsequently, all key parameters with assigned degrees of importance from Questions 5 - 8 were analysed and compared for all three protein sources (soybean meal, fish meal, and BSF defatted meal). The comparison was conducted based on the results of comprehensive literature research regarding the nutritional properties and ecological aspects of each protein source, as well as data about logistical aspects and average market price. The emphasis was placed on the parameters with the highest degree of importance according to the respondents' assessment in the survey (with value of more than 50%).

4. Literary research

4.1. Bioeconomy concept and definition

The bioeconomy is based on the idea of applying biological principles and processes in all sectors of the economy and to increasingly replace fossil-based raw materials in the economy with bio-based resources and principles (Birner, 2018). The first Bioeconomy Strategy in Europe was adopted in February 2012 by the European Commission as a strategy for "Innovating for Sustainable Growth: A Bioeconomy for Europe". The main purpose of the Bioeconomy Strategy was to propose „a comprehensive approach to address the ecological, environmental, energy, food supply, and natural resource challenges" that EU and the rest of the world are facing (EC, 2012). However, there is still no uniform definition of what exactly bioeconomy is, and its understanding varies in different countries (Barañano et al., 2021). The Bioeconomy Strategy document itself describes bioeconomy as „*the production of renewable biological resources and their conversion into food, feed, bio-based products, and bioenergy. It includes agriculture, forestry, fisheries, food, and pulp and paper production, as well as parts of chemical, biotechnological and energy industries*". The document also specifies bio-based products (based on the European Committee for Standardization CEN - Report on Mandate M/429 (2008)) as those „*that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilized*" (EC, 2012).

There is no consensus on when and by whom the term bioeconomy was coined first. Even more confusion is caused due to interchanging the terms "bioeconomy" and "bioeconomics". The latter precedes the occurrence of bioeconomy and according to Bonaiuti (2014) it can be traced back to Jiří Zeman, a Czechoslovakian academician who used the term in the late 1960s to underline 'the biological substance of the economic process in almost every respect'. However, some authors (Barañano et al., 2021) point out that the term "bioeconomics" was used even earlier by Hermann Reinheimer in his book "Evolution by Co-operation: A Study in Bioeconomics" already in 1913. Nevertheless, the most prominent author of the term "bioeconomics" is considered to be Nicholas Georgescu-Roegen, who highlighted the biological origin of economic process and was among the first economists to examine the interconnection between economic growth and natural environment in terms of thermodynamics

(Mayumi, 2001). In his key work “The Entropy Law and the Economic Process” Georgescu-Roegen (1971) expresses his opinion about the ever-increasing use of natural resources which must eventually lead to their exhaustion. According to some authors Georgescu-Roegen's works between the 1970s and 1980s laid a foundation for such economic thoughts as “ecological economics” (Mayumi, 2001) or “degrowth” (Bonaiuti, 2014).

With regard to the term “bioeconomy” according to von Braun (2014), it has developed gradually and in 1997 two geneticists, Juan Enriquez and Rodrigo Martinez were the first who defined the concept of bioeconomy. Their contribution became the basis for the EU's formal initiatives regarding bioeconomy. Nevertheless, the earlier meaning of the term was linked to the application of biological knowledge for industrial and commercial applications (Birner, 2018) and its use can be found in scientific databases already in the 1970s. Soon after the first debates about bioeconomy in the late 1990s the European Commission realized the potential of the bioeconomy concept. The father of the European bioeconomy is considered to be Christian Patermann, who, at that time was a Program Director for "Biotechnology, Agriculture and Food" Research at the Research Directorate-General of the EC. He played the key role in promoting the bioeconomy concept in Europe and was one of the first who realized not only the bioeconomy's potential to replace fossil-based resources with bio-based resources but also its potential to become a policy concept in the EU that could address some challenges the region faces (Birner, 2018).

The development of the bioeconomy concept in the EU was influenced also by the Lisbon Strategy from 2000 that aimed by 2010 to make the EU "*the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion*" (Lisbon European Council, 2000). Therefore, the term “bioeconomy” was tagged with “knowledge-based” to emphasize the significance of the research and innovation as well as the importance of highly skilled labor for boosting the bioeconomy market (Barañano et al., 2021). In 2005 at the EC conference named “New Perspectives on the Knowledge-Based Bio-Economy,” the European Commissioner for Science and Research Janez Potočnik presented the concept of “knowledge-based bioeconomy” (KBBE). The title of his speech “Transforming life sciences knowledge into new, sustainable, eco-efficient and competitive products” was quoted as the first official definition of the KBBE. Another significant event that laid the foundations for the KBBE concept in Europe took place in Germany in 2007. It was a conference called "En Route to the Knowledge-Based Bio-Economy" where key stakeholders from all three sectors (government, industry, and academia) outlined the perspectives of the KBBE for the next 20 years (McCormick and Kautto, 2013). The conference was hosted by the German Presidency of the Council of the European Union and resulted in the so-called "Cologne Paper" in which results and findings from the key stakeholders' workshops were presented. During the 6 workshops were discussed such areas like Framework, Food, Biomaterials and Bioprocesses; Bioenergy; Biomedicine and New Concepts and Emerging Technologies (Lang, 2022).

Allain et al. (2022) points out that the terms "bioeconomics" and "bioeconomy" have fundamentally different, sometimes even contradictory meaning. The author refers to the work of Georgescu-Roegen (1971) who presented bioeconomics as a tool how to solve the environmental crisis through degrowth and low-tech innovations. While bioeconomy concept according to Allain et al. (2022) considers economic growth through the application of biotechnology in various industries along with the use of large amounts of biomass.

The term "bioeconomy" is also often being interchanged with the term "bio-based" economy. However, based on the study of Staffas et al. (2013) there is a slight difference which lies in the original meaning of both terms. The author explains that the term "bio-based economy" is mostly used to emphasize the replacement of fossil-based resources with biomass resources. Whereas the term "bioeconomy" rather refers to the part of the existing economy that includes biotechnology, life science and related technologies for production of renewable biological resources and their use in areas such as agriculture, forestry, fisheries, bioenergy, food and feed production. Some authors perceive the difference between the terms explained by Staffas et al. (2013) even more deeply and link bio-based economy to production of non-food goods from bio-based sources whilst bioeconomy is considered to encompass both bio-based economy and food and feed production (Barañano et al., 2021).

Despite of ambiguity of the terms different governments and international organizations agree that be it "bioeconomy", "bioeconomics", "bio-based economy" or "knowledge-based bioecnomy" the transition to more sustainable production and consumption model has undeniably significant importance for keeping the development of our society within the planetary boundaries (Cudlínová et al, 2017). In Table 1 are presented the most significant and relevant definitions of bioeconomy worldwide. An increasing strategic interest in the bioeconomy concept worldwide was pointed out by the Organization for Economic Co-operation and Development (OECD, 2006) almost twenty years ago. In the work "The bioeconomy to 2030: designing a policy agenda" 3 elements that are involved in bioeconomy were highlighted: biotechnological knowledge, renewable biomass, and integration across applications. Biotechnology was considered the one that plays an important role in the economic output.

Table 1: Definitions of Bioeconomy in the world

Author / originator	Definition	Year
Juan Enriquez and Rodrigo Martinez, American Association for the Advancement of Science (AAAS) meeting, Philadelphia	all economic activity derived from scientific and/or research activity focused on understanding mechanisms and processes at the genetic/molecular levels and its application to industrial process	1997
OECD	the aggregate set of economic operations in a society that use the latent value incumbent in biological products and processes to capture new growth and welfare benefits for citizens and nations.	2006
European Commission	the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy	2012
Bioeconomy Blueprint, USA	based on the use of research and innovation in the biological sciences to create economic activity and public benefit	2012
European Bioeconomy Alliance	the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy via innovative, efficient technologies. In this regard, it is the biological motor of a future circular economy, which is based	2016

	on optimal use of resources and the production of primary raw materials from renewably sourced feedstock.	
Bioeconomy Council of the German Government, Global Bioeconomy Summit	The production, utilization and conservation of biological resources, including related knowledge, science, technology and innovation, to provide information, products, processes and services across all economic sectors, aiming toward a sustainable economy.	2018
European Commission, Updated Bioeconomy Strategy	The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services.	2018

Source: author's compilation based on the sources indicated in the table

4.2. Bioeconomy strategies across the globe

4.2.1. EU + EFTA

As was mentioned above the first Bioeconomy Strategy in Europe was adopted in 2012. However, according to Patermann and Aguilar (2018), its origins go back to 1982 when the EC started preparation for the implementation of the EU Framework Programmes in Biotechnology and Life Sciences. The authors also highlight the Bioeconomy dedicated activity within the Programme Horizon 2020 (2014–2020) and the creation of a public-private partnership of bio-based industries as the two most significant impacts of the EU Bioeconomy Strategy. The European Bioeconomy Strategy has five goals: (1) ensuring food security, (2) managing natural resources sustainably, (3) reducing dependence on non-renewable resources, (4) mitigating and adapting to climate change, and (5) strengthening the EU competitiveness and creating jobs. To move towards these objectives an Updated Bioeconomy Strategy (2018) proposed an Action Plan that was adjusted to the environmental, economic, and societal challenges Europe is facing. The Action Plan includes 14 concrete actions divided into three main areas:

1) *strengthening and scaling up the bio-based sectors by unlocking investments and markets*
    - *mobilize stakeholders in developing and deploying sustainable bio-based solutions*
    - *launch a €100 million circular bioeconomy thematic investment platform*
    - *analyze enablers and bottlenecks for the deployment of bio-based innovations*
    - *promote and develop standards*
    - *facilitate the deployment of new sustainable biorefineries*
    - *develop substitutes to fossil-based materials that are bio-based, recyclable and marine biodegradable*
2) *local bioeconomies deployment across the whole of Europe*
    - *launch a strategic deployment agenda for sustainable food and farming systems, forestry and bio-based products*
    - *launch pilot actions for the deployment of bioeconomies in rural, coastal and urban areas*
    - *support regions and EU countries to develop bioeconomy strategies*
    - *promote education, training and skills across the bioeconomy*
3) *better understanding of ecological boundries*
    - *enhance knowledge on biodiversity and ecosystems*
    - *monitor progress towards a sustainable bioeconomy*
    - *promote good practices to operate the bioeconomy within safe ecological limits*
    - *enhance the benefits of biodiversity in primary production*

However, even before the adoption of the European Bioeconomy Strategy, few EU member states published their dedicated bioeconomy strategy at a national level. The first of them was Germany in 2010 with its National Research Strategy 'BioEconomy 2030' followed by the National Policy Strategy on Bioeconomy in 2013. According to the data from the Updated Bioeconomy Strategy (2018) besides Germany, the Dedicated bioeconomy strategy at the national level as of March 2018 had six more EU member states: Finland, France, Ireland, Italy, Latvia, and Spain. Several EU member states had a Dedicated bioeconomy strategy at the national level under development (Austria, Estonia, Hungary, Lithuania, and the Netherlands) including the United Kingdom which was a member state as well at that time. The rest of the member states had other policy initiatives dedicated to bioeconomy or other related strategies at a national level. In Table 2 the status of EU member states regarding different bioeconomy strategies as of March 2018 is compared to the status as of October 2023. The status as of October 2023 is also shown in the Figure 1.

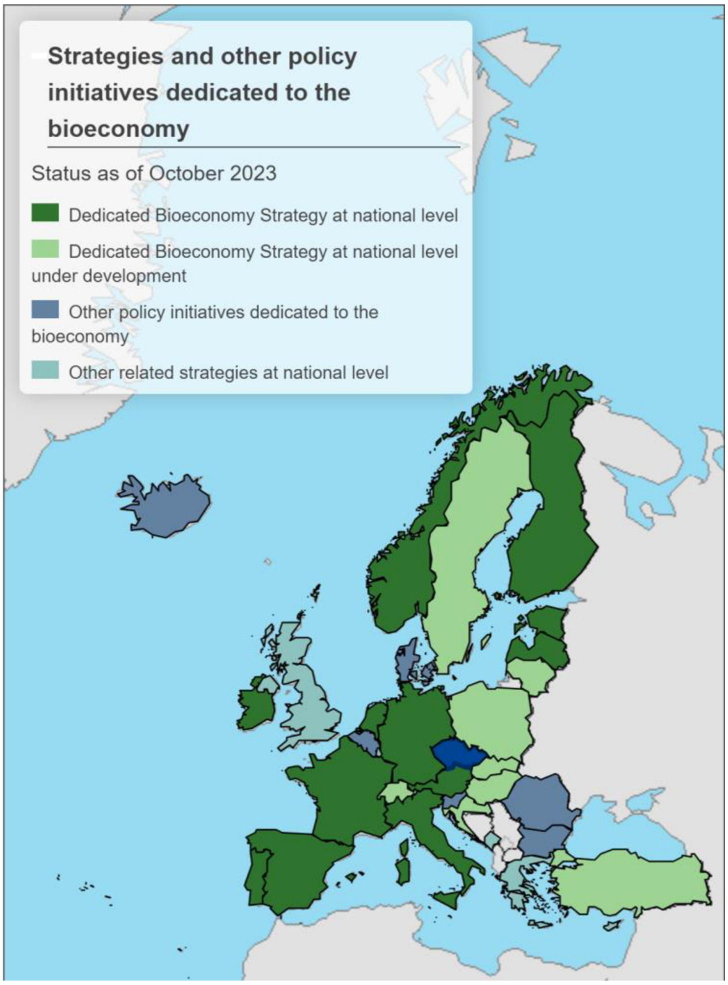
Table 2: Bioeconomy strategies in the EU as of March 2018 and October 2023

Strategy type	March, 2018	October, 2023
Dedicated bioeconomy strategy at the national level	Finland, France, Germany, Ireland, Italy, Latvia, Spain, Norway	Finland, France, Germany, Ireland, Italy, Latvia, Spain, Portugal, the Netherlands, Austria, Estonia
Dedicated bioeconomy strategy at the national level under development	Austria, Estonia, Hungary, Lithuania, the Netherlands, United Kingdom	Croatia, Czech Republic, Hungary, Lithuania, Poland, Slovakia, Sweden, Switzerland
Other policy initiatives dedicated to the bioeconomy	Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Poland, Romania, Slovakia, Slovenia, Sweden, Switzerland	Belgium, Bulgaria, Denmark, Slovenia, Romania
Other related strategies at national level	Cyprus, Greece, Portugal	Cyprus, Greece

Source: author's compilation based on the data from the European Commission's Knowledge Centre for Bioeconomy, 2023

So far, the last country that has published its bioeconomy strategy at the national level is Estonia (October 2023). Croatia, Czech Republic, Hungary, Lithuania, Poland, Slovakia, Sweden, and Switzerland have still their bioeconomy strategy at the national level under development. From EFTA countries Norway is the only one which has its bioeconomy strategy adopted at the national level. From non-EU and non-EFTA countries shown on the map (Figure 1), the one that has a bioeconomy strategy at the national level under development is Turkey which also is a member of the European Union–Turkey Customs Union and has access to the free movement of some goods with the EU. As for United Kingdom, its bioeconomy strategy at national level named Growing the bioeconomy: a national bioeconomy strategy to 2030 adopted in December 2018 was withdrawn after the Brexit and replaced with a new document named UK Innovation Strategy: Leading the future by creating it (BEIS, 2021).

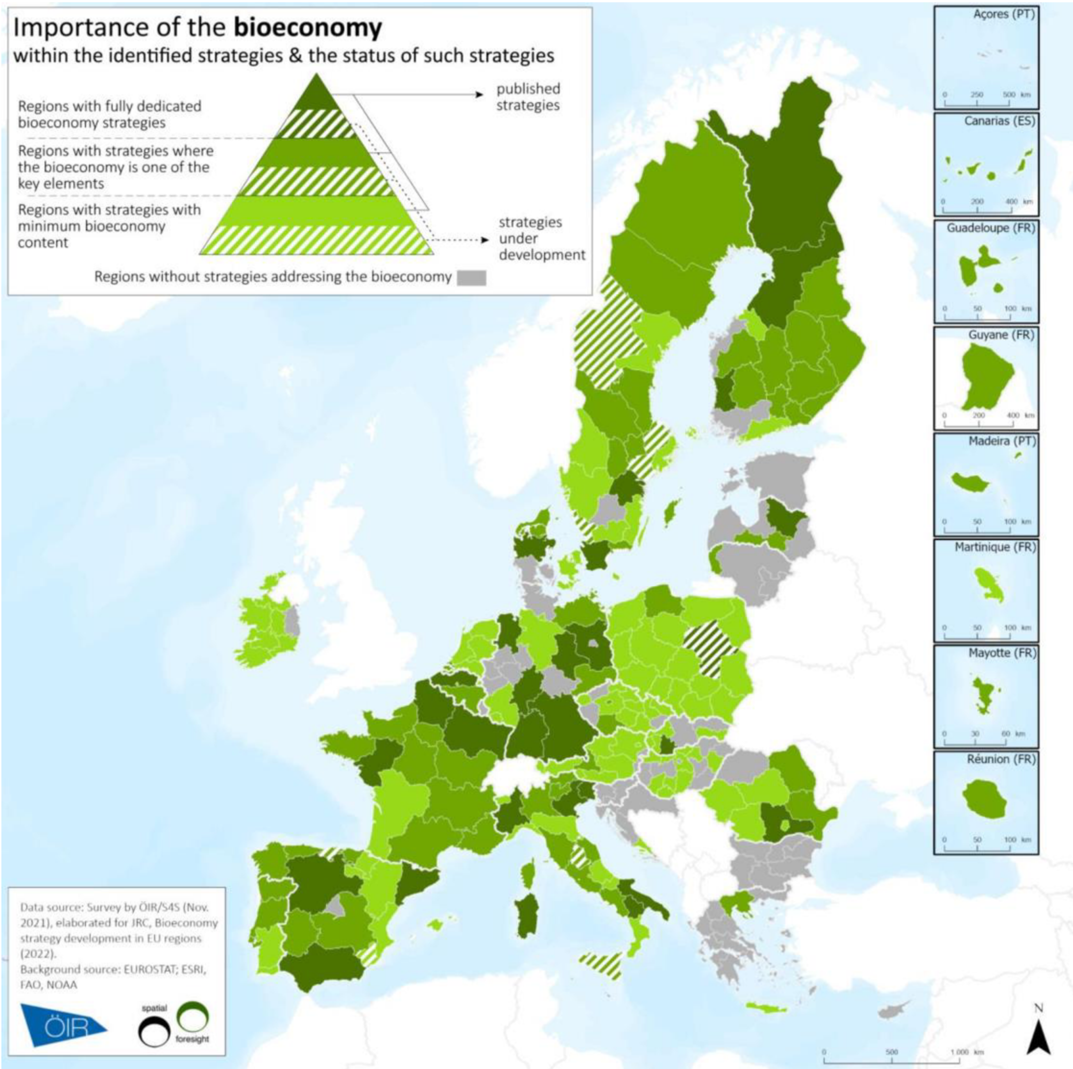
Figure 1: Strategies and other initiatives dedicated to the bioeconomy in Europe



Source: European Commission's Knowledge Centre for Bioeconomy, 2023

In terms of regional bioeconomy strategies according to the mapping (Figure 2) conducted by the Joint Research Centre (JRC, 2022) for the European Commission's Knowledge Centre for Bioeconomy, there are 194 regions that either have an established strategic framework for the bioeconomy or are currently developing one. At the regional level within the EU, there are a total of 359 strategies that are relevant to the bioeconomy. Out of these, 334 have been formally documented as strategies, action plans, roadmaps, etc., while the remainder are in the stages of development. A significant increase in a number of published regional bioeconomy strategies was noted after the revised EU Bioeconomy strategy in 2018 was launched.

Figure 2: Bioeconomy strategies at the regional level in the EU.



Source: JRC, 2022

As can be seen from Figure 2 the regions with already published fully dedicated bioeconomy strategies in the EU are 7 regions in Germany, 6 in Italy, 3 in Finland, Spain, and France, 2 in Sweden, and in Denmark, Latvia, Lithuania, Romania, Slovakia, the Netherlands, and Belgium there is 1 in each. One such kind of regional strategy is in Poland under development. The rest of the regions in the above-mentioned countries have regional strategies where either Bioeconomy is one of the key elements or with minimum bioeconomy content. In certain regions, there are several strategies pertaining to the bioeconomy on a different level. However, on this map, each region is represented solely by its highest-ranking strategy within the strategy pyramid. EU member states with no regional strategies with bioeconomy concept at all are: Bulgaria, Croatia, Estonia, and Slovenia.

The presence of regional bioeconomy strategies is generally influenced by two key factors. Firstly, in countries that are both large and decentralized, it's more common to find bioeconomy strategies at the regional level. Secondly, the existence of a national bioeconomy strategy often means that its principles are integrated into regional and local initiatives, potentially leading to fewer independent strategies at the regional level. In such scenarios, the bioeconomy at the sub-national level is typically incorporated within broader strategic contexts. Nonetheless, even in the presence of a national strategy, regional frameworks might still be developed to tailor actions to regional specifics and to address unique regional characteristics.

4.2.2. USA and Canada

As shown in Table 1 the term bioeconomy was first used in the USA in 1997 at a meeting of the American Association for the Advancement of Science. After that, the concept of bioeconomy was promoted and in 2012 the "National Bioeconomy Blueprint" was released by the Obama administration. The initial goal of the US Bioeconomy Strategy was the transition from fossil to bio-based fuels, but in course of time, it has expanded to more activities including bio-based products generation, etc. (Aguilar et al., 2019). National Bioeconomy Blueprint has laid out five strategic objectives that have the potential to help achieve economic growth and deal with societal need:

- *Support R&D investments that will provide the foundation for the future US. bioeconomy.*

- *Facilitate the transition of bioinventions from research lab to market, including an increased focus on translational and regulatory sciences.*
- *Develop and reform regulations to reduce barriers, increase the speed and predictability of regulatory processes, and reduce costs while protecting human and environmental health.*
- *Update training programs and align academic institution incentives with student training for national workforce needs.*
- *Identify and support opportunities for the development of public-private partnerships and precompetitive collaborations — where competitors pool resources, knowledge, and expertise to learn from successes and failures.*

The early achievements toward those objectives were highlighted in the document. Also with the government, industry, and public contribution key elements necessary for achieving the potential of the US bioeconomy were identified: a full spectrum of basic and applied R&D activities performed by academic, government, and private sectors; public-private partnerships; a supportive commercialization system for bioinventions; innovative regulatory policies that reflect government awareness of needs for and impediments to progress; a skilled and creative workforce; public support for technological advances; the flexibility to accommodate the evolving needs, discoveries, and challenges. According to the National Bioeconomy Blueprint, it is expected that the US Bioeconomy Strategy will have the biggest impacts on the biomedical, agriculture, and industrial sectors (The White House, 2012). In September 2022 the National Biotechnology and Biomanufacturing Initiative was launched by the Biden Administration in order to accelerate biotechnology innovation and expand the US bioeconomy in multiple sectors (CRS, 2022).

Canada published its Bioeconomy strategy in 2019 named “Leveraging our Strengths for a Sustainable Future”. The definition of the bioeconomy was adopted from the Updated Bioeconomy Strategy of the European Commission (2018, Table 1) and the greatest emphasis was placed on biotechnology as the main competitive advantage of Canada's Bioeconomy Strategy. The incorporation of biological processes into production systems for producing energy, fuels, chemicals, and materials defines industrial biotechnology which is believed to replace traditional chemical processes and ensure economic, environmental, and social sustainability. It is important to note that the National Biotechnology Strategy in Canada was published already in 1983 and renewed by Canadian Biotechnology Advisory Committee in 1998 (CBAC, 2005). At the same time, Canada's Bioeconomy Strategy implies an essential role of the Circular Economy in achieving sustainability goals. As well as the EU, Canada emphasizes combining its bioeconomy strategy with the circular economy concept for better addressing the environmental challenges and more efficient use of natural resources. It must be noted that Canada's Bioeconomy Strategy was created in cooperation with more than 400 participants from the Canadian industry sector and reflects their insights and needs (BIC, 2019). As a result, four key priority areas were recommended to take an action on:

- *Creating agile regulation and government policy;*
- *Establishing biomass supply and stewardship of the natural capital including agricultural and forestry;*
- *Building strong companies and value chains;*
- *Building strong sustainable innovation ecosystems with an emphasis on value chain creation, job training and skills development.*

4.2.3. Asia-Pacific, Africa and Latin America

Outside of the EU and North America, the first countries that adopted dedicated national bioeconomy strategy were Japan, Malaysia, and South Africa.

Even though Japan's Bioeconomy Strategy itself was published in 2019; the Japanese government adopted Biomass Nippon Strategy already in 2002. It was the first strategy for Japan at the national level for utilizing biomass as a valuable source taking into account technological, social, and economic aspects (Kuzuhara, 2005). Current Japan's Bioeconomy Strategy advances biotechnology and aims to "realize the most advanced bioeconomy society by 2030" achieving 92 trillion yen (USD 837 billion) which is around a 50% increase in comparison to 2018-2020. The market size increase is expected in three main segments: 1/Bio-manufacturing (engineering biology-based biofoundry and biorefinery; R&D support for bio-plastics); 2/ Primary production (automated agriculture, employment of latest genome editing technology-based breeding; large wooden architecture design and construction); 3/ Health care (bio-drug development and production systems; large-scale genome database) (Onho, 2021).

However, according to the Global Bioeconomy Policy Report (Teitelbaum, et al., 2020) Malaysia was the first country in Asia to start off developing the bioeconomy concept at the national level. The development of the concept started with the National Biotechnology Policy published in 2005 and concentrated on the biotechnology application in the three main areas: agriculture, healthcare, and industry. In 2012 the Malaysian Government launched the Bioeconomy Transformation Programme that included a comprehensive plan for the bioeconomy development. The third country from Asia-Pacific region (after Japan and Malaysia) with the adopted bioeconomy strategy is Thailand. In 2019 the Thai government in cooperation with 500 experts from the private and public sector published Roadmap "Bio-Circular-Green Economy (BCG) in Action: The new Sustainable Growth Engine". The document focuses on four strategic sectors: 1/agriculture and food; 2/medical and wellness; 3/bioenergy, biomaterial and biochemical; 4/ tourism and creative economy with the combined economic value expected to grow from 3.4 trillion THB (about USD 109 billion, 21% of GDP) to 4.4 trillion THB (about USD 141 billion, 24% of GDP) during 5 years (Kumagai, 2022).

The pioneer in promoting the bioeconomy in Africa is South Africa with its dedicated Bio-Economy Strategy published in 2013. However, South Africa already had an experience with initiatives moving the country towards a greener economy. In 2001 National Biotechnology Strategy was adopted which resulted in the establishment of several regional innovation centers and promoted international cooperation (Cloete, et al., 2006). Nonetheless, bioeconomy initiatives in Africa are on the rise. A dedicated macro-regional bioeconomy strategy for Eastern Africa was launched in 2020 by seven countries and focused on technology transfer and business development in the field of bioinnovation. The initiative was supported by Sweden and includes Burundi, Ethiopia, Kenya, Rwanda, Tanzania, South Sudan, and Uganda (Teitelbaum, et al., 2020).

Among Latin American countries Costa Rica is the first and only to adopt a dedicated national bioeconomy strategy in 2020. Nevertheless, other countries like Argentina, Brazil, Uruguay etc. keep working on dedicated strategies under guidance of macro-regional organizations for several years. Although, the process of adopting bioeconomy strategies at national level is slow, the bioeconomy model has gained significant importance in the region and is promoted as the one with the potential to achieve the sustainable development goals. For instance, in 2019 the Latin American

Bioeconomy Network was established to promote the bioeconomy as a regional development strategy (IACGB, 2020). A year earlier also the Inter-American Institute for Cooperation on Agriculture (IICA, 2018) published its Bioeconomy and Production Development Program as a part of the 2018-2022 Medium-term Plan which is intended to guarantee sustainability for 34 IICA's Members States over the next 25 years.

4.3. Circular economy concept and definition

The concept of circular economy was first introduced by Pearce and Turner (1989) who described the impact of natural resources on economic systems and investigated the linear and open-ended characteristics of contemporary economic systems (Geissdoerfer et al., 2017; Sverko Grdic et al., 2020). Their research was based on previous studies of Boulding (1966) and his idea of the Earth as a closed circular system in which the economy and environment should coexist in equilibrium (Geissdoerfer et al., 2017; Ghisellini et al., 2016). Various definitions of circular economy can be found in the literature. Nevertheless, most authors agree on a "closed-loop system" in which waste generation is minimized through the careful design of new products, and materials constantly circulate in an industrial process (Sverko Grdic et al., 2020). Closed-loop systems are understood as industrial systems in which resource effectiveness increases through reusing and recycling industrial "nutrients" to extract their maximum value with minimum waste (Jørgensen and Remmen, 2018).

Originally principles of the circular economy were based on the 3R model: Reduce, Reuse, Recycle. These principles were basic for green manufacturing developed in the 1990s from lean manufacturing, which is based on 1R: Reduce systems (Jawahir and Bradley, 2016). Later it was upgraded to the 6R model: Reuse, Recycle, Redesign, Remanufacture, Reduce, Recover (Sverko Grdic et al., 2020) which provides more sustainable manufacturing by simplifying the optimal use of energy, raw materials, and other resources, and producing minimal wastes and emissions at the end (Jawahir and Bradley, 2016). In recent times however various numbers and sequences of R-value retention options can be found in the literature, from the 3R to 10R model causing inconsistency (Campbell-Johnston et al., 2020). For instance, the advisory report 'Circular economy: from a wish to practice' published by the Dutch Council for the Environment and Infrastructure (Rli, 2015) includes 9R model (Refuse, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover) for reducing dependence on imported raw materials.

The main objective of the Circular economy is to change the classic linear production model (produce-use-dispose), focusing on products and services that minimize waste and other types of pollution. The linear economy model doesn't take into consideration the environmental nor societal impacts of its concept. Such kind of imperfect manufacturing approach is unsustainable in a long term and threatens current political and economic systems (Jawahir and Bradley, 2016). However, some authors criticize the circular economy concept due to its vagueness, lack of clear definition, and proper planning (Korhonen et al., 2018a; Corvellec et al., 2022). Kirchherr et al., (2017) examined 114 articles that contained CE definitions and 95 of them were different, which can be linked to the different perceptions of the concept by different people. At the same time, the authors analyzed how often the three basic principles of the CE (reduce, reuse, recycle) appear in the examined definitions. According to their results the "recycle" was the most frequently used component in the CE definitions (79%), almost 75% of definitions contained the word "reuse" and the "reduce" component was found in almost 55% of them. Ghisellini et al. (2016) also pointed out that worldwide "recycling" is more promoted in the CE concept than "reuse". Although under the Waste hierarchy of the European Commission's Waste Framework Directive (WFD, 2008) prevention (reduce) and reuse must be prioritized over recycling. There are concerns (Corvellec et al., 2022), that focusing on recycling will lead to keeping the problem of unsustainable production and consumption unsolved. Moreover, given the fact that recycling of many materials is more energy-intensive than producing products from primary sources, such a CE model could, paradoxically, result in more greenhouse gases release (Allwood, 2014), which goes against the objectives of the CE concept. Nevertheless, if the Waste hierarchy is followed properly the circular economy concept has the potential to reduce environmental impacts.

The most well-known definition of the CE belongs to the Ellen MacArthur Foundation from 2012 (Kirchherr et al., 2017), which describes it as 'an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models'. The foundation was formed in 2010 the United Kingdom with the aim to promote and accelerate the transition to the CE model and for this purpose works with all three sectors: government, business, and academia. In 2017 the Platform for Accelerating the Circular Economy (PACE) was launched at the World Economic Forum in Switzerland. The Ellen MacArthur Foundation was one of the main founding members of the platform that unites several multi-national corporations, representatives from government and business sector with dozens of experts from around the world (Sikdar, 2019). Other selected definitions of CE are listed in Table 3 based on the findings of Nobre and Tavares (2021). The authors also identified six CE-related basic principles (9R Framework; Waste Hierarchy; Clean and Renewable Energies; Upcycle; Resource Efficiency; CE Categories) and eighteen CE-related concepts (Bioeconomy; Biomimicry; Blue Economy; Carbon Footprint Reduction; Closed Loop; Design Out Waste; End Of Life Strategies; Green Economy; Green Manufacturing; Green Supply Chain; Industrial Ecology; Industrial Symbiosis; Life Cycle Assessment; Performance Economy; Regenerative Design; Reverse Logistics; Waste To Value).

Table 3: The list of selected Circular Economy definitions

Author	Definition	Year
Bakker et al., 2014	*The circular approach contrasts with the traditional linear business model of production of take-make-use-dispose and an industrial system largely reliant on fossil fuels because the aim of the business shifts from generating profits from selling artifacts, to generating profits from the flow of materials and products overtime.*	2014
Bocken et al., 2016	*Circular business models can enable economically viable ways to continually reuse products and materials, using renewable resources where possible.*	2016
Geissdoerfer et al., 2017	*A regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.*	2017

Ghisellini et al., 2018	*Circular economy (CE) as a new model of economic development promotes the maximum reuse/recycling of materials, goods and components in order to decrease waste generation to the largest possible extent. It aims to innovate the entire chain of production, consumption, distribution and recovery of materials and energy according to a cradle-to-cradle vision.*	2018
Korhonen et al., 2018b	*CE is a sustainable development initiative with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system. CE promotes high value material cycles alongside more traditional recycling and develops systems approaches to the cooperation of producers, consumers, and other societal actors in sustainable development work.*	2018

Source: modified from Nobre and Tavares, 2021

4.3.1. Circular Economy Action Plan

The transition from the traditional linear model to a circular economy is supported by the European Union and other governments and institutions (Michelini et al., 2017). Interestingly, the pioneer in the research and also implementation of the CE principles is China. The Circular Economy Promotion Law of the People's Republic of China was adopted already in 2008 and has the 3R model (reduce, reuse, recycle) in its core (Kirchherr et al., 2017). According to the Web of Science database the expression "circular economy" was first mentioned in 2003 by Chinese authors and even to this day, China keeps the leading position in the number of publications on the CE. Mathews and Tan (2016) claim, that even though the country is the world's biggest producer of waste, it has the most advanced solution for its management.

Along with China, the EU is considered as the most prominent contributors to the CE research. In terms of policy implementation, the document named "Closing the loop - An EU action plan for the Circular Economy" was adopted in 2015. It consisted of 54 actions to support the transition towards a circular economy. Those actions were intended to cover the whole life cycle: production, consumption, waste management, the market for secondary raw materials and a revised legislative proposal on waste. In March 2020 the European Commission published the new Circular Economy Action Plan (CEAP) named “For a cleaner and more competitive Europe” (EC, 2020). The main objectives of the new CEAP among others are:

- *make sustainable products the norm in the EU*
- *empower consumers and public buyers*
- *ensure less waste*
- *make circularity work for people, regions and cities*
- *lead global efforts on circular economy*

The new CEAP became one of the main building blocks of the European Green Deal which was adopted by the European Commission in 2019 with the ambitious goal to make Europe a climate-neutral continent by 2050 (EC, 2020).

4.3.2. EU circular economy monitoring framework

The EU Circular Economy Monitoring Framework is a mechanism established by the European Union to track and assess progress towards a more circular economy. This framework is part of the EU's broader strategy to promote sustainable growth and environmental protection. The framework aims to monitor the transition to a circular economy within the EU, focusing on reducing waste, improving resource efficiency, and lowering the environmental impact of production and consumption. The framework employs a set of indicators to measure progress. These indicators cover areas such as waste generation, recycling rates, resource productivity, and the share of recycled materials in the economy. Based on the assessment of the indicators the progress towards circular economy goals is evaluated both for each Member state and the EU as a whole. The collected data and insights from the monitoring process inform EU policy-making, helping to shape future initiatives and directives in line with circular economy principles. The monitoring framework aligns with other EU policies and strategies, such as the Green Deal, ensuring a cohesive approach to sustainability and environmental protection. Part of the framework's role is to raise public awareness and educate about the benefits and practices of a circular economy, encouraging sustainable consumption patterns among EU citizens. The original framework was introduced in 2018 as a part of the EU Circular Economy Action Plan (EC, 2023a).

Currently, the revised Circular Economy Monitoring Framework as of 15 May 2023 proposed by the European Commission contains 11 indicators (most of which have additional sub-indicators) divided into 5 thematic sections: 1/ production and consumption; 2/ waste management; 3/ secondary raw materials; 4/ competitiveness and innovation; and 5/ global sustainability and resilience. A detailed description of the indicators according to their thematic focus is presented in Table 4 (EC, 2023a).

Table 4: Indicators for the EU Circular Economy Monitoring Framework

Thematic secton	No	Indicators	Sub-No	Sub-indicators	Units of measuremenet
Production and consumption					
	1	**Material consumption**			
			1a	Material footprint	tons per capita
			1b	Resource productivity	EUR/kg
	2	**Green public procurement***			
	3	**Waste generation**			
			3a	Total waste generation	kg per capita
			3b	Total waste generation (excluding major mineral waste) per GDP	kg per EUR
			3c	Generation of municipal waste	kg per capita
			3d	Food waste	kg per capita
			3e	Generation of packaging waste	kg per capita
			3f	Generation of plastic packaging waste	kg per capita
Waste management					
	4	**Overall recycling rates**			
			4a	Recycling rate for municipal waste	%
			4b	Recycling rate for all waste excluding major	%

			mineral waste	
	5	**Recycling rates for specific waste streams**		
		5a	Recycling rate for overall packaging waste	%
		5b	Recycling rate for plastic packaging waste	%
		5c	Recycling rate for electrical and electronic equipment waste that is separately collected	%
Secondary raw materials				
	6	**Contribution of recycled materials to demand for raw materials**		
		6a	Circular material use rate	%
		6b	End-of-life recycling input rates	%
	7	**Trade in recyclable raw materials**		
		7a	Imports from outside the EU	tons
		7b	Exports to outside the EU	tons
		7c	Intra-EU trade	tons
Competitiveness and innovation				
	8	**Private investments, jobs and gross value added related to circular economy sectors**		
		8a	Private investments	% GDP
		8b	Employment	% employment
		8c	Gross value added	% GDP
	9	**Green innovation**		
		9	Patents related to waste management and recycling	number and number per million inhabitants

Global sustainability and resilience				
	10	**Global sustainability**		
		10a	Consumption footprint	index 2010=100 and times the planetary boundaries is transgressed
		10b	GHG emissions from production activities	kg per capita
	11	**Resilience**		
		11a	Material import dependency	%
		11b	EU self-sufficiency for raw materials	%

Source: modified from EC, 2023.

** Indicator under development*

Given the different socio-economic and technological conditions in each Member State, country-specific indicators may be proposed in their national circular economy strategies and plans. As far as the Czech Republic is concerned, the indicators proposed by the European Commission will primarily be used to monitor the circular economy. However, according to the needs of the implementation of the Czech Republic's Circular Economy Strategic Framework 2040, which was approved in December 2021, other indicators proposed in other strategies and plans for the implementation of the Sustainable Development Goals may also be used (Circular Czechia 2040, 2021).

4.4. Sustainable Development

The initial concept of Sustainable Development was articulated by the United Nations Commission on Environment and Development, defining it as the *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland, 1987). Building on this foundation, in 1997 the United Nations Agenda for Development expanded the definition and stated that *"development is a multidimensional undertaking to achieve a higher quality of life for all people. Economic development, social development, and* *environmental protection are interdependent and mutually reinforcing components of sustainable development".* This statement aligns with Elkington's (1997) introduction of the "triple bottom line" concept (encompassing people, profit, and planet), which advocates that companies pursuing profits should simultaneously address social and environmental impacts. This approach recognizes economic growth, social development, and environmental preservation as intertwined and mutually beneficial components of sustainable development. This triple bottom line forms the essential framework of Sustainable Development's three core pillars: social (people), economic (profit), and environmental (planet) aspects. Beyond the sustainable development, these pillars are also crucial to the Corporate Social Responsibility (CSR) concept, as noted by Ebner and Baumgartner (2006).

Table 5: The main principles of Sustainable Development and CSR pillars

Economic	Social	Environmental
- proper corporate governance and management - smart growth - long range planning - cost savings - rejection of corruption - transparency between organization and its stakeholders	- quality of life - education and human capital development - retraining of redundant - employees and outplacement - equal opportunity - work life balance - stakeholder relations	- resource management - environmental protection - negative environmental impacts reduction - environmentally friendly production - ecological investments - green technologies - environmental principles - incorporation into process of supplier selection

Source: modified from Kunz, 2012 and Mensah, 2019

Table 5 shows the main principles common both for the Sustainable Development and Corporate Social Responsibility concepts. Economic pillar addresses the profit of organizations. In traditional economic theory increasing the profit is supposed to be the main objective of any firm (Becker, 1962; Sahut et al., 2012). However, profit at any cost is not what the economic pillar in terms of CSR is about. It rather means better management and changing company's orientation from short-term goals to a long-term and from maximum to optimal profit. Nevertheless, since companies will generally seek to satisfy their financial interests first and foremost, the economic pillar should thus precede the other two pillars, but respecting the social and environmental aspects (Ferauge, 2012).

4.4.1. Sustainable Development Goals

In 2015, the United Nations (UN) adopted the Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development (Figure 3). This agenda, as ElAlfy et al. (2020) note, strives to strike a balance between economic growth, social inclusion, and environmental sustainability. Fonseca et al. (2020) highlight the SDGs' commitment to eliminating extreme poverty and securing a sustainable future for all global citizens. Sachs et al. (2019) emphasize that realizing these goals necessitates profound changes across various sectors in every UN (United Nations) member state, including government, society, academia, and particularly business. Mio et al. (2020) underscore the critical role of the business sector in addressing the SDGs.

Figure 3: UN Sustainable Development Goals

Source: UN 2030 Agenda for Sustainable Development (2015)

However, as Sachs et al. (2019) observe, a common challenge is the lack of a unified approach among different sectors in effectively implementing the SDGs. This difficulty may arise partly because the concept of Sustainable Development itself is not clearly defined. Mensah (2019) warns of the danger of Sustainable Development becoming a mere cliché, overused to the point of losing its original, substantive meaning.

4.4.2. Corporate Social Responsibility

CSR represents a paradigm shift for companies, urging them to transition from short-term objectives to long-term goals and from pursuing maximum to optimal profits, as highlighted by Sahut et al. (2012). According to the Green Paper (2001), socially responsible companies conduct themselves in a manner that considers the needs of both their internal and external environments, contributes to sustainable development, maintains transparency, and overall enhances societal well-being. The adherence to CSR principles can yield several long-term advantages, such as building a competitive edge, enhancing legitimacy and reputation, and even reducing costs and risks (Lindgreen and Swaen, 2009).

Despite the increasing global popularity of CSR, its implementation faces certain limitations (Wang et al., 2018). One challenge lies in the absence of a universally clear definition of CSR, leading to varied perceptions among different stakeholder groups and potentially conflicting goals (Sheehy, 2015). Another challenge stems from the voluntary nature of CSR, resulting in not all companies embracing it (Perez-Batres et al., 2010). Finally, there is a notable issue concerning the measurement and reporting of CSR performance. The absence of a standardized method for assessing and reporting CSR activities allows companies to employ manipulative tactics or release CSR reports selectively when they perform well (Wang et al., 2018). Nevertheless, the integration of CSR principles into the strategic management of companies is strongly advocated by intergovernmental organizations such as the United Nations, the European Union, the Organization for Economic Co-operation and Development, and numerous other international non-governmental organizations (NGOs) (ElAlfy et al., 2020; Green Paper, 2001).

Sahut et al. (2012) describe CSR as a "*manifestation of the principles of sustainable development*", suggesting it can shield companies from crises through its three core pillars. Rahim (2013) points out the interconnection between CSR and Sustainable Development, emphasizing their collective role in advancing society's broader development. However, Perez-Batres et al. (2010) caution that CSR and Sustainable Development, while related, are not interchangeable, these are distinct concepts with differing objectives and outcomes. Nevertheless, CSR strategies and stakeholder expectations are increasingly influenced by the Sustainable Development Goals (SDGs), as noted by ElAlfy et al. (2020).

In light of the UN's main SDGs, the EU's commitments under the Green Deal, and the Farm to Fork strategies, there is a growing incentive for companies, particularly in the food and feed sectors, to adopt more sustainable business models (Schebesta et al., 2021). This trend is especially pertinent for emerging industries, like the insect industry, highlighting the importance of sustainable practices in these developing sectors.

4.4.3. Sustainability measurement and social reporting

Due to existing concerns on using CSR principles merely as public relations (PR) tool (Tworzydło et al., 2021), it was getting more and more urgent to introduce standards for measuring and objectively assessing CSR activities. As the number of companies claiming to carry out the CSR principles grows, so does the number and variety of activities that companies undertake in this area. Consequently, the number of annual reports on CSR is growing as well (Wang et al., 2018). However, the problem remains how to verify the truthfulness of the statements made in these reports and how to generally define the criteria according to which the social responsibility of particular company could be objectively assessed and compared. Moreover, the voluntary nature of CSR caused great contradictions among its supporters and opponents (Wang et al., 2018). While international organizations or organizations representing corporate interests insist on the voluntary nature of CSR, influential NGOs demand for a mandatory and legally enforceable CSR framework. Proponents of voluntariness argue that mandatory CSR enforcement would mean the end of innovation and creativity in this field and reduce the whole thing to solely on ticking boxes of further forms. Moreover, they see it as impossible to find a single CSR template that could be applied to all companies regardless of size, area of business activity or local context (Perkiss, et al., 2019). The supporters of a mandatory CSR framework see the main threat in the reduction of CSR to mere creating the impression of social responsibility, where companies only talk about the good things and hide the bad. Moreover, there is a fear that a voluntary approach to CSR does not have sufficient power to make companies truly accept the concept (Kunz, 2012).

Nevertheless, there are several global initiatives that strive to standardize the measurement of CSR activities (Galant and Cadez, 2017). Based on global standards companies voluntarily publish CSR reports, also known as sustainability reports, or social accounting reports. Some of them are described below.

- *Global reporting initiative (GRI)* is considered as the most widely used standard in the world for sustainability reporting (del Mar Alonso-Almeida, 2014). The GRI reporting framework is developed to help organizations in their sustainability reporting process. It's a reporting guidance that includes all of the issues an organization should monitor to assess its sustainability performance. The GRI sustainability reporting guidelines provide the principles that establish how to report and the standard disclosures that establish what to report on. GRI standard disclosures enable consistency and comparability. The guidelines can be used by organizations of all sizes and types operating in any location (Wang et al., 2018). However, Hopkins (2005) notes that there is a lack of a clear concept, instructions, and methodology for reports preparation.
- *OECD Guidelines for Multinational Enterprises* are a set of recommendations formulated by governments for the responsible business conduct of multinational enterprises. The recommendations are addressed to multinational enterprises operating in or from the 50 countries that adhere to the Guidelines. Even though, OECD Guidelines are non-binding, the adhering countries are required to set up a National Contact Point (NCP) to implement and promote the Guidelines and provide a grievance mechanism to resolve "specific instances" relating to non-observance of the Guidelines by companies (OECD, 2021). The OECD Guidelines cover a wide range of issues like corporate governance principles, transparency, human rights, employees' relations, environmental welfare, corruption and bribery, stakeholders' engagement, etc. (Gordon, 2001).
- *AccountAbility's AA1000 Series of Standards* were first introduced by the Institute of Social and Ethical AccountAbility (ISEA) which are used by public and private organizations on a voluntary basis to demonstrate their performance in social accounting, responsibility, and sustainability (Göbbels and Jonker, 2003). One of the main objectives of the institute is to support

social and ethical accounting, auditing and reporting (SEAAR) and for this purpose was developed a set of principles, among which the central is the principle of accountability (consisting of transparency, responsiveness, and compliance) and the principle of inclusivity which defines an organization's accountability as accountability to all stakeholder groups (ISEA, 1999).

There is also a number of further CSR standards, such as *ISO 26000* - a guidance on social responsibility designed for use by all types of organizations to encourage commitment to responsible practice (Gilbert et al., 2008); *ISO 14000* – the tool related to environmental management, which helps organizations in minimizing negative impact on the environment, it includes policy development, planning, implementation, monitoring and review (Gjølberg, 2009); *UN Global Compact* – a direct initiative of the United Nations to encourage organizations to incorporate into theirs strategies the Ten Principles derived from 4 areas of human rights, labor, the environment and anti-corruption (Gjølberg, 2009); *Social Accountability 8000 (SA8000)* – is an auditable certification standard developed by the Council on Economic Priorities for ensuring ethical workplace conditions at organizations of any size. It addresses issues like child labor, forced labor, discrimination, working hours and others (Göbbels and Jonker, 2003), etc.

However, certain large enterprises in the EU were obliged to disclose some non-financial data under the Non-Financial Reporting Directive (NFRD) already from 2017. From the financial year 2024, this directive was replaced with the Corporate Sustainability Reporting Directive (CSRD) which was adopted in the end of 2022 and considerably expanded the number of companies that will have to provide sustainability information (Hummel and Jobst, 2024). Now, large enterprises have to disclose their impacts on the environment, human rights and social standards in accordance with the ESG (environmental, social, governance) reporting.

4.5. Food waste

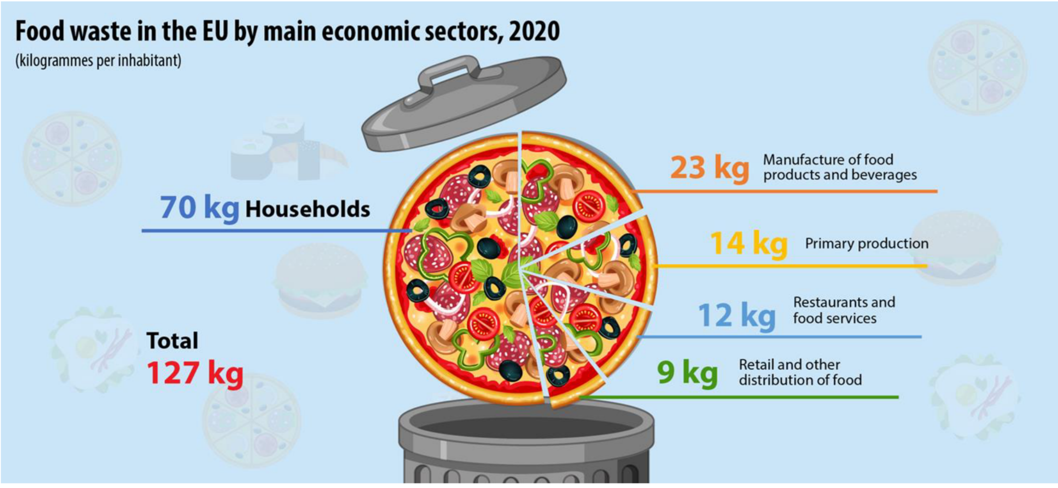
According to the report of the High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2014) of the UN Committee on World Food Security "Food loss and Waste (FLW) refers to a decrease, at all stages of the food chain from harvest to consumption in mass, of food that was originally intended for human consumption, regardless of the cause". It is important to distinguish between the terms "food loss" and "food waste". While "food loss" refers to “a decrease, at all stages of the food chain *prior to the consumer level*”, the term "food waste" encompasses "food appropriate for human consumption being discarded or left to spoil *at consumer level*". Therefore, HLPE (2014) considers as FLW following food losses and waste along the food chain (only edible parts of food intended for human consumption are included): harvest losses; post-harvest losses; process losses; distribution losses; consumer waste. However, it is important to notice, that losses and waste of the raw agriculture production for non-food uses and non-edible parts of food are not included in the FLW, which makes the available amount of biodegradable waste worldwide even higher.

The Waste and Resources Action Programme, a climate action NGO based in the UK (WRAP, 2008) suggests categorizing food waste as *avoidable, possibly avoidable* and *unavoidable* food waste. While the meaning of the second category (possibly avoidable food waste) is questionable since for some people certain parts of food can be edible and for others non-edible, the first and third categories are clearly defined. Avoidable food waste is an edible part of food that "has been thrown away because it is no longer wanted or has been allowed to go past its best". Unavoidable food waste is a non-edible part of food that "results from food preparation" such as “meat bones and hard vegetable or fruit peels”. It is important to note that unavoidable food waste as defined by WRAP (2008) is not considered FLW under the HLPE (2014) definition.

As claimed by the Food and Agriculture Organization (FAO) of the UN, every year about one-third of food intended for human consumption is lost or wasted. 14% of which is lost in the period between harvesting and before reaching consumers. Further 17% is wasted by retailers and especially by consumers in households. The numbers are going to get even worse since FAO expects more than 9 billion people by 2050 which will increase the demand for food and feed and therefore the amount of biowaste. Food loss and waste cause a number of issues connected to the unnecessary release of greenhouse gas emissions, wastage of organic matter and nutrients, etc. (Araya, 2018). Moreover, a significant amount of biowaste is still being landfilled, which contributes to landfills structure collapse due to the decomposition of the organic matter (Elmi et al., 2021).

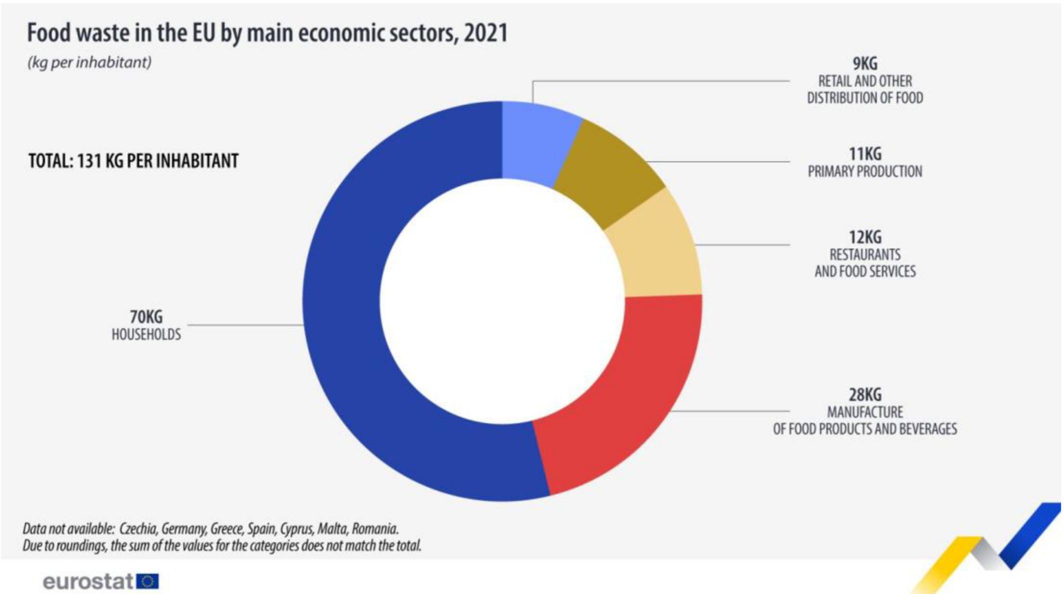
As show data from EUROSTAT (Figure 4 and 5) in 2020 and 2021 there was generated 127 kg and 131 of food waste respectively per inhabitant in the EU. This consists of 70 kg of household waste in both years, 12 kg of restaurants and food services waste, and 9 kg of the waste generated in retail and other distribution of food as for both years as well, and 23 kg of waste from food products and beverages manufacturing, and 14 kg waste from primary production in 2020, and 28 kg and 11 kg in 2021 respectively.

Figure 4: Food waste in the EU by economic main sectors, 2020



Source: EUROSTAT, 2020

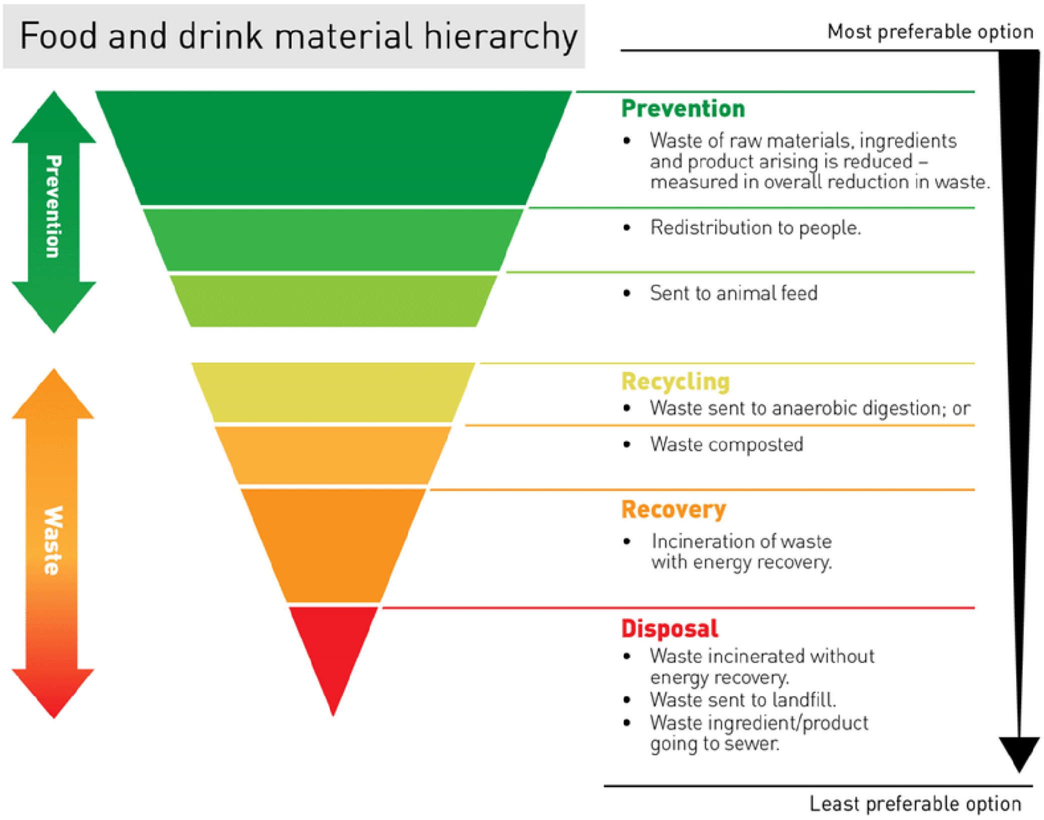
Figure 5: Food waste in the EU by economic main sectors, 2021



Source: EUROSTAT, 2021

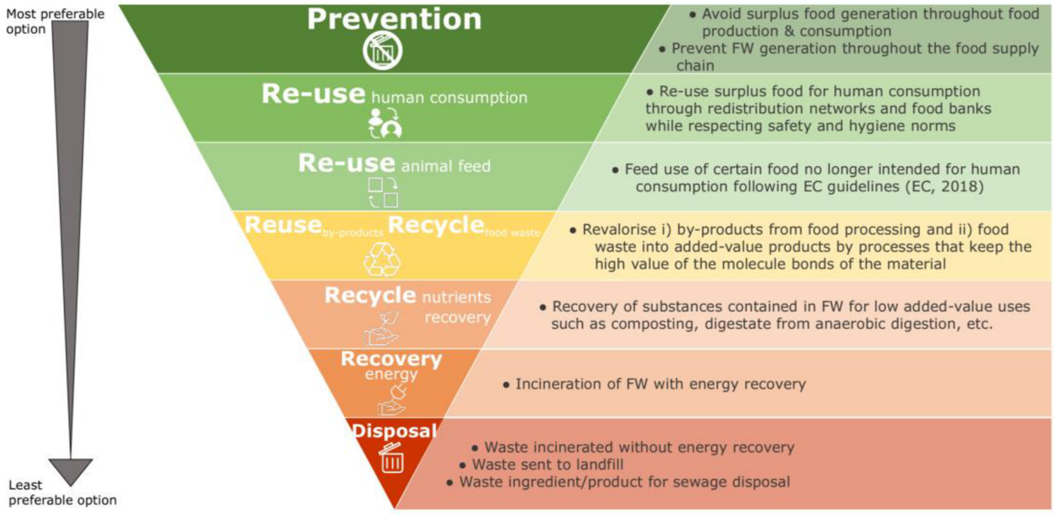
In terms of municipal waste despite the WFD (2008) recommendation to prefer prevention in the five-step Waste Hierarchy, its amount still increases. And according to different sources biodegradable waste represents, about 60% of it. In 2018 the European Commission published an amendment to the WFD (2008) in order to support the EU transition to the circular economy. For this purpose, a list of necessary measures was designed for the Member States. Among others, the preparation for reuse and recycling of municipal waste shall be increased to a minimum of 55% by weight by 2025, 60% by 2030, and 65% by 2035. As regards to food waste, it is recommended to promote prevention and reduction accordingly to the UN 2030 Agenda for Sustainable Development (2015). Especially targets like "Halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains by 2030" should be given the highest priority (EC, 2018).

Figure 6: Food and drink material hierarchy



Source: WRAP, 2016

Figure 7: Hierarchy for prioritization of food surplus, by-products, and food waste prevention



Source: JRC, 2020.

In addition, accordingly to the Food Waste Reduction Targets adopted the European Commission in July 2023, Member States are obligated to implement necessary actions to achieve a reduction in food waste by the end of the year 2030, specifically in processing and manufacturing by 10% and a reduction in retail and consumption sectors jointly by 30% including restaurants, food services, and households (EC, 2023b). Currently, the most preferable options supposed to be used for food waste treatment are shown in Figure 6 developed by WRAP (2016) based in UK and Figure 7 developed by JRC (2020) for the European Commission's Knowledge Centre for Bioeconomy. The recommendation from both sources is based on the WFD (2008) and "prevention" is the most preferable option followed by "reuse" which considers redistribution to people and use for animal feed. Next comes "recycling" - waste sent to anaerobic digestion or composted. A less preferable option is incineration of waste with energy "recovery". The least preferable option is "disposal" - waste incineration without energy recovery, waste sent to landfill or sewer.

Therefore, the implementation of innovative food waste/biowaste management technologies that are in accordance with the circular economy principles is essential for mitigating negative environmental and economic impacts (Vea et al., 2018). One of the promising methods for food waste or biowaste reduction is its utilization via insects. Moreover, this method allows turning waste into a variety of value-added products such as protein feed, fertilizers, oil, and many others (Cappellozza et al., 2019).

4.6. Insect industry

The insect industry is relatively young. The number of companies interested in business with insects started to increase rapidly in 2014 after the first international conference on insects as food and feed "Insects to Feed the World" (Payne et al., 2016) which took place in Wageningen, the Netherlands and gathered more than 400 participants from 45 countries. The conference marked a significant milestone in acknowledging the professional insect industry. For the first time, leaders from the feed industry, insect breeders, academic institutions, NGOs, and various stakeholders came together to discuss the latest advancements in research, business, and policy-making within this emerging sector. The possibility to utilize some kinds of waste streams to produce high-value-added products like animal feed, fertilizers, cosmetics, or even human food (Verheyen et al., 2018; Singh and Kumari, 2019) has attracted new companies of different sizes to enter the market in the last two decades.

4.6.1. Environmental, economic, and social impacts

Even though scholars around the world agree that insect rearing for food and feed purpose is environmentally friendly, there is still a lack of data on the sustainability of the production system itself (Halloran et al., 2016). Van Huis and Oonincx (2017) also note that the development of the technology for insect production and monitoring its environmental impact needs more research, however, authors see great potential in the concept in terms of sustainability. The authors highlight the main advantages of insect production in comparison to livestock production from the environmental sustainability point of view:

- less land use and water consumption
- less greenhouse gas emissions
- higher feed conversion efficiency
- ability to transform low-valued biowaste into high-value products
- possible usage of some insects as food or feed and possible replacement of fish meal, soybean meal, etc.

In addition to the five above-mentioned environmental advantages, Cortes et al., (2016), Madau et al., (2020), and Oonincx et al., (2012) also point out simple technology and fast return on investment as further benefits of insect farming. And

Madau et al. (2020) underline that the insect industry has the potential to improve the environmental, social, and economic aspects of agri-food systems.

Payne et al., (2016) note that along with the environmental impacts, monitoring of the economic and social impacts of the insect industry is also necessary and all three indicators are essential for the successful implementation of the concept. Laurenza and Carreño (2015) claim that insect production for food and feed is economically beneficial, especially in a long run. However, Madau et al., (2020) state that there is limited data on the economic assessment of the concept. Nevertheless, according to Ragossnig and Ragossnig (2021), the effect of the economy of scale could help to move to more cost-efficient production by decreasing the production costs per ton of protein and optimizing the overall production processes.

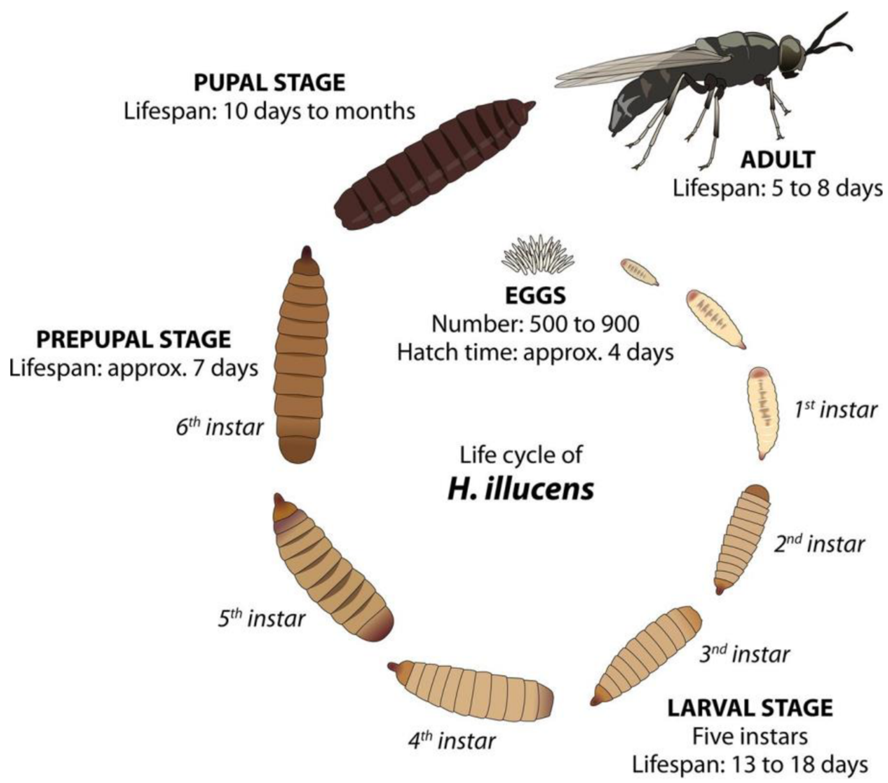
Another obstacle slowing down the promotion of edible insects on the EU market is the attitude of the European population towards insects. Recent research shows there are social and psychological barriers among the European population in acceptance of insects as food (Skotnicka, et al., 2021). Nevertheless, the growing number of companies engaged in the edible insect production in the EU shows promising outlook (Mishyna et al., 2019) and it is expected that gradually more people will be including insects in their diet. For better consumer acceptance Payne et al. (2016) recommend raising the awareness of the population on the environmental and societal benefits of using insects as food and feed. Authors also suggest that the value of edible insects must be explicitly acknowledged by academics in the field and underline the necessity of further research on consumer attitudes and sociocultural factors.

Nevertheless, the overall economic outlook for the insect industry in the world is positive. According to the report presented by Meticulous Research® (2023a), the global edible insect market only will grow at a Compound Annual Growth Rate (CAGR) of 29% from 2023 to 2032 to reach USD 16.39 billion. This report includes whole insects, insect powder, and insect meal of crickets, BSF, and mealworms. And, for instance, the global BSF market, which includes different forms of BSF products for various applications states expectations of 30.8% and USD 3.96 billion increase at a CAGR during the forecast period of 2023 to 2033 (Meticulous Research®, 2023b). From this forecast, it can be deduced, that the number of jobs will increase as well, which will contribute to the social benefits of the concept. Moreover, in terms of social impact, involving rural communities in the insect business could improve their material welfare and help to achieve the sustainability of local agriculture (Payne et al., 2016). Barragan-Fonseca et al. (2020) also agree that engaging smallholder farmers in the insect industry is essential for a stable society since the concept could enhance their livelihood and social status.

4.6.2. Black Soldier Fly

Black Soldier Fly larvae are known for their ability to metabolize organic waste and convert it into high-quality insect biomass (entomass, with almost equal protein and fat mass proportion). BSF larvae are able to efficiently process a wide range of organic materials from food waste to manure. They can be reared and harvested without special equipment and are safe for humans. The larvae do not accumulate pesticides nor mycotoxins (Wang a Shelomi, 2017) and, what's more, have antibacterial activity against some bacteria like *Salmonella typhimurium, E.coli* and *Pseudomonas aeruginosa* (Auza et al, 2020).

Figure 8: BSF life cycle



Sorce: De Smet et al., 2018

The life cycle of the BSF consists of five stages: egg, larvae, prepupa, pupa, and adult (Figure 8). The color of the larvae is changed from yellow-white during the egg stage to dark brown at the pupal stage. At the adult stage flies have a black color, they don't feed at all and can survive for about 8 days on the fat gathered from the larval stage. Female lays 500 – 900 eggs, that are about 1 mm in length and hatch in 4 days. The larval stage consists of 5 instars and takes from 13 – 18 days; the 6th instar is the prepupal stage which may take 7 days, after that pupal stage follows and takes from 10 days to months in case of low temperature or insufficient food, etc.

According to Barragan-Fonseca et al. (2017), BSF larvae composition is highly suitable for animal feed as they contain from 37% to 63% of protein and high concentration of minerals like manganese, iron, zinc, copper, phosphorus, and calcium. However, authors recommend only partial replacement of conventional feed for poultry, pigs, or fish with BSF larvae (10% - 50%) since the complete replacement would lead to a reduction in growth. It is caused by several factors, but the main role is in the high content of fat (7% to 39% in dry matter) and ash (9% to 28% in dry matter).

Besides animal feed, BSF larvae could be used to produce biofuel (Li et al., 2015), cosmetic ingredients (Verheyen et al., 2018), human food (Matthäus et al., 2019), or pet food (Kotob et al., 2022), etc. Another valuable product of BSF larvae is their frass (excreted residues of insects), which can be used as an organic fertilizer or soil amendment (Quilliam, et al., 2020). The ability to valorize different types of organic waste and a variety of value-added products that can be produced from BSF larvae give them the significant potential to contribute to the sustainable development of many areas. Moreover, many scholars (Ojha et al., 2020; Jensen et al., 2021) highlight that processing agricultural waste or food waste via insects and returning nutrients to the soil in the form of fertilizers from their frass follows the circular economy principles.

4.6.3. Legal aspects

The lack of data on economic assessment is also connected to the legal aspects of food and feed safety of insects and insect-based products, especially in Western countries (Laurenza and Carreño, 2015). Due to the EU's outdated legislation, the companies engaged in the insect industry were slowed down in entering the market (Belluco et al., 2017). However, the regulations are slowly loosening. The protein originating from the following eight insect species is now allowed as a feed for some farmed animals in the EU: Black Soldier Fly (*Hermetia Illucens*), yellow mealworm (*Tenebrio molitor*), common housefly (*Musca domestica*), lesser mealworm (*Alphitobious diaperinus*), banded cricket (*Gryllodes sigillatus*), field cricket (*Gryllus assimilis*), house cricket (*Acheta domesticus*), and Silkworm (*Bombyx mori*). First this protein source was allowed as a feed for aquaculture in 2017 (IPIFF, 2022). Later live insects were also permitted as poultry feed. However, full approvement of the insect-processed animal proteins (PAPs) as a poultry and pig feed came in August 2021 (Montanari et al., 2021). Table 6 shows possibilities of using insects as animal feed according to the EU regulations.

Table 6: An overview of the EU regulatory possibilities for using insects as animal feed

Insects as feed	**Ruminant animals**	**Aquaculture**	**Poultry**	**Pigs**	**Pets**	**Fur and other animals (e.g. zoo)**	**Technical uses** (e.g. cosmetic industry, bio-based fuels, production of other bio-based materials such as bioplastics)
Insect proteins (PAPs)	⊗	⊕	⊕	⊕	⊕	⊕	⊕
Insect fats	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Whole insects (untreated)	⊗	⊗	⊗	⊗	⊕	⊕	⊕
Whole insects (treated)	⊗	⊗	⊗	⊗	⊕	⊕	⊕
Live insects	⊗	⊕	⊕	⊕	⊕	⊕	⊕
Hydrolysed insect proteins	⊕	⊕	⊕	⊕	⊕	⊕	⊕

Source: modified from IPIFF (2022)

Cells marked with light blue are limited to Black Soldier Fly *(Hermetia Illucens)*, Common Housefly *(Musca Domestica)*, Yellow Mealworm *(Tenebrio Molitor)*, Lesser Mealworm *(Alphitobius Diaperinus)*, House cricket *(Acheta Domesticus)*, Banded cricket *(Gryllodes Sigillatus)*, Field Cricket *(Gryllus assimilis)* and Silkworm *(Bombyx Mori)*. Live insects with the yellow marked cells are allowed *if authorized by the national competent authority of the Member State where the product is being commercialized*. And items marked with grey are allowed *if authorized by the national competent authority of the Member State where the product is being commercialized, under the specific conditions applicable to processed pet food (in case the product is intended for use as processed pet food).*

Moreover, regulations on insects for human consumption are even stricter, since edible insects are considered a Novel Food in the EU. This results in a costly and time-consuming process, which for each product requires market authorization granted by the European Commission after the safety evaluation by the European Food Safety Authority (EFSA) and an approvement from the EU Member States (IPIFF, 2021). This fact may discourage companies from producing and selling insects as food (Belluco et al., 2017). However, despite the legal obstacles, the number of companies in the field of BSF larvae rearing (as well as other insect species is now allowed as food and feed) is growing every year. These enterprises expect that soon BSF products could become substitutes for a wide range of products like protein supplements, meat alternatives, cookies, as well as cosmetic ingredients (Fowles and Nansen, 2020).

Table 7: Authorized substrates for insects intended for all applications

Feed materials of vegetal origin	
Feed materials of animal origin Regulation (EC) No 999/2001 (Article 7 and Annex IV, Chapter 1 and 2)	*- hydrolyzed proteins, collagen and gelatine or blood products derived from non-ruminants (including compound feed containing such products)* *- hydrolyzed proteins from ruminant hide and skins* *- dicalcium phosphate and tricalcium phosphate of animal origin (including compound feed containing such phosphates)* *- fishmeal*
Former Foodstuffs Regulation (EC) No 999/2001 (Annex IV, Chapter II)	*- without meat and/or fish* *- only products containing the following ingredients of animal origin: eggs and egg products; milk, milk products and milk-derived products; honey; rendered fat; collagen; gelatine* *Above mentioned ingredients must have been previously processed (either prior to their intended use as food product or after being requalified as animal-by-product).*

Source: modified from IPIFF (2022)

Another key aspect that affect insect producers is requirements on substrates as feed for insects. Insects cultivated within the European Union are classified as 'farmed animals' according to the EU Animal By-Products (ABP) legislation, specifically outlined in Article 3(6)16 of Regulation (EC) No 1069/2009. As a result, they are permitted to be fed only with feed materials suitable for this animal category. These regulations are applicable regardless of the intended use of insect-derived products, including purposes such as pet food, fur animal feed, or various technical applications like biofuel production, cosmetics, and biochemistry (IPIFF, 2022).

Table 8: Prohibited substrates for insects intended for all applications

'Feed Marketing' Regulation - Regulation (EC) No 767/2009 (Annex III)	*- feces and separated digestive tract content* *- hide treated with tanning substances* *- seeds and other plant-propagating materials (treated with plant protection products)* *- wood or other materials derived from wood, which have been treated with wood preservatives* *- waste derived from urban, domestic, and industrial waste treatment* *- packaging from agri-food products and parts thereof* *- protein products obtained from yeasts of the Candida variety cultivated on n-alkanes*
EU Animal By-Products (ABP) Regulation (EC) No 1069/2009	*- catering waste*
Regulation (EC) No 999/2001 (Annex IV, Chapter 1 and 2)	*- PAPs from ruminants, PAPs from poultry animals; PAPs from swine animals and PAPs from farmed insects and PAPs from other non-ruminants except fishmeal* *- blood products from ruminant animals* *- hydrolyzed proteins of animal origin and derived from ruminants*

Source: modified from IPIFF (2022)

In Table 7 and Table 8 is given an overview of authorized and prohibited substrates for insects intended for diverse uses (food, feed, technical uses). According to the 'Feed Marketing' Regulation, specifically Regulation (EC) No 767/2009 animals, raised in the EU including insects, must receive only safe feed.

4.7. Feed market

The global feed market plays a crucial role in supporting the livestock, poultry, aquaculture, and pet industries by providing essential nutrients for animal growth, health, and productivity. The increasing global population drives demand for animal products, boosting the need for animal feed. As incomes rise, there is a shift towards protein-rich diets, impacting demand for livestock and poultry feed. On the other hand, evolving regulations related to animal welfare, environmental concerns, and food safety influence feed formulations. Exploration of alternative protein sources to reduce dependence on traditional protein feeds has become a trend in recent years (Otero et al., 2022).

The main traditional protein sources used as animal feed are soybean and fishmeal (Carlberg et al., 2018; Olsen et al., 2023). Although the production of soybeans in the EU is gradually increasing (2.8 million tons in 2019, which was twice more than a decade earlier), it still demonstrates a significant dependency on imports, primarily sourced from Brazil and Argentina. Concerning global soybean exports intended for animal feed, food products and biofuel, the biggest exporters are Brazil and the US with 75 and 65 million tons per year, which represents 85% of global exports. Next are Argentina, Paraguay, and Canada with about 7.7 million tons, 5 million tons and 4.4 million tons respectively (Rauw et al., 2023).

Regarding the fish meal, its predominant consumption in aquaculture feed is concentrated in Asia. In 2021, China led with a share of 41% of global fishmeal usage, while other Asian nations accounted for an additional 28%. Europe utilized 10%, Latin America 13%, and the Middle East 4%. However, fish meal consumption in the EU has a declining trend. As per the most recent European Market Observatory for Fisheries and Aquaculture Products report (EUMOFA, 2023) it has reached around 450,000 t in 2022, which is 40% less than in 2009. The report also states that the EU generates between 370,000 to over 520,000 tons of fishmeal annually and is considered a net importer of fishmeal. The fishmeal produced in the EU is mainly exported to Norway, the UK, and Canada and as for imported fish meal to the EU the main partners are Peru, Norway, and Chile. In terms of global fish meal usage in specific industries in 2020, more than 75% went to aquaculture, around 20% to pig feed, almost 4% to poultry feed and the rest to other purposes. For comparison, in 1960 it was almost 50 / 50% for pig and poultry feed and a negligible amount around 1% for aquaculture (IFFO, 2022).

Various studies have evaluated substitution of soybean or fish meal with BSF meal. The results showed that BSF meal has similar nutritional values and a replacement up to 50% of soybean or fish meal is possible without adverse effects (Barragan-Fonseca et al., 2017; Attia et al., 2023). Higher levels of replacement may result in reduced growth rate, deteriorated palatability of the feed mixture and lower protein digestibility. However, the processing method of BSF larvae and the type of substrate the larvae were feed on also play a significant role in the nutritional values of the resulting product. Nevertheless, thanks to a wide range of BSF products it is possible to substitute with them many types of feed ingredients currently used. In addition, BSF producers can also benefit from the use of larvae frass and offer it as an organic fertilizer or soil amendment (Quilliam, et al., 2020).

Table 9: The list of BSF products and their possible substitutes

	BSF product	Substitutes
Group 1	meal	soybean meal, fish meal, meat and bone meal, etc.
Group 2	live larvae	live earthworm, yellow mealworm, morio worm, buffalo worm, etc.
Group 3	dried larvae	dried locust, crickets, silkworm, gammarus, shrimps, yellow mealworm, etc.
Group 4	extracted oil	soybean oil, palm oil, sunflower oil, flaxseed oil, rapeseed oil, etc.
Group 5	frass as a fertilizer	compost from composting plant, fermentation residues from biogas station

Source: own elaboration based on literature research

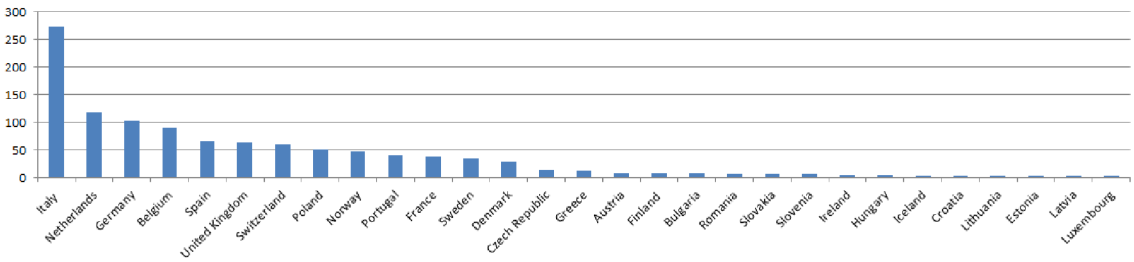
Table 9 summarizes BSF products divided into five groups and possible substitute suitable for each group of BSF products. First four groups represent BSF products suitable for use in feed and last fifth group shows a possibility to utilize BSF larvae excrement (frass) as a fertilizer or soil amendment.

5. Results and Discussion

5.1. H1

In total, more than 1000 publications, almost 400 patents, and at least 60 companies in the field of BSF rearing in the EU and EFTA Member states were included in this research.

Figure 9: The list of countries in the EU + EFTA with scientific records in the field of BSF



Source: own elaboration based on the data from Web of Science

As can be seen from Figure 9, scientific interest in BSF in Europe began in the second decade of the 21st century and was rapidly increasing since then. Figure 9 and Table 10 also shows that among the EU and EFTA Member states the leader in publishing about BSF is Italy, followed by Netherlands and Germany. However, it should be mentioned that the affiliation of the publication with one specific country is not always appropriate due to the fact, that in the scientific community, the research in many cases is conducted at an international level. Similarly, it is with the ownership of patents. It is difficult to determine to which country it belongs, especially when applied by multinational enterprises via World Intellectual Property Organization or the European Patent Office.

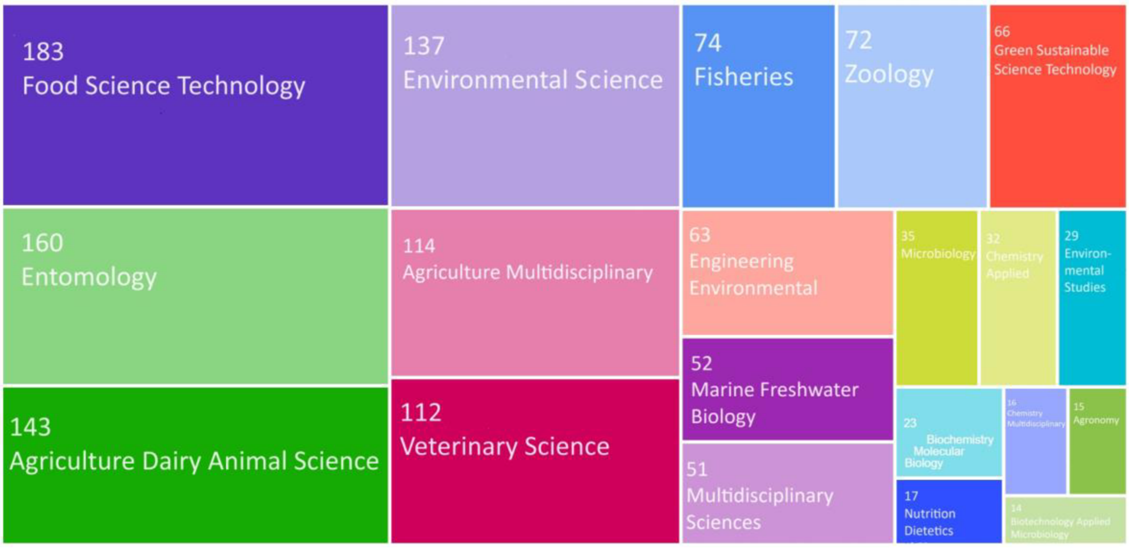
Figure 10 illustrates the most frequent Web of Science Categories of journals with BSF publications in the same geographical area and period. Interestingly, Food Science Technology is the most frequent category, followed by Entomology, Agricultural Dairy Animal Science, Environmental Science, Agriculture Multidisciplinary, etc. This shows that scientists from various fields are engaged into BSF research. The total number of publications in Table 10 and Figure 10 don't match since every journal covered by the Web of Science Core Collection may be assigned up to 6 categories.

Table 10: Number of publications in the field of BSF in each of the EU + EFTA Member state during 2010 – 2022

EU + EFTA	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2010 - 2022
Italy		1			2	3	3	20	24	41	56	63	58	**271**
Netherlands				1		4	3	8	10	16	23	32	18	**115**
Germany		1	1			4	2	4	11	12	20	25	29	**109**
Belgium						3	2	5	11	10	14	19	18	**82**
United Kingdom		1		1	1	3	1	4	6	9	15	17	12	**70**
Switzerland		1		1		4	2	5	4	10	7	14	10	**58**
Spain	1	1	1	2	2	3	1	3	2	6	9	14	18	**63**
Poland							2	4	4	3	9	16	13	**51**
Norway			1					1	3	8	6	11	18	**48**
Sweden				1		1	1		1	8	5	10	7	**34**
France					1	2			1	7	5	10	8	**34**
Portugal								2	4	2	6	5	19	**38**
Denmark						1	1	1	1	2	3	9	10	**28**
Austria						1		1	1	2	3	6	3	**17**
Slovakia			1	1		2			1	1		1		**7**
Greece							1			1	2	4	3	**11**
Czech Republic								1	1		1	3	4	**10**
Slovenia							1				2	3	0	**6**
Romania											3	1	3	**7**
Bulgaria											2	4	2	**8**
Croatia										1			2	**3**
Hungary											1		3	**4**
Lithuania											1	2		**3**
Finland											1	3	0	**4**
Iceland								1				1	1	**3**
Estonia													2	**2**
Latvia													1	**1**
Luxemburg													1	**1**
Total	**1**	**5**	**4**	**7**	**6**	**31**	**20**	**60**	**85**	**139**	**194**	**273**	**263**	**1088**

Source: author's compilation based on the data from Web of Science

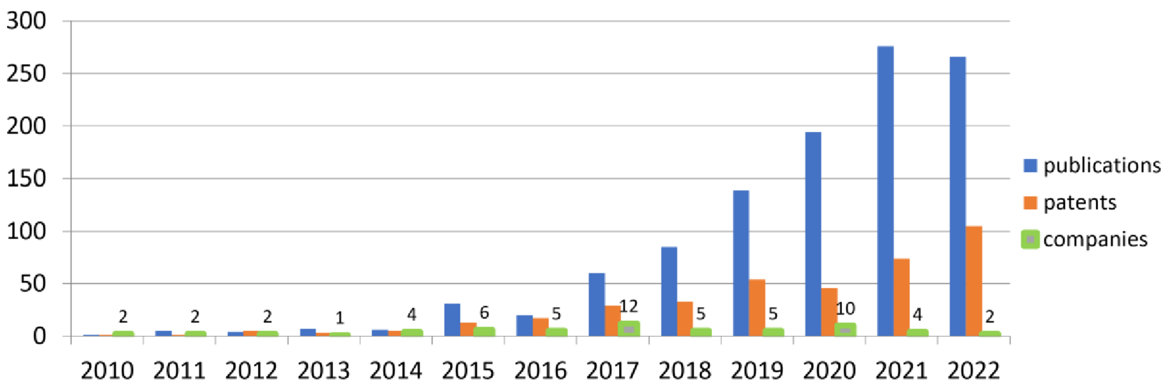
Figure 10: The most frequent Web of Science Categories of journals with BSF publications.



Source: Web of Science

Another fact which may affect the results is that scientific publications with the ground-breaking results are often presented to public with a time delay caused not only by the journals review process itself, but also due to the fact, that first the results are being commercialized. Moreover, the process of commercialization, for instance, in the form of patent may itself take a couple of years. Nevertheless, despite all the above-mentioned inaccuracies, it can be stated, that there is a rising trend in the number of publications and patents in the field of BSF rearing in the last decade which can be seen from Table 10 and Figure 11.

Figure 11: Annual increases in the number of publications, patents, and established companies in the field of BSF rearing in the EU + EFTA Member states (2010-2022)



Source: own elaboration

Concerning the number of companies, Figure 11 shows there are fluctuations in its development. This could be caused by a variety of factors. First of all, very likely not all companies engaged in BSF rearing were included in this research since some of them couldn't be easily found in the procedure described in 3.1.1., for instance, due to the lack of a website in English language. Nevertheless, all major players in the EU and EFTA such as Ynsect (France), Protix (Netherlands), Bioflytech (Spain), etc. (Skyquest, 2022; Grossule et al, 2023) were included in the analysis. A relatively higher amount of newly established BSF companies in 2017 and 2020 can be connected with the expectations of more favorable legislative changes in the EU. In 2017 the protein originating from seven insect species including BSF was allowed as feed for aquaculture and in 2021 it was fully approved as poultry and pig feed (Montanari et al., 2021). The exponential increase in the number of publications about BSF and the growing number of companies interested in its commercialization is also pointed out by Tomberlin and van Huis (2020).

Table 11: Spearman correlation between numbers of published publications, patents, and established companies during 2010 – 2022

Variable	**publications**	patents	companies
publications	1.000000	0.947662	0.446102
patents	0.947662	1.000000	0.438892
companies	0.446102	0.438892	1.000000

Source: own elaboration based on the data from Statistica software

The results of statistical analysis of the collected data using Spearman correlation based on pairwise combinations between three investigated indicators (number of publications, number of patents and number of companies) are shown in Table 11. The coefficient of almost 0.95 showed a significant relationship between the number of publications and the number of patents which is not surprising.

Table 12: Poisson regression for the number of publications and patents during 2010 – 2022

Effect	**patents -** Reliability test type 3 Distribution: POISSON Link function: LN			
	Degrees of freedom	Ln-likelihood	Chi-square	**p**
publications	12	-232.611	407.4841	0.00

Source: own elaboration based on the data from Statistica software

Results of the Poisson regression (Table 12) also showed a statistically significant relationship between the number of publications and the number of patents with a p-value equal to 0 indicating high statistical significance (Sellers and Shmueli, 2010). Similar relation has the number of publications and the number of business entities with a p-value around 0.014 (Table 13), which is less than the significance level of 0.05 and thus is considered statistically significant (Myers et al., 2010).

Table 13: Poisson regression for the number of publications and companies during 2010 – 2022

Effect	**companies -** Reliability test type 3 Distribution: POISSON Link function: LN			
	Degrees of freedom	Ln-likelihood	Chi-square	**p**
publications	12	-33.3983	25.21735	0.013826

Source: own elaboration based on the data from Statistica software

Based on the results of this study it can be stated that all three indicators (the number of publications, patents, and companies in the field of BSF rearing) are interconnected and develop together. Although at first glance it seems that the H1 has been confirmed, the limitations connected with the chosen data shouldn't be neglected. As the most substantial limitations could be stated: 1/ time delay in the publication of patents and scientific papers; 2/ patent assignment to a specific country; 3/ companies' geographic allocation (many companies, decide to move their business to other countries due to the business environment).

5.2. H2

It is noteworthy that the highest number of publications and BSF companies (including major players) are in countries with established Bioeconomy strategies on the national level such as Italy, Netherlands, Germany, France, etc. (Table 14). Moreover, most of those member states' Bioeconomy strategies, especially their latest updated versions, consider insects as a potential solution for various sectors, including food and feed production, waste management, and alternative protein sources. For instance, in the National Bioeconomy Strategy of Germany (BMBF, 2020) the use of insects and also algae, fungi, and microorganisms is stated as a necessary step to achieve sustainable production in both agriculture and industry. Therefore, the German Federal Government commits to supporting such practices with appropriate funding measures.

As well a New Bioeconomy Strategy for a Sustainable Italy (BIT II, 2019) mentions that insects, algae, etc. have the potential for developing alternative protein sources. Also, Bioeconomy a Strategy for Austria (2019) has recommended the insect protein produced from biowaste as an attractive source of protein for the future. It is stated in the Strategy that the production of insect protein could decrease dependence on imported feed, and it could be achieved without using additional land, also the concept could contribute to better utilization of otherwise unused nutrients. Even though Austria is not among those member states with the highest number of publications or companies in the field of BSF rearing, it has adopted its Bioeconomy strategy as one of the last, therefore the latest solutions and achievements in the insect industry could be incorporated in the strategy.

Table 14: The list of countries with established Bioeconomy strategies at the national level and with the highest number of publications and companies.

	Number of publications	Number of companies	Number of major players
Italy	274	4	2
Netherlands	118	8	2
Germany	103	9	2
Spain	65	4	2
UK	63	6	3
Norway	48	0	0
France	38	8	4

Portugal	38	1	1
Austria	17	3	2
Finland	4	3	1
Estonia	2	0	0
Ireland	0	1	1

Source: own elaboration

In Table 14 were included EU and EFTA Member states with the highest number of publications and companies in the field of BSF rearing and at the same time with established Bioeconomy strategies at the national level. The UK was also included in the Table 14 since at the time of the research it was still a member of the EU and even after the Brexit and its national Bioeconomy strategy was withdrawn another strategy related to the bioeconomy was adopted at the national level.

Table 15: Numbers of publications and companies in the field of BSF rearing in the member states with dedicated Bioeconomy strategy at the national level under development or other policy initiatives related to the bioeconomy

	Number of publications	Number of companies	Number of major players
Belgium	89	1	
Switzerland	58	3	
Poland	51	2	1
Sweden	34	1	
Denmark	29	2	
Czech Republic	14	0	
Greece	11	0	
Bulgaria	8	1	1
Romania	7	1	
Slovakia	6	0	
Slovenia	6	0	
Hungary	4	2	
Lithuania	3	1	
Croatia	3	1	
Lichtenstein	0	1	

Source: own elaboration

As can be seen from Table 15, among Member states with dedicated Bioeconomy strategy at national level under development or other policy initiatives related to the bioeconomy, there are only few countries with high publication numbers and only 1 or 2 BSF companies in most of them. Moreover, those are rather small or medium enterprises with a little influence on the market. Noteworthy are one located in Poland and the one in Bulgaria, both can be considered as a major player.

Regarding EFTA member states, only Norway has established Bioeconomy strategy on the national level which, by the way, mentions insects as a renewable biological resource for new advanced production opportunities (Norwegian Ministries, 2016). In the Web of Science database, 48 publications were found as for Norway and 61 for Switzerland. In terms of companies' numbers, 3 were found in Switzerland and 1 in Lichtenstein.

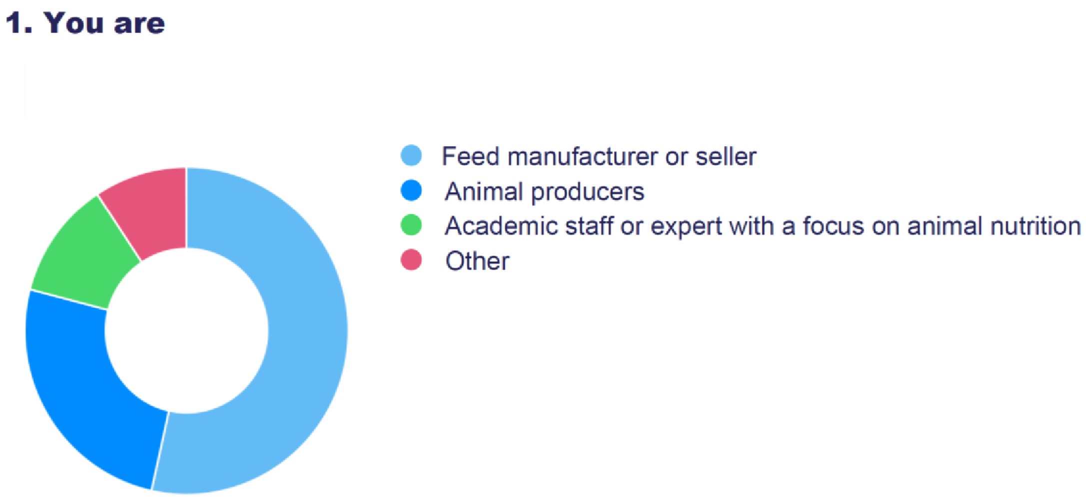
Based on the above-mentioned results, it can be stated that having established a dedicated Bioeconomy strategy on the national level positively affects the development of the business and academic achievements in the field of BSF rearing in the given country. Therefore, it's possible to consider the H2 as confirmed. However, further research is needed to investigate whether the high numbers of publications and companies in countries with dedicated Bioeconomy strategy on the national level is conditioned by the fact of having the strategy itself or another reasons like government financial support or other more favorable conditions.

As the insect production sector grows and regulatory restrictions are eased, it is anticipated that the insect industry will play an increasingly significant role in advancing the bioeconomy concept (Skrivervik, 2020). This is particularly likely once the use of food waste as a substrate for feeding insects becomes permissible.

5.3. H3

The survey named Feed ingredients competitiveness analysis was sent out among nearly one hundred potential respondents in the Czech Republic. The questionnaire was disseminated among feed manufacturers, feed sellers, local farmers, other relevant stakeholders and in the local scientific community with the focus on animal nutrition. Vast majority of stakeholders were contacted by targeted emails. The questionnaire was closed on the ninth day, after more than 24 hours without new response and when the number of recorded responses reached forty-three. One additional response arrived by email after the survey was closed, but this was not included in the statistics. The Survio® platform recorded sixty-six visits, forty-three of which resulted in filled out questionnaire. Therefore, the survey completion rate based on Survio® results is 65%. However considering the total amount on sent out questionnaires, the actual survey completion ratio may be around 40%. Taking into account that no reward was promised for completing the questionnaire it could be indirectly deduced that the target group was likely well-chosen and the questionnaire was filled in by competent persons. The fact that the majority of respondents completed the questionnaire during the workweek, with minimal engagement on weekends, suggests that participants likely perceived the survey as relevant to their professional activities. Such kind of a survey related to BSF products competitiveness analysis was conducted for the first time in the Czech Republic. Overall feedback of the respondents was quite positive, which looks promising in case of an effort of placing BSF products for farm animals on the local market.

Figure 12: Question 1

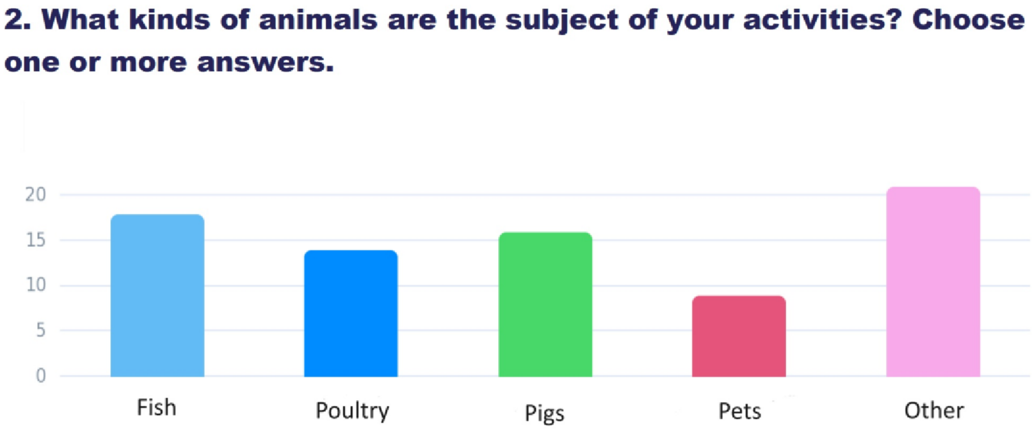


ANSWER	AMOUNT	RATIO
Feed manufacturer or seller	23	54%
Animal producers	11	25%
Academic staff or expert with a focus on animal nutrition	5	12%
Other	4	9%

Source: data processing based on Survio® results

From Question 1 (Figure 12), which was aimed at determining the category of respondents, it follows that more than half of them (54%) are manufacturers or sellers of animal feed, one fourth are animal producers (25%), five respondents (12%) are academic staff or expert with a focus on animal nutrition and four respondents (9%) answered “Other” which includes two teachers, one fish processing technician and one respondent that indicated himself as both manufacturer of animal feed and animal producers. It can be stated that got responses were well-balanced among the different categories of respondents, since the questionnaire was mainly aimed at the feed manufacturers and sellers as well as animal producers. And exactly from those two categories was obtained the highest number of responses.

Figure 13: Question 2



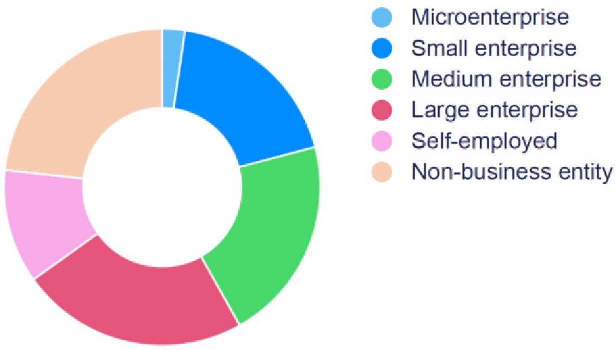
ANSWER	AMOUNT	RATIO
Fish	18	42%
Poultry	14	33%
Pigs	16	37%
Pets	9	20%
Other	21	49%

Source: data processing based on Survio® results

The results of the Question 2 (Figure 13) which was aimed at identifying the categories of animals that are the subject of respondents' activities show that 42% run their activities in the fish sector, 37% in the pigs' sector, 33% focus on poultry and 20% on pets. However, since respondents could choose more than one answer, nearly half of them (49%) indicated also other animals like cattle (18 respondents) which is equal to the fish sector, rabbits (5 respondents), 2 of each sheep, goats, horses, forest animals, and 1 insect. This can be explained by the fact that more than half of respondents were manufacturers or sellers of animal feed, therefore their offer includes feed for different types of animals. Diversification of the production and breeding portfolio is a common practice. Even though cattle, sheep, and goats are less relevant in the context of this research since ruminant animals are not yet allowed to be fed with insect proteins in the EU (Table 6) their number well illustrates the local state of agriculture.

Figure 14: Question 3

3. According to the currently valid legislation, your activities fall into the category of:



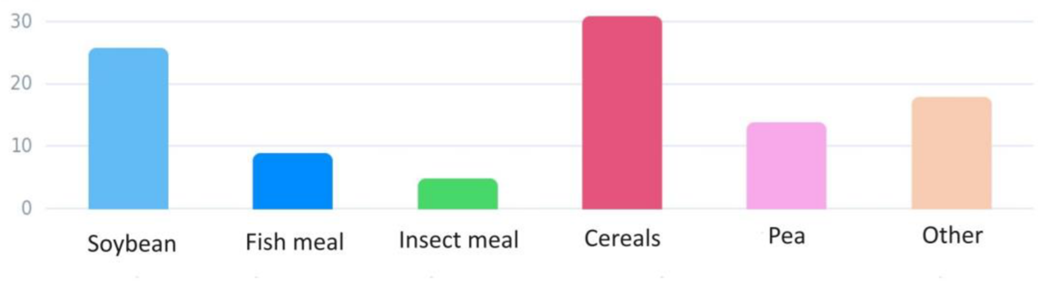
ANSWER	AMOUNT	RATIO
Microenterprise	1	2%
Small enterprise	8	19%
Medium enterprise	9	21%
Large enterprise	10	23%
Self-employed	5	12%
Non-business entity	10	23%

Source: data processing based on Survio® results

Question 3 (Figure 14) revealed to which category each respondent belongs from the legal point of view. Approximately the same amount of large (10), medium (9), and small (8) enterprises took part in the survey, which means that the questionnaire reached out to a representative sample. One respondent was identified as a microenterprise, five as self-employed, and ten as a non-business entity (mostly academic staff or expert with a focus on animal nutrition). Since enterprises belong to the most numerous group of respondents, it can be deduced that the following answers of the questionnaire will well reflect the current situation on the feed market and the results of the survey will be meaningful.

Figure 15: Question 4

4. Indicate which of the following ingredients do you use as a main nutritional source (either alone or in a mixture). Choose one or more answers.



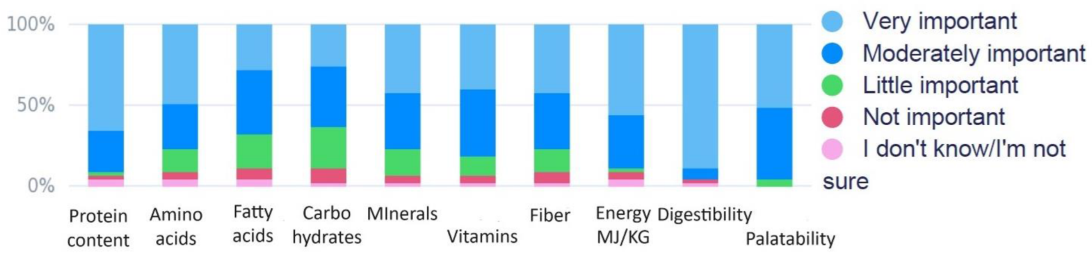
ANSWER	AMOUNT	RATIO
Soybean	26	61%
Fish meal	9	21%
Insect meal	5	11%
Cereals	31	72%
Pea	14	33%
Other	18	42%

Source: data processing based on Survio® results

The results of Question 4 (Figure 15) showed that the majority of respondents use soybean (61%) and cereals (72%) as a main nutritional source in their feed mixtures. Almost 42% of respondents use other nutritional sources. Most common animal by-products not intended for human consumption (according to Regulation (EC) No 1069/2009) for those in petfood sector. Also plant sources like canola and sunflower extracted meal, grass, clover, potato flakes, corn, or potato starch, apple pomace, and algae. Only five respondents use insect meal in their feed mixtures. Three of them are a non-business entity with a focus on the fish sector and two enterprises with a focus on pets. Fourteen respondents (33%) use pea as a main nutritional source in their feed mixtures and only nine respondents (21%) use fish meal. This can be explained by the fact that fish meal is three times more expensive that the soybean meal (Indexmundi, 2024a and Indexmundi, 2024b) and even though, the demand for fish meal on the global market is still high, it's not likely to significantly increase production due to environmental issues (Nagappan et al., 2021).

Figure 16: Question 5

5. Please rate the degree of importance of each nutritional property of the feed (or main nutritional component).

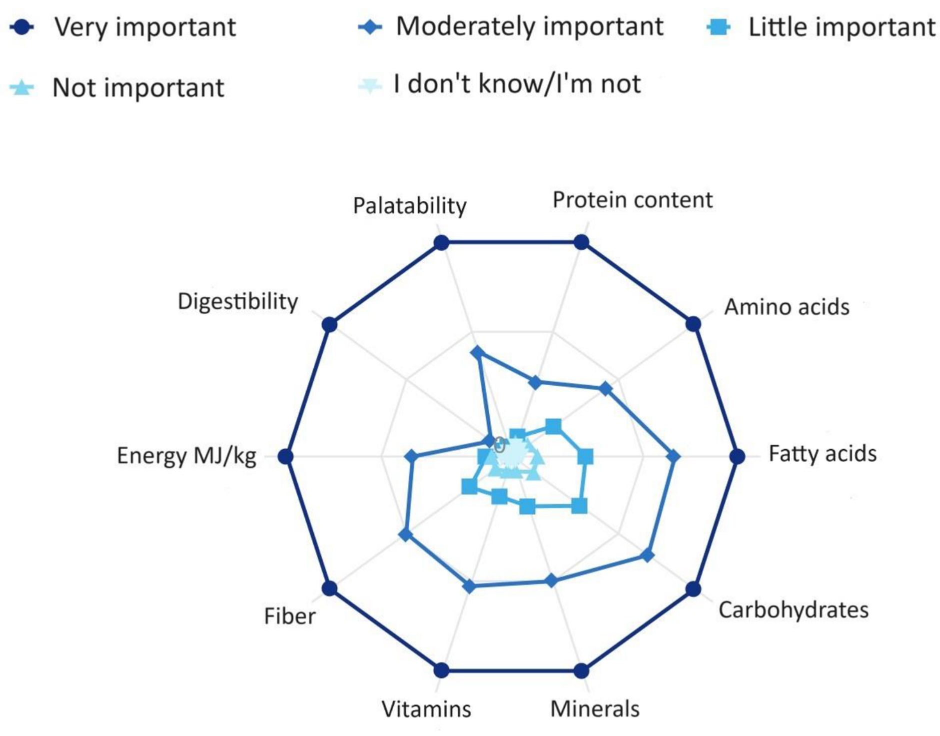


	VERY IMPORTANT	MODERATELY IMPORTANT	LITTLE IMPORTANT	NOT IMPORTANT	I DON'T KNOW/I'M NOT SURE
Protein content	28 (65%)	11 (26%)	1 (2%)	1 (2%)	2 (5%)
Amino acids	21 (49%)	12 (28%)	6 (14%)	2 (5%)	2 (5%)
Fatty acids	12 (28%)	17 (40%)	9 (21%)	3 (7%)	2 (5%)
Carbohydrates	11 (26%)	16 (37%)	11 (26%)	4 (9%)	1 (2%)
Minerals	18 (42%)	15 (35%)	7 (16%)	2 (5%)	1 (2%)
Vitamins	17 (40%)	18 (42%)	5 (12%)	2 (5%)	1 (2%)
Fiber	18 (42%)	15 (35%)	6 (14%)	3 (7%)	1 (2%)
Energy MJ/kg	24 (56%)	14 (33%)	1 (2%)	2 (5%)	2 (5%)
Digestibility	38 (88%)	3 (7%)	0	1 (2%)	1 (2%)
Palatability	22 (51%)	19 (44%)	2 (5%)	0	0

Source: data processing based on Survio® results

When the degree of importance of feed nutritional properties was evaluated in the Question 5 (Figure 16), the vast majority of respondents indicated almost all parameters as "very important" or "moderately important", which is well visualized in Figure 17. Very important are especially, "digestibility" (88%) "protein content" (65%), and "energy" (56%). For around half of respondents "very important" is also "palatability" (51%) and “amino acids” profile (49%). "Little important" are "carbohydrates" according to 26% of respondents, "fatty acids" to 21%, "minerals" to 16% of respondents, and "amino acids" and "fiber" to 14% of them. Only one respondent (a large enterprise focused on a petfood production) indicated that "digestibility", "protein content" and "energy" are "not important", while "palatability" is "very important" and "minerals" and "fiber" are "moderately important". One respondent (a small enterprise, focused on fish farming) was not sure about 8 out of 10 parameters and indicated only "energy" and "palatability" as "very important". Another small enterprise (fish feed manufacturer) couldn't evaluate "protein content", amino acids" profile, "fatty acids", neither "energy" and marked those parameters with "I don't" know/I'm not sure". The visualization of Question 5 via Radar chart is shown in Figure 17.

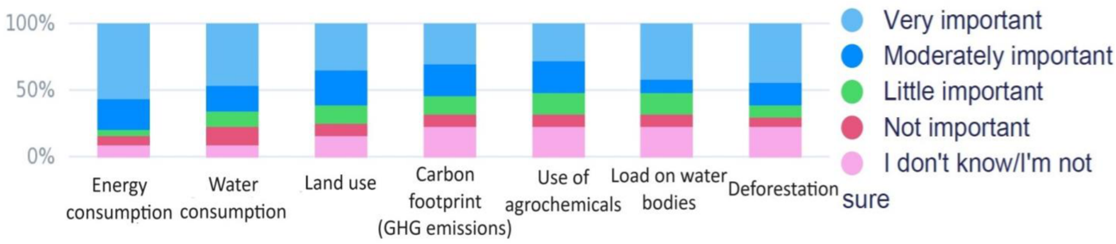
Figure 17: The visualization of Question 5



Source: data processing based on Survio® results

Figure 18: Question 6

6. Please rate the degree of importance of ecological aspects (how important is it to you that feed production has the least possible impact on the environment).



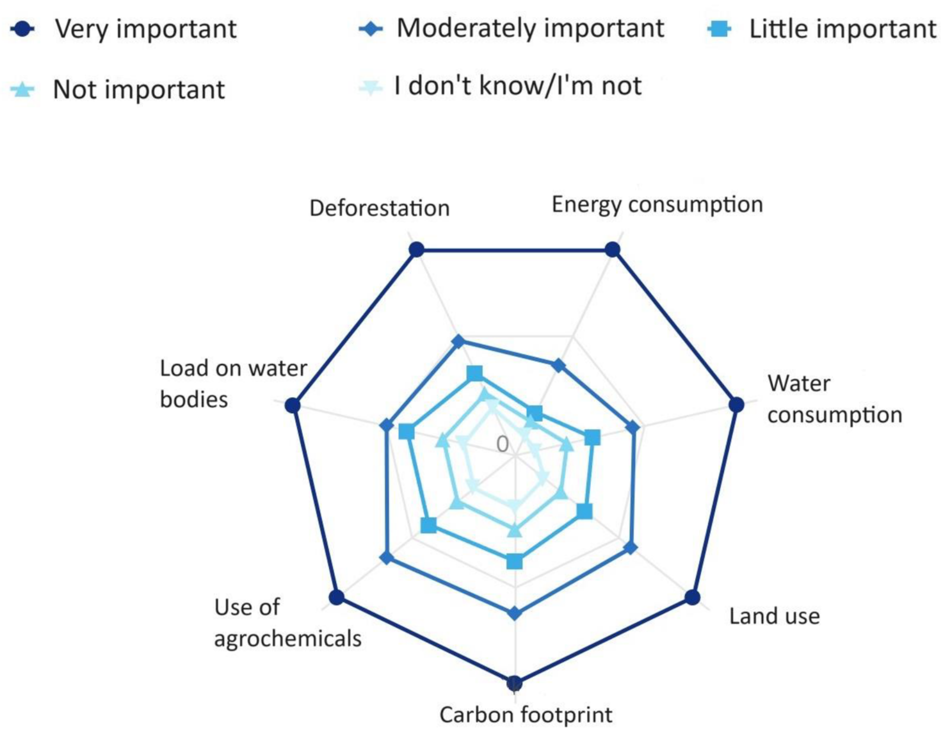
	VERY IMPORTANT	MODERATELY IMPORTANT	LITTLE IMPORTANT	NOT IMPORTANT	I DON'T KNOW/I'M NOT SURE
Energy consumption	24 (56%)	10 (23%)	2 (4,7%)	3 (7%)	4 (9%)
Water consumption	20 (47%)	8 (19%)	5 (12%)	6 (14%)	4 (9%)
Land use	15 (35%)	11 (26%)	6 (14%)	4 (9%)	7 (16%)
Carbon footprint (GHG emissions)	13 (30%)	10 (23%)	6 (14%)	4 (9%)	10 (23%)
Use of agrochemicals	12 (28%)	10 (23%)	7 (16%)	4 (9%)	10 (23%)
Load on water bodies	18 (42%)	4 (9%)	7 (16%)	4 (9%)	10 (23%)
Deforestation	19 (44%)	7 (16%)	4 (9%)	3 (7%)	10 (23%)

Source: data processing based on Survio® results

Regarding ecological aspects evaluation in Question 6 (Figure 18) more than half of respondents (56%) indicated “energy consumption” and almost half of them (47%) “water consumption” as “very important” aspect in the feed production. Only four respondents (9%) were not sure or didn’t know how to evaluate the degree of importance of those two aspects. Three respondents (7%) marked “energy consumption” as “not important” and six respondents (14%) did so with the “water consumption”. “Deforestation” was another aspect marked as “very important by 44% of respondents and as “moderately important” by 16.3% of respondents. This reflects the fact that usage of soybean ingredients in the feed among respondents is on a high level. Also 42% of respondents consider “load on water bodies” as “very important”, 9% as “moderately important” and 16% as "little important”. This reflects the lesser usage of fish meal in comparison of soybeans among the respondents.

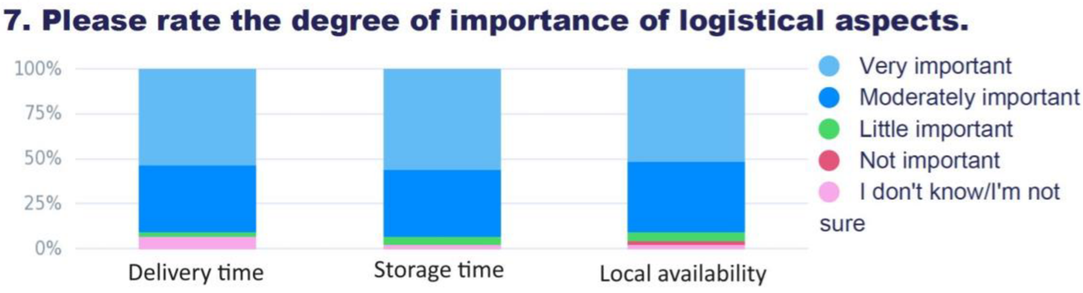
“Land use”, “carbon footprint”, and “use of agrochemicals” have similar results. Around one third of respondents indicated those three aspects as “very important”, around a quarter marked them as “moderately important”, 15% give them little importance, and only four respondents (9%) consider those aspects as “not important”. Ten respondents (23%) were not sure or didn’t know how to evaluate “carbon footprint”, “use of agrochemicals”, “load on water bodies”, and “deforestation”. This can be explained by the lack of information on impacts of those ecological aspects and inability to express them in a monetary form. The visualization of Question 6 via Radar chart is shown in Figure 19.

Figure 19: The visualization of Question 6



Source: data processing based on Survio® results

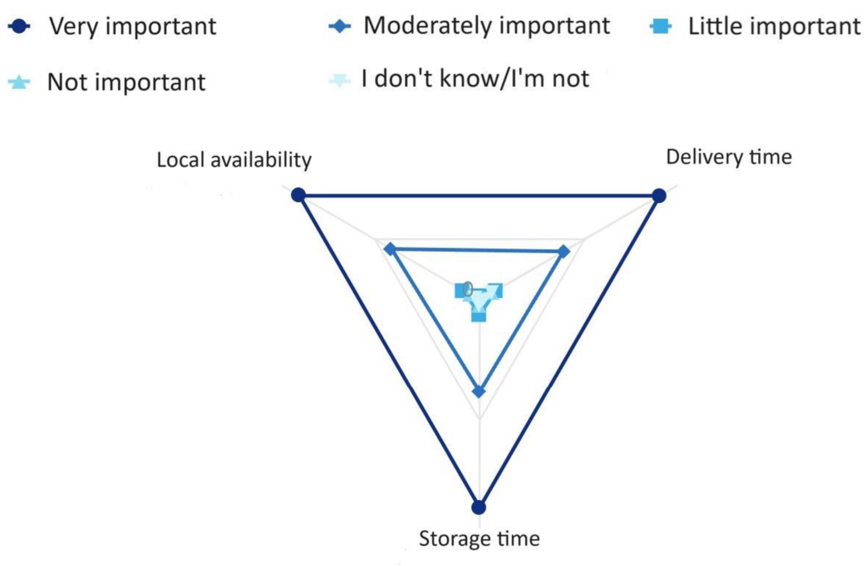
Figure 20: Question 7



	VERY IMPORTANT	MODERATELY IMPORTANT	LITTLE IMPORTANT	NOT IMPORTANT	I DON'T KNOW/I'M NOT SURE
Delivery time	23 (54%)	16 (37%)	1 (2%)	0	3 (7%)
Storage time	24 (56%)	16 (37%)	2 (5%)	0	1 (2%)
Local availability	22 (51%)	17 (40%)	2 (5%)	1 (2%)	1 (2%)

Source: data processing based on Survio® results

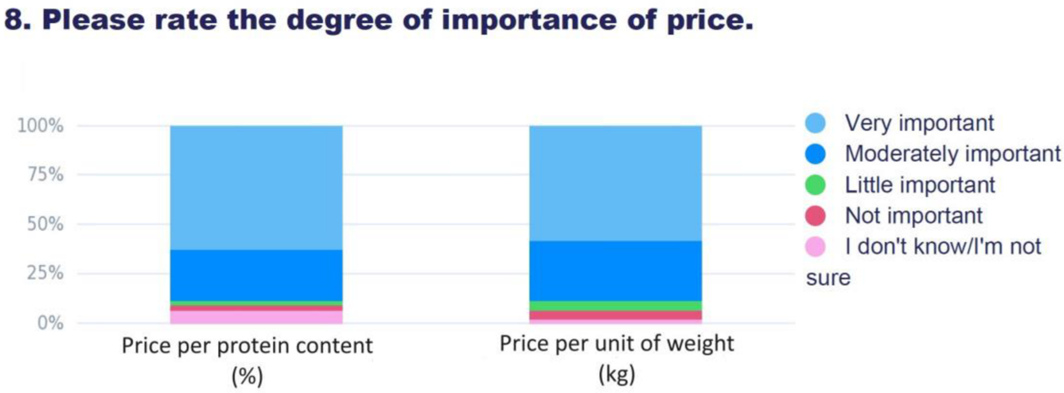
Figure 21: The visualization of Question 7



Source: data processing based on Survio® results

The results on the degree of importance of logistical aspects in the Question 7 (Figure 20) are completely straightforward. More than half of respondents consider all three logistical aspects as "very important" and around 38% of them as "moderately important", which means that in total for more than 90% of respondents "delivery time", "storage time", and "local availability" are quite significant, which can be well seen from Figure 21. Nobody indicated “delivery time” neither “storage time” as “not important” and only one respondent indicated “local availability” as “not important”. Only few respondents didn’t know or weren’t sure how to evaluate these parameters. The visualization of Question 6 via Radar chart is shown in Figure 21.

Figure 22: Question 8

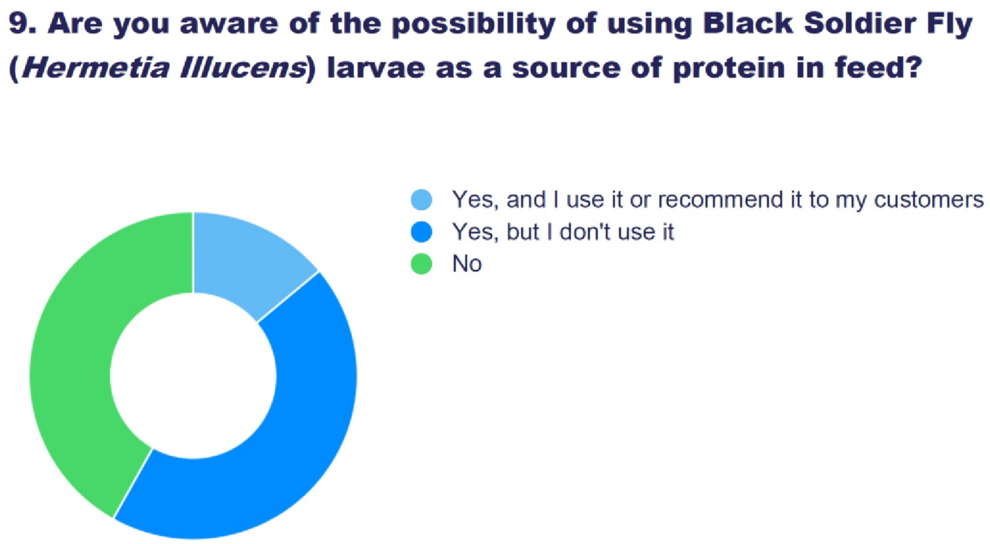


	VERY IMPORTANT	MODERATELY IMPORTANT	LITTLE IMPORTANT	NOT IMPORTANT	I DON'T KNOW/I'M NOT SURE
Price per protein content (%)	27 (63%)	11 (26%)	1 (2%)	1 (2%)	3 (7%)
Price per unit of weight (kg)	25 (58%)	13 (30%)	2 (5%)	2 (5%)	1 (2%)

Source: data processing based on Survio® results

In terms of the price degree importance in Question 8 (Figure 22) 63% of respondents consider as “very important” “price per protein content” and 58% “price per unit of weight”. Roughly one third of respondents assigned medium importance to the “price per unit of weight (kg)” and a quarter of them to the “price per protein content (%)”. However, these results may be affected by responses from the non-business sector because this category of respondents may have limited business experience. Based on consultations with feed producers and sellers higher importance is given to the price per protein content.

Figure 23: Question 9



ANSWER	AMOUNT	RATIO
Yes, and I use it or recommend it to my customers	6	14%
Yes, but I don't use it	19	44%
No	18	42%

Source: data processing based on Survio® results

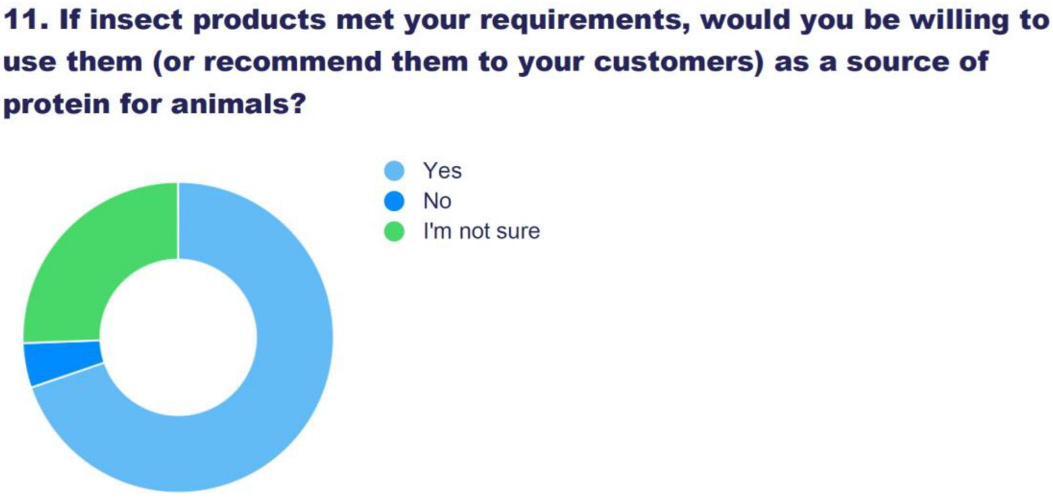
The awareness of BSF larvae usage in feed products was quite high (Figure 23). More than half of respondents (58% = 14% + 44%) were aware of this possibility in the Question 9. However, expectedly, the number of respondents that use BSF larvae or recommend it to their customers was low, only six responses (14%). Moreover, four of them were from non-business sector (mostly academic staff with the focus on fish nutrition) which means that their responses may not reflect the number of those who actually use BSF meal in feed mixtures. Only two enterprises, both from petfood sector (one large and one medium) reported that they use BSF meal in their products. In both cases, these are imported products to the Czech Republic.

Figure 24: Question 10

Source: data processing via WordCloud Generator

Question 10 was aimed at finding out what requirements insect products have to meet for respondents to be willing to use them or recommend them to their customers. Eighteen (42%) out of forty-three respondents underlined "price" as the most essential requirement for them to be willing to use insect products. Seven respondents (16%) indicated "availability" on the market and approximately the same amount of respondents stated "quality" as their requirements. Also "digestibility" and "palatability" requirements were found among answers to Question 10 (Figure 24). One respondent was concerned about legislation related to insect protein production, especially in the case of simultaneous production of feed for ruminants and monogastric animals in the same place. Another respondent stated that "*insects must be bred and produced in Central Europe. Breeding outside the EU is not acceptable at all"*. For complete answers see III. Attachments. Only one respondent didn't answer to Question 10. Despite it was mandatory question, the respondent put hyphen (-) instead of the text.

Figure 25: Question 11



ANSWER	AMOUNT	RATIO
Yes	30	70%
No	2	5%
I'm not sure	11	25%

Source: data processing based on Survio® results

However, the willingness to use insect products in feed in case these products meet the requirements of the respondents is quite high, almost 70% (Figure 25). Only two of forty-three respondents answered "no" to Question 11. One of them was from non-business sector, a teacher with a focus on animal nutrition, who stated that he *doesn't want to use insect* because in his opinion *there is no evidence of benefits neither for human nor for animal use*. The second one was a large enterprise with a focus on cattle breeding, who only stated that he *doesn't support insects*. Nevertheless, he marked the survey as interesting in the Question 14.

Eleven out of forty-three respondents (25%) weren't sure if they were willing to use insect products as a source of protein in animal feed. Most of them are those who didn't have any information about the possibility of using BSF larvae as animal feed and answered "no" to Question 9. Only one out of those indecisive eleven respondents was from an academic sector (with a focus on fish nutrition), who stated that he *doesn't have enough information on possible allergies caused by insects, nor on heavy metals, pesticides, or other chemical substances that insect* *products may contain*. Moreover, he underlined that *rearing outside of the EU isn't acceptable for him*.

The rest ten indecisive respondents were from business sector: two large enterprises, three medium, four small enterprises, and one self-employed. As the reason for their indecision all of them stated the lack of information in Question 12. A couple of them weren't sure if the animals would like it and one small enterprise stated that their feed supplier doesn't offer insect products.

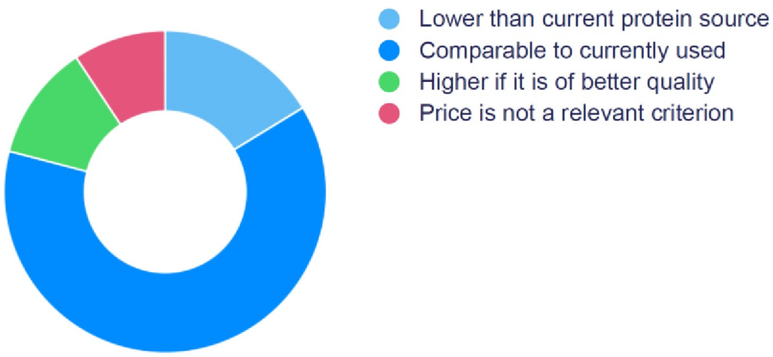
Figure 26: Question 12

Source: data processing via WordCloud Generator

In Question 12 respondents described the reason of their answer to Question 11. Those eleven respondents who answered "I'm not sure" regarding their willingness to use insects as a protein source (Question 11) explained the reasons for their indecision in Question 12 mostly by lack of information about insect feed (Figure 26). One of the two respondents who answered "No" to Question 11 stated "*I don't support it*" and the second one "*I don't want to use insect protein. It is not demonstrably good for humans or livestock*" as the reason of their answer. However, the majority of respondents willing to use insect products stated digestibility and high-quality protein source, especially for poultry and fish as a reason of their willingness (for complete answers see III. Attachments). Only one respondent didn't answer to Question 10. Despite it was mandatory question, the respondent put hyphen (-) instead of the text.

Figure 27: Question 13

13. What price range would you be willing to accept for an insect protein source?



ANSWER	AMOUNT	RATIO
Lower than current protein source	7	16%
Comparable to currently used	27	63%
Higher if it is of better quality	5	12%
Price is not a relevant criterion	4	9%

Source: data processing based on Survio® results

The willingness among respondents to accept insect products as feed was supported also by their willingness to accept the price of these products comparable to currently used protein sources (Figure 27). 63% of respondents would accept comparable price range with the currently used protein sources. Five respondents (12%) would even accept higher price if the quality of insect products is better than the currently used protein sources. On the contrary seven respondents (16%) would prefer price lower than the currently used protein sources. Most of those seven respondents weren't aware of the possibility of using BSF products as feed, therefore answered "no" to the Question 9 or weren't sure about the willingness to accept insect products, therefore answered "I'm not sure" to the Question 11.

Figure 28: Question 14

Source: data processing via WordCloud Generator

In the last question, respondents were asked to write any comments regarding the possibility of using insects in feed or any comment to the questionnaire itself. Question 14 was the only question that wasn't mandatory to answer. Despite, thirty-two (74%) respondents (which is quite high number for an optional answer) wrote some comment and eleven (26%) respondents left in blank. The feedback was very diverse (for complete answers see III. Attachments). Many respondents again pointed out the issue of high price and local unavailability (Figure 28). Some respondents were worried about the shelf life of insect products and their gradual degradation. One respondent underlined that "*for large-scale factories, consistent quality, quantity and price per digestible parameters are important*". Another respondent stated that "*there is no open market in the EU yet, it is a closed B2B, so our shareholders are considering own breeding outside the Czech Republic*". After the price and unavailability issues the lack of information and lack of experience are the most frequent comments on the possibility of using insects as feed. However, overall feedback from respondents was positive. Even the one who answered he is not willing to use insects as feed in Question 11, commented it was "*interesting*" in Question 14. And a cattle producer who noted that insect feed is "*probably a less relevant topic for cattle*" agreed with the statement that it has "*great potential in poultry and pigs*".

The comparison of soybean meal, BSF meal, and fish meal based on the respondents' answers on degree of importance of nutritional properties, ecological aspects, logistical aspects, and price and the literature review regarding each parameter of those three products is presented in Table 16, where the data in the blue cells show parameters of a similar value for soybean meal, BSF meal, and fish meal. The data in the green cells represent competitive advantages and the data in orange cells competitive disadvantages of each product. The value of the data in the grey cells cannot be clearly determined. The values of the degree of importance for each parameter given in the last column represent the ratio of respondents stated that the parameters in Question 5 – 8 of the questionnaire are "Very important".

Table 16 shows that in terms of nutritional parameters all three protein sources have similar properties. The exact composition of each meal varies depending on different factors such as the processing method, the type of substrate, which was fed to larvae, the origin destination where it comes from in case of soybean, the origin and type of fish the fish meal was produced from, etc. Each of the three meals is suitable for an animal diet depending on the specific animal need.

As for ecological aspects, soybean meal has the highest number of orange cells in Table 16, which reflects higher negative impact on the environment (all ecological parameters except the "load on water bodies", which is difficult to determine). In case of fish meal "energy consumption", "carbon footprint", and "load on water bodies" are the parameters with negative impact on the environment, thus they are given an orange color. BSF meal has all ecological parameters in green color, except of "energy consumption" which in some cases can be high if the heating is needed for BSF larvae rearing. However, in comparison with energy consumption related to soybean meal production the energy consumption needed for BSF meal production is still low. Therefore, this parameter has a grey color for BSF meal.

In terms of logistical aspects, the disadvantage of both soybean and fish meal is that they are not locally available in the Czech Republic and are imported. This could be the advantage of BSF meal in case of the local mass production. However, the biggest disadvantage of BSF meal is its current market price, which is eight times higher than the price of soybean meal and 2.7 times higher than the price of fish meal.

Detailed description of each parameter for all three products is given below.

Table 16: Key parameters for soybean meal, BSF meal and fish meal production

Evaluation criteria	Soybean meal	BSF meal	Fish meal	Degree of importance (%)
Nutritional properties				
Protein content (%)	50	60	70	**65**
Amino acids	well-balanced	well-balanced	well-balanced	**49**
Fatty acids	low content of omega-3	Lauric acid	high content of omega-3, EPA, DHA	28
Carbohydrates (%)	20 - 30	22	less than 5	26
Minerals	Cu, K, P	Ca, Cu, Fe, Mn, P, Zn	Ca, P	**42**
Vitamins	choline, niacin, E	B1, B2, C, E	A, B12, D, E, choline, biotin, selenium, iodine	40
Fiber (% of DM)	3 - 7	5 - 10	less than 5	**42**
Energy MJ/kg	15 - 18	21 - 24	20 - 25	**56**
Digestibility (%)	82 - 91	85 - 99	90	**88**
Palatability				**51**
Ecological aspects				
Energy consumption (GJ/t)	high level			**56**
Water consumption (L/t)				**47**
Land use (ha/t)				35
Carbon footprint (kg CO2 eq./t)				30
Use of agrochemicals	high level			28
Load on water bodies			high level	**42**
Deforestation				**44**
Logistical aspects				
Delivery time				**54**
Storage time (months)	6 - 24	12	6 - 24	**56**
Local availability		N/A		**51**
Price				
Price per protein content (EUR/% in kg)	0.01	0.07	0.02	**63**
Price per unit of weight (EUR/kg)	0.5	4	1.5	**58**

Source: own elaboration based on the survey results and literature research

Price

Soybean is currently the first-choice feed due to its relatively low price (wholesale 0.4 – 0.5 EUR / kg). The cost-effectiveness of soybean production is driven by various factors beyond subsidies, geographic locations, and fuel prices. While transportation costs matter, other elements that contribute to soybeans' affordability are: (1) high yield per hectare (usually in the range of 2.5 up to 4.1 t); (2) highly mechanized cultivation and harvesting methods; and (3) global production by competing major players (United States, Brazil, Argentina, and China) which stabilizes prices and ensures suppl. Although transportation costs impact soybean prices (import taxes, etc.), they are just one aspect among many shaping soybeans economic affordability worldwide.

Fish meal prices can be influenced by various factors, and they may fluctuate over time based on market conditions, global fish stocks, demand from various industries (such as aquaculture and animal feed), and other economic factors. Even though fish meal has 40% higher protein content in comparison with soybean meal, the current price of fish meal (1.5 – 1.7 EUR / kg) is 300% higher than the price of soybean meal (Indexmundi 2024a and Indexmundi 2024b), which results in an effort to replace fish meal by soybean meal.

Traditionally, the price of fishmeal has exhibited a robust correlation with the price of soybean meal, as both serve as crucial protein components in animal and aquaculture feeds. The connection is apparent in the soybean meal cross-price elasticities computed by Tveterås and Tveterås (2010), which predominantly show positive values, ranging from -0.066 to 0.321 for different countries. In terms of own-price elasticity fishmeal exhibits a modest level of inelasticity. However, authors note that demand for fish meal from aquaculture sector (for example from salmon production sector) may be more elastic than the demand from other sectors like pig or poultry production. It is explained by the fact that even though increased salmon production puts pressure on fishmeal prices (which is the predominant cost element in fish production), new technologies have come up with new possibilities for substituting fish meal with other protein sources. Whereas in poultry and pig production utilized fish meal share has decreased so much (IFFO, 2022) that the remaining demand is expected to be more inelastic.

The price range of BSF meals produced in the EU or EFTA Member states varies from 3 - 9 EUR/kg. However, companies selling BSF products usually do not reveal their prices publicly and mostly cooperate in B2B (business-to-business) concept. This study calculates with the wholesale price of 4 EUR/kg which was obtained from a company producing BSF meal in Germany. In Table 16 the BSF meal price is marked with orange color since it is 8 times higher than the price of soybean meal and 2.7 times higher than the fish meal price in terms of price per unit of weight. As for price per protein content, the BSF meal price is 7 times higher than the soybean meal price and 3.5 higher than the fish meal price, therefore the price parameter of the BSF meal is marked in orange. Both soybean meal and fish meal prices are marked in green color indicating that these products are cheaper in comparison with the BSF meal. Nevertheless, it can be expected that in case of higher amount of BSF meal available on the market the price will decrease and get more attractive for the feed or animal producers also with respect to the environmental benefits of BSF products.

Nutritional properties

Protein content

The protein content of soybean meal, BSF meal, and fish meal may vary depending on several factors, especially on the processing method, the type of substrate which was fed to larvae (Barragan-Fonseca et al., 2017), etc. However, according to the average values found in literature it can be stated that all three ingredients are quite similar in terms of crude protein content and amino acids profile. Karr-Lilienthal et al. (2004) compared soybean meals from five different geographic regions processed under the same conditions and found crude protein content ranging from 47.4 to 58.5% of dry matter basis. Schiavone et al. (2017) investigated crude protein content in partially defatted and highly defatted BSF meal with results ranging from 55.3 to 65.5% of dry matter basis. According to Choi et al. (2020) study on nutritional composition of fish meals from different types of fish originating from various regions, the crude protein content varies from 58.8 to 71%.

Fatty acids

The fatty acid profiles of BSF meal, fish meal, and soybean meal can vary based on factors such as the species used, diet, and processing methods. The fatty acid profile of BSF meal is often characterized by a balanced mix of saturated and unsaturated fatty acids and its crude fat content varies from 8.9 – 14.8% of dry matter basis (Cullere et al., 2016; Zabulionė et al., 2023). Lauric acid is the most abundant, however also are present palmitic fatty acid, oleic fatty acid or myristic fatty acid which contributes to better flavor (Zabulionė et al., 2023). Fish meal is typically rich in omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These omega-3 fatty acids are essential for the health of aquatic animals and can also be beneficial in the diets of animals higher up the food chain, including poultry and livestock. The crude fat content in different fish meals may vary from 8 to 19% of dry matter basis (Choi et al., 2020). Soybean meal is generally lower in fat compared to fish meal, around 1-3% (Banaszkiewicz, 2011), and its fatty acid profile is predominantly composed of polyunsaturated fats, with a significant amount of linoleic acid.

Mineral content

Mineral content in soybean meal depends on the destination where it comes from, but most commonly it is a good source of phosphorus (P), potassium (K), and copper (Cu) (Karr-Lilienthal et al., 2004). According to Hossain and Bhuiyan (2023) BSF meal has an abundance of minerals like iron (Fe), manganese (Mn), phosphorus (P), zinc (Zn), calcium (Ca), and copper (Cu), however other minerals are also present and depend on the substrate that larvae were fed on and the stage of their growth. Main minerals in fish meal are calcium (Ca) and phosphorus (P) (Cho and Kim, 2011), but in different amount fish meals usually content most of the minerals.

Vitamins

In terms of vitamins fish meals naturally content essential vitamins, including choline, biotin, vitamins B12, A, D, and E, as well as trace elements such as selenium and iodine (Cho and Kim, 2011). Soybean meals usually contain choline, niacin, vitamin E, etc., but no vitamin B12 (Brown et al., 2008). Abd El-Hack, et al. (2020) and Zulkifli et al. (2022) detected vitamins B1, B2, C and E in BSF meals.

Carbohydrates

The actual carbohydrate content can vary among different batches and products. Generally, BSF meal is considered to have a moderate carbohydrate content, and specific values may range from 10% to 30% (Zabulionė et al., 2023), while in fish meal is relatively low, often less than 5%. Soybean meal typically contains a moderate level of carbohydrates which can vary, but it is generally around 20-30%. Carbohydrates in soybean meal include fiber, sugars, and complex carbohydrates (Ween et al., 2017).

Fiber

The fiber content in soybean meal and BSF meal can vary based on factors such as the source, processing methods, and the part of the plant or insect used. Banaszkiewicz (2010) has reported the fiber content in soybean meal between 3.1 – 7.2% of dry matter that is mainly composed of both soluble and insoluble fiber. Generally, BSF meal is considered to have a moderate fiber content, and specific values may range from 5% to 10% or more. Fish meal has usually fiber content less than 5% (Yakubu, 2020).

Energy

The gross energy content in soybean meal typically ranges from 15 to 18 MJ/kg (Wang et al., 2006). The energy value is influenced by the protein and fat content in soybean meal, as well as the specific soybean variety and processing methods. Fish meal is known for its high protein and fat content, and the gross energy content is generally higher compared to soybean meal. Gross energy values for fish meal often range from 20 to 25 MJ/kg (Buyukcapar and Kamalak, 2007). The high energy content is due to the presence of both proteins and fats. The gross energy content in BSF meal is typically in the range of 21 to 24 MJ/kg (Schiavone et al., 2017), depending on factors such as larval diet composition.

Digestibility

The digestibility in soybean meals varies a bit depending on the country of origin and is around 82 - 91% (Karr-Lilienthaletal et al., 2004). It contains anti-nutritional factors such as trypsin inhibitors and lectins, which can impact digestibility in monogastric animals like pigs and poultry. Heat processing methods, such as extrusion or roasting, are commonly applied to soybean meal to improve its digestibility. The digestibility of BSF meal can be influenced by the substrate on which the larvae are raised and the composition of their diet. BSF meals used in animal feeds, including for poultry and fish, indicated good digestibility and nutrient absorption by these animals. Especially for fish the digestibility BSF meals reached high values of around 85 – 99% (Radhakrishnan et al., 2022). Apparent digestibility coefficients for fish meal can be quite high, often exceeding 90%. The excellent amino acid profile and nutrient content contribute to its high digestibility in aquatic and terrestrial animals (Allan et al., 2000).

Palatability

Soybean meal's palatability can vary among different species. Generally, it is considered palatable for many livestock and poultry species, especially when it is properly processed to reduce anti-nutritional factors that can affect taste. Fish meal is often highly palatable due to its strong fishy odor and flavor. Many aquatic and carnivorous species find fish meal attractive in their diets, contributing to its widespread use in aquaculture and feeds for carnivorous animals. The palatability of BSF meal can vary based on the larval diet and processing methods. Research suggests that BSF meal can be palatable for certain animal species, although according to some authors (Schiavone et al., 2017) levels higher than 33% can decrease palatability in some animals, however, efforts are made to optimize the diet to enhance palatability.

It can be stated that in terms of nutritional properties all three products have very good performance and the selection of the product depends on the needs of specific animals. From this reason nutritional parameters for soybean meal, BSF meal, and fish meal are marked in blue color in Table 16.

Ecological aspects

Energy consumption

Comparing the energy consumption in the production of soybean meal, fish meal, and BSF meal involves considering various stages of the production process, including farming or cultivation, processing, and transportation. Specific values can vary based on factors such as geographic location, production practices, and technology used. Soybean cultivation typically involves energy-intensive processes such as planting, harvesting, and transportation. Additionally, the processing of soybeans into soybean meal includes steps like drying, grinding, and extraction, which also consume energy. The energy consumption can be influenced by factors like the use of fertilizers and pesticides in cultivation. The production of fish meal involves several stages, including fishing, processing, and drying. Energy consumption in fish meal production can vary based on fishing methods, transportation of fish to processing plants, and the efficiency of drying processes. Energy-intensive fishing practices may contribute to higher overall energy consumption. The energy consumption in BSF meal production is influenced by factors such as larval rearing conditions, substrate sourcing, and processing methods.

Many factors go into the energy intensity of soybean meal production, and it can be stated that no two products are the same. Dalgaard et al. (2008) summarized that 1 hectare of soybean (yield 2.63 t ha^{-1}) produced in Argentina required: 16 kg of phosphate fertilizer; 42 L of diesel and 4 L of engine lubricant. However, it should be noted that such crop production (without regeneration of soil organic matter, without the supply of all fertilizers, etc.) is only sustainable for a few years. To make matters worse, only a few of the available analyses in the literature take into account the energy requirements associated with the use of agrochemicals (insecticides, molluscicides, herbicides, fungicides, etc.) or other agronomic operations. Worse still, in case of use in the EU, it must be considered that additional energy requirements are needed for the transportation to logistics hubs and ports, then the transportation across the Atlantic Ocean (10,500 km), extrusion and inter-EU transport to the customer. In less developed countries such as China or India, agricultural mechanization is more backward, so energy costs can be higher (Lopez et al., 2020). And not to make things too easy, yields and quality indicators for soya products can vary by tens of percentages not only with regard to the continent of origin but also with regard to variety, weather and more. Mousavi-Avval et al. (2011) conducted a robust analysis that attempted to account for labor; machinery; agrochemicals; fertilizers; irrigation; seed and electricity. While this is probably the most detailed analysis published to date, there are still new and novel inputs that could be considered. The total energy input in soybean cultivation was calculated to be 35.37 GJ ha^{-1} (for which soybean with energy value of 80.8 GJ ha^{-1} was obtained). Taking into account that the average yield is currently most often around 2.8 t ha^{-1} (Specht et al., 1999; Board and Kahlon, 2011), the energy required to grow 1 ton of soybean can be estimated (with a reasonable degree of imprecision) at (35.37 GJ ha^{-1} / 2.8 t ha^{-1} = 12.64 GJ t^{-1}) 12.64 GJ t^{-1}. Assuming that the soybeans travel to the customer 10,500 km by ship (0.15 MJ t^{-1} km-1; Barreiro et al., 2022;

Mondello et al., 2023), 500 km by rail (0.3 MJ t^{-1} km^{-1}; Fernández et al., 2016; Merchan et al., 2020) and 500 km by road transport (0.4 MJ t^{-1} km^{-1}; Streimikiene et al., 2013; Gnap et al., 2020), the energy demand of transport can be estimated at 14.57 GJ t^{-1} (calculation as follows: 12.64 GJ t^{-1} + 10,500 km *0.15 MJ t^{-1} km^{-1} + 500 km * 0.3 MJ t^{-1} km^{-1} + 500 km * 0.4 MJ t^{-1} km^{-1} = 14.57 GJ t^{-1}). However, the energy requirements do not end there (drying, preservatives and other factors are omitted for simplicity), soybeans need to be milled into soybean meal using an extruder (it is assumed that the losses from all milling processes are 2% and around another 3% of the product can get lost on the journey from farmer to customer; Dalgaard et al., 2008). The energy needed for processing 1 ton of soybeans into soybean meal is roughly 16.13 MJ t^{-1} (Thomas et al., 2015; Preece et al., 2017) which means that the total energy cost of 1 t soybean meal is around 14.77 GJ (farming + transport + extrusion = 12.64 GJ t^{-1} + 1.93 MJ t^{-1} + 16.13 MJ t^{-1} = 14.77 GJ t^{-1}).

The calculation of the energy consumption of BSF meal production can be complicated by the fact that BSF meal is most often only one of several products (Mertenat et al., 2019). As for the usual energy inputs, these include: (1) biowaste treatment (grinding, mixing and manipulation); (2) energy demands of the rearing technology (ventilation, lighting, heating, cleaning procedures, manipulation); (3) harvest of larvae (harvesting, separation, drying, hygiene); residue management (composting, transport, hygiene) and (4) refining of the final product. Nevertheless, it is the necessity of heating that determines the energy requirements of rearing insects. Considering how minimalistic the life requirements of insects are, heating makes up, according to Boakye-Yiadom (2022) some 82% of the entire energy need.

Kaushik and Médale (1994) reviewed a large list of factors that influence the energy needs of fish meal production. The price and related energy demand of fishmeal production is thus a strategic issue for fisheries in many countries. It is therefore not surprising that savings in the energy intensity of fishmeal production are the subject of many studies (Oosthuizen et al., 2020). There are relatively many fishmeal production technologies, and many are difficult to compare with each other (Ahmad and Ibrahim, 2016; Hall, 2011). The greatest energy demands are connected with the fact that fishmeal undergoes temperature treatment at 95 °C

(Hilmarsdottir et al., 2020). Bosch et al. (2019) reviewed that 44 GJ are needed to produce 1 t of fish meal.

However, the calculations from different authors vary a lot and it can be stated that there is no one universal method how to calculate total energy consumption for any of soybean meal, fish meal or BSF meal. Nevertheless, due to the high energy consumption both for soybean meal and fish meal described above, this parameter is marked in orange color in Table 16.

Water consumption

The water consumption in soybean meal production is primarily associated with the cultivation of soybeans rather than the processing of soybean meal. Mohammadi et al. (2013) reported that some 3303 m^3 of water is needed per hectare and if the average yield of 2.63 t ha^{-1} is used consistently (as in the previous calculations), it is possible to arrive at a need of 1256 m^3 of water t^{-1}. Further water contamination occurs in connection with around 12,000 km of transport. So, the color given to this parameter for soybean meal in Table 16 is orange.

Guo et al. (2021) reported, that BSF rearing is water friendly as 84% of incoming to the process via feedstock is evaporated back to the environment; 8% is metabolized into the BSF and 8% remains in the compost. Mertenat et al., (2019) reported using of 25 L water per 21 ton of BSF, which presents some 1.2 L per ton of fresh BSF. During subsequent processing into BSF meal, they report some 8.3 L per cleaning and 49 L per washing (all per 21 tons of BSF). This gives altogether some 4 L water t^{-1}. Also, Mohammadi-Kashka et al. (2023) as well as Smetana et al. (2019) indicate that the freshwater depletion is small, therefore this parameter is given a green color.

While water is utilized in certain aspects of fishmeal production, its overall necessity in the process is relatively low (Hardy, 2006). The primary focus lies in efficiently processing and preserving the nutritional value of the fish (Han et al., 2018). While water is employed for cleaning the fish and some processing steps, the volume required is modest compared to other agricultural or industrial processes as modern fishmeal refineries are already designed to use condensed process vapors to meet water requirements (Olsen and Hasan, 2012; Luthada-Raswiswi et al., 2021). Fishmeal production is largely driven by the need to utilize fish by-products effectively rather than being water-intensive. Therefore, while water plays a role, it is not a significant factor in the overall production process and the "water consumption" parameter is marked in green in Table 16.

Land use

Reckless cultivation of soybeans is one of the main reasons for the disappearance of tropical forests. Esteves et al. (2016) pointed out that the impact of intensive soybean production can be traced via satellite imagery. Especially tropical soils lose their fertility very quickly and if the cycle of organic soil mass is not stabilized in them after cultivation, they are quickly degraded and become completely barren within two decades. Given that the average (meaning also environmentally and economically optimal) soybean yield is currently around 2.6 t ha^{-1}, approximately 0.4 ha^{-1} is needed for 1t of soybean meal. Orange color was given to "land use" parameter for soybean meal in Table 16.

Insect rearing is not land-intensive, and usually only a few (2 at maximum) m^2 are sufficient to produce 1 ton per year, depending on the intensity of rearing (Bosch et al., 2019; Kragt et al., 2023). Fishmeal production requires relatively little space compared to other agricultural or industrial activities (Luthada-Raswiswi et al., 2021). Unlike large-scale crop farming or industrial manufacturing, fishmeal plants can be compact and efficiently designed to process significant quantities of fish by-products in a relatively small area (Galkanda-Arachchige et al., 2020). Additionally, advancements in technology have further enhanced the efficiency of fishmeal production, allowing for higher yields in smaller spaces while minimizing environmental impact (Hodar et al., 2020). "Land use" parameter for both BSF meal and fish meal is marked with green in Table 16.

Carbon footprint

Miller and Theis (2006) assessed the carbon footprint of soya meal with 3 different mathematical models (GREET; EIO-LCA and SimaPro) and arrived at 3 different values. However, the key finding is that the majority of the carbon footprint is associated with the use of fuels for agricultural machinery and fertilizing. Zortea et al. (2018) summarized soil preparation (limestone, glyphosate, process and other products); seed treatment and sowing (phosphorus, potassium, seeds and other processes and products); growing period (diesel, pesticides, glyphosate and other processes and products); harvest (diesel and other processes and products) and came to 734 kg CO_2 eq t^{-1}. Rocha et al. (2014) reported 206 kg CO_2 eq t^{-1}, Raucci et al. (2015) came only to 186 kg CO_2 eq t^{-1}. This parameter was marked in orange in Table 16.

There is no consensus in the literature regarding the quantification of carbon footprint linked with BSF meal production. The consensus is, however, that insect rearing is a better alternative than if biowaste was left to self-degrade and rot without control. There is therefore a large agreement that the carbon footprint is negative and rather represents an avoided carbon footprint. Mertenat et al., (2019) reported an average CH_4 production of 0.4 g and N_2O production of 8.6g t^{-1} of organic household waste treated which is approximately 75 times less than the literature on composting technology. For example, Guo et al. (2021) came to similar conclusions and argued that carbon sequestration through product utilization overlaps both released emissions during processing and released emissions from additional energy input (17.36 kg CO_2 eq t^{-1} of food waste). Therefore, green color was given to the “carbon footprint” parameter for the BSF meal.

The carbon footprint of fish meal production is difficult to determine. Some authors state lower values in comparison to soybean meal or other agricultural crops production (Mitra et al., 2024). However, taking into account GHG emissions released during fish capture and fishmeal transportation (Robb et al., 2017), "carbon footprint" parameter was marked with orange in Table 16.

Use of agrochemicals

The high demands for soy fertilization are generally known. Parischa and Tandon (1993) reported that soybean yielding some 2.5 t ha^{-1} removed from 1 hectare 125 kg nitrogen; 23 kg phosphorus; 101 kg potassium; 22 kg sulphur; 35 kg calcium;19 kg magnesium; 192 g zinc; 866 g iron; 208 manganese and 74 g copper. The reason why they are so high is that soy is grown most often in subtropical and tropical locations, where the soils have a weak ability to retain nutrients (low sorption capacity) and so it is necessary to fertilize these low-fertile soils intensively. Optimum fertilizer doses differ according to variety, expected yield, soil characteristics and other circumstances. However, based on current state of knowledge, the parameter “use of agrochemicals” soybean meal was given orange color in Table 16. The production of fish meal and BSF meal are not directly connected to the use of agrochemicals. The indirect connection may appear in case of using cereals or other sources that require the use of agrochemicals as feed for BSF larvae or fish, therefore "use of agrochemicals" parameter for both of these meals was marked in green.

Load on water bodies

Intensive soybean cultivation can exert significant pressure on water resources due to the extensive use of fertilizers and irrigation which always depends on the farmer and his skills and responsibility. Dalgaard et al. (2008) stated that while soybean cultivation has an undetectable impact on water contamination, refining 1 t of soybeans to soybean meal is associated with 17 mg BOD5 (Biological Oxygen Demand); 61 mg COD (Chemical Oxygen Demand) and 4 mg nitrate. The application of fertilizers, particularly nitrogen and phosphorus-based compounds, can lead to nutrient runoff into nearby water bodies, causing eutrophication and harming aquatic ecosystems. Nevertheless, in Table 16 it is marked in grey color since the real impact of soybean meal production on water bodies is not possible to assess. Inherently, insect production in general and thus neither production of BSF meal does not load water bodies, so it was marked in green color. Fish meal production can have negative impacts on the load on water bodies due to overfishing, bycatch, habitat destruction, and pollution by discharged wastewater from processing plants if not managed properly, so the given color for this parameter is orange.

Deforestation

With an average yield of 2.6 t ha^{-1}, approximately 0.4 ha is needed to produce 1 t of soybean meal. Because soybean is grown intensively mainly in the tropics and subtropics, until recently, forests were burned down to grow it. However, according to some studies originally deforestation was caused by cattle pasturing and later those areas were grabbed for soybean cultivation. This caused indirect deforestation in other areas where cattle pasture was moved (Barona et al., 2010). It is important to note that after the extensive deforestation observed in the Brazilian Amazon during the early 2000s (caused both by soybean and beef production), there has been a substantial reduction in forest loss. Even though annual deforestation rates related to soybean production decreased from over 2.7 million hectares in 2004 to 0.5

million hectares in 2012 (Gollnow et al., 2018), in Table 16 it is marked with orange color.

The production of fish meal itself does not directly cause deforestation that's why it is marked with green color. However, there are some indirect connections between fish meal production and deforestation that are worth considering. The aquaculture industry has been moving toward the use of plant-based ingredients, including soybean, as a substitute for fish meal in feeds. Neither production of BSF meal is directly connected to deforestation, however in case soybeans are used as a substrate for BSF larvae rearing in can have an indirect impact. Both fish meal and BSF meal are marked with green color for deforestation parameter.

Logistical aspects

Delivery time

Delivery times both for soybean and fish meal may depend on many factors, including supplier, country of origin, transport conditions and current logistics or geopolitical circumstances. In the case of the Czech Republic, the vast majority of the demanded quantity of both products is imported. Own production of fish meal in the Czech Republic is negligible and consists of local freshwater fish. As for soybean production, there are successful efforts to cultivate soybeans in the Czech Republic and its production increased during recent years but is still very low in comparison to overall demand. In Table 16 "delivery time" parameter both soybean and fish meal is marked in blue color since the deliveries from suppliers abroad are arranged well ahead, so local feed producers or sellers can get in just in time. Delivery time for BSF meal is marked with orange color because there is not well-established customer-supplier chain for the Czech Republic.

Storage time

The storage time of soybean meal and fish meal can vary depending on factors such as storage conditions, temperature, humidity, fat content, etc. Proper storage practices are essential to maintain the quality and nutritional value of meals. When stored under optimal conditions, both meals can typically be stored for several months to a year without significant loss of quality. Some of the available soybean and fish meal products on the market even state storage time up to 24 months (De Alencar and Faroni, 2011). However, it should be taken into account that long storage can lead to lipid degradation and a reduction in protein content. For this reason, often antioxidants are added to fodder meals, especially to fish meal (Hossen et al., 2013). Conditions for the BSF meal storage are similar to those for soybean and fish meals. Longer storage is achieved by higher degree of defatting. Generally, most of the available BSF meal products on the market have a storage time of twelve months. Since all three products have approximately similar storage times blue color was given to all of them in Table 16.

Local availability

Local availability of both soybean meal and fish meal was explained above (Delivery time). Both products are imported to the Czech Republic which implies that none of them is locally available to cover whole demand. Moreover, increase of the local production of soybean and fish meal to the level which is necessary to cover the whole demand is unlikely in near future, so the given color is orange. As for “local availability” for BSF meal the given color in Table 16 is grey, since currently there is no mass production in the Czech Republic, however the feasibility of the BSF production is quite high, which means possible local availability without seasonal fluctuations.

As can be seen from the values of the degree of importance of each parameter (Table 16), the most important (more than 50%) for the survey respondents are: protein content, energy, digestibility, and palatability (from the nutritional properties), energy consumption (from ecological aspects), all parameters from logistical aspects (delivery time, storage time, local availability) and both price parameters (price per protein content, price per unit of weight).

In terms of nutritional parameters, BSF meal is a highly competitive product when compared to soybean and fish meal. Regarding energy consumption, it can be stated that a much lower amount of energy is needed for BSF meal production than for soybean or fish meal production. However, energy consumption that may be needed in case of heating during BSF larvae rearing shouldn't be neglected. Under current conditions of the feed market in the Czech Republic, only the storage time is a comparable parameter from the three logistical aspects. Due to the fact that the BSF products market is not yet established in the Czech Republic and suppliers of BSF meal are missing, it isn't possible to estimate delivery time and local availability. Nevertheless, in case of mass production BSF meal could gain a competitive advantage because it would be produced locally and the need of the import from long-distance related to the soybean and fish meal could be eliminated.

In terms of price, at first glance it seems like BSF meal can't compete to soybean and fish meal. However, considering the environmental benefits of BSF products and rising pressure on enterprises to be more environmentally sustainable, it can be stated that BSF meal has a potential to become a competitive substitute to soybean and fish meal. Moreover, it is expected, that the price of BSF products will decrease with the expansion of the production in the EU market. In addition, cost connected with BSF larvae rearing can be reduced by using waste heat (for instance, from biogas plants). Therefore, H3 can be considered as confirmed.

6. Conclusion

Based on the results of this research it can be concluded that biowaste processing using BSF larvae and their use in subsequent production of value-added products is a promising concept in the perspective of circular bioeconomy. The concept is gaining popularity all over the world. However, due to legislative obstacles companies in the EU faced a significant disadvantage and were slowed down in placing their products on the market. On the other hand, the EU enterprises had enough time for deeper research in the field and as soon as legislation allowed BSF companies in the EU were among those with the cutting-edge technologies ready to produce high quality protein for animal feed and other value-added products. Urgent need of better biowaste management and at the same time the necessity of alternative protein sources boosts the development of the insect industry which seems to be a promising solution not only for these two issues. Production of BSF larvae and other insects can have wide-ranging positive economic, environmental, and social impacts such as less greenhouse gas emissions, better food waste/biowaste management practices, waste valorization, job creation in rural areas, less dependence on imported animal feed, fertilizers, etc. In addition, the increase of the competitiveness of the entire agri-food system. Moreover, the concept is in accordance with both the EU Bioeconomy Strategy and the Circular Economy Action Plan and, therefore has the potential to contribute to the achievement of the European Green Deal's objectives. Nevertheless, the support of academic, private, and public sectors is essential for the proper development of the insect industry and thus circular bioeconomy in general.

The results of this study showed that there is a significant correlation between business development and the scientific achievements of local academic sectors in the field of BSF rearing in the EU and EFTA Member states. All three indicators (the number of publications, patents, and companies in the field of BSF rearing) developed together. However, some limitations could affect each of the indicators, for example, 1/ time delay in the publication of patents and scientific papers; 2/ patent assignment to a specific country; 3/ companies' geographic allocation (many companies, decide to move their business to other countries due to the business environment).

Another finding of the study was that in countries with established Bioeconomy strategies on the national level, the number of publications and companies in the field of

BSF rearing is considerably higher in comparison to those countries with Bioeconomy strategies on the national level under development or other policies related to bioeconomy. On one hand, it can be interpreted as a government effort to support research and development in the field, especially in terms of ensuring alternative protein sources. On the other hand, further research is needed to investigate whether there are other circumstances affecting the development of the insect industry in EU and EFTA member states.

Regarding the competitiveness analysis, based on the findings of this work, defatted BSF meal has the potential to become a competitive substitute for products such as soybean meal and fish meal. Even though the actual price of BSF meal is higher, it should be taken into account that the price of BSF products reflects more favorable environmental practices in comparison with soybean and fish meal production. Moreover, due to the UN Sustainable Development Goals, the EU's Green Deal policy and the Corporate Sustainability Reporting Directive, it can be deduced that the major players on the feed market are getting under pressure to look for more environmentally friendly sources for their business activities and to require the same approach from their suppliers or partners. It is also necessary to emphasize, that BSF production includes a wide range of products, so the producers can benefit from portfolio diversification. Along with BSF meal, more value-added products like BSF oil suitable for cosmetics or the pharmaceutical industry will contribute to the total revenue.

7. Summary and keywords

This dissertation thesis underlines the promising potential of biowaste processing using Black Soldier Fly (BSF) larvae with the subsequent production of value-added products such as feed components, fertilizers, cosmetics, etc. The concept is gaining global popularity, although legislative challenges initially hindered EU companies, resulting in delays in the placement of BSF products on the market. Nevertheless, EU enterprises, leveraging the time afforded by evolving legislation, emerged with cutting-edge technologies, positioning them to produce high-quality protein for animal feed and other value-added products. The study reveals a significant correlation between business development and scientific achievements in the field of BSF rearing in the EU and EFTA Member states. Another finding of this study was that countries with established Bioeconomy strategies at the national level show higher numbers of publications and established companies in the field of BSF rearing compared to those with Bioeconomy strategies under development or other bioeconomy-related policies. However, the biggest finding of this study is the results of the BSF meal, soybean meal and fish meal competitiveness analysis for the first time conducted in the Czech Republic. The comprehensive analysis showed that BSF meal has the potential to compete with products like soybean meal and fish meal despite its current market price is still a major drawback. The main benefits of the BSF meal are well-balanced nutritional properties and demonstrated positive ecological impact. It was also discovered that under the current conditions, the key bottlenecks are insufficient BSF products supply and the overly strict EU legislation which causes challenges in the price competitiveness. However, based on the review accompanied by the competitiveness analysis results and taking into account political trends, it can be concluded that industrial insect rearing represents a significant commercial potential.

Keywords: bioeconomy; circular economy; competitiveness; feed; insect protein

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I. List of figures and tables

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II. Attachments

1. The survey introduction

Feed ingredients competitiveness analysis

Dear respondents,

as part of my research on the topic of the competitiveness of feed ingredients, I would like to ask you to participate in this short questionnaire.

Your opinion and experience are very valuable and will help to better understand what aspects (such as price, quality, availability, nutritional values, etc.) you consider as key parameters when choosing feed ingredients for your needs.

The questionnaire is anonymous, it contains of 14 questions and takes approximately 5-6 minutes to complete. The results of this survey will be used for academic purposes only.

Sincerely,

Anna Maroušková,

Department of Regional Management and Law
Faculty of Economics
University of South Bohemia
Studentská 13
370 05 České Budějovice
Czech Republic
email address
mobile phone number

2. The questionnaire

1. You are: Choose one answer.
   - o Feed manufacturer or seller
   - o Animal producers
   - o Academic staff or expert with a focus on animal nutrition
   - o Other

2. What kinds of animals are the subject of your activities? Choose one or more answers.
   - o Fish
   - o Poultry
   - o Pigs
   - o Pets
   - o Other

3. According to the currently valid legislation, your activities fall into the category of: Choose one answer.
   - o Microenterprise
   - o Small enterprise
   - o Medium enterprise
   - o Large enterprise
   - o Self-employed
   - o Non-business entity

4. Indicate which of the following ingredients do you use as a main nutritional source (either alone or in a mixture). Choose one or more answers.
   - o Soybean
   - o Fish meal
   - o Insect meal
   - o Cereals
   - o Pea
   - o Other

5. Please rate the degree of importance of each nutritional property of the feed (or main nutritional component). Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".

- Protein content
- Amino acids
- Fatty acids
- Carbohydrates
- Minerals
- Vitamins
- Fiber
- Energy MJ/kg
- Digestibility
- Palatability

6. Please rate the degree of importance of ecological aspects (how important is it to you that feed production has the least possible impact on the environment). Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".

- Energy consumption
- Water consumption
- Land use
- Carbon footprint (GHG emissions)
- Use of agrochemicals
- Load on water bodies
- Deforestation

7. Please rate the degree of importance of logistical aspects. Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".

- Delivery time
- Storage time
- Local availability

8. Please rate the degree of importance of price. Please assign one of the following statements to each parameter. "Very important", "Moderately important", "Little important", "Not important", or "I don't know/I'm not sure".

- Price per protein content (%)
- Price per unit of weight (kg)

9. Are you aware of the possibility of using Black Soldier Fly (Hermetia Illucens) larvae as a source of protein in feed? Choose one answer.

- Yes, and I use it or recommend it to my customers
- Yes, but I don't use it
- No

10. What requirements do insect products have to meet for you to be willing to use them (or recommend them to your customers) as a source of protein for animals?

11. If insect products met your requirements, would you be willing to use them (or recommend them to your customers) as a source of protein for animals? Choose one answer.

- Yes
- No
- I'm not sure

12. Whatever your previous answer was, please describe the main reasons.

13. What price range would you be willing to accept for an insect protein source? Choose one answer.

- Lower than current protein source
- Comparable to currently used
- Higher if it is of better quality
- Price is not a relevant criterion

14. Here please write any comments on the possibility of using insects in feed or on the questionnaire itself.

3. The answers on open-ended questions

Question 10

What requirements do insect products have to meet for you to be willing to use them (or recommend them to your customers) as a source of protein for animals?

1. To be an alternative to a standard product.
2. To be cheaper.
3. Price, sufficient quantity for inclusion in feed production, stability of quality, form - must not be dusty, thermostable.
4. According to the legislation, we cannot work with animal protein in operations where simultaneously feed for ruminants and monogastric animals is being produced.
5. Good palatability and price affordability.
6. Availability and suitable application in feed mixtures.
7. Economic value
8. Economically and nutritionally meaningful
9. Insect protein must be comparable in price with similar raw materials or a combination of raw materials. Currently, the price is too high to be used in nutrition in commercial farms (I cannot compare the Petfood sector). At the last calculation on the recommended dose of a comparable nutritional value, the price of the feed would be significantly higher. Economically, it doesn't make sense yet, despite the gradual price reduction. In the future, it will certainly make sense if insect farms operate in an automated mode using waste and waste heat.
10. Insects are not a part of the mixtures we get.
11. There are no suppliers.
12. There is a lack of customer awareness, there is no demand and indeed no offers from suppliers.
13. We have no specific requirements, only that the carp take it, and it is for a reasonable price.
14. Competitive price as for possible alternative source.
15. Quality and price.
16. The quality of the raw material, the low content of chitin (allergen), another factor is the real impact of insect breeding. In Europe, insects need heating, must

fed with professional poultry feed, then showered and further processing. It is rather a supplement source in addition to other sources.

17. Quantity and price affordability in comparison to other products.
18. They must have been bred and produced in Central Europe. Breeding outside the EU is not acceptable at all.
19. They would have to be on the market.
20. I am not a nutritionist; I will forward the questionnaire to competent person.
21. I don't have enough information.
22. We have no experience.
23. I have no experience.
24. I can't breed it; I don't even know where to buy insects.
25. I don't know
26. Lower price
27. Protein content
28. Growing crops on your own farm
29. Price performance ratio
30. Regular availability in large volume and fixed price
31. Production efficiency - price and digestibility ratio
32. Insects are currently not relevant to our segment
33. Reasonable price, ecological breeding of insects without unwanted substances
34. Reasonable price of the nutrients contained
35. The fish would have to take it
36. Easy availability.
37. Dried, capability to be mixed into BARF (originally Bones And Raw Food diets, later changed to Biologically Appropriate Raw Food, author's remark)
38. We are concerned about the high price, it is primarily an import
39. Custom packaging. Availability. Price of NL (nitrogen, author's remark)
40. I see them as a suitable source of nutrients. I am willing to use them. It depends on the supplier of feed ingredients.
41. I don't want to use them.
42. I don't know
43. -

Question 12

Whatever your previous answer was, please describe the main reasons.

1. Currently, insects are expensive.
2. An alternative source of protein of animal origin.
3. Availability and use in the future.
4. The benefit for health is particularly important and of course the effect on the IOFC (Income Over Feed Costs, author's remark).
5. Economic advantage. Availability. Nutritional quality.
6. Insect protein is of high-quality.
7. Insects are still an underutilized source of nutrition.
8. Insects have a lot of benefits, but I don't know anyone here who keeps them for business.
9. Our supplier does not offer insects.
10. We would like to buy more; the problem is the low volume on the market.
11. As mentioned, if the price matches comparable products, then it makes sense to use. The main reason for the high price of insect protein is the fact that many projects work with a high proportion of manual labor, do not have a properly set nutritional need and are energy-intensive for breeding. Applicability always depends on the calculation of nutrients at certain price levels, for some categories of animals the palatability factor is also important (pigs/calves).
12. Like any other effective resource.
13. I am aware of the benefits of using insect protein as a meat alternative.
14. Quality protein.
15. Little experience.
16. I have doubts about the production cycle of the insect (what it is fed on) and thus it represents competition for the raw materials that are already being used for something else.
17. I think that it does not yet have potential in dairy cow nutrition in terms of price/performance ratio, storability, and dosage.
18. I don't want to use insect protein. It isn't demonstrably good for humans or livestock.
19. I don't have enough information.

20. We don't have experience, we only buy ready-made mixtures, the condition is that the granules can be blown into the tank near the water, they are cheap, and they don't crunch.
21. I have no prejudices about insect protein.
22. I don't support it.
23. I don't know.
24. We don't know how the fish will react.
25. I don't know if one can feed with insects.
26. Never heard of feeding on insects.
27. Limited resources of marine fish to produce fish meal (protein) for feed.
28. Insects are a natural part of the diet for poultry.
29. As other protein, important is the growth rate while maintaining the price.
30. I would consider this option for veterinary diets. For now, the price/performance ratio is unsatisfactory.
31. I will pass it on to a nutritionist.
32. It will be about the price.
33. With respect to the source.
34. We still know nothing about allergies and intolerances to the individual components of insects for humans and animals + we have no idea what exactly insects contain in terms of heavy metals, pesticides, ATB (antibiotics, author's remark) and other drugs and chemical substances that are supplied to the market (there are no globally uniform standards).
35. Digestibility, price, availability.
36. People probably grow these things themselves at home in small quantities, no supplier has ever offered us insects.
37. Carbon footprint.
38. Insects didn't improve palatability for dogs or cats.
39. Highly effective protein source in particular.
40. Due to the instability of crop yields and their dependence on the weather, the amount of fertilizers and chemical protection products used, this source of protein is more reliable and effective.
41. The supply chain is completely missing.
42. NL (nitrogen, author's remark) source for the future.
43. -

Question 14

Here please write any comments on the possibility of using insects in feed or on the questionnaire itself.

1. It would be nice to have something affordable, we would definitely use.
2. Further research in this area is desirable. Higher concentrations of insect meal can have adverse effects on animal growth and health.
3. Farming of insects?
4. Insect protein is of high quality, I see its wider use in our conditions as unrealistic.
5. We have already evaluated insect protein in the company, its use depends primarily on price, nutritional value and applicability to individual categories of animals. For meat/egg/milk farms, price vs. performance is also essential. This is due to the fact that production is burdened with a very low gross margin, and if you want to make money, you need to produce a large volume. The situation is different in the petfood sector, customers accept a higher price. The gross margin on these products is extreme and it won't have that much of an impact on the price.
6. As with other resources, sustainability and environmental impact are important.
7. Maybe there will be a problem with the shelf life of insects.
8. I think it still needs time.
9. I think that the introduction of the questionnaire with the expression of importance is unnecessary. Every component of feeding is important, or I misunderstood the author's point. However, I perceive the use of insects in feed positively as a source of animal protein. In combination with the use of food residues or rendering waste, either in the feed itself or in the production of insect protein, we can reduce the consumption of plant feed components and thus make it easier for nature. I wish you success.
10. Our feed supplier does not offer insects
11. I don't like it
12. Some insect products were tested at the branch in Hungary, but eventually backed off.
13. I don't have the experience or enough information to use insects in feed.
14. I don't have experience, it's hard to say.

15. We have no idea if it is legal or what the administrative work is related to this feed.
16. I don't know what to do with it, I'd be afraid that it would escape and cause some damage.
17. Regarding insects for fish we have several publications, however fishermen are conservative and are not interested in it.
18. The question is how long this protein source will last in stored feed, and whether degradation occurs after a certain period of time. What is the shelf life.
19. There is no open market in the EU yet, it is a closed B2B, so our shareholders are considering their own breeding (outside the CZ).
20. For large-scale factories, consistent quality, quantity and price per digestible parameters (not only protein but also other quality parameters) are important.
21. I will forward to the nutritionist.
22. We are happy to participate in the next steps to assess the usefulness of insects as a source of protein. We wish you much success.
23. The fish should be fine with insects.
24. Nobody feeds insects here.
25. So of course, the price would be decisive
26. Probably a less relevant topic for cattle. Great potential in poultry and pigs.
27. Suitable for veterinary diets.
28. We already have insect protein in some feeds and treats for dogs and cats, but so far there is not much interest in these products.
29. All feeds are very expensive.
30. A possible high-performance stable source of protein.
31. The use of insects for feed purposes can certainly represent an interesting alternative to other sources of protein and AMK (amino acids, author's remark) in the future.
32. Interesting.

III. List of Abbreviations

AAAS - American Association for the Advancement of Science

ABP - Animal By-Products

AT - Austria

BE – Belgium

BCG - Bio-Circular-Green (Economy)

BG – Bulgaria

BIC - Bioindustrial Innovation Canada

BIT - Bioeconomy Strategy for a Sustainable Italy

BMBF - National Bioeconomy Strategy of Germany

BSF - Black Soldier Fly

CA – California

CAGR - Compound Annual Growth Rate

CBAC - Canadian Biotechnology Advisory Committee

CE - Circular Economy

CEAP - Circular Economy Action Plan

CEN - The European Committee for Standardization

CH – Switzerland

CSR - Corporate Social Responsibility

CSRD - Corporate Sustainability Reporting Directive

CY - Cyprus

CZ - Czechia

DE - Germany

DHA - docosahexaenoic acid

DK - Denmark

EC - European Commission

EE – Estonia

EFTA - European Free Trade Association

ESG - Environmental, Social and Governance

EU - European Union

EP - The European Patent Office

EPA - eicosapentaenoic acid

FAO – Food and Agriculture Organization

FI – Finland

FLW - Food loss and waste

FR – France

GB - Great Britain (refers to United Kingdom in Google patents database)

GDP - Gross domestic product

GHG - Greenhouse Gas

GR – Greece (refers to Greece in Google patents database)

GRI - Global reporting initiative

H1 – 1st hypothesis

H2 – 2nd hypothesis

H3 – 3rd hypothesis

HLPE - High-Level Panel of Experts

HU – Hungary

IACGB - International Advisory Council on Global Bioeconomy

IE – Ireland

IFFO - The Fishmeal and Fish Oil Organisation

IICA - Inter-American Institute for Cooperation on Agriculture

IPIFF - International Platform for Insects as Food and Feed

IS – Iceland

ISEA - Institute of Social and Ethical AccountAbility

ISO - International Organization for Standardization

IT – Italy

JRC - Joint Research Centre

KBBE - Knowledge-Based Bio-Economy

LI - Liechtenstein

LT - Lithuania,

LU - Luxembourg

LV – Latvia

MT – Malta

NCP - National Contact Point

NFRD - Non-Financial Reporting Directive

NGOs - non-governmental organizations

NL – Netherlands

NO – Norway

OECD - The Organisation for Economic Co-operation and Development

PACE - Platform for Accelerating the Circular Economy

PAPs - processed animal proteins

PL - Poland

PT – Portugal

RO – Romania

R&D - Research and Development

SE – Sweden

SEAAR - Social and Ethical Accounting, Auditing and Reporting

SDGs - Sustainable Development Goals

SI – Slovenia

SK – Slovakia

THB - Thai Baht

US – The United States of America

USA - The United States of America

USD - The United States dollar

UN – United Nations

WO - World Intellectual Property Organization

WFD - Waste Framework Directive

WRAP - Waste and Resources Action Programme