ECONOMICS WORKING PAPERS

VOLUME 7

NUMBER 2

ISSN 1804-9516 (Online)

2023

ECONOMICS WORKING PAPERS

Volume 7 Number 2 2023

Publisher: University of South Bohemia in České Budějovice
Faculty of Economics

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Edition: 5, 2023

ISSN: 1804-9516

ECONOMICS WORKING PAPERS

ECONOMICS WORKING PAPERS. Published by Faculty of Economics. University of South Bohemia in České Budějovice• The editor's office: Studentská 13, 370 05 České Budějovice, Czech Republic. Contact: tel: 00420387772493, Technical editor: Markéta Matějčková, e-mail: matejckova@ef.jcu.cz • ISSN1804-5618 (Print), 1804-9516 (Online)

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Food Waste Management via Insect Production in the Perspective of Circular Bioeconomy

Maroušková, A.

Abstract

The amount of different types of waste around the world is growing every year. Especially a growing amount of food waste is in desperate need of better management practices. At the same time, European Union (EU) is striving for becoming the world's first climate-neutral continent which requires immediate solutions for issues like waste management, sustainable production, competitive resource-efficient business models, etc. For achieving these goals, business models fulfilling principles of circular bioeconomy are highly supported by the EU. One of such business models could be the rearing of Black Soldier Larvae (BSF) on various types of biowaste and their use for value-added products like animal feed, fertilizers, biofuel, cosmetic ingredients, etc. This study reviews adopted Bioeconomy strategies and investigates the state of the research and development in the field of BSF rearing through statistical analysis of the available scientific publications, published patents, and established companies in the EU and European Free Trade Association (EFTA) Member states. The results show an exponential increase in all three indicators in the last decade.

Keywords: bioeconomy, biowaste, circular economy, insect production, sustainability

JEL Classification: O13, Q01, Q57

1. Introduction

1.1. Research background

The continuously growing amount of various types of waste represents one of the biggest challenges all around the world. Especially, food waste represents a problem that needs an immediate solution, since a significant part of it is still being landfilled even in the EU (Di Maria et al., 2018) which causes many environmental and economic issues. These are, among others, greenhouse gases release due to the organic matter decay in the landfill; landfills' bodies collapse; lower competitiveness of agri-food products due to rising costs for waste management (Huang and Fan, 2016; Agovino et al., 2020). On the other hand, the global population growth results in an increasing demand 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 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 waste into many 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 and contribute to the transition to environmentally sustainable food systems. Moreover, insects are considered an important component for enhancing the circularity of the bioeconomy since they 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. Therefore, this work deals with an overview and comparison of existing Bioeconomy Strategies on different levels and their influence on the development of the insect industry. Last but not least, the correlation analysis on the number of published publications, patents, and established companies in the field of one selected insect species (Black Soldier Fly) rearing is conducted in the EU and EFTA member states.

1.2. Research objectives and hypotheses

The main objective of this work is to analyse the correlation between the number of published scientific publications, patents, and established companies in the field of BSF rearing in the EU and EFTA Member states. The development of these 3 indicators could be affected by the current Bioeconomy strategies adopted by the members states. Therefore, the number of published publications and established companies will be compared between member states with established Bioeconomy strategies on the national level and member states with Bioeconomy strategies on the national level under development or other policies related to bioeconomy.

Main hypothesis:

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.

Sub-hypothesis:

Established Bioeconomy strategies on the national level positively affect the development of the business and academic achievements in the field of BSF rearing.

2. Literature review

2.1. Bioeconomy concept and definition

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 Europe 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) as those „that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised" (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 (2016), 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" (EU, 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 OECD already in 2009. 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 on optimal use of resources and the production of primary raw materials from renewably sourced feedstock.	2016
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

2.2. Bioeconomy strategies across the globe

2.2.1. Europe

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
    - mobilise stakeholders in developing and deploying sustainable bio-based solutions
    - launch a €100 million circular bioeconomy thematic investment platform
    - analyse enablers and bottlenecks for the deployment of bio-based innovations

- promote and develop standards
- facilitate the deployment of new sustainable biorefineries
- develop substiutes 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 February 2022.

Table 2 Bioeconomy strategies in the EU as of March 2018 and February 2022

Strategy type	March, 2018	February, 2022
Dedicated bioeconomy strategy at the national level	Finland, France, Germany, Ireland, Italy, Latvia, Spain	Austria, Finland, France, Germany, Ireland, Italy, Latvia, Portugal, Spain, the Netherlands
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
Other policy initiatives dedicated to the bioeconomy	Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Poland, Romania, Slovakia, Slovenia, Sweden	Belgium, Bulgaria, Estonia, Denmark, Slovenia, Romania
Other related strategies at national level	Cyprus, Greece, Portugal	Cyprus, Greece

Source: European Commission's Knowledge Centre for Bioeconomy

2.2.2. 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 U.S. 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 U.S. 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 Strategy in 1998 (CBAC).

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.

2.2.3. 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 "realise the most advanced bioeconomy society by 2030" achieving 92 trillion yen (US$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 (UN ECLAC, 2019). 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.

2.3. Circular Economy

2.3.1. Circular economy concept 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 in an industrial process materials constantly circulate (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

2.3.2. 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).

2.4. 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 (CFS) “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 Organisation (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).

EUROSTAT (2020) estimated 127 kg of food waste per inhabitant in the EU in 2020. This consists of 70 kg of household waste, 23 kg of food products and beverages manufacturing, 14 kg from primary production, 12 kg of restaurants and food services waste, and 9 kg of the waste produced in retail and other distribution of food. Despite the WFD (2008) recommendation to prefer prevention in the five-step Waste Hierarchy (prevention-reuse-recycle-recovery-disposal), the amount of generated municipal waste 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).

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).

2.5. 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). 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.

2.5.1. 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 and water usage;
- less greenhouse gas emissions;
- higher feed conversion efficiency;
- ability to transform low-valued biowaste into high-value products;
- ability of some insects to be used as feed and food and to replace 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.

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 seven 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*) and house cricket (*Acheta domesticus*). First this protein source was allowed as a feed for aquaculture in 2017. Later live insects were also permitted as poultry feed. However, full approvement of the insect protein as a poultry and pig feed came in August 2021 (Montanari et al., 2021). On the other hand, 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 is growing every year. These enterprises expect that in the near future 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).

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® (2019), the global edible insect market only will grow at a Compound Annual Growth Rate (CAGR) of 24.4% from 2019 to 2030 to reach USD 7,956.7 million. 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 34.7% and USD 3.4 billion increase at a CAGR during the forecast period of 2020 to 2030 (Meticulous Research®, 2021). 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.

2.5.2. 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). 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 for the production of 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 is follows the circular economy principles.

3. Methodological framework

Firstly, current Bioeconomy strategies in the EU Member states and the rest of the world were reviewed. Secondly, assessment of the current state of academic and business development in the field of BSF rearing was performed in the EU and EFTA Member states. Obtained data were statistically analysed. Different forms of generalized linear models are widely used in analysing count data. For purpose of this study Poisson regression model was chosen to analyse the relation between number of publications, patents and companies in the field of BSF rearing in Europe. The Poisson regression model is one of the forms of generalized linear models which is widely used in analysing count data (Dean and Lawless, 1989).

3.1. Bioeconomy strategies review

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.

3.2. Statistical analysis

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 analysed via the Statistica 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 analysed via the Poisson regression model. 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 analysed in the same manner, picking the latter as a response variable.

3.2.1. 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 (Great Britain, 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 on 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).

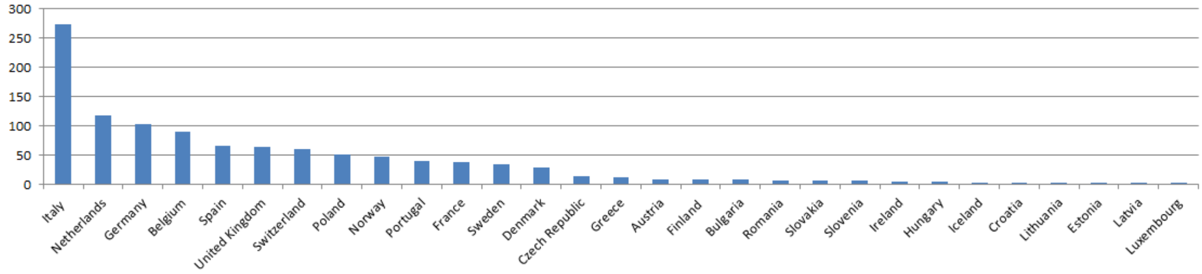
The quantification of companies was conducted via: 1/ Google search engine (Alphabet, Inc., USA); 2/ LinkedIn a social media platform for business; 3/ literature (Wang and Shelomi, 2017; Skyquest, 2022; Grossule et al, 2023) and 4/ International Platform of Insects for Food and Feed (IPIFF). The year 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).

4. Results and discussion

4.1. Main hypothesis

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

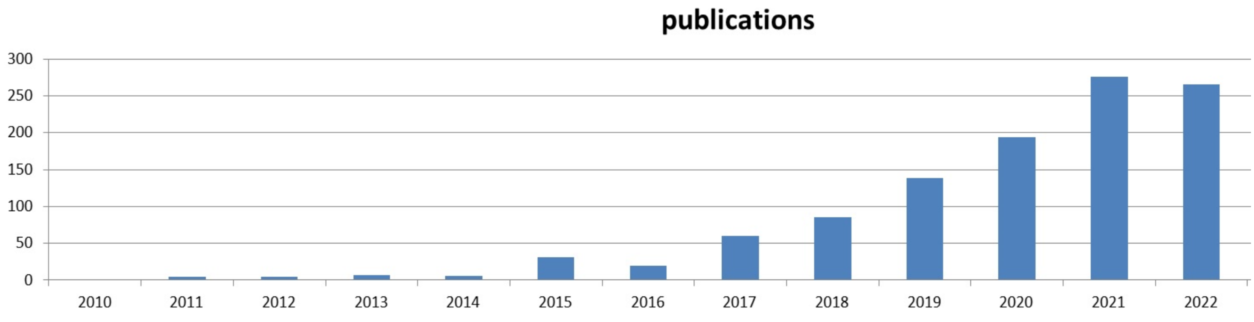
Fig. 1 The list of countries in the EU + EFTA with scientific records in the field of BSF



Source: Web of Science

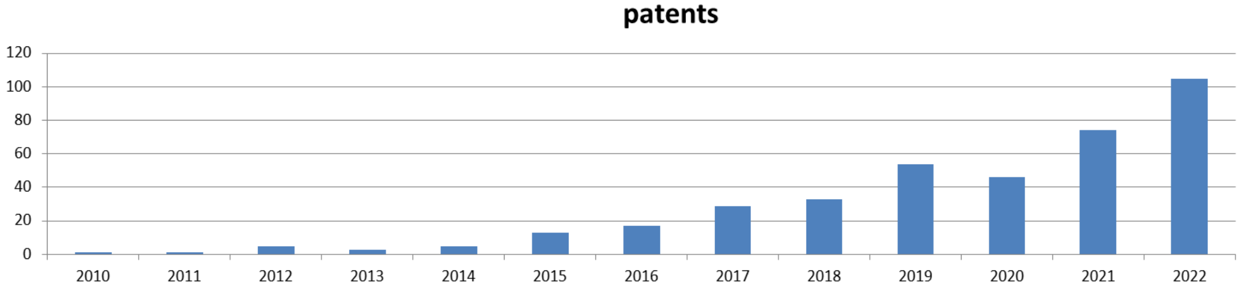
As can be seen from Figure 1, scientific interest in BSF in Europe began in the second decade of the 21st century and was rapidly increasing since then. Figure 1 shows that among the EU and EFTA Member states the leader in publishing about BSF is Italy, followed by Netherlands and Germany. However, it 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.

Fig. 2 Publications number development in the EU + EFTA during 2010 - 2022



Source: Web of Science

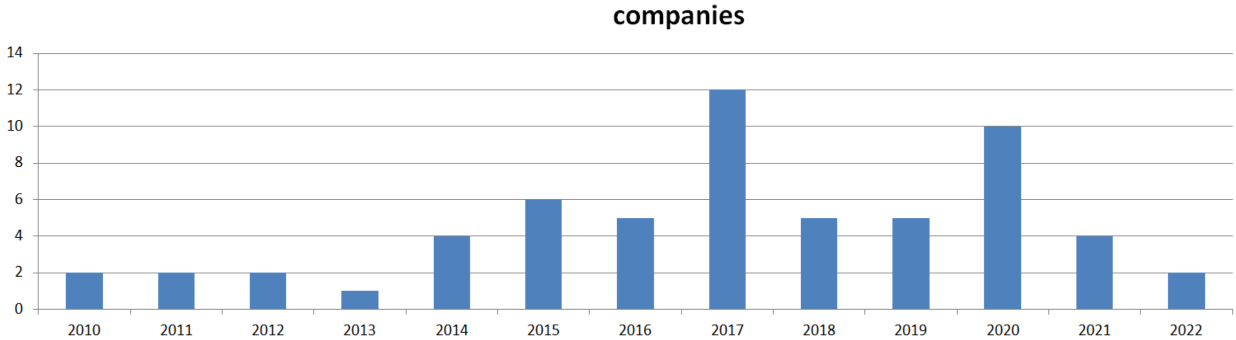
Fig.3 Patents number development in the EU + EFTA during 2010 - 2022



Source: Google Patent database

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 Figure 2 and Figure 3.

Fig.4 Companies number development in the EU + EFTA during 2010 – 2022



Concerning the number of companies, Figure 4 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 3.2.1., for instance, due to the lack of a website in the English language. Nevertheless, all big 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).

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 3. The coefficient of almost 0.95 showed a significant relationship between the number of publications and the number of patents which is not surprising. Results of the Poisson regression (Table 4) 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 5), which is less than the significance level of 0.05 and thus is considered statistically significant (Myers et al., 2010).

Table 3 Spearman correlation between numbers of published publications, patents and established companies and 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

Table 4 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

Table 5 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

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 main hypothesis 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).

4.2. Sub-hypothesis

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 6). 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 utilisation 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 6 The list of countries with established Bioeconomy strategies on the national level and with the highest number of publications and companies.

	Number of publications	Number of companies	Major players
Italy	274	4	BefBiosystems, BugsLife
Netherlands	118	8	Protix B. V., InsectEngineers
Germany	103	9	Hermetia, Illucens GmbH
Spain	65	4	BioflyTech, EntomoAgroIndustrial
UK	63	6	Better Origin, Beta Bugs, Entocycle
France	38	8	Ynsect, NextProtein, Mutatec, InnovaFeed

In Table 6 were included 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 on the national level. However, the rest of the member states with dedicated Bioeconomy strategy on the nanional level are also worth to mention. For example, Austria and Finland with 3 BSF companies each or Portugal with 39 publications.

Table 7 Numbers of publications and companies in the member states with dedicated Bioeconomy strategy at national level under development or other policy initiatives related to the bioeconomy.

	Number of publications	Number of companies	Major players
Belgium	89	1	
Poland	51	2	HiProMine S.A.
Sweden	34	1	
Denmark	29	2	
Czech Republic	14	0	
Greece	11	0	
Bulgaria	8	1	Nasekomo
Romania	7	1	
Slovakia	6	0	
Slovenia	6	0	
Hungary	4	2	
Lithuania	3	1	

Croatia	3	1	
Estonia	2	0	

As can be seen from Table 7, 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 companies with the little influence on the market. Noteworthy are HiProMine S.A. located in Poland and Nasekomo in Bulgaria, both can be considered as a major player.

With regard to 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 sub-hypothesis as confirmed. However, further research is needed to investigate wether 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.

5. Conclusions

Based on the results of this research it can be concluded that biowaste processing using Black Soldier Fly 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 the ones with the cutting-edge technologies ready to produce high quality protein for animal feed and other value-added products. Desperate 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 like less greenhouse gas emissions, better food waste/biowaste management practices, waste valorisation, job creation in rural areas, less dependence on imported animal feed, fertilizers, etc., and above all, 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.

Acknowledgments

The author would like to express a gratitude to her supervisor doc. Ing. Eva Cudlínová, CSc. and also to family members for the support during the research.

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