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Role of bioeconomy towards the realisation of Sustainable Development Goals

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1. INTRODUCTION

In the 21st century, we are facing many global economic challenges. The big question, how we can save the Earth and humankind if the mineral and some biological resources run out or just not get them from other countries, has more relevance today than before. Constant challenges for development are a stress for all living things. Thus, we need to change our attitude and processes to be more sustainable and use the biological origin materials rationally. To keep the economy and the Earth sustainable for the next generations, we need to analyse the currently available bioeconomy system. My thesis topic is the role of bioeconomy towards the realisation of Sustainable Development Goals, because the bioeconomy requires increasing attention at regional and global levels. Its importance is unquestionable as the worldwide crisis of available raw materials (e.g., feedstock) is one of the biggest challenges of humankind. In our age, some scientists consider the bioeconomy as a solution to the growing environmental issues. For many years, the effects of climate change and the lack of resources have been threatening us, but now, it is a daily threat we constantly experience. Climate change and other global happenings already have a geographical and spatial effect on the agroecology system and severely influence all economic sectors. The seriousness of these problems is indisputable, as we are daily experiencing this affect on our “skin" (e.g., quality of food).

Even though developed countries get almost all biological origin products more easily and quickly than developing countries, there is no country in the world that could not feel the effect of the stalling of the global supply chain, no matter if there are already tested processes or policies created to avoid these kinds of situations. That is why the United Nations’ Sustainable Development Goals (SDGs) are getting more critical. The 17 goals that should be reached by 2030 and 2050 (the strategic ones) are closely linked to the bioeconomy (e.g., hunger eradication, life below water and life on land). Nowadays, we declare the bioeconomy as the newest and most sustainable economy. However, many people think this is a new approach to developing countries’ economies, it is the oldest one we know. Human activity has been intrinsically linked to using materials of biological origin for thousands of years. Throughout the evolution of the human species, we can observe that the various human needs were initially met using biologically derived materials. The first human need is to survive, i.e., eat food which is naturally of biological origin. Later on, the safety as a human need was also met by biological materials, such as wood, fur for clothing and leather for footwear. Therefore, we can say that using biologically derived materials is an integral part of human development. We can clearly see that biologically derived materials have been inseparable from humans since prehistoric times.

However, the empty regions have rapidly urbanised from the Stone Age until today. New techniques and phenomena control the world. The importance of agriculture has become more and more crucial. One of our important present-day phenomena is globalisation. It is not new, but it is less old than the bioeconomy. With the spread of money and trade exchanges, the distance between nations and continents has disappeared, and almost everything is now available to everyone. If a country needs relief, another can send it there from the other part of the planet. In the 21st century, plenty of markets are built on globalisation, and barter trade is one of the most essential cross-border transactions between countries. There are so many articles on the topic of globalisation, so I will not explain more detail about it here, just mention its importance for the whole world. My dissertation will emphasise the import and export transactions as input-output analysis between the countries. Using biological origin materials that have been produced in one country and using them in another raises tons of questions, and for the answer, we need to examine it by a multidisciplinary approach. I am using economic-, network and time series analysis and statistical models to clarify the effect of the usage of bio-based materials.

Production, consumption, and waste management. These are terms that all manufacturers must clarify and create a strategy that can be sustainably managed. Sustainable agricultural production is pivotal for maintaining productive land and ensuring food security. However, reaching sustainability in agriculture is challenging due to certain factors, such as climate change, economic constraints (e.g. subsidies), and the need for effective waste management. Traditionally, agricultural production used non-renewable resources, which led to overexploitation and significant waste generation. The extraction rate of natural resources has increased continuously since 1990. And it necessitates a shift towards sustainable development models that produce more food and energy with fewer fossil fuels and minimal waste.

The bioeconomy's key point is the strategy. It is essential in this sector as it offers a detailed plan for attaining sustainable, resilient, and inclusive expansion. By implementing a strategic plan centred on innovation and knowledge, individuals involved in the bioeconomy industry can capitalise on the advantages of sustainable biological resources and address significant environmental, social, and economic challenges. Strategically, the bioeconomy will enhance efficiency and maximise resource utilisation. It is helping protect communities against economic downturns by fostering local industries that are self-sustaining and renewable. A well-defined strategy enables governments and businesses to bolster bioeconomy sectors with firm competitive edges, establishing regions or countries as frontrunners in the global bioeconomy market. The bioeconomy strategy provides a sustainable growth vision that can adapt to changing circumstances like new technologies, economic shifts, or environmental challenges. This vision sets the foundation for continuous improvement, encouraging flexibility and responsiveness to new developments in bio-based resources.

The use of different agricultural and biological materials in variant sectors of the economy has changed significantly in recent years and decades. Still, in the longer term, it can be said that the use of biological materials for non-food industrial purposes is of significant importance for developed countries, and how to achieve the so-called circular economy, i.e. how to reintroduce various biological and non-biological materials into the social and economic development cycle with as little waste and energy consumption as possible. This leads to the development of a circular economy. It cannot be emphasised enough that the concepts of circular economy and bioeconomy are not synonymous in any way, as circular economy encompasses a much broader range of issues, which will be discussed in more detail in the literature review later.

The 21st century is the age of consumption. Consumption is the other cornerstone of agriculture and sustainability. Approximately a third of the world's food is wasted, which jeopardises the sustainability of global resources, food security, and the world's water percentage. Adequate consumption management can improve wealth (on the land and in the water, equally), propose sustainable agricultural practices, and help adapt to accept the impacts caused by climate change. However, fair production and fair consumption are not available for everyone. There are still many people in the world who are starving or almost starving. Until the UN solves this problem within its SDG program, decent livelihood and consumption will be impracticable relatively. However, using biologically derived materials in the food and pharmaceutical industries is essential, and these products are an integral part of everyday life in developed societies.

Waste management is another pillar of sustainability and the bioeconomy. The agricultural sector is one of the big sectors that generates millions of tonnes of waste annually. Significant portions of these are discarded without treatment. Sustainable waste management involves recycling, reusing, and reducing waste, which can mitigate environmental impacts and enhance the profitability (upcycling and value addition, where waste is transformed into high-value products beyond traditional compost or fertiliser) of the food supply chain. For example, converting agricultural waste into organic fertilisers through composting can improve soil fertility. Plus, integrating waste management into the food-water-energy nexus can optimise the use of agricultural and organic waste streams, converting them into energy or value-added products (biomass).

I have added one weightier factor to the circle of bioeconomy. Money. It is well known that since the appearance of money in the world, its importance has increased day by day. Sustainable production is not easy, and it never was. The new technologies need more money, and new regulations and taxes have been imposed on all the actors within the supply chain. Producing environmentally friendly and optimising all available resources is expensive. Manufacturers indirectly pass these prices on to the consumer, making products more expensive. In today's inflationary world, it is tough for the average consumer to be committed to sustainability and the bioeconomy because of the difficulties of living. But there is some hope. Slowly but surely, the number of people consciously buying food or other products from sustainable sources is increasing.

Here, I would like to highlight the impact of the bioeconomy on communities. A bioeconomy with a holistic approach requires a knowledge-based society. Innovation has become part of everyday life, and available resources and technology need to be coordinated at macro and micro levels to achieve sustainable, robust and green growth. Now, in the Fourth Industrial Revolution, when digitalisation and artificial intelligence, biology, chemistry, and physics need to be managed in a harmonised way together, this seems hyper-complex. Not everyone can do everything, and our lives cannot be entrusted entirely to artificial intelligence, however simple it might be. Educating the population is essential for the setup, continuous management, maintenance and development of bioeconomy processes. In addition, there are other benefits to society, such as job creation and economic growth, environmental awareness, improved food security systems and supply chains, use of renewable energy sources, as well as reducing the impacts of climate change, boosting local economies and stabilising geopolitics, while also shaping and strengthening social cohesion and community awareness.

My personal motivation to work on this thesis is very simple. The change in agriculture and the whole economic system. I have gluten intolerance, so I must read all the ingredients on the packages, whether it is food, drink or medicine. It is more complex to analyse from a holistic perspective the whole bioeconomy, and the operation of the intercontinental chains (food, supply and value chain) impresses me. In 2024, in the middle of tons of problems (economic and social), I still believe that the operation of the import-export markets and their sustainability is fundamental, not just for myself or others who have any intolerance or disease, but for all people. When I started working on my dissertation, I settled on seven hypotheses that I am answering in my work. In my thesis, I will present how the bioeconomy can positively impact the environmental friendliness of various economies and carbon dioxide emissions. I will also show what the bioeconomy system looks like in several countries and which sectors are involved in it, apart from agriculture. Because the bioeconomy is not just an economic approach, it must be a new life approach.

2. RESEARCH GOALS AND HYPOTHESES DEVELOPMENT

My hypotheses are focused on the impact of the bioeconomy in several countries and economies. During my research, I realised that many national and international studies concerning the size of the bioeconomy sectors, but many of them were focused just on some components of the sector (e.g. food industry). This approach does not offer the possibility of getting a more holistic picture, analysing the various components of the bioeconomy sector as a part of a larger, national or supra-national unit. With this research, my aim is to help enhance the resilience, sustainability, and economic contributions of the bioeconomy in the V4 countries (Poland, Hungary, Czech Republic, and Slovakia) by analysing its value chain, trade flows, and environmental impact. If its share in GDP can be increased while reducing CO_2 emissions, supporting geopolitical stability, and promoting biodiversity through diversified bio-based industries. This will involve identifying strategic areas for investment in bioeconomy sectors, fostering innovation in sustainable practices, and encouraging the cultivation of diverse plant species to boost regional economic growth and environmental sustainability.

2.1. Research goals

The introduction section presents the importance of topics and shows the reason of my dissertation theme. Although there have been a few studies in recent years that examine the place, position and role of the bioeconomy in the macroeconomy and the way it is reflected in the economies of different countries, but in general, comprehensive works that are not limited to a single country (e.g. Netherlands, the Czech Republic, Poland), not just one region (e.g. V4 countries or Western Europe), but the bioeconomic performance of the various major countries of the world, and to consider it in its complexity and to examine these issues in a clear and transparent way. However, such correlations and studies have not yet been found in the literature. **Thus, my research can be considered as a gap-filling study in the context of the bioeconomy as a whole, not only for one country or region, but in the context of different countries.** Meanwhile, **in my research, I try to combine spacious-temporal, i.e. taking into account both spatial and temporal processes, longitudinal, i.e. taking place over time, and transversal, i.e. cross-sectional studies**. By this, I mean that I am not just taking a simple snapshot of the relative and absolute importance of the bioeconomy in different national economies. I do not only want to establish indicators of the absolute and relative importance of the bioeconomy in terms of value-added and total gross value-added in the economies of different countries but also to examine how the bioeconomy has changed in different countries and whether these interactions show any correlation between them. **I look at both cross-sectional and longitudinal relationships.**

2.2. Hypotheses development

Research questions

In the framework of my thesis, I searched for responses to several questions. Based on a survey of the current literature, all of these are relevant to a better understanding of complexity in the global, European, and Central-East European development of bioeconomy.

*These **research questions** are as follows:*

RQ1: How can be characterised the European Bioeconomy in the context of Global bioeconomy systems?

RQ2: How can contribute the modern logistical planning system to the decreasing of the environmental burden of logistical operations in the supply chain of products of the bioeconomy?

RQ3: How can be characterised the importance of various parts of bioeconomy in the national (Hungarian) and East-Central European context?

RQ4: What is the role of the bioeconomy in the value chain in the V4 counties, taking into consideration the foreign trade among these countries?

RQ5: How will the structure of the V4 countries change when the share of biological materials is increasing in the input of such branches of the national economies, which currently apply a relatively low quantity of biological materials?

RQ6: A fundamental problem of bioeconomy is the stable supply of raw materials. How can be determined such a portfolio, which is capable to satisfy the demand of high profitability and low risk in agricultural production sphere?

RQ7: How can help the computer-based calculation methods and simulation systems the economic planning of systems, aiming at non-food use of biological materials?

Based on these questions, in line with the relevant literature, I have formatted the system of ***hypotheses*** as follows:

H1: The European bioeconomy system plays an above-average role in the acceleration and multiplication of economic development, even in the most developed states.

H2: The combination of modern methods of logistical planning can efficiently decrease the environmental burden caused by the transportation of products of bioeconomy.

H3: The East-Central European countries can be characterised by a relatively developed agriculture, which is why the role of the bioeconomy is highly important in the national economies. The bioeconomy systems are extremely complex and open ones, which is why they can exercise a positive effect on general economic development based on their accelerative and multiplicative effects.

H4: There is intense cooperation and collaboration among the bioeconomy subsectors among V4 countries based on geographical proximity and utilisation of possibilities of the optimal division of work.

H5: Based on their historical traditions, the non-food use of agricultural products is widely applied, e.g. in pharmaceutical or textile industries.

H6: The adverse consequences of climate change exercise a negative effect on the stability of the income–generating capacity of the Hungarian bioeconomic system, but portfolio optimisation is a suitable method for finding the optimal land use solution structure. There is a feasible possibility to find an optimal balance between the production value and risk in setting up the portfolio of agricultural production systems.

H7: The non-food use of agricultural products can be an important driver of economic development, especially in the less favoured areas of Hungary.

3. LITERATURE REVIEW

3.1. The concept and development of the bioeconomy

HARARI (2015) wrote in his book that around 70,000 years ago, the cognitive revolution boomed and followed the agricultural revolution later. At that time, the ancestors did not have any special tools for farming or fishing, and they used plain tools like flint and lance. However, later in the development, we have seen increasing use of artificial, industrially produced materials, such as the use of coal from mining for energy production or the application of carbon-hydrogen based tools for processing plastics, for example, which have been used in recent years and decades for packaging, clothing and footwear. Bioeconomics, the science of the widespread use of biological materials, is therefore not essentially new, but the concept has only emerged in recent decades in management science and economics literature. The concept itself is extremely heterogeneous, and there is much debate about its meaning because, ultimately, all human activity is based on the productive activity of a biological materials (as the 19th century German philosopher Marx stated: value can only be produced by labour), and at the same time, the whole of economics is designed to maximise the welfare of a biological material and to satisfy the needs as far as possible.

3.1.1. The origin of the bioeconomy

According to FINLAY (2003), a new movement emerged in the 1920s and 1930s to develop a new industry called "chemurgy" in the US. The aim was to create agricultural-based industrial products. This was the foremost groundwork action that planted the seeds of the modern bioeconomy. The definition of "bioeconomy" appeared for the first time at the end of the 1990s. In connection with the foregoing, we can say that bioeconomy is an old-new concept that has been defined by ENRIQUEZ (1998) at the AAAS (American Association for the Advancement of Science) Meeting that "all economic activity derived from scientific and/or research activity focused on understanding mechanisms and processes at genetic/molecular levels and its application to industrial process". This was one of the initial formal applications of the concept associated with the bioeconomy within academic contexts. The next huge milestone in the evolution of the bioeconomy concept was the issuance of Executive Order 13134, marking the introduction of bio-based economy concepts and initiatives by the U.S. government (UN, 2024).

3.1.2. The evaluation of the bioeconomy

As the new millennium began, new concepts and more ideas were created for the bioeconomy. In 2001, JUMA and KONDE from Harvard University presented a report named "The New Bioeconomy" at the United Nations Conference on Trade and Development held in

Geneva (JUMA & KONDE, 2001). Although the report did not offer a standardised definition, it addressed the effects of contemporary biotechnology and the markets it influenced. In 2002, Chinese researchers conducted a study and released a standardised definition indicating that the bioeconomy was an economy focused on the research, development, and application of life sciences and biotechnology, built upon biotechnology products and industries, and represented a new economic model aligned with the agricultural, industrial, and information economies. This definition encompasses both primary meanings and broader interpretations and stands as one of the earliest recognised standardised definitions of the bioeconomy found.

In 2003, management experts in biotechnology from the Chinese Ministry of Science and Technology proposed a definition of bioeconomy, stating that it was an economy founded on biological resources and biotechnology, emphasising the production, distribution, and utilisation of biotechnological products (WANG, 2004). During that period, the OECD and the European Union outlined the bioeconomy, with the EU describing it as a bioeconomy driven by knowledge. The concept of bioeconomy—often called the “bio-based economy” or “knowledge-based bio-economy” (KBBE)—is characterised as an economy that relies on renewable biological resources, such as those derived from plants and animals, as the essential elements for materials, chemicals, and energy. This kind of economy has the potential to satisfy various sustainability criteria concerning environmental, social, and economic aspects, provided it is designed and executed thoughtfully.

Despite efforts to achieve sustainability, the key global biophysical indicators, such as climate change and biodiversity loss, are getting worse. In his book, ATTENBOROUGH (2020) concludes that we live too comfortably and contentedly in our current lives until we have a solid reason to break our habits and make changes to create a more liveable planet. The indicators currently on the political agenda propose new ways of structuring societies and economies to facilitate the transition to a more sustainable way of life within geophysical and social boundaries (FISCHER et al., 2007).

3.2. The essential part of the bioeconomy: Biomass

The concept of the bioeconomy has been developed and promoted as a new sustainable and knowledge-based economic model with renewable biomass at its core (SILLANPÄÄ - NCIBI, 2017). However, there is no significant difference between bioeconomy and the bio-based economy and these two terms have been used in the literature interchangeably (STAFFAS et al., 2013). Although the European Commission has defined biomass: "Biomass is organic, non-fossil material of biological origin (plants and animals) used as a raw material for the production of biofuels" (EUROSTAT, 2023). The European Parliament and the Council (2018) defined biomass earlier as "the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin" (Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources). ALBRECHT et al. (2012) categorised biomass resources into three groups: primary (extracted directly from the resource), secondary (extracted from the processing of primary biomass resources) and tertiary (consumer residues, used vegetable oils, animal fats, packaging waste, etc.).

Biomass is now projected to play an important role in meeting the global climate targets set in the Paris Agreement (CREUTZIG et al., 2015, DAIOGLOU et al., 2019, ROGELJ et al., 2018, ROSE et al., 2014). The European Union implemented the biomass to the Renewable Energy Directive in 2009, and later, in 2018, adjusted it with forest biomass. (EUROPEAN COMMISSION, 2023) According to LEWANDOVSKI et al. (2018), the bioeconomy, often referred to as the so-called biobased economy, involves the production of biobased resources and their conversion into food, feed, bioenergy, and biobased materials. BELL and his colleagues (2017) suggest that certain biomass resources, such as waste, are still underutilised. SHEPPARD and his colleagues (2011) also point out that more marginal land is being used for biomass production. These marginal lands are often valuable for natural functions such as biodiversity. More research and technological development would be needed to exploit this biomass potential in a sustainable way, for which innovation is an essential factor. This value chain includes the primary production of bio-based resources and the transformation of these products into value-added products through processing and sale on the market.

3.2.1. The evaluation of the bioeconomy definition during the years

VENKATRAMANAN and his co-authors (2021) consider that, indeed, biological resources, as feedstock for biotechnological and microbiological processes, generate a wide range of ecosystem services and stimulate the bioeconomy. According to DUQUE-ACEVEDO et al. (2020), the agri-food industry is the world's largest biological sector, producing the largest amount of biomass, and thus has recently become a major input for the bioeconomy over time. Agro-economics was basically concerned with examining the economics of agricultural and food production and the role of agriculture and the food industry in the national economy in its various contexts. When macroeconomic analyses were concerned, they usually started from Leontief's input-output matrices and carried out some analyses based on them. A more significant step forward was the emergence in the 1970s of the concept of agribusiness, which sought to include not only agriculture and the food industry but also agriculture and the related industries (back-industries), so-called related and service industries. Examples of these were the manufacture of agricultural machinery, fertilisers, food machinery and food packaging. It follows that this was a much broader interpretation of those economic activities outside agriculture and the food industry that could be linked in some way to the supply of food and the development of food supply in other economies. In the United States of America in particular, this research has been a major success and has generated a significant response from researchers in the field. However, bioeconomics is new in many respects. GAWEL and his colleagues (2019) agreed that the sustainable bioeconomy needs three requirements:

1. Viable of the resource base,
2. Sustainability in production and products (from the producer and the customer side),
3. Circular material movements.

The sustainability of the bioeconomy can be achieved by applying the principles of circularity. A sustainable bioeconomy is a paradigm shift from a fossil fuel-based economy to a bio-based economy, driven by a focus on sustainability, resource efficiency and a circular economy. But some authors consider bioeconomy to be "inherently circular" (CARREZ and VAN LEUWEN, 2015, SHERIDAN, 2016). However, as BUGGE et al. (2016) have pointed out, there seems to be little consensus on what the bioeconomy actually means.

Like all modern new sciences, bioeconomics is at a stage today where even the basic concepts and terms are not clearly understood. That is why there are so many different definitions of bioeconomics. There are many definitions of bioeconomics that have emerged in recent years, and these vary considerably in terms of the depth and breadth of the concept. Bioeconomy is a relatively new approach to the description and analysis of socio-economic systems, that goals need more attention (MAKSYMIV et al., 2021). Since its origin, a mushrooming of definitions can be observed (MACIEJCZAK and HOFREITER, 2013). The bioeconomy is a central part of European policy, that's why from our point of view, the definition adopted by the EU is a question of crucial importance. The EUROPEAN COMMISSION (2020) defines the bioeconomy, as ***„using renewable biological resources from land and sea, like crops, forests, fish, animals and micro-organisms to produce food, materials and energy"***, and this is what I accept as bioeconomy definition for my dissertation. This definition seems to extend the concept of bioeconomics quite broadly. But, of course, there are also more restricted interpretations of bioeconomics. FRISVOLD et al. (2021) think that the bioeconomy lacks a precise definition, as various perspectives exist regarding this relatively new concept. Different experts look at it from various angles, making it a fascinating but complex topic. For instance, BUESO (2017) emphasizes the crucial role of biotechnology in shaping this field. At the same time, PHILP (2013) highlights the importance of biological resources and ecological factors.

A number of studies, including a notable one by DAYSTAR et al. (2018), explore a range of topics related to the bioeconomy. Another typical example of this is the definition of bioeconomy developed by MORRISON and GOLDEN in 2015, whereby bioeconomy includes agriculture, forestry, the use of forest products, the use of natural fibres such as cotton, the production of bio-based engine propellants, the use of bio-based chemicals, enzymes, materials created by combining bio-based feedstock and plastics, and above all packaging materials. But this concept excludes from the scope of bioeconomy conventional agricultural production, the basic aim of which is to produce food, feed and energy from biological sources, showcasing just how diverse—and sometimes confusing—the bioeconomy can be.

The ideas of the bioeconomy range from those closely linked to the increasing use of biotechnology across sectors (WIELD, 2013) to those that focus on the use of biological materials (MCCORMICK - KAUTTO, 2013). Others push for a transition towards locally embedded eco-farms that use local best practices as a starting point (MARSDEN, 2012). Thus, when describing the bioeconomy, it has been argued that its meaning continues to be "a stream" (PFAU et al., 2014, PÜLZL et al., 2014, p. 386) and that the knowledge-based bioeconomy can be characterised as a "master narrative" (LEVIDOW, BIRCH, and PAPAIOANNOU, 2013, p. 95), which is open to very different interpretations (BUGGE et al., 2016). WYDRA (2020) wrote that the bioeconomy represents a new industrial approach designed to tackle major societal, environmental, and economic challenges, including resource depletion, food insecurity, and climate change. There are three major aspects to reconcile the different perspectives on the bioeconomy:

1. **the OECD and the US focus on processes that transform raw materials into valuable products using biotechnology and life sciences,**

2. **the European Union's emphasis on the use of biomass resources such as biological resources and waste as food, feed, energy and industrial products, and**

3. **the focus of environmental scientists and NGOs on sustainability and planetary boundaries** (KLEINSCHMIT et al., 2014).

Previous research have examined all three aspects of sustainability for a considerable period, either in a comprehensive manner (EGENOLF and BRINGEZU, 2019) or by analyzing them individually—environmental (BRIZGA et al., 2019), socio-economic (JAROSCH et al., 2020), and economic environmental (JANDER et al., 2020).

While the first European Bioeconomy Strategy focused on bioeconomy research and innovation to address major societal challenges (EUROPEAN COMMISSION, 2012a, 2012b), the updated European Bioeconomy Strategy (EUROPEAN COMMISSION, 2018a) emphasises the need for sustainability and circularity in the bioeconomy. The sustainable bioeconomy "can turn bio-waste, residues and discards into valuable resources and can create the innovations and incentives to help retailers and consumers cut food waste by 50% by 2030. (EUROPEAN COMMISSION, 2018a). In the future, the European Union and the individual Member States can formulate a comprehensive bioeconomy strategy in line with their current documents, believe OLÁH et al. (2021). ESCOBAR and LAIBACH (2021) in their article find that both bioeconomy and circular economy strategies in the European Union will promote the future of circularity to increase resource efficiency and energy security. Developing bioeconomy can enable both economic growth and environmental benefits through the conversion of renewable biological resources (DEVANEY and HENCHION, 2018, LOKKO et al., 2018, PHILP, 2018, DUPONT-INGLIS and BORG, 2018).

According to CALICIOGLU and BOGDANSKI (2021), to achieve economic growth, access to fundamental services must be ensured, and sustainable consumption must be encouraged. ELHEDDAD et al. (2020) argue that achieving economic growth in the context of energy transformation is the best way forward in developing sustainable, less polluting economies. In their work, DOU and SARKIS (2018) believe that the main reason for greening the supply chain of companies is to address the environmental difficulties caused by the industry and its operations. Environmental challenges can occur in different atmospheres, such as air, water or land, and at different levels: global, regional and local, for example: global warming (climate change), deforestation, water pollution and waste disposal. According to LANDRIGAN and colleagues (2017), environmental pollution caused more than 9 million premature deaths in 2015, three times the number attributed to AIDS or tuberculosis in the same period. In his presentation in Gödöllő, BAKHSI (2022) said that **we are exploiting the planet to the limit**: nature provides us with services worth at least 125 trillion dollars (plants, wildlife, air purification), three times GDP, 50% of global GDP is at very high or medium risk, and the damage that climate change is causing is becoming increasingly challenging to remedy (or irreversible), costing at least 300 billion dollars a year.

Beyond these, there are physical, reputational, regulatory and market risks, which also have a major impact on our environment. We must also remember that there is no other "system" on Earth like nature, which has been able to maintain and renew itself for thousands of years. KIRCHER (2019) in his work states that two decades ago, increasingly scarce fossil resources were seen as the main driver of resource exchange, but since then the ecological impacts of the current economic system have come to the foreground. LIOBIKIENE et al. (2020) point out that Lithuania, Estonia, Hungary, Austria, the Netherlands, Austria and the United Kingdom are countries where **specific bioeconomy strategies have been adopted at the national level.**

3.2.2. New field needed: the macroeconomics of bioeconomics

From my point of view, it is more appropriate to refer to the broader concept of biological material use. It is difficult to define in practice how far food production goes and where the non-food use of substances of biological origin begins since some agricultural products are often the same. The product can also serve as a raw material for the production of agricultural products.

Thus, **there is not necessarily a sharp distinction between the use of biological materials for food and other purposes**, but it should also be recognised that a significant proportion of the by-products of the **use of biological materials for food industrial purposes can serve as input** for the use of materials in various other areas. Although JÁMBOR and TÖRÖK (2012), in their congress summary argue that the study of bioeconomics does not include any aspect of pharmaceutical production, **which is**, in my opinion, **a misconception if bioeconomics is considered in a broader sense**. If we look at bioeconomy in a broader sense, it is important to consider that different food and non-food uses are addressed separately and distinctly. It is also very important to see that the transition between biological and non-food uses is relatively free and wide open, depending on the current economic policy situation. This is also backed up by PUTTKAMMER and GRETHE (2015), who argue that environmental and agricultural economics is increasingly focusing on the centrality of social (non-scientific) perceptions in decision-making processes in the context of the bioeconomy.

At the same time, there are many questions that have not been addressed by science so far but which would be very important to understand how the use of bio-based materials will be different and how it will be qualitatively new for the structure of the economy as a whole. So, the use of biological materials means a change in the whole structure of the economy. Many situations may arise in which a radical rethinking of what is known about the functioning of the economy is needed in order to review the structure of the economy. Hence, **efforts to achieve a bioeconomy must consciously go beyond approaches that seek only a relatively one-sided response to different technological alternatives. Research is needed that also provides answers to the question of how different bioeconomic solutions and changes in the structure of the economy that build on the extensive application of bioeconomy induce transformations throughout the year and how these transformations influence macroeconomic processes.**

As a consequence, a **new field of study must be created: the macroeconomics of bioeconomics, which is concerned with how bioeconomic processes transform and modify macroeconomic processes and the extent to which they contribute to their modification**. More broadly, a radical transformation of production and consumption systems. This issue has received relatively little attention in recent years. The bulk of research has been concerned partly with technological developments related to the bioeconomy and partly with the predominantly microeconomic differences in how the evolution of biological systems is examined in the context of a product or product-market combination. Overall, I concluded that **research on the concept of bioeconomy has become of particular interest in recent years. There is a broad social consensus that developed countries should move towards a bioeconomy or circular economy, but the deeper reasons for this and its effects on the structure of the economy have not yet been investigated.**

3.2.2.1. Results of economic and econometric research in the field of bioeconomy

The first statement in the situation analysis which part of the research is based on is that world agricultural production is causing significant environmental pressures and that this is contrary to the long-term sustainable development goals, including those set by the United Nations. Before going into an analysis of this, it should also be noted that the technical and technological progress in EU agricultural production has enabled an unprecedented abundance of food supply and an adequate and safe food supply in Europe. This is illustrated by the fact that, for example, the proportion of French households spending on food has halved in half a century, from 30% to 15%. Today, a medium-sized Hungarian supermarket offers as much variety as the entire Hungarian food industry did thirty years ago. An EU-wide system of food safety control and regulation is in place, the number and proportion of food safety inspections are steadily increasing, and food-borne illnesses have decreased.

The bioeconomy can potentially improve the resilience of bio-based systems, food production, and energy systems in the aftermath of the pandemic (GALANAKIS et al., 2022). According to FARCAS et al. (2020), the pandemic was the most opportune moment to change economic problems. Agricultural production is being characterised by decreasing environmental pressure. This is clearly illustrated by the fact that EU agriculture today emits 28% less greenhouse gases (FUELSEUROPE, 2022) than it did thirty years ago, with a substantially decreasing amount of total fertiliser and essentially the same level of pesticide use, while the inflation-adjusted value added of EU agricultural production has increased by 13%. It is a well-known and important feature of the functioning of agricultural and food production systems that the decisions taken at the time of their implementation are very long-term, as the lifetime of a plantation or production equipment can be several decades. In the international literature, this has been confirmed by the calculations of CRISTÓBAL (2008), among others. Even longer time horizons should be considered when making decisions on water governance (YEVJEVICH, 1995). According to JANSSEN and ITTERSUM (2007), food-related decisions have a long-term impact on the socio-economic structure of a geographical area. STEENGE (2004) points out that the planning horizon of different bodies and organisations rarely exceeds 5-7 years. Consequently, long-term foresight is essential in making decisions about the agrifood sector. This cannot be achieved without using the environment as a resource. How intensively we use these resources is still an open question. The regulatory system must be reformed to achieve extensification of production, and ecological considerations should always take priority over economic considerations in decision-making. The declared goal is clear: to make Europe's agriculture smaller and greener. In my understanding, this could be done if three conditions are met at the same time:

1. the effects of climate change will have a positive impact on European agriculture: more products can be produced safely and predictably,
2. the European Union can supply domestic demand quickly and easily from imports,
3. the EU economy can absorb the fall in domestic and export commodity prices resulting from the fall in output without any major shock.

But currently none of these conditions are met because: there are many models to quantify the impacts of climate change. These include one that suggests a significant increase in production (used in the study), but this is only one of the possible climate scenarios. Nevertheless, other sources (e.g., VAN MEIJL et al., 2016, HASEGAWA et al., 2018, DEEPAK et al., 2019) conclude that climate change will adversely affect Europe's agricultural production: crop yields could fall by 5-15% in the next fifty years. Past decades in the global economy have also been characterised by the fact that the price level of agricultural products has risen less than of energy commodities and industrial goods. But today the trend seems to be reversing. The three primary reasons for this are (1) land transformation due to climate change, (2) population growth, and (3) changing diet patterns. The impact of diet pattern change is particularly noteworthy: according to COLEN et al. (2018), each unit increase in GDP implies a 1.3 unit growth in demand for beverages, 0.5 unit growth in demand for dairy and eggs, and 0.5 unit growth in demand for meat. FEMENIA (2019) calculates that global food income elasticities are highest for animal products: 0.71-0.82 in Asia and 0.80-0.84 in sub-Saharan Africa. This means that if we accept the projections of major international organisations that Africa's economy will grow by at least 5% per year from 2022 to 2030, this alone will increase animal product consumption in the region by more than a third.

FAVA et al. (1991) drew attention to the energy price explosion as early as the early 1990s, but the energy consumption is still endless, even though energy prices have doubled since the start of the Russian-Ukrainian war. The bioeconomy, based on agricultural production and the processing of agricultural products, is a key area of the EU economy. The European food industry has a turnover of almost €1,100 billion (let's not forget that the CAP's annual subsidy is €60 billion), 11.4% of the value added generated by the EU's manufacturing industry, almost the same as its value creation (11.8%), higher than that of the manufacture of motor vehicles (10.6%) and metalworking (9.3%). The European food industry employs 4.5 million people, which is almost equivalent to the Hungarian active workforce (for the whole country). If we look at the bioeconomy as a whole, not only the food industry but also other industries that process agricultural inputs, we can see that the European bioeconomy today generates €2.230 billion in turnover, €613 billion in added value and employs 17.506 million people (FOODDRINKEUROPE, 2022). World agricultural and food production has grown significantly in recent decades, but we still do not know how food production will be structured to meet this growing demand. It is not possible to answer the question by simple trend extrapolation because we are witnessing several natural (e.g. global warming) and social processes (e.g. globalisation) that make long-term forecasting impossible simply by projecting current processes into the future.

3.2.2.2. Circular economy ≠ Bioeconomy

Overall, the use of different agricultural and biological materials in different sectors of the economy has changed significantly in recent years and decades, but in the longer term, the use of biological materials for non-food industrial purposes is of major importance for developed countries, and how to achieve the so-called circular economy, i.e. how to reintroduce various biological and non-biological materials into the social and economic development cycle with as little waste and energy consumption as possible. This, therefore leads to the development of a circular economy.

It cannot be overemphasised that **the concepts of circular economy and bioeconomy are in no way synonymous**, as circular economy covers a much broader range of issues. A circular economy recycles the products manufactured at the end of their life cycle with minimal waste and resources. The primary priorities of a circular economy are waste minimisation, reuse, recycling, remanufacture and repair (FOGARASSY and HORVÁTH, 2018). An important part of circular economy being the reuse of different industrial or mineral materials in different or similar analogous or completely different uses, so, for example, if glass bottles used for various packaging are collected and reused, either as packaging material or in some other, different area (construction), this is a clear example of the circular economy. But it is evident that in this case, there is no direct link with the bioeconomy since the concept of bioeconomy does not cover the whole set of production and reuse processes described above.

However, there are areas where the concept of bioeconomy can be closely linked to circular economy. A typical example of this is when the products or by-products of various agricultural, food or non-food industrial uses are used for some other use, whether food or non-food. So, a typical implementation of the circular economy concept can be seen in livestock production models where the fermentation produced by livestock production is used either to produce organic manure or to produce other purposes (energy use) for this by-product with a high energy content, such as bio-fermenter or biogas. This is a typical case of using a by-product for agricultural purposes and converting it to energy. However, it is also clear that the concept of a circular economy fits in well. It is also the case where we reuse agricultural or food products and try to find ways to recycle these agricultural, food or other production products.

3.2.2.3. Bioeconomy and UN’s SDG

I can conclude that a broad consensus is emerging among the world's leading economic powers that the bioeconomy can make a significant contribution to the practical realisation of development goals that address the long challenges facing human society. As SHUAI et al. (2021) argue in their work, the UN’s SDGs have gained more attention and are highlighted in scientific life, and the bioeconomy could help to achieve some in the future. A typical example of this is that there is a lot of overlap between the bioeconomy and the UN's long-term sustainability goals. This overlapping system can be clearly tracked in the table below (Table 1.), which is intended to show how the different objectives of the UN's long-term development goals fit into the different areas of the bioeconomy and the issues related to the development of the bioeconomy.

Table 1. Fourteen of the seventeen UN Sustainable Development Goals and their links to bioeconomy transformation

Sustainable Development Goals (SDGs)	**Bioeconomic link to the goals**
No poverty	Developing the bioeconomy can also contribute to job creation and poverty reduction in some regions
Zero hunger	Modernising the bioeconomy can increase resilience and self-sufficiency at regional and EU level
Good health and well-being	Recycling reduces the environmental burden
Clean water and sanitation	Bioeconomy innovation can help to improve complex water management and make optimal use of water resources in water stressed areas
Affordable and clean energy	Bioeconomy offers sustainable use of bio-based materials for energy production
Decent work and economic growth	Bioeconomy-based developments can trigger profound changes in employment structure and generate additional demand
Industry, innovation and infrastructure	Bioeconomy development offers a wide range of innovative solutions for the economy
Reduced inequalities	Bioeconomy provides an opportunity for the development of disadvantaged areas
Sustainable cities and communities	New opportunities for recycling waste
Responsible consumption and production	New opportunities to develop short supply chains
Climate action	Reduce greenhouse gas emissions
Life below water	Bio-based, circular solutions to reduce the environmental impact of seas, oceans and lakes
Life on land	Complex bio-based circular economy systems
Partnership for the goals	Transferring knowledge to developing and emerging economies to achieve their bioeconomy goals

Source: Own creation, 2023

The above combination of factors implies that the European Union and all developed countries are committed (at least in words) to putting the bioeconomy into practice to an increasing extent. This means that materials of natural origin, which either have a tradition of use, such as textile plants in the textile industry or various forestry products in the furniture and construction industries, should be used to an even greater extent than materials of industrial origin. However, they can also be seen as a new combination in terms of use: the increased use of bio-based pharmaceutical raw materials and the expanding use of new bio-based medicines and pharmaceuticals. Nevertheless, many homoeopathic medicines are made from biological materials, and today, many diseases are still cured only by treatments using chemical ingredients.

3.2.3. Bioeconomy of the Visegrad countries

The Visegrad cooperation was established on the base of historical traditions (RÁCZ, 2013) on the ruins of the Western wing of the „The Council for Mutual Economic Assistance" (SCHMIDT, 2016) at the beginning of the integration process of Central-Eastern European countries into the European Union. Its founding members were Czechoslovakia, Hungary and Poland. The transformation of the first one into Czech and Slovakia lead to four member states of this cooperation. Hereinafter, these countries will be referred to as V4 states. These states can be characterised by numerous similarities, in socio-economic development path, as they have been situated for centuries on the semi-periphery of Europe (LEHOCZKI, 2022).

A specific feature of the development of these states is a relatively high biomass production potential (VÁSÁRY AND SZABÓ, 2018; LAZORCAKOVA ET AL.,2022), the utilisation of which is an important European and national priority, in line with the Sustainable Development Goals of the United States (CISMAȘ ET AL., 2023). On the base of these factors, the analysis of the actual and potential place and role of the bioeconomy is a question of high importance from the point of view of policy development. There is a wide range of definitions of bioeconomy. For simplicity, in the current study, I will apply the approach of the Global Bioeconomy Summit (2018), according to which "bioeconomy is the production, utilisation 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". This rather broad definition is widely accepted by leading scholars in the field (TRIGO ET AL., 2023; PROESTOU ET AL., 2024).

Most studies on this subject have primarily concentrated on a specific product category, sector (KARVONEN et al., 2017), or regional elements linked to the issue or the bioeconomy (PHILIPPLIDIS et al., 2014). My dissertation focused on a detailed look at how biological-based alternatives can replace fossil-derived products that could impact the economy and environment.

Its centre of attention is the Visegrad countries (V4)—Poland, the Czech Republic, Slovakia, and Hungary— exploring the implications of these shifts within the context of each nation. Through input-output analysis, the research intends to simulate various scenarios and shed light on the potential advantages and challenges of making this important transition. These countries share several similarities concerning economic development and biomass resources. In 2017, the bioeconomy produced a value between 4 billion and 33 billion euros in the V4 countries. From 2008 to 2017, the bioeconomy's share in these nations rose from 44 billion euros to 55 billion euros, indicating a growth of 25%. In 2017, the V4 countries represented 9% of the bioeconomy within the European Union. Although the EU bioeconomy represented 4.2% of the overall economy, it produced a higher value-added proportion in the V4 region, specifically 4.6% in the Czech Republic, 4.7% in Slovakia, and 7% in both Poland and Hungary.

In 2017, the bioeconomy productivity average in the V4 countries was below the EU average. Thus, Poland had a value added per employed person of approximately 13.000 euros, whilst Slovakia, the Czech Republic, and Hungary recorded amounts of 23.000 euros and 24.000 euros, respectively. In contrast, the average for the EU was much greater at 34.000 euros. From 2008 to 2017, however, the V4 nations saw improvements, with productivity increasing by 20-40%. Despite this progress, their productivity levels remain at least 30% lower than the EU average (RONZON et al., 2018). In the same year (2017), the agriculture and food sector (comprising food, beverages, and tobacco) comprehended 60-75% of the value added to the bioeconomy of the V4 countries.

Mostly, around two-thirds of the additional value came from the agriculture and food industries, while wood products and furniture recorded 4% to 13%, the forest-based bioeconomy from 3% to 16%, paper from 4% to 7%, and textiles from 2% to 4%. The production of bio-based chemicals, medications, plastics, and rubber contributed 3% to 10% of the added value, with Poland at 3% and the remaining three countries between 5% and 10%. From 2008 to 2017, all sectors, apart from bio-based chemicals, pharmaceuticals, plastics, and rubber (excluding biofuels), showed no significant changes in their value-added share, while agriculture and the food sector preserved their leading status with a two-thirds share of the value added as you can see in the below table in percentage distribution (Table 2).

Table 2. Value added in the bioeconomy of the Visegrad countries, in percentage distribution by sectors in 2017

Countries	**Agriculture**	**Bio-based chemicals, pharmaceutic**	**Bio-based electricity**	**Bio-based textiles**	**Fishing and Aquaculture**	**Food, beverage and**	**Forestry**	**Liquid biofuels**	**Paper**	**Wood products and**
HU	50%	10%	1%	2%	0%	26%	3%	0%	4%	4%
CZ	32%	5%	0%	3%	0%	32%	10%	0%	5%	13%
SK	36%	6%	1%	4%	0%	22%	16%	0%	4%	11%
PL	34%	3%	1%	2%	0%	37%	4%	0%	7%	12%

Source: Own creation based on Ronzon et al. (2018)

The Visegrad Group, or the V4 for short, refers to a group of not accurately small Central European nations — to be sure, most have comparatively populations between 5–10 million each (except Poland at nearly 38 million). This characteristic makes these countries less than ideal because there are not big markets to generate solid domestic demand; this is something that Poland, for the size of the country it has, can partially overcome. As an assembly economy, Slovakia within V4 countries and even the Czech Republic and Hungary are often associated with that tag. These countries have small, open economies closely linked to European markets that primarily dictate their export performance. Most of their exports go to the European Union, pointing at other sources of economic stability and development for them in the wider EU space. The three global challenges mentioned above create strong incentives for the V4 countries to limit their dependence on non-renewable energy supplies. At present, they have an alarming energy dependency, which is covered by 50-60% of the imports. This scenario not only highlights the fragility of these countries but also demonstrates an immediate opportunity to improve energy efficiency throughout their economies. The solution to these issues and larger sustainable energy landscape is renewable energy production itself. It is also worth noticing that V4 countries target a quite low, and thus less ambitious level of below 20 % of renewable energy in gross final energy consumption (GEC) for 2020. In the end, these countries did meet its target for their 2020 goal, with a share of renewable energy sources in gross final consumption of between 13-16% reached by 2021 according to Eurostat (EUROSTAT, 2021). It shows progress, and there is further potential for progress in their energy strategies going forward.

The agricultural biomass leads the biomass flows. Waste and by-products from biobased production compose a foundation for the creation of innovative value chains. Wood-based biomass creates approximately 20%-30% of the overall biomass supply, which contains exports of roundwood and wooden pellets. The bioeconomy also encloses fisheries and aquaculture, featuring imports of fishmeal, oil, and seafood. Bio-based industries that offer significant value added and require less labour intensity make considerable value added per worker. The labour market in the V4 bioeconomy is less specialised than that of older Member States, and productivity levels in the agriculture, food, and forestry sectors fall below the EU average.

Policies related to the bioeconomy should be incorporated into the more comprehensive economic development strategy to boost productivity while reducing energy intensity. From the perspective of regional policy, incorporating a bioeconomy into local industries could create opportunities for advancing established sectors in rural regions (LEHTONEN and OKKONEN, 2013). WOŹNIAK and TWARDOWSKI (2018) explain that Poland does not have a single strategic plan for the bioeconomy. The Polish economy has three sectors that play a dominant role in the economy, namely agriculture, agri-food processing and forestry. Closely related to this is the work of CHOVANCOVÁ et al. (2021), which points out that neither the Czech Republic nor Poland among the V4 countries is willing to reduce greenhouse gas emissions at the expense of the economy. Furthermore, LUSTINGOVÁ and KUSKOVA (2006) in their work emphasised that the fact could not clearly demonstrate that organic farms have a lower environmental impact, neither in Czech nor in German studies. ŁĄCKA et al. (2020) find that Poland's economy is one of the most export-driven among the Visegrad countries, while the Czech Republic has one of the largest economic exports. Among the V4, Slovakia's exports are the weakest, while Hungary is only slightly stronger.

Hungary possesses significant biomass resources, with an estimated total biomass potential of approximately 350 to 360 million tonnes. From this data, around 105 to 110 million tonnes comprise primary biomass reproducing annually. Hungary is mainly an agricultural region, making up about 60% of the country's territory. (BAI et al., 2015) In view of the bioeconomy, Hungary has been engaged in the development of the bioeconomy as a component of larger European Union projects and regional collaboration initiatives. Nonetheless, the report of the OECD (2023) has not painted a very good picture of the country. The transition of the food industry towards a circular economy through biomass presents substantial opportunities. It can play a crucial role in Hungary's economic growth, efforts to combat climate change, and environmental preservation, all of which are vital for the country's bioeconomy. In particular, Hungarian agriculture and its closely related sectors (e.g. the food industry) constitute the most important part of the Hungarian economy. The report also notes that the demand for raw materials in the Hungarian economy is expected to increase in the future, putting significant pressure on the environment. This could pose environmental, competitiveness and economic risks in the future.

The document also includes policy recommendations on strengthening awareness of the transition to a bio-economy and targets to be achieved by 2040.

The V4 countries have different pathways to transition towards a sustainable and circular bioeconomy. For instance, they can pull tasks from the development of the automotive sector, which includes research and innovation activities, a dual education system, and an established supply network. Furthermore, improving energy efficiency and utilizing renewable energy sources in the current bio-based industry can help reduce dependence on energy imports. Growing freshwater aquaculture can provide higher value-added opportunities for employment, while a strong focus on education in bioeconomy-related fields is required. It is also important to develop spin-offs that create new value chains for bio-materials extracted from waste and by-product streams, as these contribute significantly (60%-75%) to the value added in the current bioeconomy. The bioeconomy is showing across all sectors that involve biomass production and processing. With a dedicated bioeconomy policy, it may be able to maintain its market share amidst the evolving EU economic landscape that is steering towards achieving carbon neutrality by 2050.

3.2.4. European Bioeconomy System

The literature places great emphasis on studying the bioeconomy in Europe (OLS and BONTEMPS, 2021), evaluating the effects on land use spillovers (BRUCKNER et al., 2019), and the need to conduct a systematic review of methods and results (HURMEKOSKI et al., 2021; DIMA et al., 2022). Above I presented the value-added related to the Visegrad countries, so I will skip these countries in this section and some other European countries because the space is limited.

In 2022, TÖBBEN et al. point out that a holistic view of the bioeconomy is essential to make a difference not only in the EU but also in other countries around the world. In their article, they highlight that employment and GDP have shown a positive trend in relation to the bioeconomy over the past period. Despite its potential, the European bioeconomy faces several challenges.

One significant issue is the lack of comprehensive data and monitoring frameworks to assess the bioeconomy's impact effectively (RONZON & M'BAREK, 2018; ROBERT et al., 2020). MAINAR-CAUSAPÉ et al. (2021), while there is a relatively good availability of secondary data on traditional bioeconomy activities, information about newer biomass sources and bio-based activities is limited. This lack of data significantly hinders the ability to assess the economic significance of these emerging sectors within national economies. Although in the following, I will show some evidence of how the bioeconomy works in several European countries.

3.2.4.1. Northern Europe

The Nordic bioeconomy focuses on a shift towards sustainability. This involves substituting unsustainable, fossil-fuel-based resources by enhancing by-products and waste, as well as developing circular and sustainable solutions within local communities. The Nordic Region has a high potential in biomass. Countries like Sweden, Norway, and Finland are well known for their forests, whereas Denmark has abundance in areas that are helpful for farming. The percentage share of forest biomass consists of 70% of the total biomass, whereas 20% of the total biomass is contributed by the agriculture residues. Overall, figures indicate a robust growth path, very important contributions to national GDPs, and continuous investment in innovation and sustainability practices.

Finland

The bioeconomy is, according to the Ministry of Economic Affairs and Employment of Finland, one of the most important sectors in the economy of Finland and places it among the forerunners in the European bioeconomy. In 2022, the annual value added by the bioeconomy reached EUR 29 billion and created 13% of all value added to the national economy (TEM.FI, 2023; ARASTO et al. 2021). The forest sector represented 36 %, which is EUR 10.5 billion, of the total value added to the bioeconomy. In contrast, the value addition from the paper industry has fallen by 11 % compared to 2021. One-fifth of all the jobs contributed by the bioeconomy come from the forestry sector. On the plus side, value added by the energy sector was 12% higher in real terms compared to 2021. Food-that is, for the most part, agriculture and food manufacture-accounted for 16% of total bioeconomy value added. On the minus side, in total the value added within food in real terms has been down 14% on the year-earlier figure.Within agriculture specifically, value added decreased by 6 %, which was notably less than the declines experienced in several other sectors (LUKE.FI, 2023). In Finland, at the heart of the transition lay that mass production is transforming into high-value-added products. In this country, the bioeconomy and innovation in genes are driving the economy. (BOSMAN & ROTMANS, 2016)

Norway

"The history of Norway is a story about the oceans." /Norwegian Ocean Strategy/

Norway is strong in the bioeconomy but in the so-called "blue bioeconomy" as it has the 2nd longest coastline in the world, and Norway will remain the leader of the ocean nation. (NORWEGIAN MINISTRY OF TRADE, 2019) ERIKSSON et al. (2018) highlighted that "the Government wants to increase agricultural food production, through rationalisation and increased research and development on the genetic potential in plants and animals, and through improved breeding" (ERIKSSON, 2018. p.230). In their work, PLEYM ET AL. (2021) have also predicted the Norwegian bioeconomy growth significantly, with the government estimating a potential increase in marine bioresources contributing up to 10% of the national economy by 2030. The Norwegian report of the value creation based on productive oceans by 2050 (2012) projected that the combined production of micro and macro algae would be 20 million tons by 2050, with a value-added of around 4 billion euros. CAPASSO & KLITKOU (2020) confirmed that in Norway, specific bioeconomic sectors could be more successful than others by exploiting the special advantages. According to the Nordic Statistics database (2024) Norway catches the most fish, 2 135 861.5 thousand tonnes in 2023.

Denmark

Denmark is the biggest importer of proteins to feed the animals. Around 1 million tonnes of protein intended for animal feed are imported. Furthermore, the consumption of animal protein is projected to rise by 70 % by the year 2030. (STATE OF GREEN, 2018) This country is strong in biomass potential; it is focusing on agriculture and bioenergy. The Danish bioeconomy in 2020 was supposed to contribute about 9% to the national GDP, with substantial investments especially in biogas production and bio-based materials (KHAN et al., 2021, REFSGAARD et al., 2021). Also, the policies put forward by the government have facilitated innovation in green technologies. This has brought about the gradual rise in bioeconomic activities, especially within the agricultural sector, with organic farming growing by about 20% every year (SCORDATO et al., 2021).

Sweden

Sweden is another leader in the bioeconomy development, especially in the field of sustainable forestry and bio-based materials. The Swedish bioeconomy has employed approximately 330,000 people and was worth approximately 6% of the national GDP in 2015, with serious investments in biorefineries and the manufacturing of biofuels (SOCACIU, 2014). Around 50% of the value added comes from bioeconomic sectors (e.g. agriculture and forestry, food, wood, paper and pulp), and the other 50% comes from partially (or "processed materials") bioeconomy industries (e.g. textiles, construction and chemistry). (BIOINNOVATION.SE, 2020) The Swedish bioeconomic sector is continuously developing, launching innovative projects and sustainable practices because the country has devoted itself to reaching the carbon-neutral goal by 2045. (KRISINFORMATION.SE, 2023)

3.2.4.2. Western Europe

Belgium

Belgium's strongest "bioeconomy sector" is the pharmaceutical sector. It has the highest value added in the country's value chain compared to the others. (BICONSORTIUM.EU, 2024) According to SILVA (2021), Belgium's labour productivity in the bioeconomy field is as solid as that of Sweden, and its circularity rate is almost 22%, which is quite encouraging for the future. As reported by JRC Dataset (JRC, 2024), Belgium's value added of biomass producing and converting sectors was 25 billion euros in 2021.

Germany

Germany has a very detailed and comprehensive bioeconomy strategy (BIOECONOMY-INTERNATIONAL.DE). It is strongly committed to greening the economy and investing a lot of money – from 2010 to 2016, 2.4 million euros as stated on the BIOOEKONOMIE.DE (2024) website - in R&D projects. EFKEN et al. (2016) argued that in 2010, the bioeconomy represented 6% of the GDP, and around 5 million employees (10% of all employees) worked in bioeconomic sectors. The recently published Monitoring the German Bioeconomy (2024) report shows that in Germany more than 200 million tonnes of biomass from agriculture and fisheries was used by the German bioeconomy in 2020, and the biomass contributed 12% of the total energy and 49% of the renewable energy. Regarding the labour market, Germany shows a decreasing trend in 2020, but in the GDP view, it is the same as it was in 2010.

France

The Grand Est region is a major French agro region because 50% of its surface (RÉGION GRAND EST, 2020) is devoted to this sector. The region's agriculture yields significant quantities and diverse types of biomass for both food and non-food applications. The economic participants are key players in the French market with products such as beetroot, rapeseed, barley, corn, wheat, and alfalfa, as well as in the European market with hemp. This agricultural biomass (excluding forests) represents the most promising opportunity for valorisation in a bioeconomic context within the area, with an anticipated growth of 70% by 2050 (DIAKOSAVVAS and FREZAL, 2019; PHILP and WINICKOFF, 2019). In 2021, The Directorate General of Economic and Environmental Performance of Enterprises of France published information about the French bioeconomy, which is still available on the French Government site (AGRICULTURE.GOUV.FR, 2024). According to this, the French bioeconomy has a lot of advantages: it created 1.9 million jobs in the regions, 10% of chemicals and materials are produced from biomass, and 60% of the renewable energy is gained from biomass.

The Netherlands

The Netherlands has prepared the ground for a strong bioeconomy with highly developed agro-cultural, logistics and chemical sectors. In the Netherlands, approximately 1,200 firms operate within the bio-based economy, with the majority being small and medium-sized enterprises (SMEs). In 2016, firms within the bio-based economy allocated more than €200 million towards research and development efforts. (EUROPEAN COMMISSION, 2018b) HEIJMAN and SCHEPMAN (2018), in their work, envisioned that the Dutch Bioeconomy size would grow to

7% in 2020. As reported by JRC Dataset (JRC, 2024), the Netherlands' value added of biomass producing and converting sectors was 35 billion euros in 2021. It is clearly seen that the Netherlands is quite strong in liquid biofuels – creating bioethanol from starch sources like wheat and tapioca and generating biodiesel from vegetable oils, primarily palm oil (LANGEVELD et al. 2016) - and bio-based electricity production.

3.2.4.3. Southern Europe

Italy

The Italian bioeconomy is one of the largest bioeconomy in Europe, and it is a core pillar of the national economy. FAVA et al. (2021) think the Italian bioeconomy sectors can restore Italy's rural and coastal areas and stimulate economic growth and local job possibilities. The last report about the Italian bioeconomy (INTESA SANPAOLO, 2024) emphasises that the sector grew in 2023 by 2.2% and employed 2 million people. In 2023, the bioeconomy produced 10% of all value added to the total economy. The strength of the bioeconomy in Italy is proved by the fact that in 2023, 808 innovative start-ups were surveyed, representing 6.6% of all companies listed in the special register. A significant portion of these innovative start-ups in the bioeconomy, which are distributed across the country, are primarily focused on the R&D sector (45%), with the agri-food sector following at 25%. The agri-food sector is crucial to the overall bioeconomy in Italy, contributing over 63%. Technology also plays a vital role in this industry. Despite being significantly smaller than their European counterparts, Italian food companies excel in product innovations, boasting a 20% share compared to the EU27 average of 12%.

Additionally, Italy leads in process innovations with a remarkable 36%, surpassing its main competitors by more than 15 percentage points. In Italy, sustainability plays a big role. Italian companies attach increasing importance to activities to reduce waste in various forms, some of them, for example, by recycling. Selective waste collection is also a social issue in Italy; for example, personal experience shows that in the province of Imperia (in Sanremo), waste must be collected separately per household. If this is not done, the authorities impose a fine.

Spain

Spain adopted its 2030 Bioeconomy Strategy in 2015. 4 autonomous regions also have a specific bioeconomy strategy for their territories. Spain has carried out a study to assess the potential of biomass at regional level by November 2023, as part of the Agroalnext programme. The report focuses on the management of agricultural waste (59%) and livestock waste (11.87 million tonnes per year) but also mentions municipal solid waste (5.70 million tonnes per year), the third most important type in the country. Waste from processed vegetables amounts to 2.81 million tons per year, and animal waste 0.87 million tons. (AGROALNEXT, 2023) From these data, it is clear that waste management is an important problem for the country to be addressed in order to reduce the environmental burden, and in the process, bio-economic indicators would increase. TERCEÑO GÓMEZ (2023), in his work, thinks that the distribution of organic products is concentrated in only a few sectors in the country. Within the organic sector, textiles, biochemicals and wood products account for about 22% of the total supply of the organic sector. According to data from JRC (JRC, 2024), the bioeconomy sector in value added of biomass producing and converting sectors was 75 billion euros in Spain in 2021.

Portugal

GONÇALVES et al. (2021) highlight that the wood sector in Portugal exhibits a diverse landscape concerning circularity, demonstrating various methods of resource utilisation and valorisation within the industry. In 2015, over half of the forest biomass extracted was utilised for material purposes, while the rest was for energy uses. By 2017, the agriculture and livestock sector represented a quarter of the added value and accounted for 59% of total employment. The forestry sector, primarily supported by forestry industries, contributed to 24% of the bioeconomy's turnover, amounting to 9.8 billion euros, and provided approximately 76,500 jobs, which is 11% of employment in this field. On the other hand, the fisheries and aquaculture sector still have a marginal role, generating only 5% of the turnover (1.9 billion euros) and 3% of employment (22,000 jobs) (GPP.PT, 2021). According to the 2024 European Innovation Scoreboard, Portugal is a moderate innovator country and its performance by 83.5% of the EU average in 2024 (EUROPEAN COMMISSION, 2024). The country’s bioeconomy contributes nearly 20 billion euros in annual turnover, positioning it favourably to spearhead Europe’s bioeconomic transformation. Key sectors driving Portugal’s economy include agri-food, forestry-based industries, marine-based sectors (fisheries, algae, and aquaculture), and chemical industries. In terms of production value, the leading industries within the bio-based processing sectors are food and beverages, pulp and paper, and wood processing. (BIOCONSORTIUM.EU, 2021)

Greece

The worldwide economic crisis had a considerable effect on Greece's forestry sector, leading to a substantial decline in both employment and overall output from 2008 to 2017 (SPANOS et al., 2021). KARAMETOU and APOSTOLOPOULOS (2010) identified Greece as one of the EU nations with the lowest levels of productivity. The annual production of waste in Greece is 58 million tons per year, including agricultural and industrial waste (53%) and livestock manure (47%). Only 3% of the total biomass is used for bio-economy applications (BIOGOV.NET, 2024).

3.2.4.4. Central and Eastern Europe

Croatia

Croatia is a part of the BIOEAST Initiative to develop knowledge and prepare the Member States for the bioeconomy transition. (BIOEAST.EU, 2024) The "field to fork" chain creates around 70% of the value added within the bioeconomy and employs 71% of the total persons employed in bioeconomy sectors. The forest-based bioeconomy represents 19% of the value added and 20% of employment in the bioeconomy. In contrast to the more labour-intensive sectors, such as the production of bio-based chemicals, pharmaceuticals, plastics, and rubber, make up 5% of the value added while accounting for only 2% of employment in the bioeconomy (KULISIC et al., 2021). According to JRC Dataset (JRC, 2024), Croatia's value added of biomass producing and converting sectors was 4 billion euros in 2021. The agricultural sector is the biggest bioeconomy sector in the country, followed by food and wood.

Romania

The country has really good circumstances to develop bio-based products and give more focus to the bioeconomy, because the country is rich in diverse natural resources. Romania is a part of the BIOEAST Initiative which aims to develop knowledge and prepare the Member States for the bioeconomy transition like Croatia above (BIOEAST.EU, 2024). As reported by the JRC Dataset (JRC, 2024), Romania's value added of biomass producing and converting sectors was 18 billion euros in 2021. According to AVRĂMESCU (2020), who analysed the turnover about the Romanian bioeconomy, the contribution of agriculture (37.4%) was lower than the input of this sector to the employment in the bioeconomy sector (81%), and the lowest input provided by biofuels and bioelectricity (almost 0).

As VIVIEN et al. (2019) argue in their work, the bioeconomy holds significant promise for driving sustainable economic growth and can generate job opportunities in both rural and industrial regions. In the European Union, over 17 million jobs are associated with the bioeconomy, producing a worldwide revenue of more than 2.4 trillion euros. These figures account for 4.7% of the EU's gross domestic product and 8.3% of its workforce (BIOECONOMY ALLIANCE, 2022).

According to the JRC Dataset information (JRC, 2024) for the Bioeconomy in the EU 27, in 2021, almost 18 million people worked in the biomass-producing and converting sectors. This data shows that the value added per person employed is 42 thousand euros. The Nordic countries clearly have a solid Bioeconomy Strategy, and statistics also show turnover and industry activities. Some of the other European countries have bioeconomy strategies, and those who do not have joint alliance to develop their country's economy (like V4 countries). At the end of 2024, I would say that there are still a ton of things to do to the bioeconomy transition in Hungary and in neighbouring countries, too (e.g. agricultural and technological development).

3.2.5. Short outlook – Sri Lanka, where the bioeconomy almost failed

Sri Lanka

There are also countries where war problems are occurring within countries, such as Sri Lanka, which has tried to move to a bioeconomic economy of its own with various import restrictions, which has brought the country close to bankruptcy. (WORLD ECONOMIC FORUM, 2022) Since then, the World Bank Group has already been working to help the Sri Lankan economy. Its economy grew by 5% in Q1 of 2024, thanks to the construction, food and beverage manufacturing and tourism-related services. Although many goals have been set, the country's macroeconomy is still fragile. The implementation of key fiscal, financial, and monetary policies is essential to improve Sri Lanka's economic situation (WORLD BANK GROUP, 2024). The above case illustrates the need to build partnerships based on cooperation and security at the government level to deal with global challenges (XU et al., 2021).

3.2.6. Future of the agriculture: Bioeconomy and AI

The implementation of artificial intelligence (AI) into the bioeconomy shows one of the most significant technological transformations of our time. Potentially, it can revolutionise how we can produce food, develop medicines, manufacture biological products, and focus on pressing environmental challenges. In 2025, this kind of harmony in the technology field is already reshaping numerous sectors and creating exceptional opportunities for sustainable growth and innovation. AI's analytical capabilities, predictive power, and process optimisation potential emphasise the bioeconomy's development and make it more precise, efficient, and responsive to global challenges at the same time.

As previously mentioned, the bioeconomy will enhance efficiency, maximise resource utilisation and conserve and regenerate biological resources. It also combines an innovation, technology and knowledge base that we need not only today but also in the future to apply sustainable solutions in different processes. It is well known that a central element of bioeconomy has been the treatment of environmental pollution in industries that rely on the use of biological resources. Nowadays, some bioeconomy actors are already using superpowers such as AI to increase efficiency and develop different capabilities. For example, 30MHz, a Dutch company, developed a smart agriculture solution for growers to optimise crop management. The solution, built on AWS services, processes greenhouse data and provides real-time insights for better crop outcomes (AWS, 2025).

With forecasts showing that "as much as 60% of the physical inputs to the global economy could, in principle, be produced biologically" (WORLD ECONOMIC FORUM, 2024a), the technological convergence of artificial intelligence and biology is opening new opportunities for sustainable production and consumption. This offers a transforming chance to substitute biological alternatives based on renewable energy for petrochemical-based systems.

National policies all around reflect the increasing awareness of artificial intelligence's part in the bioeconomy. Bioeconomy policies emphasising technologically driven methods to maximise natural biological resources are being adopted by nations more and more. Many countries have underlined after the COVID-19 epidemic how strong bioeconomic infrastructures, supported by modern technologies, can improve resilience in public health and more general economic systems (WORLD ECONOMIC FORUM, 2024b). A significant change in our understanding of economic growth and environmental sustainability is indicated by the global commitment to creating AI-enhanced bioeconomies.

One of the oldest bioeconomy sectors is agriculture. However, the application of AI technologies is significantly changing this industry. To maximise agricultural operations and resource utilisation, modern farming increasingly depends on data-driven methods that employ artificial intelligence (AI) to assess data from several sources, such as sensors, satellites, drones, and weather forecasts. Farmers can use precision agriculture methods that increase harvests while avoiding environmental effects thanks to AI technologies. Based on site-specific variables and predictive modelling, these systems assist in determining the best crop, seed, and resource utilisation choices (INTERREG, 2020). For example, farm machines equipped with AI can collect and analyse thousands of data points daily, providing real-time insights on soil conditions, crop health, water usage, and weather patterns. This information allows farmers to make more informed decisions about planting, fertilising, irrigating, and harvesting—improving both productivity and sustainability. Seasonal forecasting powered by AI offers another valuable tool for agricultural planning. The models can predict weather patterns months in advance, helping farmers adapt their strategies to anticipated conditions. Remote sensing technologies are transforming field monitoring and management. For example, we can manage our agricultural machines from another city and check the status of the crops. Beyond all of this, AI can help and optimise food supply chains by improving processing, storage, distribution, and waste reduction, plus improving food security.

The application of AI in the bioeconomy has appeared globally. Numerous regions and countries created and adopted strategies specific to their contexts, resources, and capabilities. This international focus reflects the universal applicability of these technologies and the recognition of their strategic importance for economic competitiveness and sustainability.

According to MUNKHOLM (2024), China is a leader in both artificial intelligence and biotechnology, is developing comprehensive strategies to integrate these fields and recognises their potential for economic growth and national competitiveness, and the country has established industrial clusters focused on AI and biotechnology, invested heavily in R&D and infrastructure, and put in place supportive policies, including tax incentives, subsidies and support for research projects. China is exporting biotech innovations to global markets - including pharmaceuticals, medical devices and agricultural technologies - showing that China is aiming to become a key supplier of biotech products.

In the US, the latest executive orders have addressed the safety of artificial intelligence and the development of the bioeconomy, recognising the critical intersection of these technologies. The proposed creation of an Office for the Coordination of Bioeconomy Initiatives has been proposed to support agency collaboration, cross-cutting assessment, and transparency of future biotechnologies (ISSUES IN SCIENCE AND TECHNOLOGY, 2023).

The bioeconomy is a pillar of the European Union, and it is towards a circular and low-carbon economy, modernising its industrial base, creating new value chains, and developing greener industrial processes. Hungary does not have a bioeconomy strategy after all; it has an AI strategy that was published in 2020 (EUROPEAN COMMISSION, 2021).

In spite of thousands of potentials for AI in the field of bioeconomy, significant challenges must be addressed to fully realise this potential. For example, technical obstacles, economic barriers, social considerations, and certain governance questions that will shape how these technologies develop and are deployed.

4. METHODOLOGY

In this section, I will examine how added value can be created through the greater involvement of the bioeconomy in the national economy and macroeconomy in the various national economies and in the national economies' production processes, and what this means for the national economies' gross and net output in terms of their export-import balance, macroeconomic balance and sustainability, i.e. their environmental impact. Moreover, I will develop scenarios of what factors might contribute to the increasing uptake of the bioeconomy in the future of a relatively developed OECD member state and identify the main macroeconomic planning issues that have been instrumental in triggering the debate on social and economic planning in this area.

The analysis of the importance of bioeconomic processes and the application of non-food uses of biological materials thus shows a particular trend in human society. Obviously, when food use and world food security are still to be resolved in many aspects, this issue is less critical than when it is less of a focus of interest. Already in the 1970s, MEADOWS and his co-authors (1972) in their work " The Limits to Growth " and GOLDSMITH et al. (1972) in their study " A Blueprint for Survival " published predictions that called attention to the world population explosion and the finite resources. In another literature review by PFAU et al. (2014), it was found that it is a problem that, in some cases, organic production does not reduce greenhouse gas emissions as expected and this effect sometimes remains unclear. BERNERS-LEE (2020) explains in his book that **solutions to manage greenhouse gases and conserve biodiversity need to be found as soon as possible, because the number of extinct species is increasing every year, which would not only shorten the food chain, but could also lead to old and new diseases.** The 1980s marked the emergence of a tendency to think that, in parallel with (and partly instead of) the unilateral pursuit of economic considerations, the role of ecological factors and the protection of natural resources was steadily increasing (WEINSCHENCK, 1986).

4.1. Portfolio analysis

Research portfolios are primarily practised to manage private R&D initiatives, but they have also been adopted by public research organisations as a method to oversee and analyse specific research activities (WALLACE AND RAFOLS, 2015). Analysing these portfolios aids in determining if the organization's efforts align with its strategic objectives and often includes benchmarking. Plus, it facilitates the prioritization of projects, identifies gaps, and highlights redundancies. The term has a strong background in corporate finance, referring to strategies for managing collections of securities (SHARPE, 1963). According to HUANG (2010), a portfolio consists of a collection of different securities, and the portfolio analysis is a quantitative approach used to choose an optimal portfolio that aims to balance maximising returns while minimising risks in various uncertain situations.

Public research organisations leverage portfolio analysis to formulate their strategies and evaluate the overall impact of their projects (ROGERS AND BOZEMAN, 2001). Researchers can take advantage of portfolio analysis in various ways. For one, they can achieve organization-wide economies of scale. For instance, an output portfolio —defined as one based on a specific type of scientific output rather than similar activities or impacts (ROGERS AND BOZEMAN, 2001)— can encompass a diverse array of scientific activities and fields. The results of the research contribute to a particular type of policy document known as impact assessments, which follow a specific structure and address designated research questions. This process enables organisations to lower research costs across various domains by standardising their contributions to the science-for-policy framework.

Furthermore, portfolio analysis helps scientists better comprehend the needs of those who benefit from their research. Research aimed at influencing policy is designed to support goals that lie outside of the scientific realm itself (SAREWITZ AND PIELKE, 2007), and no individual scientist or research team can single-handedly make a significant impact. By adjusting themselves within an organisation's research portfolio, scientists can pull knowledge externalities that build up their potential to influence policymaking and may also deepen their scientific understanding. However, it is not just scientists who can do portfolio analysis. It is commonly performed by fund managers, asset managers, private investors, and companies to evaluate and enhance the performance of their investments, and there are three well-known methods.

Portfolio analysis methods:

BCG Matrix:

I would say that this is the model that almost everyone is familiar with, as it is already taught in most secondary schools specialising in economics, marketing or both. The BCG Matrix, made by the Boston Consulting Group, is often referred to as Growth-Share Matrix. It divides into the company's portfolio into four segments: ***Stars*** (characterised by high market share and high market growth), ***Cash Cows*** (high market share but low market growth), ***Question Marks*** (low market share with high market growth), and ***Dogs*** (low market share and low market growth). This framework helps businesses allocate their resources more efficiently across different segments.

McKinsey Portfolio Model:

The McKinsey Portfolio model, often named the ***Nine-Box Matrix***, is a more sophisticated version of the BCG Matrix. It sets business units across two key dimensions: market attractiveness and the strength of the business unit. Market attractiveness is evaluated based on factors like market growth, potential, competitive intensity, and profitability. Meanwhile, the strength of the business unit is gauged by elements such as market share, product quality, brand reputation, and capacity for innovation. This model enables companies to visually represent their business units in a nine-box grid, facilitating improved decision-making in terms of investments and resource distribution.

Markowitz Portfolio Model:

The Markowitz Portfolio model, often called ***modern portfolio theory***, is a mathematical framework created by Harry Markowitz. It helps investors to form their portfolios to maximise returns while managing a specific level of risk. The model emphasises the importance of diversifying investments to reduce risk. A fundamental premise of the model is that investors tend to be risk-averse, which leads them to seek an ideal balance of risk and return in their investment portfolios.

In my research, I have used the following calculation to see different portfolios for different situations.

```
yield <- read.csv("C:/Rdata/yields_calculated1.csv")
returns <- yield[,2:10]
funds <- colnames(returns)
yield<-read.zoo(yield)
init.portfolio <- portfolio.spec(assets=funds)
init.portfolio <- add.constraint(portfolio=init.portfolio, type = "box",
min=c(0.275,0.234,0.074,0.006,0.005,0.003,0.012,0.166,0.047),
max=c(0.327,0.358,0.128,0.011,0.016,0.007,0.023,0.218,0.103))
minSD.portfolio <- add.objective(init.portfolio,type="quadratic_utility", risk_aversion=0.05)
opt <- optimize.portfolio(R=yield, portfolio=minSD.portfolio, optimize_method = "DEoptim",
trace=TRUE)
summary(opt)
```

4.2. Input-output analysis

During the literature analysis, I have faced with the problem that the majority of authors analysed the bioeconomy just from the point of view of macroeconomics or just from point of view of microeconomics. There is a gap between these two realms. That's why in my dissertation I tried to apply the toods and approaches of both disciplines. The availability of input-output models that already include information on, in particular, the environmental burden of different sectors is a valuable help. The conceptual origins of input-output analysis date back to the early developments of modern economic thinking by PHILIPS (1955). However, it is most closely associated with the analytical framework established by Wassily Leontief, a German-born economist who later became a Soviet American and who developed this analysis further (LEONTIEF and STROUT, 1963). The well-known formula that outlines the structure of economies with multiple (n) sectors is:

$$\overline{p} = \overline{\overline{A}}\,\overline{p} + \overline{d}$$

where p represents the production vector for various sectors, and A marks the matrix that shows how different branches are utilised in the reproduction process. This is an $n \times n$ matrix that shows how sector i utilises the output of sector j. This matrix is labelled as the consumption matrix or the technology coefficient matrix in its normalised version. The vector d means external demand. In an open economy $d \neq 0$, whilst in a closed economy $d = 0$. Later POLENSKE (1974) modified this formula, and it is also commonly used. The Leontief-Strout model has been reformulated within the entropy maximisation framework by WILSON (1970), establishing a direct connection between commodity flow modelling, input-output analysis, and linear programming.

Nowadays, free software is available, such as the input-output software package in R. Obviously, the simplest way to analyse the input-output ratios of different countries is to use Leontief's inverse calculation. Using this, I could investigate how changes in the additive demand for products in a particular product group or sector affect the behaviour of the matrix as a whole, and hence I planned to determine the change in the Leontief index for different countries, as well as the change in the Leontief inverses. This is a significant factor that I think is important and could provide new information on what kind of additional demand will be generated for a product by the transition to bioeconomy.

„ The Leontief inverse is derived from the input-output table A=[a_ij] where

$$a_ij = z_ij/X_j,$$

where z_ij is the input from i required in the production of j. X_j is the corresponding input in each column. The Leontief inverse is then computed as

$$(I - A)^{-1}$$

Observe we result with the following system

$$X=Lf$$

Therefore, element l_{ij} is interpreted as the ratio of final demand for sector j contributing to the total production in sector i." (WADE – SARMIENTO BARBIERI, 2020, p. 27.)

As a result of the analyses that have been done, it will be possible to identify the specificities and differences in the functioning of bioeconomic systems in different countries. And **how the transition to bioeconomy will also affect the macroeconomic parameters of countries**. The environmental burden characteristics of these sectors have helped me to determine the extent to which the application of bioeconomic models and the transition to a bioeconomic system will help protect air quality and increase the efficiency of other non-renewable resources, such as land management. XU et al. (2023) think that the monthly input-output table can be integrated with econometric models to forecast the future sectoral economic structure. By incorporating sectoral environmental accounts, predictions related to environmental issues like carbon emissions can be made, allowing for proactive adjustments to mitigate these negative impacts.

Basically, the Leontief model was created for analyses of national economies, but this kind of model was created by ISARD (1953) also, and some supplements were added later by MOSES (1955). The research on feedback mechanisms carried out within an enhanced economic base-regional income multiplier model created by BROWN (1967) and STEELE (1969), highlighted the significance of these factors, particularly in smaller, highly open regional economies.

However, it can also be adapted to develop multi-regional models (FU et al., 2021; LEONTIEF and STROUT, 1963). Using this method, it's possible to define other multipliers. Such as the household income multiplier vector suggests that an increase in final demand for the output of sector *i* will result in a new calculation for household income, accounting for all direct and indirect effects (EMONTS-HOLLEY et al., 2020). This provides extra insights when assessing the best way to distribute subsidies. The value-added multiplier measures how the creation of value-added in various sectors responds to shifts in demand (SHISHIDO et al., 2000). The value-added indicator is treated as a more appropriate measure for assessing a sector's contribution to economic performance compared to fluctuations in gross output. The growing capacity to establish connections between input-output mechanisms and various regional models has contributed to the ongoing advancement of regional input-output analysis (HEWINGS, 1985).

Leontief's model allows for an estimate of how changes in demand impact production, employment, and income generation within a society. By summarising various industries' column and row values, we can gain insights into the relative significance of different sectors. LAHR (1993) analysed the contributions of various sectors to national economies, highlighting that the majority of resources should be allocated to those sectors that can drive economic development in both backward (supplying) and forward (absorbing) branches of the national economy. The total of the rows in the Leontief inverse matrix represents backward linkages or output multipliers for different sectors, which can be calculated as follows:

$$X_j = \sum_{i=1}^{n} b_{ij} X_i + I_j$$

The overall backward linkages are obtained by summing the columns of the inverse values of the Leontief coefficients:

$$BL_i = \frac{\Sigma_{i=1}^{n} l_{ij}}{n^{-1}\Sigma_{j=1}^{j=n}\Sigma_{i=1}^{i=1} l_{ij}}$$

Forward linkages can be viewed as the sum of the rows of the Ghoshian inverse (THEIL and GOSH, 1980):

$$FL_j = \frac{n^{-1}\Sigma_{i=1}^{j=n} g_{ij}}{n^{-2}\Sigma_{j=1}^{j=n}\Sigma_{i=1}^{i=1} g_{ij}}$$

Key sector analysis provides two composite indicators for every sector: one that quantifies backward linkages and another for forward linkages (MILLER and BLAIR, 2009).

Additionally, it is important to account for the spillover effects resulting from the rising demand in various sectors. Systematically, the question occurs: how can we measure the impact of changes in one element of the intersectoral flow? This implies that a modification in the intersectoral flow of a specific element affects other intersectoral flows (SONIS et al., 1996). Various algorithms have been created to assess these "spin-off" effects. In the most straightforward scenario, a change in a single element (a_{ij}) within the technical coefficient matrix leads to incremental adjustments all over the matrix. The first-order (primary) effects can be measured using the first-order field of influence indicator, which is calculated by multiplying the j_{th} row of the Leontief matrix by the i_{th} column (OKUYAMA et al., 2002).

Concurrently, rises will occur in other values within the matrices, which is why further calculations need to fully understand the impacts of these changes. This brings us to the recursive calculation. The factors leading to changes in the structure of input-output matrices can be examined using the output decomposition method (SONIS et al., 1996). This approach distinguishes between changes in the I/O matrices caused by demand effects and those resulting from shifts in technology, as indicated by the Leontief-inverse and the interaction of these two components. Additionally, the same decomposition can be applied to assess whether the changes are driven by developments within the sector (self-generated) or from external influences (non-self-generated).

4.3. Network analysis

Our whole world is built on a network. We can talk about society, neurobiology, physics or our economic system; we can see a connection everywhere. But behind this, there is a complex system that determines the interactions between the elements of that system (BARABÁSI, 2024). Network theory and complexity theory are also central to the world of forecasting (VESPIGNANI, 2020).

Many large networks typically exhibit a property where the connectivity of vertices adheres to a scale-free power-law distribution. This characteristic arises from two fundamental processes: (i) networks grow continuously by adding new vertices, and (ii) new vertices tend to connect preferentially to already well-connected nodes. A model that incorporates these two elements successfully replicates the observed stationary scale-free distributions, suggesting that the evolution of large networks is driven by strong self-organising dynamics that transcend the specifics of each individual system (BARABÁSI and ALBERT, 1999). According to JANOSOV (2023), a "network is simply, but in conceptual terms, a system of interconnections of "anything" that are "somehow" related" (JANOSOV, 2023, p.87).

The explosive development of network science is well illustrated by *Google Books' Ngram Viewer*. This tool is extraordinary in that it shows the frequency of the myriad of different word combinations and phrases in the books digitalised by Google, split by year. I used this tool to check the occurrence of the term *bioeconomy* from 1998 (from the first definition by ENRIQUEZ) to 2022.

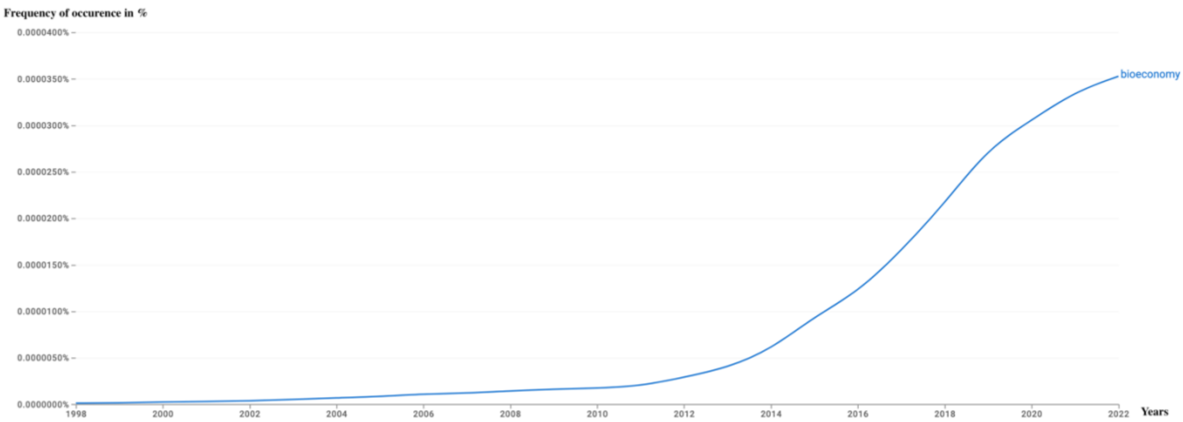

Figure 1. Frequency of bioeconomy

Source: Own research by Google Books Ngram Viewer, 2024

Figure 1 shows a timeline, and it is clear that the bioeconomy as a concept started to become more widespread in the early 2000s and has been " flying" since about 2012. The EU Bioeconomy Strategy and the publications of several other authors, e.g. LEWANDOWSKI, definitely contribute to this.

The networks are often specified as complex networks because of their intricate characteristics. One notable aspect of this field is ecosystem network analysis (ENA), which is an important area within network ecology. The input-output table can be viewed as a network, and network analysis—a relatively recent interdisciplinary method (ALBERT and BARABÁSI, 2002)—can be utilised for its study (BORGATTI et al., 2009; LI et al., 2017). HANNON (1973) was the first to apply input-output analysis to ecosystems, enabling the examination of both direct and indirect flows among constituents and illustrating the structure of ecosystems. Since 2010, research connecting Input-Output tables and networks has seen a significant rise, particularly gaining traction after 2015 (CARVALHO, 2012, MCNERNEY ET AL., 2013, XU ET AL., 2011, AN ET AL., 2015, KAGAWA ET AL., 2015, MALUCK & DONNER, 2015). Input-output networks are distinct from networks in other fields because of their high levels of connectivity, weighted nodes, and directional links.

This type of analysis represents the connections between entities (in this context, sectors) in the form of a graph. This graph, denoted as $A=(V, E)$, is composed of a collection of vertices (nodes) (V) and a collection of edges (E). In this context, the vertices represent different sectors, while the edges illustrate the value flows between them. Each edge, represented as (i,j), is directed and assigned a non-negative weight, denoted as a_{ij}. By definition, the graph may include self-loops since a sector can consume its own products. To grasp the relative significance of various sectors in the value flow, network analysis centrality concepts can be utilised. Assessing the position of a specific node within a network is challenging when relying on a single indicator, as determining the centrality of an actor is complex (for example, one node may have numerous connections that are weak, while others have fewer but stronger connections). This complexity has led to the creation of a diverse array of network centrality indicators.

There are various indicators of centrality, and their number has been increasing. One of the most straightforward measures is network centrality, which indicates the number of connections a node has. Closeness centrality reflects the "embeddedness" of a node within the network; a high value suggests that many nodes are situated near the node being examined (CRESCENZI et al., 2016). In the context of social networks, a high level of closeness centrality can be interpreted as a sign of popularity, while for sectors, it indicates the significance of a particular sector in the circulation of materials and values across the national economy. Degree centrality also serves as a measure of a node's "embeddedness" in the network (YUSTIAWAN et al., 2015). Meanwhile, eigenvector centrality gauges a node's influence by considering the impact of its neighbouring nodes (RUHNAU, 2000).

Network centrality serves as a useful metric for characterising a specific node based on its position within the network, determined through the clustering of edges. According to WANG et al. (2012), this measure is more suitable for defining the positions of various nodes compared to the previously mentioned metrics. Understanding node centrality is quite complex, leading to the existence of multiple indicators. In this instance, we utilised four indicators to assess the centrality of different sectors. The first indicator is closeness centrality, a commonly used measure for node positions. A higher value of this indicator signifies a more central position for the node.

Information centrality is defined by the harmonic mean of path lengths that terminate at a specific node. The centrality measure introduced by TANG et al. (2015) accounts for both the centrality of nodes and their connections with neighbouring nodes. Eigenvector centrality, also referred to as a prestige score, computes the influence of a node by paying attention to its importance in terms of relations (RUHNAU, 2000). The weighted degree is another perspective to view the edge centralities in a network (OPSAHL et al., 2010).

Analysing networks within input-output systems can enhance agent-based simulations by revealing interactions between economic and environmental factors (WANG et al., 2024). For instance, the influence of heat waves on the global supply chain network can be linked to the connectivity of the network (WENZ & LEVERMANN, 2016), or models may demonstrate the decrease in industrial output after an earthquake (INOUE & TODO, 2019) by utilising both real-world data and simulations. As noted by AN et al. (2024), various network metrics, like degree centrality and eigenvector centrality, have been well incorporated into input-output theory, whereas others, including closeness and betweenness centrality, require further development for effective use in input-output systems.

"I think the next century will be the century of complexity."
/Stephen Hawking/

5. RESULTS AND THEIR DISCUSSION

5.1. The raw material basis of the Hungarian bioeconomy system

5.1.1. Macroeconomic aspects of drought management

If we look at the situation of Hungarian agriculture in terms of preparing for drought, the question inevitably arises that we would need to mobilise a significant amount of capital, even from a macroeconomic point of view. But the big dilemma is whether we should invest this money in the development of agriculture to increase its resilience and whether this is really the optimal allocation of the available material resources. Answering this question requires the analysis of macroeconomic data and the application of models at the national economic scale. In order to examine the justification for agricultural investment, it is certainly worthwhile to make complex economic comparisons.

The exploration of the interrelationships between sectors, the study of how significant a sector is, has been the subject of research for centuries (MARX, 1867), but only LEONTIEF's (1941) classic work made a real breakthrough. This was the basis for the development of the Model of Interindustry Relations (MIR), or input-output analysis. However, the combination of the MIR analysis and network research allows a new approach. The MIR is essentially a directed graph, whose vertices are the value flows between sectors and edges are the value flows between sectors, and therefore the MIR can be viewed as a network. Network science developed in the second half of the twentieth century based on graph theory to study interconnected natural, social and economic systems (ALBERT & BARABÁSI, 2002). In recent decades, it has become clear (1) that understanding networks is essential for understanding natural and social systems (BARABÁSI, 2024) and (2) that natural and social phenomena and processes can be described in the same way using the conceptual and mathematical apparatus of network analysis (CSERMELY, 2004). The data on the network science of each country are collected from the OECD database (OECD, 2016). The matrix contains evaluable data for 44 sectors, i.e. 44×44.

If we analyse Hungarian data, the most obvious option is to analyse the relationship between the different macroeconomic sectors. The most commonly used method for analysing input-output systems is to use the so-called Leontief indices obtained by inverting the matrix of technical coefficients. Leontief indices show the effect that an increase in demand per unit value for the products of a given sector, such as agriculture, has on the growth of market demand for the products of other sectors.

To use a simple and very common example, if there is an increase in demand for the products of livestock production, this will obviously not only increase demand for other agricultural sectors, such as the production of animal feed, but also require the development of the processing industry. If more food processing machinery is needed, this will mean both an increase in imports and an increase in demand on the part of the Hungarian machinery industry. In turn, the production of machinery requires a wide range of other industrial goods, from specialised branches of the engineering industry to the extractive industries or the manufacture of rolled products. The resulting increase in demand from the steel industry to the energy sector, from the construction industry to the distributive trades, contributes to the expansion of the market.

The extensive use of the Leontief index and, more broadly, of input-output methods provides a broad opportunity to better understand the place of individual sectors in the complex system of the macroeconomy.

If we look at today's Hungarian economy in the light of the latest available statistics for 2020 (Table 4.), it is clear, that agriculture and the food industry have a significant role to play in stimulating the economy as a whole, compared to many other sectors of the economy. That is, while any surplus demand in the direction of agricultural production generates a surplus demand of HUF 2.16 in the economy as a whole, it cannot be said that agricultural development is merely a means to an end in itself.

The Leontief index is commonly used in world economic issues, but this index is based on the logic of market economies and mainly looks at the effects of changes in demand. This is not the case with drought - and crop fluctuations more broadly. In this case, it is not the change in demand due to the logic of a market economy that we need to look at, but the impact of the change in supply on the economy as a whole. This is a question that is alien to traditional economic analysis, but the analysis of exceptional situations requires this type of analysis. This is why the computational solution developed by Ghosh is important, as it quantifies the impact of unexpected changes in supply. The calculation of Ghosh inverses is similar in many respects to the determination of the Leontief index. By summing up the individual Ghosh inverses, we can get an idea of the shocks to the national economy caused by changes in supply. By extrapolating the Ghosh inverses to the Hungarian economy as a whole, it is clear that supply changes in agriculture have a very strong impact on many other areas of the economy.

Consequently, it is of the utmost importance to be able to manage the changes in agricultural production. From the calculations presented, a change in unit supply has a multiplier effect on the national economy as a whole and there is hardly another productive sector where it is so significant. It follows that the economic importance of investment and development in stabilising the supply of agricultural products goes far beyond the agricultural sector and underlines the importance of complex water management.

Table 3. Main characteristics of the structure of the Hungarian economy

Sectors	Leontief index	Ghosh index	The impact of changes in the supply of agricultural products on other sectors
Agriculture, hunting, forestry	2.16	5.12	1.24
Fishing and aquaculture	2.13	1.12	0
Mining and quarrying, energy producing products	1.92	1.08	0
Mining and quarrying, non-energy producing products	2.41	1.19	0
Mining support service activities	2.11	1.06	0
Food products, beverages and tobacco	2.67	6.28	0.42
Textiles, textile products, leather and footwear	2.27	1.56	0
Wood and products of wood and cork	2.49	1.63	0.01
Paper products and printing	2.50	2.24	0.01
Coke and refined petroleum products	2.69	11.73	0.01
Chemical and chemical products	2.56	4.56	0.03
Pharmaceuticals, medicinal chemical and botanical products	2.28	2.62	0.01
Rubber and plastics products	2.54	3.80	0.02
Other non-metallic mineral products	2.44	3.01	0.01
Basic metals	2.81	3.89	0.01
Fabricated metal products	2.50	3.55	0.01
Computer, electronic and optical equipment	3.19	6.75	0.02
Electrical equipment	2.80	4.24	0.01
Machinery and equipment, nec	2.70	3.74	0.01
Motor vehicles, trailers and semi-trailers	3.14	13.84	0.05
Other transport equipment	2.81	1.81	0
Manufacturing nec; repair and installation of machinery and equipment	2.23	2.53	0.01
Electricity, gas, steam and air conditioning supply	2.10	4.54	0.01
Water supply; sewerage, waste management and remediation activities	2.11	1.85	0
Construction	2.35	9.38	0.04
Wholesale and retail trade; repair of motor vehicles	1.92	7.88	0.09
Land transport and transport via pipelines	1.95	4.38	0.01
Water transport	2.90	1.24	0
Air transport	2.73	2.37	0
Warehousing and support activities for transportation	1.86	2.16	0
Postal and courier activities	1.62	1.20	0

Accommodation and food service activities	2.34	2.45	0.05
Publishing, audiovisual and broadcasting activities	2.02	1.71	0
Telecommunications	1.64	1.38	0
IT and other information services	1.55	1.64	0
Financial and insurance activities	1.64	2.12	0
Real estate activities	1.55	3.00	0.01
Professional, scientific and technical activities	1.71	3.27	0.01
Administrative and support services	1.72	2.39	0.01
Public administration and defence; compulsory social security	1.47	2.89	0.01
Education	1.35	1.79	0
Human health and social work activities	1.80	3.32	0.02
Arts, entertainment and recreation	1.82	1.75	0
Other service activities	1.81	1.59	0

Source: Own calculation, based on OECD data, 2024

5.1.2. Production Structure and its Restructuring

One obvious way to adapt to climate change would be to diversify the product mix. Unfortunately, however, the opposite is happening in this area, which means that the product structure is becoming narrower, and the production palette is being limited to fewer and fewer crops. This can be clearly seen in Figures 2 and 3, which show the share of three and five crops in the production structure based on agricultural land use. Today, the value of the five-crop concentration index has risen to over 80 %, so one of the most viable options for expanding the product structure would be to introduce new crop species. Exactly which plant species could be considered could be the subject of future research.

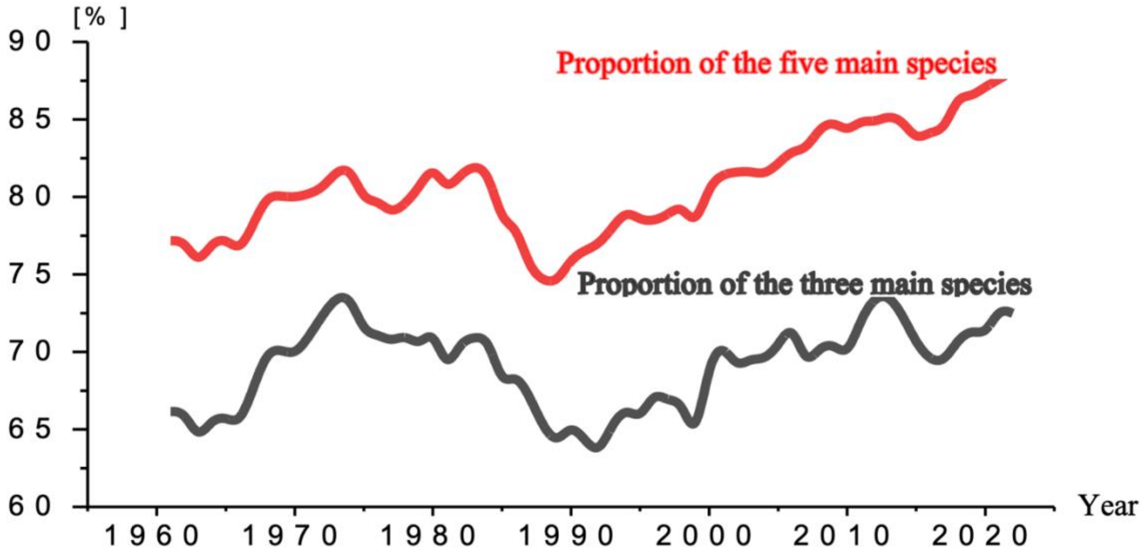

Figure 2. The three and five crops with the highest shares of arable land

Source: Own creation, 2024

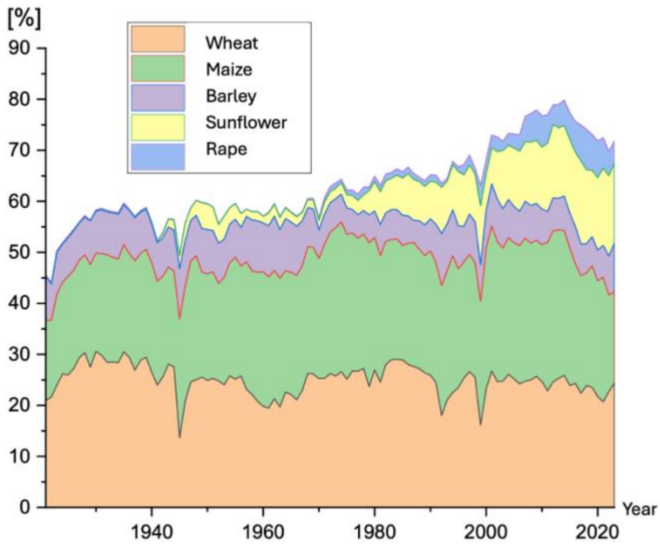

Figure 3. The five main crops currently grown as a proportion of arable land

Source: Own creeation, 2024

The production structures (hereafter referred to as portfolios, as used in financial investments) differ in terms of their expected return and the associated risk. Portfolios are considered efficient if they combine high returns with low risk. In principle, decision-makers have a wide range of options (alternatives) to choose from, but in practice, only efficient (efficiencies) portfolios will be important. Each production structure will have a different risk/return ratio. The decision maker's objective is to optimise the risk/return ratio according to his preferences.

In the first step of my work, I selected nine arable crops and calculated their yield per unit area as a product of average yields and world market prices, that shows Figure 4.

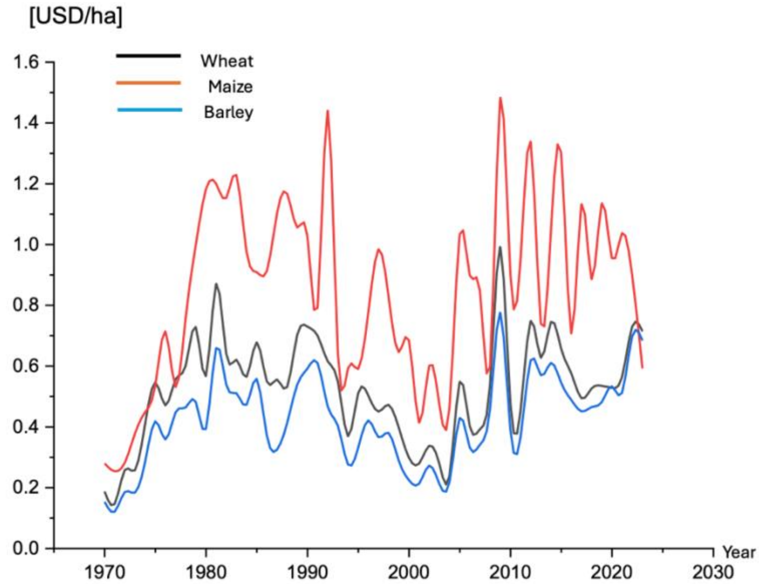

Figure 4. Yield per hectare for three crops

Source: Own creation, 2024

Then, I examined where the resulting yield curves show a break, i.e. the most recent point in time from which the time series can be considered relatively homogeneous. I found that this was a ten-year period. I then determined what the minimum and maximum production areas were in the last ten years, these were the lower and upper bounds of the model. The optimisation is based on the

$$E(R_p) = \sum_i w_i E(R_i)$$

where the R_p is the return on a given product structure, R_i is the return on each product, and w_i the importance (weight) of the different products in the portfolio.

Assuming that all available resources are used, therefore:

$$\sum_i w_i = 1$$

The portfolio spread:

$$\sigma_p^2 = \sum_i w_i^2 \sigma_i^2 + \sum_i \sum_{j \neq i} w_i w_j \sigma_i \sigma_j \rho_{pj}$$

where

σ_i is the variance of each component, while ρ_{ij} is the correlation between the components (in our case the products).

The financial return risk values for each crop are shown in Figure 5.

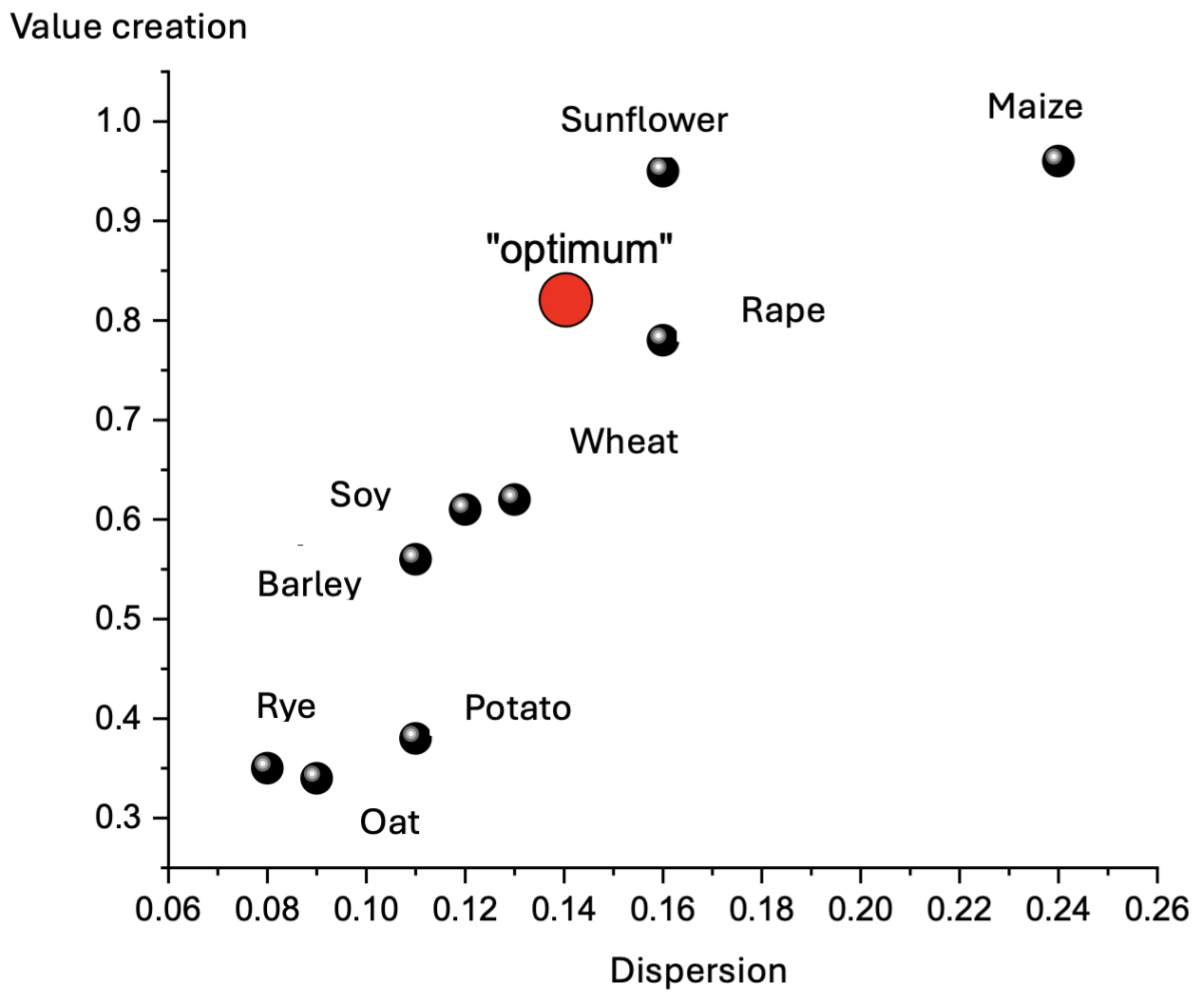

Figure 5. Financial return-risk characteristics of the crops under consideration

Source: Own creation, 2024

The above figure shows that maize and sunflower offer significant yields but carry a significantly higher risk than optimal. Yield levels are coupled with somewhat lower risk levels for rapeseed, soybean and wheat. Potatoes, oats and rice offer low yields, albeit with a relatively low level of risk. If we accept the optimisation proposal, it would seem that it would be advisable to focus on increasing the area under sunflower, but if we do so, we must also take into account two factors: firstly, the fact that the surplus production resulting from the increase in sunflower area is often used to make up for the increase in production, mainly in the lowlands, by selling the sunflower seeds directly, with very low added value. A major problem is that the production of margarine with a really high value-added content has virtually ceased in Hungary.

An evaluation of the optimisation results shows that a relative reduction in the area sown to wheat, an increase in the area sown to maize, a reduction in the area sown to barley and an increase in the area sown to sunflower are justified, with a reduction in the proportion of rape. If these proposals are accepted, it would appear that the growing importance of maize poses a number of economic policy challenges because a significant proportion of the maize currently produced is sold as a relatively low-value-added product. The European Union made a very strong commitment to increasing the use of bioethanol a few decades ago, and significant steps have been taken in this direction over time, but it is becoming increasingly clear that no arguments have been found for a significant increase in the use of bioethanol that would justify increasing or even maintaining current use rates. If we accept that the importance of maize may continue to grow in the coming years, the question arises as to what market opportunities this will open up. It is very likely that after the end of the Russian-Ukrainian war, there will be a resumption of strong Ukrainian maize exports and that we will not be competitive with them. All this suggests that improving conditions for livestock production could be a priority.

Obviously, I have compared three different goals: (1) when we want to achieve the maximal income, (2) when we want to minimise the portfolio variance, and (3) the maximal mean return per expected tail loss unit. The results highlight that the maize offers a high level of income, but the stability of the income generation of this product is relatively low. Increasing barley production is an important source of the stabilisation of income. However, the income-generating capacity of this plant is relatively low. The sunflower is an important component of the portfolio but has high volatility. On the contrary, another oil crops, the rape has an important role in the income stabilisation. Results of the calculation of optimal land use structure are presented in Figure 6.

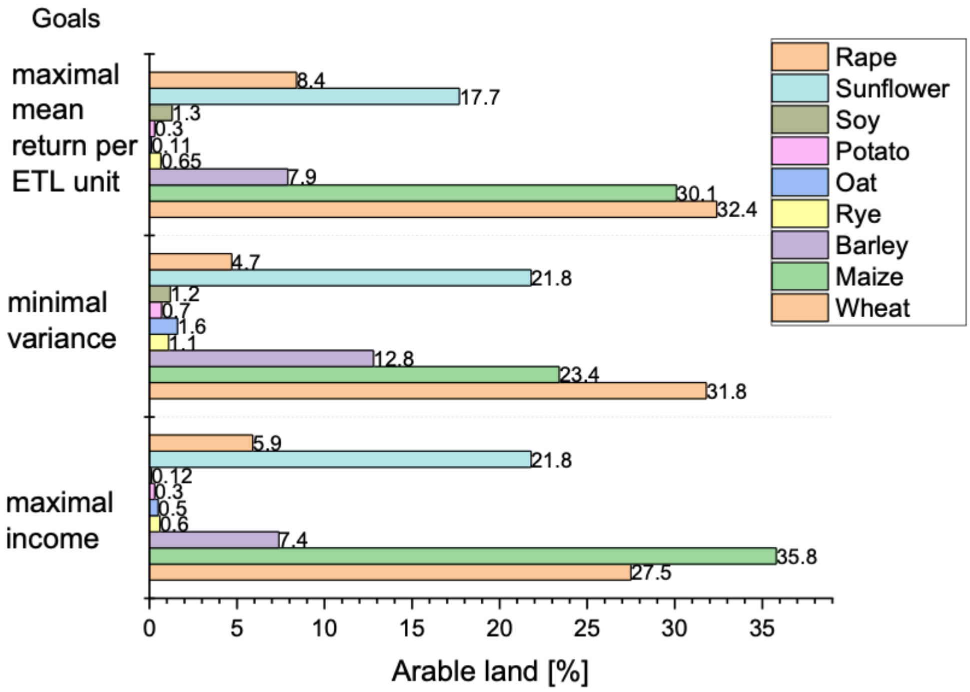

Figure 6. Optimal structure of arable land utilisation (the numbers indicate the share of various plants, in per cent)

Source: Own creation, 2025

5.1.3. The Era of Drought

It has been confirmed by tons of studies that climate change is a highly complex meteorological phenomenon. Out of these, the most important, influencing directly the agriculture, is the drought. In the context of my dissertation, I have chosen the effect of drought on the raw material basis of bioeconomy.

It is well documented that the Earth's - and the Carpathian Basin's - climate is changing significantly (GHIL AND LUCARINI, 2020). Most of researchers agree that (1) climate is becoming more extreme, with an increasing frequency of weather externalities (TRENBERTH ET AL., 2015). One of the likely causes of this is global warming and changes in ocean currents (GARCÍA MOLINOS ET AL., 2017), (2) average temperatures will rise, (3) the amount and distribution of precipitation will change, with an overall decrease likely.

The long-term development of Hungarian agriculture over the last century can be very simply divided into three phases: the first was characterised by low technological development, followed by spectacular, dynamic growth. In the last thirty years, performance has been increasingly affected by weather extremes. This can be seen in the changes in yield averages. This phenomenon is illustrated for two of our main crops, wheat and maize, in Figures 7-12.

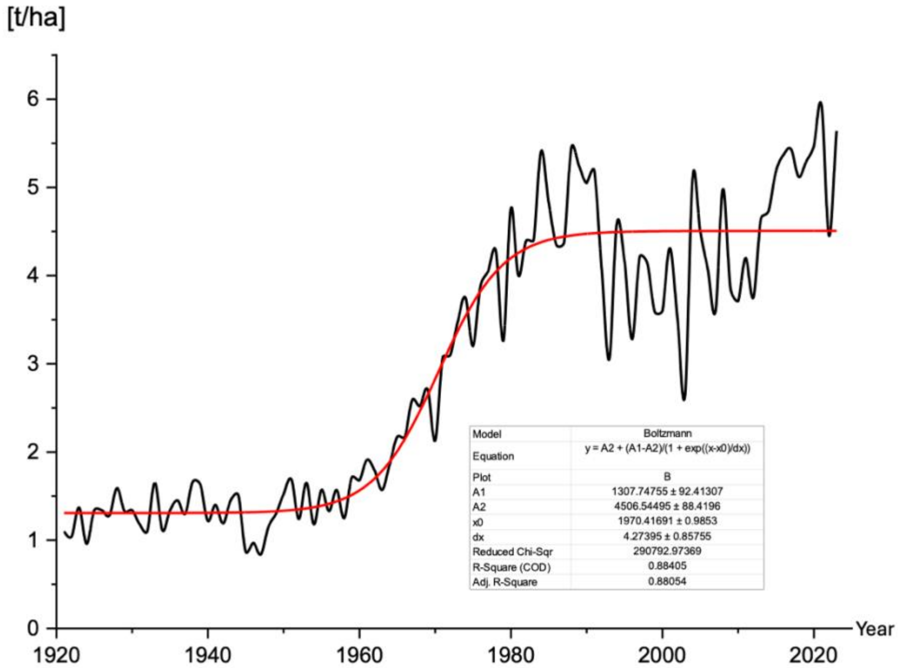

Figure 7. Changes in the wheat average yield and approximation with Boltzman diagram (1920-2023)

Source: Own calculation based on KSH's data, 2024

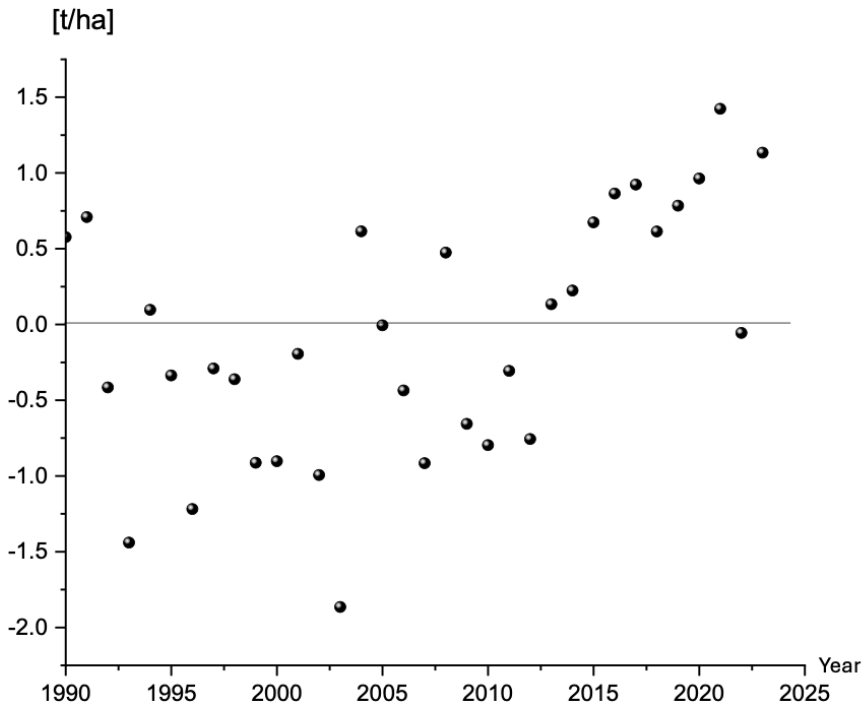

Figure 8. Deviation of the average wheat yield from the forecast (1990-2023)

Source: Own calculation based on KSH's data, 2024

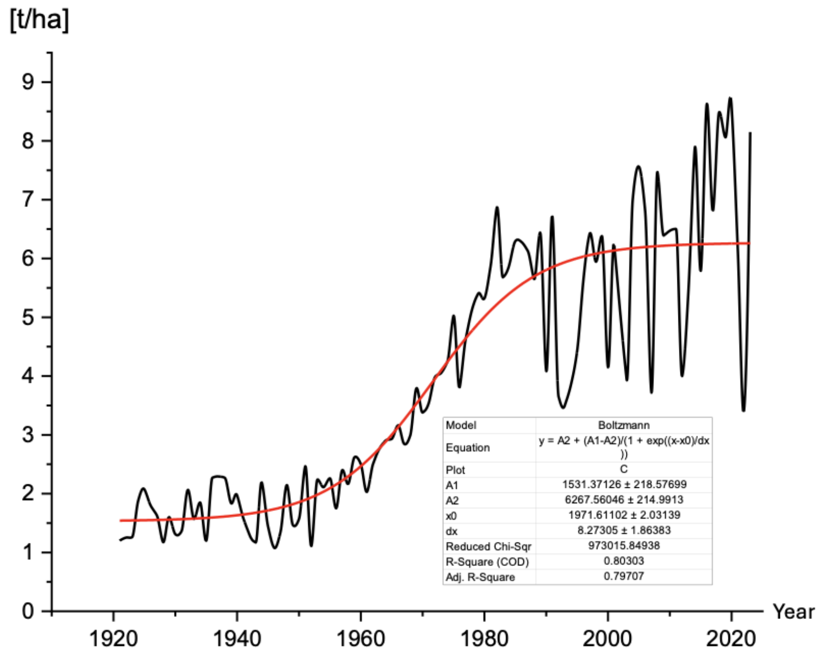

Figure 9. Variation and approximation of maize average yield with Boltzman diagram (1920-2023)

Source: Own calculation based on KSH's data, 2024

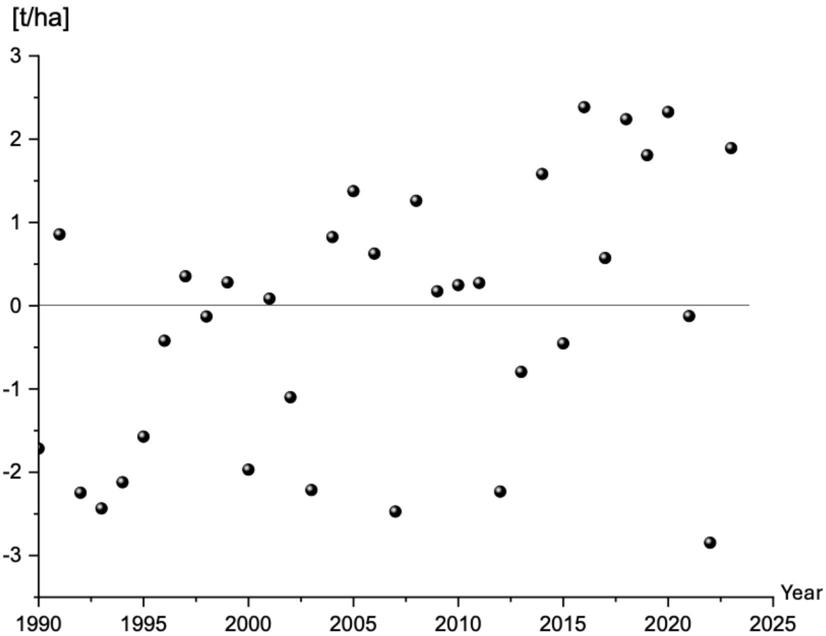

Figure 10. Deviation of maize average yield from forecast (1990-2023)

Source: Own calculation based on KSH's data, 2024

In order to measure and compare the performance of Hungarian agriculture, it is also useful to examine the relative dispersion of the production of different crops in some countries with similar agricultural production conditions. The analysis is summarised above in Table 3.

This shows that the variability of Hungarian agricultural yields for the selected crops is practically the same as the average for other countries but, in some cases, exceeds it. This fact confirms the hypothesis that Hungary is particularly exposed to agroclimatic variations in terms of the endowment of agricultural production. If we look for an answer to the question of how the development of agricultural production in terms of the average yield is related to the different countries, we can see that the Hungarian average yields show a strong similarity with the characteristics of the other countries of the Central European region.

This draws attention to the fact that our ability to exploit our domestic competitiveness results is limited in the current situation because when the average yields in our country are low, it is likely that the neighbouring countries will also have similar values.

Table 4. Trends in the relative dispersion (standard deviation/average yield) of some crops in the EU's major agricultural-producing countries, based on data for 2014-2023

	Apple	Cabbage	Grape	Maize	Peas	Potato	Carrot	Tomato	Wheat
AU	1.27	1.21	1.18	1.02	0.88	0.9	0.81	0.79	0.37
BE	1.8	1.7	1.57	1.39	1.23	1.12	1.03	0.98	0.39
BG	0.87	0.87	0.9	0.79	0.73	0.65	0.63	0.59	0.27
CR	1.04	1	1.02	0.91	0.81	0.67	0.61	0.54	0.33
CZ	0.96	0.91	0.94	0.81	0.72	0.59	0.6	0.29	0.29
FR	1.17	1.14	1.08	0.94	0.81	0.73	0.7	0.72	0.35
HU	1.03	1.01	0.98	0.86	0.75	0.64	0.61	0.58	0.34
IT	0.79	0.81	0.78	0.69	0.61	0.57	0.55	0.42	0.34
PO	0.86	0.8	0.83	0.77	0.66	0.54	0.53	0.46	0.32
PT	0.95	0.94	0.95	0.82	0.73	0.69	0.66	0.67	0.36
RO	0.83	0.77	0.8	0.69	0.59	0.59	0.59	0.3	0.3
SL	0.98	0.95	0.99	0.87	0.78	0.64	0.61	0.38	0.3
ES	1	0.95	0.94	0.81	0.71	0.64	0.61	0.53	0.36
Average relative standard deviation	1.04	1	1	0.88	0.77	0.69	0.66	0.56	0.33
Hungarian relative standard deviation compared to the group average	0.99	1.01	0.98	0.98	0.97	0.92	0.92	1.04	1.03

Source: Own calculation, based on FAOSTAT data, 2024

Several methods are used in research to measure drought intensity. In Hungarian practice, the Pálfai drought index is the most widely accepted method. If we look at the evolution of the drought index (Figure 11), it is clear that the frequency of years with significant drought has increased considerably in the recent period.

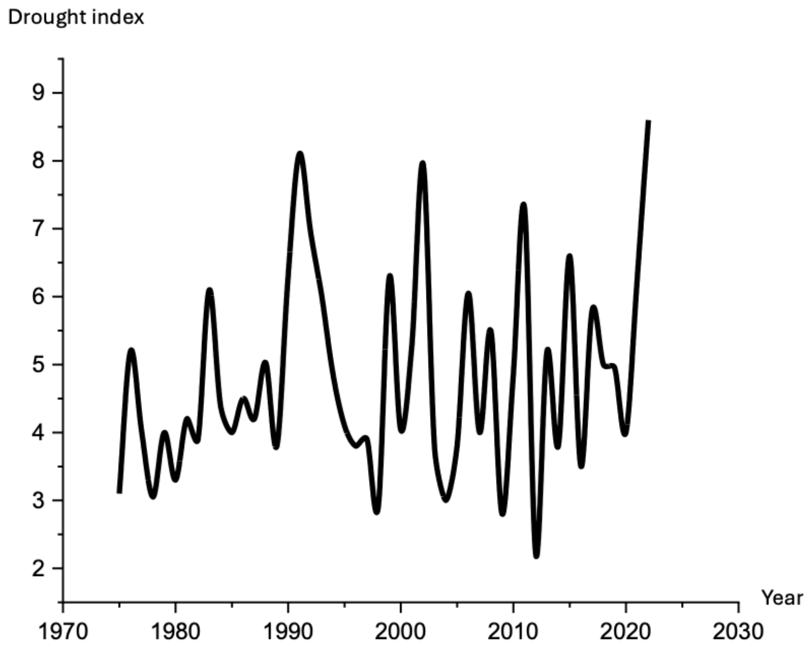

Figure 11. Changes in the Pálfai drought index in Hungary (1975-2022)

Source: Own calculation based on individual data provided by OMSZ, 2024

However, for clarity, it is also important to take into account the fact that there is little correlation between the Pálfai drought index and the yields of different crops. This implies two things: firstly, that the Pálfai drought index does not adequately reflect the stress that drought causes to crops, and secondly, it highlights the fact that agricultural technology has many tools to reduce the adverse effects of drought (Figure 12).

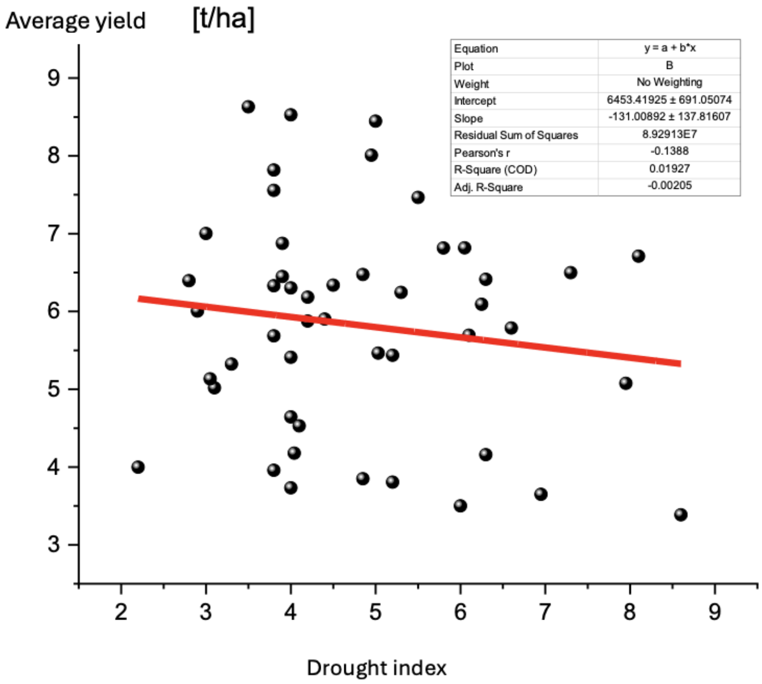

Figure 12. Pálfai drought index and average maize yield

Source: Own calculation, 2024

Based on the available information, a number of climate models have been developed in recent decades that attempt to predict the climate on a global or regional scale. Most of the climate models contain a high degree of uncertainty, and their projections contradict each other in many respects. Uncertainty is particularly high for the Carpathian Basin, where most models predict a decrease in precipitation (Figures 13-14). This is supported by trend analysis based on a number of historical facts.

Overall, the majority of the projections suggest that we should be prepared for an increase in the relative frequency of years with very high precipitation and an increase in droughts in the Carpathian Basin in the coming years due to extreme weather events. Most forecasts predict a warmer and drier climate.

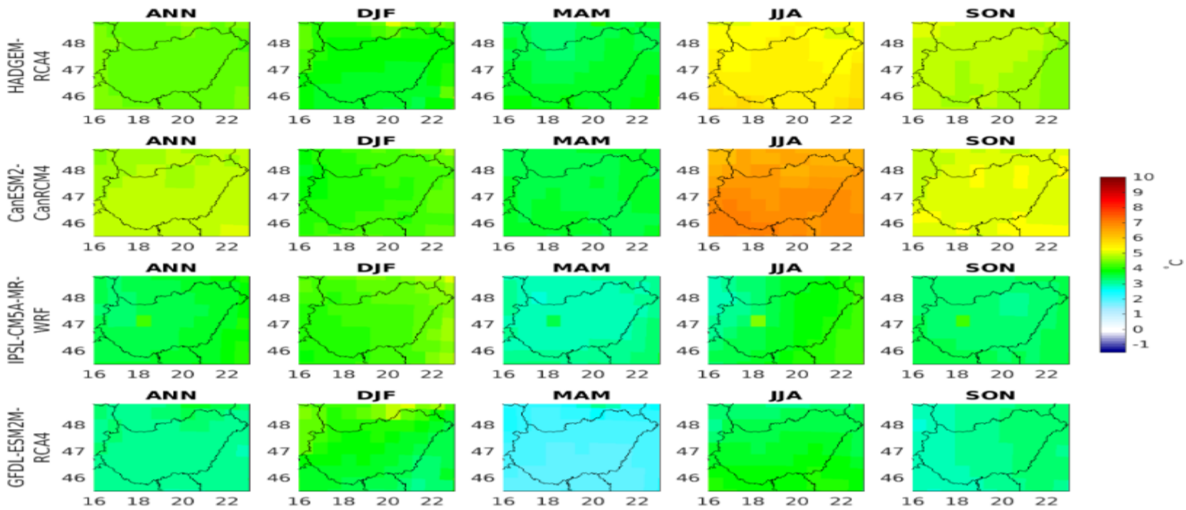

Figure 13. Projected annual and quarterly average temperatures in 2050 under four different scenarios

Source: http://www.highendsolutions.eu/page/climate_projections , 2024

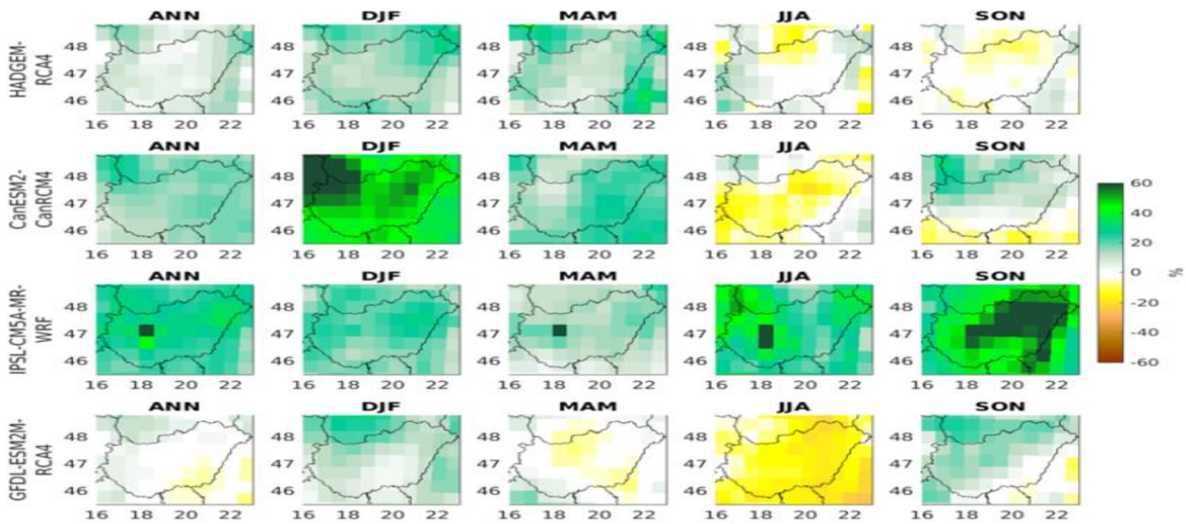

Figure 14. Projections of annual and quarterly rainfall totals for 2050 under four different scenarios

Source: http://www.highendsolutions.eu/page/climate_projections , 2024

The drought is not only affecting Hungary, of course, but also the rest of Europe, so it is important to look at the similarities between countries in terms of the consequences of drought. The possibilities for this are illustrated by correlations between the average barley and wheat yields and two horticultural examples. According to CSAJBÓK et al. (2020), barley and wheat are of particular importance for the Hungarian agricultural economy. Not only because of their centuries-old cultivation, but also because of their tolerance to climatic changes. Hungary's climate - which is characterised by cool, wet springs, timely rainy weather and these plants growth cycle that largely avoids the most extreme summer conditions - is uniquely favourable to stable and high production of barley and wheat.

Figures 15 and 16 have been constructed with the two-letter convention abbreviations of the countries in the comparison placed on the diagonal of the matrix ground, the lower third of the matrix showing the correlation relationship between the corresponding values of the different countries in the form of a dot plot or fitted curve, and the upper third of the matrix showing the correlation coefficients between the corresponding crop averages of the different countries and the measures of the closeness of the correlation relationships.

Analysing the correlations between barley yield averages, it is clear that Hungary shows a strong correlation with the barley yield averages of several Central European countries. This is strongest for Bulgaria, the Czech Republic, Austria and Italy. This is important to take into account because it highlights the fact that if average barley yields in Hungary are low, access to this product from neighbouring countries is limited. Looking at the average wheat yields, it is also clear that the average wheat yields in Hungary are very closely related to those of Slovakia, Romania and Bulgaria.

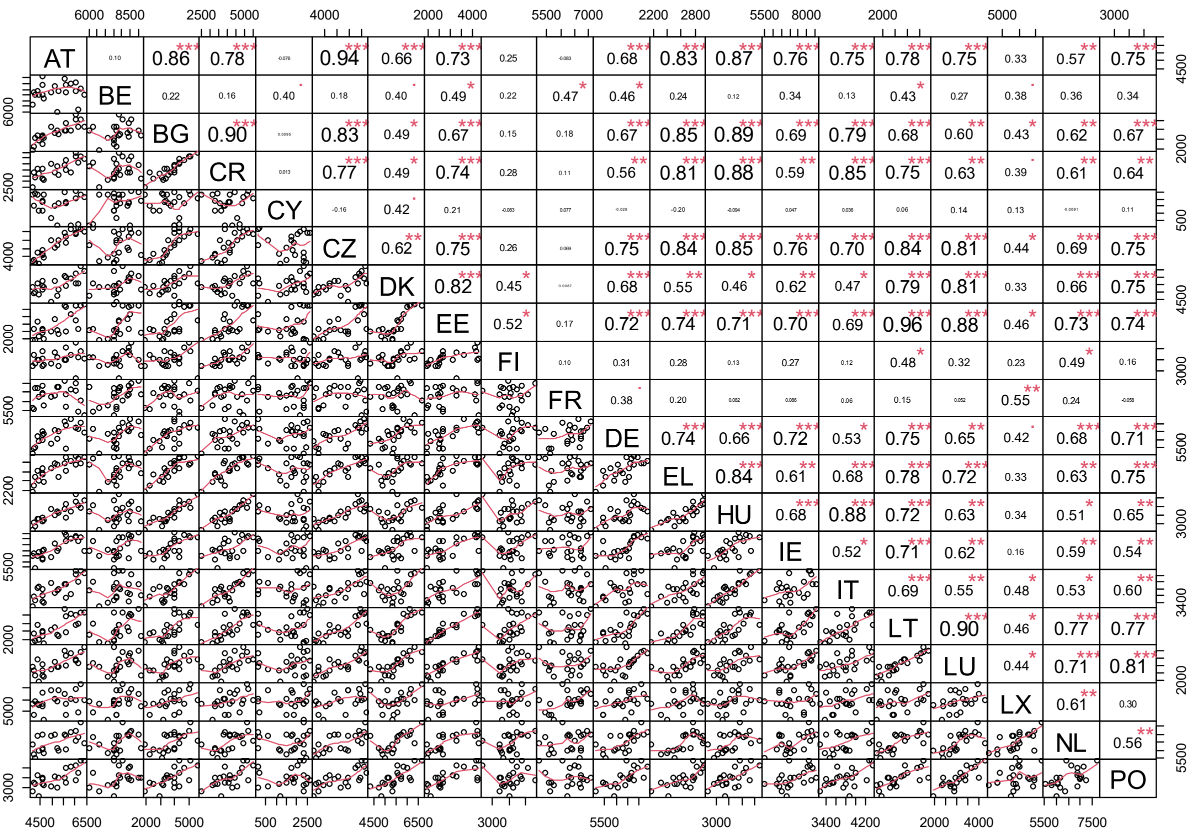

Figure 15. Matrix of correlations between barley yield averages

Source: Own calculation, 2024

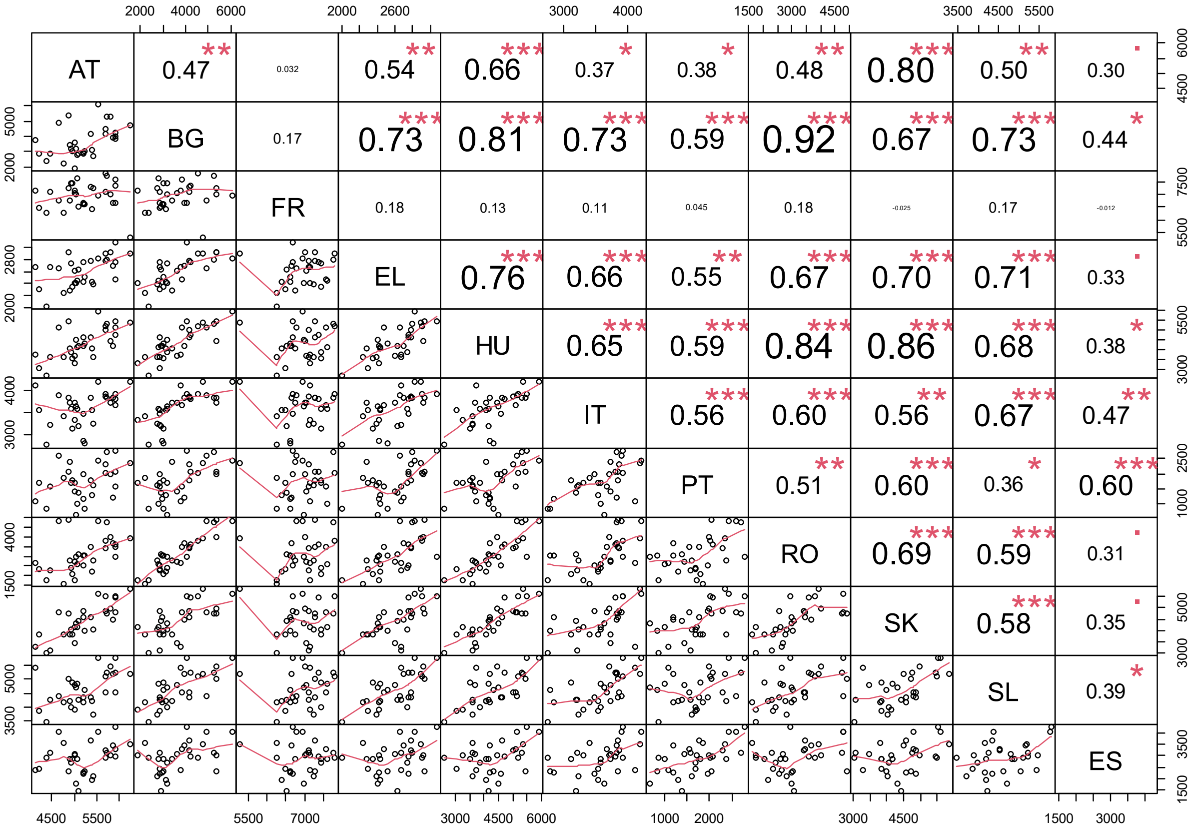

Figure 16. Regression analysis of wheat production

Source: Own calculation, 2024

From the point of view of the average yields of the different countries, the correlations presented are important because they show that European agriculture reacts in a similar way for certain products and product groups, and therefore, if we can take advantage of the potentially favourable Hungarian position, we can only do so to a limited extent.

5.2. Bioeconomy in the Visegrad countries

The economic structure of the V4 countries shows considerable similarities, and this is a characteristic feature of their bioeconomy sectors, too. The share of sectors producing or processing biological products is between 15,3 and 36,2 % of the output of producing (non-service) sectors. This ratio is the lowest in the case of Czechia and the highest in Poland. In value-added production of these sectors, the share of branches producing or processing biological materials is between 17.9% (CZ) and 35% (PL). If we take into consideration the contribution of biological materials to the performance of another sector, we can see that the value-added content of various components of the bioeconomy sector in V4 countries is different. Obviously, the share of value-added in the production value of agriculture is similar in the case of Czechia, Slovakia and Poland. In case of Hungary, this indicator is a bit higher than the other three countries. The importance of aquaculture in these countries (with the exception of Poland) is marginal, but it is interesting that in case of Czechia, the share of value added of this sector in output is more than 50% higher than in the rest of the V4 countries. The value-added content of the food industry is between 20 and 35%. If we analyse the relative importance of various sectors in value-added creation, it is obvious that the most important parts of the bioeconomy are agriculture and the food industry. Another sector's role is marginal, with the exception of Czechia, where the wood sector is important.

This fact highlights the importance of bioeconomy, but underlines the role of increasing biomaterials in the enhancement of value-added creation of bioeconomy. It is important to see that the value-added content of the bioeconomy sector is higher than in the case of various parts of the industry, e.g., the machine industry or the production of vehicles. This fact underlines the importance of the development of these sectors in increasing the value-added creation of these parts of the economy.

It is important to highlight that the bioeconomy is lesser conjuncture-prone than tourism or the car-making industry. It is well documented that in the last years, the global and European machine industry has been into a deep-rooted crisis, which has created considerable structural tensions in that field of the economy.

It is interesting that the share of agriculture and forestry has been relatively low in the activity of processing industries. E.g. in Hungary, where agricultural-based pharmaceutical production has considerable traditions, the share of agricultural products in total inputs of pharmaceutical production is less than 2.5%. In Poland, where the agro-ecological potential is suitable for the production of fibre plants(e.g. flax, hemp), the share of agriculture in the input of the textile industry is marginal.

On the base of the analysis of Leontief inverse matrices, it is obvious that the multiplier effect of the agriculture and food industry is above the average of another branch. This is an important fact from the point of view of developmental policy because it highlights the role of the bioeconomy in boosting economies.

Analysing the structure of inter-sectoral trade flows within the V4 countries reveals a noteworthy trend: the vast majority of trade flows between different sectors occur within the borders of these countries. The distribution of these trade flows follows a distinctly right-skewed pattern, which can be effectively described by a gamma or Weibull distribution. This observation indicates that most sectors are interconnected intensively with a relatively small number of other sectors. A network analysis of these sectors using Cytoscape algorithms clearly shows that the economic structure of the V4 is comprised of four distinct sub-clusters, each corresponding to a nation-state. This underscores that inter-sector connections within states are significantly more robust than those between the states themselves. The most significant connections, in terms of value flows among various sectors of the bioeconomy, are illustrated in Figure 17.

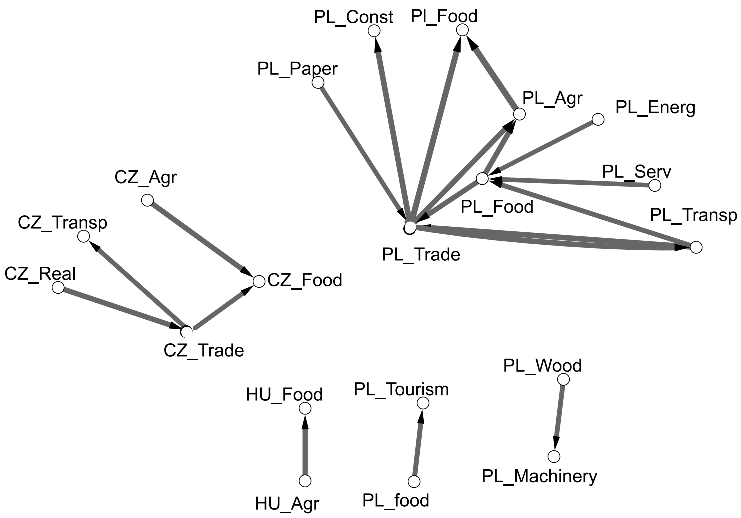

Figure 17. The most important value flows among the bioeconomy-related sectors of the V4 countries

Source: Own creation, 2025

The determination of centrality among various sectors is a highly complex issue. For this reason, I have calculated different centrality indices using the CytoNCA plugin. These indices were then compared with the corresponding averages of the producing sectors (as opposed to the service sectors) in the V4 countries. The agricultural and food industries of the V4 states exhibit above-average centrality in at least two of the centrality indicators and have been highlighted with bold formatting (see Table 5). This underscores the significance of these sectors in the functioning of national economies.

Table 5. Network position of agriculture and food industries in the V4 states

	Betweenness	Closeness	Eigenvector	Degree	Network	Information	Local average connectivity-based centrality
HU Agric	16	82	9.82E-05	2398	10	**27**	1717
HU Food	**1382**	86	0.002	4265	15	**30**	2458
CZ Agric	387	**110**	0.002	4589	22	**30**	**4561**
CZ Food	75	**116**	0.004	**5122**	19	**31**	**4692**
PL Agric	6	**119**	**0.193**	**12756**	**30**	**29**	**11438**
PL Food	**1078**	**122**	**0.379**	25208	**63**	**30**	**8772**
SK Agric	396	67	1.54E-05	**1323**	9	**30**	1229
SK Food	18	**93**	2.23E-05	1452	10	**45**	1365
National average	263	91	0.027	4617	21	26	4074

Source: Own creation, 2025

The contribution of agricultural and aquacultural product utilisation was the highest within the agriculture and food industry sector (Table 6). As anticipated, food production was the main consumer of agricultural products. The variations among different countries were quite intriguing; for instance, in Czech Republic, this share was only 60% of Hungary's corresponding figure. In Hungary and Slovakia, the proportion of agricultural products used in the chemical industry was relatively considerable. This can be attributed to substantial capacities focused on the comprehensive processing of maize, predominantly for bioethanol production, though not exclusively. In Czech Republic, the involvement of the chemical industry in utilising agricultural products is significantly lower than the global average, based on data from all countries in the database. The use of wood is a standard component in construction; however, the percentage of agricultural and forestry products in this sector is relatively low compared to most European nations. The use of biological materials for energy generation remains low, with minimal differences among the V4 countries. These variances can be attributed to the comparatively low level of agricultural product processing in Hungary. The paper industry traditionally relies on forestry products, and this sector's significant share is evident in countries where the forestry industry is particularly robust, such as the Czech Republic and Slovakia. The percentage of biomaterials utilised in the pharmaceutical sector was relatively minor. This is particularly noteworthy in Hungary, where a large-scale facility (Alkaloid Factory) was established for poppy processing (Papaver somniferum); however, as our interviews with pharmaceutical experts revealed, it was unable to compete effectively with rivals from Australia and India. Several decades ago, fibre plant production was a significant industry in the V4 nations, but cultivation of these plants has either diminished or vanished. For example, at the start of the 1960s, the area dedicated to flax production exceeded 230 thousand hectares, but today this figure has plummeted to less than 3 thousand hectares.

Table 6.The contribution of agricultural product utilisation by sectors in percentage

Sector	CZE	HUN	POL	SVK	Global average, for all countries in ICIO database
Agric	17.71	27.8	20.9	32.8	21.1
Fishing	2.67	13.99	3.57	12.15	3.68
Chemical and chemical products	0.26	2.02	0.66	3.95	2.07
Food	28.65	30.51	21.1	18.7	26.3
Energy	1.36	1.11	1.39	0.66	
Paper	3.17	0.52	2.01	12.8	3.54
Pharmaceuticals	1.98	0.59	1.26	2.1	2.24
Accommodation and food service activities	6.42	3.41	1.22	1.6	6.05
Construction	0.03	0.08	0.15	0.15	0.57
Textile	5.29	0.71	0.73	0.88	2.21

Source: Own creation, 2025

The assessment of biomass usage in the V4 countries indicates that most of these products are utilised for agricultural and food industry purposes, while the extent of their application for non-food or feed-related uses is relatively limited.

The values of the Leontief index were found to be greater than one only along the main diagonal, which aligns with findings from a general analysis of input-output tables (DOBRESCU ET AL., 2010). The average value of the L coefficients on the main diagonal is 1.095; however, in the case of agriculture, this indicator exceeded 1.15 across all V4 countries. In the food industry, the value of this indicator surpassed 1.1. Notably, the L value in both cases did not exceed 0.1 in international intersectoral relations, highlighting the relatively low level of international labour distribution among the sectors of the V4 countries.

The sum of the Leontief indices (Figure 18) serves as an indicator of an industry's capacity to mobilise other parts of the economy. This index ranged between national averages of 1.54 and 1.78. In agriculture and fishing, the index value across all countries was above 1.8, with the difference between the national average and agricultural L indices being minimal. The L index for food production was significantly higher than the national average ($p<0.05$).

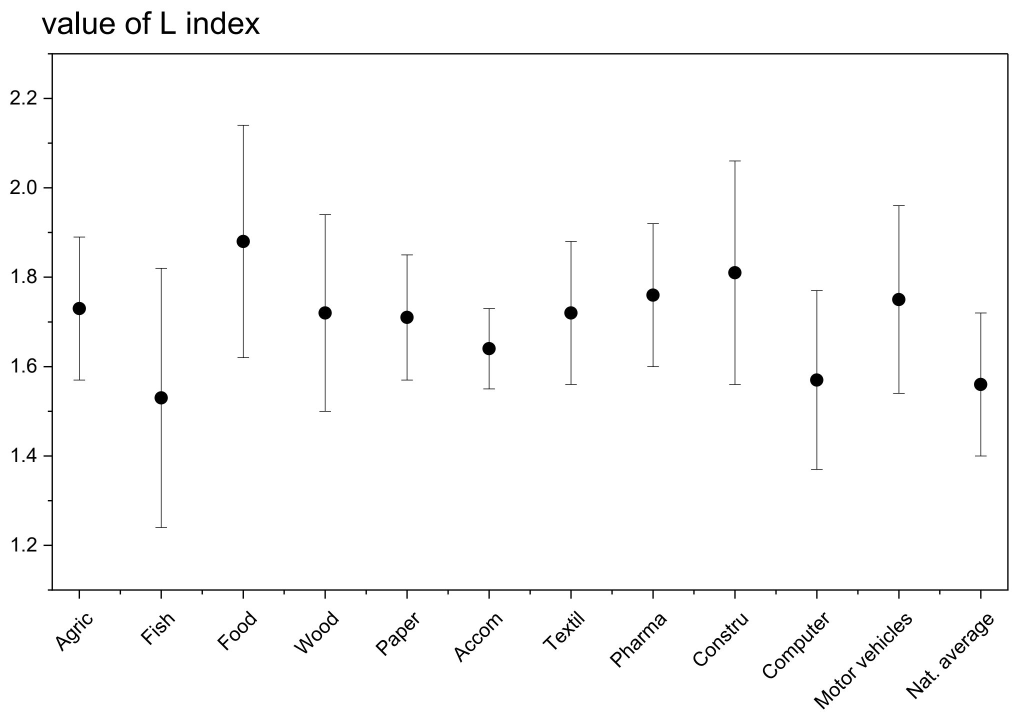

Figure 18. The total of the Leontief indices for the V4 countries

Source: Own creation, 2025

In recent decades, the V4 countries have placed an emphasis on motor vehicle production; however, the sum of L indices in this sector equalled that of agriculture and, while not significantly, was lower than that of food production. This situation underscores the vulnerability of a narrowly focused policy that prioritises motor vehicle production, as this sector alone may not be sufficient to drive significant economic development. Meanwhile, in another prominent high-tech sector, the computer industry, the value of the L index is significantly lower than that of food production.

The Ghoshian index is seldom utilised in input-output analysis (PARK, 2007); however, it is particularly significant in the context of agriculture, where excess supply can occur quite often. In the agricultural sector of the V4 states, the cumulative sum of G index values ranged from 2.02 to 2.22. This indicates that both additional demand and extra supply can lead to substantial challenges.

It can be concluded that agricultural production, when viewed cumulatively, does not significantly exceed national averages, although certain aspects, particularly food production, do show higher levels. Given the current circumstances, where the proportion of biological raw materials is relatively low in several sectors, it is essential not to overlook their importance in energising the national economy.

By calculating the indices of dispersion power and sensitivity, we identified the current and potential key sectors related to the bioeconomy in the V4 countries. The findings are illustrated in Figure 19.

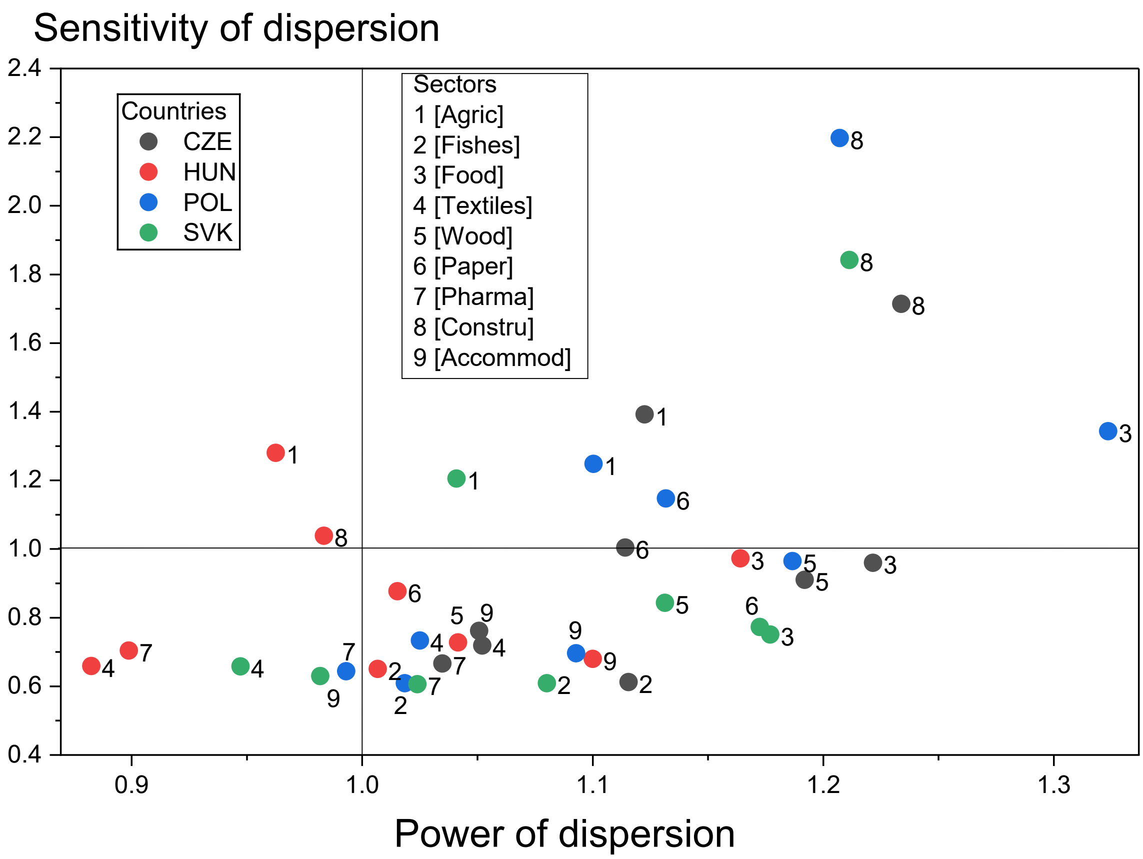

Figure 19. Dispersion of the power and sensitivity of the V4 countries

Source: Own creation, 2025

According to HA and TRINH (2018), sectors situated in the upper right quadrant of the graph have a significant impact on the overall economy. A dispersion power exceeding 1 signifies that an increase in demand for a specific sector will result in an above-average rise in demand throughout the economy. In contrast, a sensitivity of dispersion greater than 1 indicates that the sector possesses strong supply-side connections. The Polish food, construction, and paper industries, along with the construction sector in most V4 countries, are notable examples in this quadrant. This can be explained by the relatively large and intricate nature of the Polish economy (ROJEK, 2023), while the essential role of the construction sector in driving economic development accounts for the latter observation (ÇOBAN ET AL., 2025). Most of the sectors examined demonstrate an above-average dispersion coefficient, underscoring their importance as markets for input producers. This trend is largely driven by the industrialisation of agriculture and other bioeconomy-related areas (SGROI, 2022). Interestingly, the sensitivity index for dispersion generally falls below one, indicating that the current and potential elements of the bioeconomy are only weakly interconnected with other segments of the economy.

A rather strong connection could be indicated in relation to the Czech and Slovak sectors. The increasing demand for products from the Czech food industry considerably increases the demand for products from the food industry in Slovakia and vice versa. Similarly, the fishing sector of these two landlocked countries has a strong connection. Despite these cases, the relatively low levels of Leontief indices concerning the extramural activities well reflect the low level of internationalisation of bioeconomies of V4 Countries. The key sector analysis highlights the importance of the bioeconomy in the V4 countries in Table 7.

Table 7. Results of key sector analysis: direct backwards and forward linkages in bioeconomy sectors in V4 countries, the total averages for the nation

Sectors	CZE back.	CZE forw.	HUN back.	HUN forw.	POL back.	POL forw.	key sector	SVK back.	SVK forw.
Agriculture	0.38	0.54	0.17	0.63	1.01	0.59	IV	0.46	0.58
Fishing	0.41	0.31	0.07	0.28	3.19	0.6	IV	0.34	0.74
Food	0.58	0.2	0.15	0.24	2.05	0.16	IV	0.59	0.28
Textile	0.3	0.08	0.15	0.34	0.87	0.15	I	0.35	0.17
Wood	0.47	0.54	0.18	0.62	1.41	0.62	IV	0.56	0.59
Paper	0.42	0.52	0.19	0.59	1.28	0.35	IV	0.50	0.63
Pharmaceutics	0.27	0.12	0.04	0.34	4.13	0.19	IV	0.26	0.13
Electrical equipments	0.30	0.13	0.10	0.31	1.24	0.21	IV	0.45	0.22
Machinery	0.29	0.14	0.14	0.19	1.33	0.13	IV	0.41	0.19
Vehicles	0.29	0.13	0.29	0.26	0.80	0.27	I	0.42	0.20
Accommodation	0.46	0.1	0.10	0.23	1.57	0.21	IV	0.44	0.25
Average	0.32	0.34	0.16	0.45	1.37	0.43		0.40	0.40

Source: Own calculation, based on OECD data, 2024

Obviously, bioeconomy-related branches can be characterised by a high level of backward and forward linkages. This fact can be well explained by the industrialisation of agriculture and the increasing share of industrial inputs in food production. The for- and backward linkages are, in most cases, above average, too.

The analysis of the influence of the various factors on each other offers a better understanding of the effects of the bioeconomy.

In this phase, I have prepared some potential (but real) scenarios. These were as follows:

1. In Czechia, the pharmaceutical industry increases its procurations from agricultural sectors by 10 per cent. I have quantified the results of this step by calculation of change in Leontief matrix, according to the equation

$$\Delta L = \frac{\Delta a_{ij}}{1 - l_{ji}\Delta a_{ij}} F_1(i,j)$$

2. I have assumed a 1.5% increase in production in the Slovak food industry of products produced in Czechia.

Obviously, this change in the input structure of the pharmaceutical industry induces a considerable increase in demand in another sector of the national economy: this is more than 4.69. The most important change takes place in the field of the pharmaceutical industry, trade,

If we suppose an increase of 1.5 per cent in the share of agricultural products produced in the Czech Republic and processed in the food industry of Slovakia, we can expect a 3.32 increase in demand in the field of the Czech Agricultural sector (0,027), food processing (0,032). These can be explained in a rather intuitive way. But, at the same time, there is an increasing demand in Hungarian agricultural production (0,014), Polish food industry (0,019) and the agricultural sector of Slovakia (0,29), food industry (1,78), and in a wide range of other sectors of the economy of Slovakia, from trade (0,024) to warehousing (0,18). In summary, we can conclude that the intensification of the international trade flow among V4 countries is capable of boosting a wide range of sectors.

The analysis of backwards and forward linkages provides an additional perspective on the position of various sectors (see Table 8). In most instances, the backwards linkages were more pronounced than the forward linkages. This observation can be attributed to the relatively high level of utilisation of a diverse range of inputs within the bioeconomy. The connections within and between countries were notably weak for sectors that could potentially benefit from biological materials, such as the light and pharmaceutical industries. This indicates that these sectors are somewhat isolated from other parts of the national economy. It is essential to recognise that increasing the biological resources in these industries could enhance their integration with other economic segments.

Table 8. The backwards and forward linkages of some parts of the bioeconomy sector

	Sectors	Backwards linkages intra country, total	Forwards linkages intra country, total	Backwards linkages inter country, total	Forwards linkages inter country, total	Backwards linkages total	Forwards linkages total
CZ	Agric	1.8	1.91	0.08	0.06	1.89	1.97
CZ	Fishing	1.8	1.15	0.08	0.06	1.88	1.21
CZ	Food	1.96	1.33	0.09	0.05	2.05	1.38
CZ	Textile	1.69	1.55	0.07	0.07	1.77	1.62
CZ	Pharma	1.67	1.51	0.07	0.03	1.74	1.54
CZ	Wood	1.88	2.04	0.11	0.11	2	2.15
CZ	Paper	1.74	2.03	0.13	0.13	1.87	2.16
CZ	Construction	1.99	1.76	0.08	0.02	2.07	1.78
CZ	Accommodation	1.7	1.42	0.06	0.02	1.77	1.44
CZ	National average	1.85	1.72	0.05	0.05	1.91	1.77
HU	Agric	1.54	1.75	0.08	0.04	1.62	1.78
HU	Fishing	1.62	1.44	0.07	0.01	1.69	1.45
HU	Food	1.84	1.32	0.12	0.03	1.96	1.35
HU	Textile	1.36	1.31	0.13	0.04	1.48	1.34
HU	Pharma	1.44	1.23	0.07	0.04	1.51	1.26
HU	Wood	1.6	1.82	0.15	0.09	1.75	1.91
HU	Paper	1.57	1.81	0.14	0.11	1.71	1.92
HU	Construction	1.55	1.32	0.11	0.01	1.65	1.33
HU	Accommodation	1.75	1.16	0.10	0	1.85	1.17
HU	National average	1.78	1.65	0.07	0.05	1.85	1.7
PL	Agric	1.82	1.98	0.02	0.02	1.85	2
PL	Fishing	1.7	2.26	0.02	0.02	1.71	2.28
PL	Textile	2.2	1.51	0.03	0.02	2.23	1.53
PL	Light	1.69	1.32	0.03	0.04	1.72	1.36
PL	Pharma	1.65	1.3	0.02	0.03	1.67	1.33
PL	Wood	1.96	1.99	0.03	0.07	2	2.06
PL	Paper	1.87	2.03	0.03	0.07	1.9	2.11
PL	Construction	2	1.92	0.03	0.01	2.03	1.93
PL	Accommodation	1.82	1.3	0.02	0.01	1.84	1.31
PL	National average	1.88	1.79	0.03	0.03	1.91	1.82
SK	Agric	1.63	1.69	0.12	0.17	1.75	1.86
SK	Fishing	1.7	1.83	0.12	0.13	1.82	1.96

SK	Food	1.8	1.14	0.17	0.06	1.98	1.2
SK	Textile	1.48	1.18	0.11	0.07	1.59	1.24
SK	Pharma	1.58	1.2	0.14	0.08	1.72	1.28
SK	Wood	1.76	1.81	0.14	0.27	1.9	2.08
SK	Paper	1.77	1.47	0.20	0.25	1.97	1.72
SK	Construction	1.94	1.98	0.09	0.04	2.04	2.03
SK	Accommodation	1.56	1.14	0.09	0.01	1.65	1.15
SK	National average	1.76	1.62	0.09	0.06	1.85	1.69

Source: Own creation, 2025

Conversely, the forward linkages were less vigorous than the backwards ones. This discrepancy can be explained by the characteristics of the products involved, such as fresh vegetables and fruits, which are suited for direct consumption. This suggests opportunities to develop further production technologies and capacities based on biomaterials. The intra-country backwards and forward connections were significantly stronger—by one or two orders of magnitude—than the inter-country relations, highlighting the low level of economic integration among the V4 countries.

The significance of boosting the production of domestically sourced biological materials is underscored by the data on sectors that are the focus of economic policy and regarded as pillars of long-term economic development. Specifically, in areas like motor vehicle, trailer, and semi-trailer production, the values of these indicators range from 1.37 to 1.84 for backwards linkages and from 1.12 to 1.43 for forward linkages across various states.

The inverse important coefficients serve as relevant indicators for assessing the potential structural changes in the Leontief inverse matrix when certain technological coefficients vary. Following the recommendations of MILLER AND BLAIR (2009), we examined the possible implications of a 20% increase in agricultural input across various sectors, as shown in Table 9 (the indices, higher than 0.5, are emphasised in bold).

Table 9. Modifications in Leontief indices of some parts and sectors of the Czech economy, if the biomass input increases by 20%

Input sectors	Textile	Wood	Paper	Pharma	Construct.	Accom.
Agriculture, hunting, forestry	**1.819**	**11.302**	0.007	0.059	0.002	**0.558**
Food products, beverages and tobacco	0.201	**1.003**	0.002	0.012	0.001	**0.561**
Textiles, textile products, leather and footwear	**13.892**	0.135	0.004	0.016	0.000	0.019
Wood and products of wood and cork	0.043	**86.556**	0.011	0.003	0.003	0.037
Paper products and printing	0.118	**0.919**	**0.328**	0.018	0.001	0.062
Chemical and chemical products	**0.657**	**2.457**	0.007	0.031	0.004	0.074

Pharmaceuticals, medicinal chemical and botanical products	0.022	0.083	0.000	**1.121**	0.000	0.007
Rubber and plastics products	0.153	**0.625**	0.003	0.020	0.003	0.031
Other non-metallic mineral products	0.130	**0.855**	0.001	0.007	0.012	0.036
Basic metals	0.037	**0.392**	0.001	0.003	0.003	0.014
Fabricated metal products	0.151	**2.249**	0.004	0.012	0.007	0.039
Machinery and equipment, nec.	0.055	**0.364**	0.001	0.005	0.004	0.031
Motor vehicles, trailers and semi-trailers	0.087	**0.615**	0.002	0.005	0.002	0.026
Other transport equipment	0.092	**0.631**	0.001	0.007	0.003	0.036
Electricity, gas, steam and air conditioning supply	0.247	**1.225**	0.007	0.013	0.002	0.080
Water supply; sewerage, waste management and remediation activities	**0.488**	**2.573**	0.011	0.023	0.004	0.176
Construction	0.112	**0.581**	0.004	0.012	0.003	0.099
Wholesale and retail trade; repair of motor vehicles	0.223	**1.671**	0.004	0.019	0.256	0.250
Land transport and transport via pipelines	**1.598**	**7.094**	0.025	0.133	0.013	**0.617**
Water transport	0.211	**2.412**	0.008	0.017	0.004	0.083
Postal and courier activities	0.159	**1.173**	0.004	0.011	0.003	0.061
Publishing, audiovisual and broadcasting activities	0.042	0.251	0.001	0.004	0.001	**7.148**
IT and other information services	0.039	**0.305**	0.001	0.005	0.001	0.039
Financial and insurance activities	0.117	**0.760**	0.005	0.017	0.002	0.079
Real estate activities	**0.351**	**2.049**	0.010	0.033	0.007	0.204

Source: Own creation, 2025

The position of the V4 bioeconomy sectors within the global value chain is exemplified by focusing on the two most significant components: agriculture and the food industry. Notably, there are considerable differences among the countries regarding the domestic value-added content of their exports (see Table 10). This highlights the fact that Hungary, despite having a relatively high bioeconomy potential, has been unable to progress beyond its role as a raw material producer in both agriculture and the food industry.

Table 10. Visegrad countries' bioeconomy sectors within the global value chain

Countries	HUN	CZE	SVK	POL	HUN	CZE	SVK	POL
Sectors	Agric	Agric	Agric	Agric	Food	Food	Food	Food
Domestic content (% of export)	77.42	69.07	66.84	76.36	57.11	71.46	62.35	66.4
Domestic value-added (% of. export)	77.33	68.88	66.74	76.19	56.92	71.3	62.21	66.15

Domestic double counting (% of export)	0.09	0.19	0.09	0.17	0.19	0.16	0.13	0.25
Foreign content (FC) (% of export)	22.58	30.93	33.16	23.64	42.89	28.54	37.65	33.6
Foreign Value-Added (FVA) (% of export)	22.52	30.81	33.09	23.55	42.78	28.45	37.55	33.47
Foreign double counting (% of export)	0.06	0.12	0.08	0.09	0.12	0.09	0.1	0.13
GVC-backward (GVCB) (% of export)	22.67	31.12	33.26	23.81	43.08	28.7	37.79	33.85

Source: Own creation, 2025

Expected economic policy consequences:

The analysis presented has significant implications for economic policy development. The key points are as follows:

1. The definition of bioeconomy indicates that this sector relies on the utilisation of local agro-ecological resources. This is crucial because it allows for the valorisation of natural resources, eliminating the possibility of relocating production capacities based on biomaterials.
2. The agriculture and forestry sectors that produce biomass, along with those parts of the national economy that process these products, directly and significantly contribute to economic growth. They generate a demand that is above average due to multiplicative and accelerative effects. This is important because:
    a. Demand for bioeconomy products is less susceptible to unpredictable market fluctuations (for instance, during the COVID-19 pandemic, food demand remained stable, in contrast to sectors like tourism).
    b. Most bioeconomy products are consumed domestically, which means that voluntary trade restrictions from current or potential partners (such as “trade wars”) will affect the market to a relatively lesser extent.
    c. These factors suggest that the bioeconomy can play a more substantial role in overall economic stimulation compared to sectors that have received attention from policymakers in recent decades (such as motor vehicle production or manufacturing of computers and other electronic devices).
3. While overproduction can be managed in a free or well-regulated market economy, agriculture faces a constant threat of surplus due to unpredictable natural production conditions. The Ghoshian indices of bioeconomy indicate that overproduction of agricultural goods may result in considerable structural issues within national economies. Consequently, we must anticipate an increasing frequency of local product shortages and

surpluses due to global climate change, necessitating targeted development of economic, organizational, and physical infrastructures for crisis management in such situations.

4. There is a need to enhance the range of non-food applications for biomass to convert this raw material into products with higher added value. Although using biomass for energy production significantly contributes to the practical achievement of the United Nations' Sustainable Development Goals, the value-added in this case is relatively low. Efforts should be made to better integrate and utilise biological materials in sectors where their application has strong traditions (such as textiles or pharmaceuticals) or to explore new uses for biomaterials (like substituting plastic with biodegradable materials).
5. To take full advantage of economies of scale and scope, geographic proximity and similarities can foster economic collaboration among V4 countries in the development of joint bioeconomy-related projects.
6. The considerable differences between various V4 states from the point of view of intensity of their participation in the international value chain of bioeconomy products highlight the importance of searching the ways to overcome the cheap raw material producers' position.

5.3. The EU bioeconomy system

The bioeconomy has emerged over the past ten years as a new economic framework that depends on utilising and recycling biological resources instead of fossil fuels, aiming to fulfil various policy goals related to job creation and economic growth, climate neutrality, food security, energy security, biodiversity, and the management of natural resources (WESSELER & VON BRAUN, 2017). In order to achieve these objectives, governments have developed bioeconomy strategies or other related policy initiatives that focus on the different phases of both traditional and emerging bio-based value chains. Macro-regional and micro-regional bioeconomy actions have also been begun (LUSSER ET AL., 2018).

The evolving landscape has brought the advantages of the bioeconomy to the forefront of political discourse, which has also boosted business confidence (GATTO & RE, 2021). Research and innovation focus on enhancing new biomass conversion techniques, while industrial policy initiatives aim to bring bio-based innovations to the market. On the demand side, in spite of the potential challenges (SIJTSEMA ET AL., 2016), campaigns to raise consumer awareness, product labelling (CONFENTE ET AL., 2020), and initiatives for green public procurement (INTERNATIONAL ADVISORY COUNCIL ON GLOBAL BIOECONOMY, 2020) have worked to create valuable market opportunities for new bio-based products.

In the previous section, I have shown the bioeconomy rate changes in certain industries in the V4 countries. Here, I will show how the bioeconomy changes if only a unit change occurs in the economy and how it affects the other parts of the industry. I selected nine from the sectors, and I analysed whether there are linkages between the sectors. In the bioeconomy point of view these are undoubtedly the ones most closely linked to the use of biological materials in some way.

1. Agriculture – Pharmaceuticals
2. Agriculture - Food
3. Agriculture - Motor
4. Wood industry - Paper
5. Fishing - Food industry
6. Pharmaceuticals - Food
7. Textiles – Plastics

In the tables the left part shows the original input-output data from OECD report (OECD, 2021), the center present the Leontief-inverse result and the right side of the table shows the Ghosian inverse (the latter was examined for the agriculture and fishing sectors only).

Table 11. The linkages between Agriculture and Pharmaceutical sectors

Agriculture. hunting. forestry & Pharmaceuticals. medicinal chemical and botanical products					
	21	Leontief - inverse	21	Ghosh - inverse	21
AUT	**6.91**	AUT	0	AUT	0
BEL	**8.97**	BEL	0	BEL	0
CZE	**24.37**	CZE	**0.02**	CZE	0
DNK	**14.09**	DNK	0	DNK	0
EST	0.02	EST	0	EST	0
FIN	**1.54**	FIN	0	FIN	0
FRA	**15.64**	FRA	0	FRA	0
DEU	**15.44**	DEU	0	DEU	**0.01**
GRC	**3.24**	GRC	0	GRC	0
HUN	**12.12**	HUN	**0.01**	HUN	0
IRL	**5.57**	IRL	0	IRL	0
ITA	**102.46**	ITA	**0.01**	ITA	0
LVA	**0.61**	LVA	**0.01**	LVA	0
LTU	0.37	LTU	**0.01**	LTU	0
LUX	0.35	LUX	0	LUX	0
NLD	**11.45**	NLD	**0.01**	NLD	0
POL	**21.45**	POL	**0.01**	POL	0
PRT	**4.24**	PRT	**0.01**	PRT	0
SVK	**2.57**	SVK	**0.02**	SVK	0
SVN	**1.76**	SVN	0.00	SVN	0
ESP	0.02	ESP	**0.03**	ESP	**0.01**
SWE	**7.99**	SWE	0	SWE	0
BGR	**2.07**	BGR	0	BGR	0
HRV	**2.55**	HRV	**0.01**	HRV	0
CYP	0.14	CYP	0	CYP	0
MLT	0.13	MLT	0	MLT	0
ROU	0.32	ROU	**0.01**	ROU	0
		Leontief - inverse cross country		Ghosh - inverse cross country	
		AUT-HUN	0	AUT-HUN	0
		POL-HUN	0	POL-HUN	0
		DEU-HUN	0	DEU-HUN	0

Source: Own creation, 2025

Based on our experience, we could say that, based on Hungarian traditions, any change in agriculture also affects the Hungarian pharmaceutical industry, so I thought that this is certainly the case in other countries around the world, or at least in the EU. It can be clearly seen that in Table 6, based on the original data published by the OECD, there is a strong correlation between agriculture and pharmaceuticals in the EU member states, with only a few countries (EST, LTU, LUX, ESP, CYP, MLT, ROU) where the link is weak. Leontief's inverse calculation shows that if there is a higher demand in agriculture, this does not have an impact on the pharmaceutical industry in all countries. Intra-country flows cause a change in the economy in only a few countries compared to the baseline table earlier. And the Ghosh inverse results show that if there is a larger supply in the agricultural sector, this has a larger impact on the supply of pharmaceuticals in only two countries, Germany and Spain. I also performed the Leontief inverse and Ghosh inverse calculations for cross-country observations, wondering how the agricultural change in 3 countries is related to the Hungarian pharmaceutical industry. The calculations show that the impact of agricultural change in Austria, Poland and Germany has little or no effect on the Hungarian pharmaceutical industry.

I illustrate Table 12 mainly for evidence, as it is obvious to everyone that agriculture has an impact on the food industry and any significant change in agriculture has an immediate impact on the food industry. It is interesting to note that among the cross-country countries studied, only the agriculture of Germany has an impact on the Hungarian food industry, while Austria or Poland have little or no impact. This relationship is interesting in itself, because in the previous cross-country analysis of agriculture and pharmaceuticals no or weak relationship was found.

Table 12. The linkages between Agriculture and Food sectors

Agriculture. hunting. forestry & Food products. beverages and tobacco					
OECD	10T12	Leontief - inverse	10T12	Ghosh - inverse	10T12
AUT	**2793.26**	AUT	**0.13**	AUT	**0.30**
BEL	**4517.74**	BEL	**0.11**	BEL	**0.49**
CZE	**3455.48**	CZE	**0.25**	CZE	**0.36**
DNK	**2600.75**	DNK	**0.14**	DNK	**0.28**
EST	**293.63**	EST	**0.19**	EST	**0.17**
FIN	**1967.74**	FIN	**0.19**	FIN	**0.21**
FRA	**28433.24**	FRA	**0.20**	FRA	**0.36**
DEU	**22520.23**	DEU	**0.12**	DEU	**0.41**
GRC	**3276.88**	GRC	**0.22**	GRC	**0.28**
HUN	**3127.91**	HUN	**0.31**	HUN	**0.32**
IRL	**2370.15**	IRL	**0.08**	IRL	**0.26**
ITA	**18708.58**	ITA	**0.15**	ITA	**0.35**
LVA	**315.39**	LVA	**0.17**	LVA	**0.13**
LTU	**647.91**	LTU	**0.14**	LTU	**0.19**
LUX	**22.47**	LUX	**0.02**	LUX	**0.04**
NLD	**9547.57**	NLD	**0.14**	NLD	**0.32**
POL	**12177.65**	POL	**0.23**	POL	**0.46**

PRT	**3099.40**	PRT	**0.18**	PRT	**0.39**
SVK	**634.83**	SVK	**0.17**	SVK	**0.16**
SVN	**220.95**	SVN	**0.11**	SVN	**0.11**
ESP	**27780.13**	ESP	**0.24**	ESP	**0.51**
SWE	**1791.25**	SWE	**0.14**	SWE	**0.13**
BGR	**477.10**	BGR	**0.09**	BGR	**0.11**
HRV	**708.07**	HRV	**0.15**	HRV	**0.26**
CYP	**309.36**	CYP	**0.21**	CYP	**0.43**
MLT	**31.85**	MLT	**0.06**	MLT	**0.20**
ROU	**5114.87**	ROU	**0.25**	ROU	**0.31**
		Leontief - inverse cross country		Ghosh - inverse cross country	
		AUT-HUN	0	AUT-HUN	0
		POL-HUN	0	POL-HUN	0
		DEU-HUN	**0.01**	DEU-HUN	0

Source: Own creation, 2025

The next study examined whether there is a link between agriculture and the motor industry, and whether agricultural inputs are used in the production of cars. The OECD data show a strong relationship in some countries, but after calculating the Leontief inverse, only three countries show that the relationship remains strong on the demand side (CZE, LVA and ESP), and when approaching from the supply side (Ghosh inverse), we find that only one country, the Czech Republic, has an effect of changes in the supply of agriculture on the motor industry. There was no detectable relationship between the cross-country countries studied. This is illustrated in Table 13.

Table 13. The linkages between Agriculture and Motor sectors

Agriculture. hunting. forestry & Motor vehicles. trailers and semi-trailers					
OECD	29	Leontief - inverse	29	Ghosh - inverse	29
AUT	**1.15**	AUT	0	AUT	0
BEL	0.47	BEL	0	BEL	0
CZE	**18.96**	CZE	**0.01**	CZE	**0.03**
DNK	0.26	DNK	0	DNK	0
EST	0.21	EST	0	EST	0
FIN	0.31	FIN	0	FIN	0
FRA	**4.85**	FRA	0	FRA	0
DEU	**67.19**	DEU	0	DEU	0
GRC	0.04	GRC	0	GRC	0
HUN	**22.22**	HUN	0	HUN	0
IRL	0.32	IRL	0	IRL	0

ITA	**44.64**	ITA	0	ITA	0
LVA	**0.53**	LVA	**0.01**	LVA	0
LTU	0.13	LTU	0	LTU	0
LUX	0.01	LUX	0	LUX	0
NLD	**7.28**	NLD	0	NLD	0
POL	**16.15**	POL	0	POL	0
PRT	**10.15**	PRT	0	PRT	0
SVK	**12.43**	SVK	0	SVK	0
SVN	**3.46**	SVN	0	SVN	0
ESP	**69.42**	ESP	**0.01**	ESP	0
SWE	**13.53**	SWE	0	SWE	0
BGR	**2.48**	BGR	0	BGR	0
HRV	0.09	HRV	0	HRV	0
CYP	0.01	CYP	0	CYP	0
MLT	0	MLT	0	MLT	0
ROU	**0.63**	ROU	0	ROU	0
		Leontief - inverse cross country		Ghosh - inverse cross country	
		AUT-HUN	0	AUT-HUN	0
		POL-HUN	0	POL-HUN	0
		DEU-HUN	0	DEU-HUN	0

Source: Own creation, 2025

Table 14 shows the relationship between the wood and paper industries. The correlation is clear, with OECD data showing a very close relationship between the two industries in almost all countries (except IRL, CYP and MLT), yet if I use the Leontief inverse, I find that only in almost half of the 27 European countries, 17, is there only a close relationship. In the cross-country analysis, I find that the timber industries of AUT, POL and DEU have no impact on the demand of the Hungarian paper industry.

Table 14. The linkages between Wood and Paper sectors

Wood and products of wood and cork & Paper products and printing			
	17T18	Leontief - inverse	17T18
AUT	**68.31**	AUT	**0.01**
BEL	**36.34**	BEL	**0.01**
CZE	**153.85**	CZE	**0.04**
DNK	**4.78**	DNK	0
EST	**2.12**	EST	**0.01**
FIN	**534.13**	FIN	**0.04**
FRA	**215.26**	FRA	**0.01**
DEU	**250.61**	DEU	**0.01**

GRC	**1.74**	GRC	0
HUN	**2.92**	HUN	0
IRL	0.14	IRL	0
ITA	**849.08**	ITA	**0.03**
LVA	**3.45**	LVA	**0.02**
LTU	**16.84**	LTU	**0.02**
LUX	**0.76**	LUX	0
NLD	**13.20**	NLD	0
POL	**113.17**	POL	**0.01**
PRT	**42.08**	PRT	**0.01**
SVK	**22.80**	SVK	**0.02**
SVN	**4.48**	SVN	0
ESP	**113.82**	ESP	**0.01**
SWE	**490.82**	SWE	**0.04**
BGR	**1.45**	BGR	0
HRV	**5.52**	HRV	**0.01**
CYP	0.02	CYP	0
MLT	0.25	MLT	0
ROU	**29.30**	ROU	**0.01**
		Leontief - inverse cross country	
		AUT-HUN	0
		POL-HUN	0
		DEU-HUN	0

Source: Own creation, 2025

The link between fisheries and the food industry is also evident, as we receive information through all possible media about the impact of climate change, pollutants and disappearing species on aquatic fauna, which spills over to us. Looking at the 27 EU Member States, in 4 of them, there is little or almost no link between fisheries and the food industry, but if I look at the demand side and look at the economy based on the Leontief inverse, I see that if there is a surplus demand for fisheries, there are only five countries (EST, LTU, HRV, CYP and ROU) where the market responds to this change.

This is also interesting because if I look at the market from the supply side using Ghosh inverse calculations, I find that only Ireland, Luxembourg and Malta are the only countries where the market responds to changing supply. It can be seen that fishing is a supply-driven industry. This is illustrated in Table 15. It is interesting to note that cross-country calculations show that fishing in some Nordic countries has no impact on the Hungarian food industry. The question itself requires further investigation, which I would like to do in the future, whether this applies only to the 3 EU Nordic countries studied or also to Norway, which although not a member of the EU, has the largest fish economy, as mentioned earlier in the study.

Table 15. The linkages between Fishing and Food sectors

Fishing and aquaculture & Food products, beverages and tobacco					
OECD	10T12	Leontief - inverse	10T12	Ghosh - inverse	10T12
AUT	**5.35**	AUT	0	AUT	**0.06**
BEL	**9.05**	BEL	0	BEL	**0.07**
CZE	**4.22**	CZE	0	CZE	**0.07**
DNK	**87.56**	DNK	0	DNK	**0.12**
EST	**48.58**	EST	**0.03**	EST	**0.48**
FIN	**30.11**	FIN	0	FIN	**0.15**
FRA	**734.98**	FRA	0	FRA	**0.27**
DEU	**172.87**	DEU	0	DEU	**0.36**
GRC	**19.71**	GRC	0	GRC	**0.02**
HUN	**1.63**	HUN	0	HUN	**0.04**
IRL	0.36	IRL	0	IRL	0
ITA	**147.47**	ITA	0	ITA	**0.09**
LVA	**10.74**	LVA	0	LVA	**0.18**
LTU	**57.02**	LTU	**0.01**	LTU	**0.58**
LUX	0	LUX	0	LUX	0
NLD	**96.56**	NLD	0	NLD	**0.17**
POL	**122.61**	POL	0	POL	**0.72**
PRT	**23.07**	PRT	0	PRT	**0.04**
SVK	**634.83**	SVK	0	SVK	**0.27**
SVN	0.40	SVN	0	SVN	**0.03**
ESP	**136.25**	ESP	0	ESP	**0.05**
SWE	**3.92**	SWE	0	SWE	**0.02**
BGR	**12.58**	BGR	0	BGR	**0.23**
HRV	**55.59**	HRV	**0.01**	HRV	**0.16**
CYP	**14.03**	CYP	**0.01**	CYP	**0.26**
MLT	0.07	MLT	0	MLT	0
ROU	**309.18**	ROU	**0.01**	ROU	**0.57**
		Leontief - inverse cross country		Ghosh - inverse cross country	
		DNK-HUN	0	DNK-HUN	0
		FIN-HUN	0	FIN-HUN	0
		SWE-HUN	0	SWE-HUN	0

Source: Own creation, 2025

The next two sectors (pharmaceuticals and food), illustrated in Table 16, I thought it important to look at in this order because the various vitamins that are part of the pharmaceutical industry are dietary supplements, part of our daily lives. For this reason, I thought it important to examine how changes in the pharmaceutical industry affect the food industry and whether there is any link at all. The link is obvious from the OECD data, however, if we look at the demand data, we see that only three countries (BEL, IRL, SVN) have a food industry that reacts to changes in the pharmaceutical industry. Cross-country analysis shows that there is almost no link between the industries in the three countries under study.

Table 16. The linkages between Pharmaceutical and Food sectors

Pharmaceuticals, medicinal chemical and botanical products & Food products, beverages and tobacco			
OECD	10T12	Leontief - inverse	10T12
AUT	**27.74**	AUT	0
BEL	**191.71**	BEL	**0.01**
CZE	**11.14**	CZE	0
DNK	**26.15**	DNK	0
EST	0.11	EST	0
FIN	**7.07**	FIN	0
FRA	**29.46**	FRA	0
DEU	**384.07**	DEU	0
GRC	**9.21**	GRC	0
HUN	**17.53**	HUN	0
IRL	**344.28**	IRL	**0.01**
ITA	**478.10**	ITA	0
LVA	**1.45**	LVA	0
LTU	**2.60**	LTU	0
LUX	**1.87**	LUX	0
NLD	**262.73**	NLD	0
POL	**30.20**	POL	0
PRT	**20.13**	PRT	0
SVK	0.22	SVK	0
SVN	**189.06**	SVN	**0.01**
ESP	**134.43**	ESP	0
SWE	**59.43**	SWE	0
BGR	**3.25**	BGR	0
HRV	**15.76**	HRV	0
CYP	**2.33**	CYP	0
MLT	**2.71**	MLT	0
ROU	**2.44**	ROU	0
		Leontief - inverse cross country	
		AUT-HUN	0
		POL-HUN	0
		DEU-HUN	0

Source: Own creation, 2025

Nowadays, we hear a lot about different types of pollution, deserts, and landfills, where textiles and plastics accumulate (BARTLETT, 2024; LEBRETON et al., 2018). As the proliferation of plastics and the emergence of fast fashion is particularly damaging to the planet, I was curious to see if there is a link between the textile industry and the plastics industry and, if so, what type of link. This relationship is presented in Table 17. It can be clearly seen that the basic input-output data show a close relationship between the two industries in a relatively large number of countries (23), while the Leontief index of demand changes shows that the plastics and rubber industries are responsive to changes in the textile industry in only seven countries.

In the cross-country analysis, the textile industries in Austria, Poland and Germany have no impact on the Hungarian textile industry.

Table 17. The linkages between Textile and Plastics sectors

Textiles, textile products, leather and footwear & Rubber and plastics products			
	22	Leontief - inverse	22
AUT	**4.73**	AUT	0
BEL	**22.93**	BEL	0
CZE	**62.75**	CZE	**0.01**
DNK	**2.77**	DNK	0
EST	**0.95**	EST	0
FIN	**5.43**	FIN	0
FRA	**39.28**	FRA	0
DEU	**288.29**	DEU	0
GRC	**1.56**	GRC	0
HUN	**4.98**	HUN	0
IRL	0.07	IRL	0
ITA	**380.39**	ITA	**0.01**
LVA	0.18	LVA	0
LTU	**0.90**	LTU	0
LUX	**20.61**	LUX	0
NLD	**9.69**	NLD	0
POL	**88.96**	POL	0
PRT	**36.10**	PRT	**0.01**
SVK	**5.97**	SVK	0
SVN	**16.25**	SVN	**0.01**
ESP	**144.64**	ESP	**0.01**
SWE	**2.88**	SWE	0
BGR	**8.80**	BGR	**0.01**
HRV	**2.26**	HRV	0

CYP	0.02	CYP	0
MLT	0.03	MLT	0
ROU	**41.45**	ROU	**0.01**
		Leontief - inverse cross country	
		AUT-HUN	0
		POL-HUN	0
		DEU-HUN	0

Source: Own creation, 2025

5.4. Optimalisation of the logistical system of products of biotechnology: A case study on the access of Ukrainian agricultural products to the world market: challenges and responses

Ukraine has one of the highest arable land endowments on per capita base in Europe (FAOSTAT, 2024). Paired with mostly high-quality soil (ROBOCK ET AL., 2005), surface situated in the Great European Plain (HELDAK ET AL., 2019), and moderate climatic conditions (DIDOVETS, 2020), the country has excellent conditions for large-scale agricultural production. The agro-ecological potential of Ukraine has been just partly utilised in years of centralised planning (STEBELSKY,1985), but the period of system change opened new horizons for the development of privatised, large-scale agricultural enterprises (KUNS ET AL., 2016). Under these conditions, agriculture of Ukraine has achieved extremely important positions on the world market because, e.g. in 2021-22-year, Ukraine has given 41% of the global sunflower seed export, 18% of rapeseed export, 13% of corn, 17% of barley and 9% of wheat export (FAOSTAT, 2024). According to some estimations, the agriculture of Ukraine, beyond the achievement of self-sufficiency, is capable of supplying additional 400 million people with agricultural products (SZAJNER ET AL., 2024, AGRIBUSINESSUKRAINE, 2022). Agricultural exports from Ukraine have been playing an important role in the supply of numerous states, especially in the case of Pakistan and countries of the Middle East.

Ukraine has important seaports on the Black Sea coast and the Sea of Azov. Altogether, there are 18 seaports. As a consequence of the Russian hostilities in 2014, numerous ports, especially in Crimea, have been closed (e.g. Sevastopol, Yalta, Feodosiya, Yevpatoria). Because of the war, the most important ports, Odessa, Chornomorsk and Pivdenne, were not able to continue their activity. Before the beginning of the military conflict, 98% of agricultural exports were shipped by sea, but this ratio decreased to 74% in the 2022/23 economic year (AGRIBUSINESSUKRAINE, 2022).

Analysing the transport from the primary production regions to the seaports shows considerable structural changes. This can be explained by the logistic problems due to war. Formerly, the share of rail was very important in transportation, covering more than three-quarters of the total transportation. This ratio has fallen not 35% because of the disruption in the logistical infrastructure of railway transport (AGRIBUSINESSUKRAINE, 2022). Barge transportation was an important alternative, but the transport on the Dnipro River became impossible as a consequence of the war. Under these conditions, most of the transport was on the road, and nowadays, this way gives nearly two-thirds of the transportation.

One of the most important theatres of the military operations was the rim of the Black Sea, but the Black Sea Agreement (Initiative on the Safe Transportation of Grain and Foodstuffs from

Ukrainian Ports) guaranteed the export of grain and another foods on the Back Sea (GOYAL AND STEINBACH, 2023). The agreement was applicable for a "test" period of four months, but it was not renewed as a consequence of numerous controversies between the parties concerned in the guaranteeing of safe navigation. From this follows that if the hostilities will continue, there seems to be no possibility for safe navigation (STEINBACH AND YIELDRIN, 2024).

As a consequence of this, there is an increased demand to increase the role of alternative ways of transportation of agricultural goods for Ukraine (KRISHTAL, 2023). Supposing the closed trade on the Black Sea, there is a need to search for new ways for land-based transportation of Ukrainian grain. It is important to take into consideration that the land-based transportation sector is relatively developed in Ukraine. The total train performance of the Ukrainian freight train sector in 2022 was 191 billion km; this is nearly one-fifth of the total freight train performance of the EU, including Turkey (UIC, 2024).

The rapid increase in transport demand from Ukraine was a new challenge for the transportation system. As we see, there was an increase in transportation demand one or two orders of magnitude within one year (Table 18). A specific problem of the transportation system is the question of transhipment infrastructure because the Ukrainian railway system is based on Russian standards. The transfer from broad gauge (1520 mm railway to narrower so-called standard gauge railway.

Table 18. Increasing agricultural product export via western routes, 2021-2023

Country	2021	2023	Change (%)
Hungary	70.9	1737.7	2450.917
Moldova	0	60	
Poland	128.4	2730.71	2126.721
Romania	0	1452.6	
Slovakia	71.70	1022.0	1425.384
Total	270.9	7002.9	2585.05

Source: USDA, 2024

Decreasing the environmental burden caused by human activity is a general priority (MIRON, 2023). It is well known that the transportation is one of the most important sources of environmental pollution (LEBEDEVAS ET AL., 2017). The Ukrainian war raises a wide range of environmental problems; one of them is the replacement of relatively environmentally friendly sea transport by land transportation and the re-organisation of sea-based shipments from Ukrainian ports to other ones. In this chapter, I will analyse ways to reduce the environmental burden caused by this tragic situation.

In the first phase, I determined the capacity of the railway transfer points (Figure 17) on the base of open-source information.

Figure 20. The most important lines of the Ukrainian railway system and the railway transhipment points on the Ukrainian-Polish, Slovakian, Hungarian and Romanian borders

Source: Map: WIKIPEDIA, 2024; RAILWAY GAZETTE (2024), GRIGORENKO, 2023, HRICOVA (2022)

One of the most important questions in the case of transportation is the minimisation of the environmental burden caused by transportation. The environmental burden of transport of agricultural products from Ukraine was calculated on the basis of greenhouse gas (GHG) emissions because this value is a generally accepted indicator for the characterisation of the environmental burden caused by various forms of transport and another logistical activity (NOCERA ET AL., 2015). There is a rapid growth of computer-based tools, which serve to characterise the environmental footprint of various transport activities. The earliest of these is the COPERT system (BERKOWICZ ET AL., 2006). The Versit+ (BASK AND RAJAHONKA, 2017) and the EcoCalc (ZIEGLER, 2014) are widely used, too. I have applied the EcoTransIT database and information system (EWI, 2018). (AUVINEN ET AL., 2013) This is a sufficiently detailed and accurate collection of relevant pieces of information; it is freely applicable and can be characterised by a global coverage (Figure 18). According to EcoTransIT World Initiative (2022), this database is widely applied for the determination of the economic burden of transit operations. The different greenhouse gases (non-methane hydrocarbon, particulate matter, CO_2 emissions, nitrogen oxides, and sulphur dioxide) were converted into CO2 values on base of EN DIN 2012 standards. It was an important question, what type of transporting ships to apply, because there are considerable differences between the efficiency of energy resources utilisation among various ships.

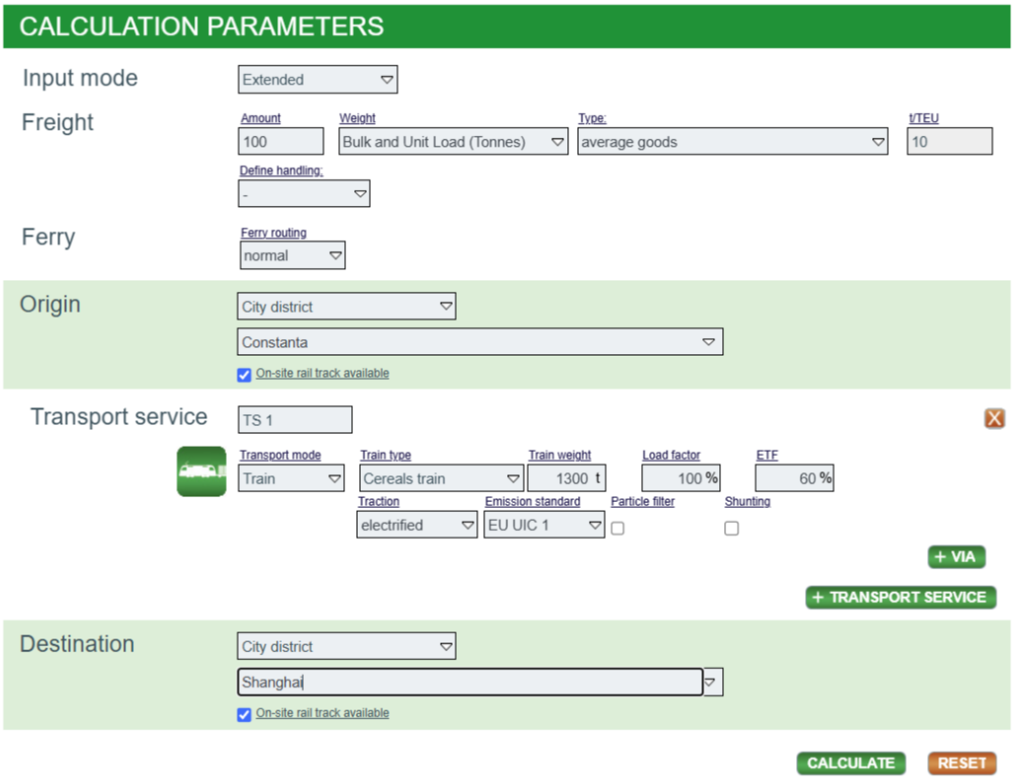

Figure 21. The calculator surface of the Ecotransit system

Source: Own screenshot from EcoTransIT, 2024

In the first phase of investigations, I have determined the environmental burden caused by the transport of cereals from various transfer points to the most important harbours. I have calculated by 1300 gross weight train, 100% load factor and 0.7 empty trip factor, which can be considered as a general number in the European freight systems. All the concerned railway lines were electrified, and the emission standards satisfied the EU UIC 1 requirements.

The transfer capacity of various railway stations was determined on the basis of the press data. Determination of the capacity of various ports was a rather difficult task. According to the definition, the effective throughput capacity of a port is the maximal quantity of all the input that is passed through the port system in a given time period, maintaining continuously the minimal required level of service. In the opinion of O'CONNOR ET AL. (2023), the capacity of the port is determined by various factors, which are called capabilities. The most important capabilities are (1) throughput, which is a physical characteristic feature of the port; (2) physical infrastructure, because the port is an integral part of the supply chain, ending the quays; (3) port service chain; (4) capital and funding. Obviously, the determination of the exact theoretical capacity of a port would be a near-impossible mission. That's why I assumed that the export of agricultural products from Ukraine can be considered as a new, “extra” task to which there are no dedicated capacities in the ports; that’s why I have divided this special task among the ports of base of their logistic performance in the former years. The source of these pieces of information was the Eurostat database on the performance of ports.

The method of analysis and optimisation was the classic transportation problem (LUATHEP ET AL., 2011).

The canonical form of the model has been as follows:

Minimise

$$c\,T\,x$$

subject to

$$\Sigma x\ ij\ \leq\ a\ i\ and\ \Sigma x\ ij\ \geq b\ j,$$

and

$$x\ i,j\ \geq 0$$

where T means the unit costs of transport, i and j are the indices of the sending and receiving points.

In first phase of the research I have determined the GHG emission values between the transfer stations and ports. These values are summarised in Table 19. Obviously, the geographical distance determines these values.

Table 19. GHG gas emissions between the transfer stations and the ports, in [t/t transported goods]

Transfer stations on the western side	**Harbours**					**Transfer capacity [t/day]**
	Hamburg	**Gdansk**	**Szczecin**	**Rijeka**	**Constanta**	
Dorogusk	0.046	0.036	0.04	0.05	0.15	13260
Hrubesow	0.046	0.04	0.041	0.05	0.14	39780
Werchrata	0.045	0.039	0.043	0.047	0.14	9945
Medyka	0.046	0.042	0.044	0.039	0.08	20287
Dornesti	0.053	0.044	0.047	0.053	0.09	12000
Záhony	0.05	0.052	0.052	0.034	0.041	1800
Cierna nad Tisou	0.045	0.051	0.052	0.039	0.045	749
Daily transfer capacity [t]	33052.15	26374.95	14689.84	1335.44	22368.62	

Source: Own creation, 2024

The optimised distribution of work to achieve minimal environmental burden is presented in Table 20. Obviously, the goods arriving at the Polish-Ukrainian border should be sent to the Nordic ports, and the goods arriving at more southern ports should be received by southern ports. The relatively low capacity of Rijeka highlights the importance of well-planned developments in case of Constanta.

Table 20. Optimal distribution of the grain, arriving at the western borders of Ukraine [% of total daily good arrivals]

Harbours	Hamburg	Gdansk	Szczecin	Rijeka	Constanta
Dorogusk		13			
Hrubesow	24		16		
Werchrata	7	2			
Medyka	2			2	15
Dornesti		11			
Záhony					2
Cierna and Tisou					6

Source: Own creation, 2024

In the next phase I have determined the environmental burden of transport of wheat to the most important markets of Ukraine. Based on the foreign trade statistics, 14 countries covered more than 80% of the wheat export of Ukraine before the war. Obviously, there are considerable differences in the environmental burden of transport (Table 21). The appropriate choice of the port is especially important when the distance is relatively short. For example, in the case of exports to Turkey, the burden on the environment is more than five times lower when we export from Constanta than from Hamburg.

Table 21. GHG gas emissions between the ports of grain export and import [t/t transported goods]

Ports	Jakarta	Alexandria	Izmir	Karachi	Kenitra	Chittagong	Aden
Hamburg	11.95	4.12	3.84	7.65	3.05	9.54	6.01
Constanta	7.39	1.28	0.70	4.72	3.53	6.48	2.91
Rijeka	7.58	1.36	1.19	4.81	3.07	6.67	3.79
Gdansk	12.37	4.52	4.42	7.98	3.44	9.84	6.27

Demand [10^4 t]	281	340	154	140	107	81.1	77.7
Ports	**Beirut**	**Jeddah**	**Bizerte**	**Bangkok**	**Assab**	**Tripoli**	**Manila**
Hamburg	4.24	5.13	3.51	11.05	8.66	3.21	12.8
Constanta	1.35	2.2	1.76	8	5.86	1.48	10.22
Rijeka	1.608	6.48	1.3	8.82	6.05	1.113	10.19
Gdansk	4.8	5.56	3.92	11.33	9.22	3.77	13.36
Demand [10^4 t]	65.8	65.5	61.8	54.9	53.7	47.7	40.9

Source: Own creation, 2024

The optimal solution is shown in Table 22. Obviously, the Middle East can be most efficiently supplied from southern harbours. Interestingly, the Rijeka–based export could be important in Pakistan's supply, too.

Table 22. Optimal division of work among various ports [10^4 t]

Ports	**Jakarta**	**Alexandria**	**Izmir**	**Karachi**	**Kenitra**	**Chittagong**	**Aden**
Hamburg							
Constanta	281		154			35.0	77.7
Rijeka				130			
Gdansk		340		10	107	46.1	
Ports	**Beirut**	**Jeddah**	**Bizerte**	**Bangkok**	**Assab**	**Tripoli**	**Manila**
Hamburg	65.8	52.4			53.7	47.7	40.9
Constanta		13.1					
Rijeka							
Gdansk			61.8	54.9			

Source: Own creation, 2024

In this case, I have analysed the sensitivity of our model. In this case, the dual values give the decrease of the goal function if the capacity of the limits in the equations can be increased. My results show that the highest value could be achieved in the case of Rijeka and the second highest in the case of Constanta.

The geographical concentration of the export of maize from Ukraine is much more concentrated than in the case of wheat. That’s why, in this case, just seven countries were enough to cover 80% of the exports (Table 23). The tendencies are similar to the case of wheat export (Table 24). Interestingly, in this case, the volumes are much larger, which is why the optimisation is even more important. Gdansk and Rijeka should have a predominant role in the supply of European markets.

Table 23. GHG gas emissions between the ports of maize export and import [t/t transported goods]

Ports	China, mainland	Barcelona	Alexandria	Chabahar	Izmir	Hayfa	Porto	Port capacity [10^4 t]
Hamburg	11.38	2.99	4.12	17.63	3.84	4.21	1.52	2605
Constanta	8.82	2.08	1.28	14.67	0.7	1.33	3	1693
Rijeka	8.99	1.6	1.36	15.24	1.19	1.579	2.54	131
Gdansk	11.9	3.15	4.52	18.19	4.42	4.77	1.96	2084
Demand [10^4 t]	791	246	220	167	107	66	64	

Source: Own creation, 2024

Table 24. Optimal division of work among various ports in case of maize [10^4 t]

Ports	China, mainland	Barcelona	Alexandria	Chabahar	Izmir	Hayfa	Porto	Optimal division
Hamburg	664							2605
Constanta			91	167	107	66		1693
Rijeka			33					131
Gdansk	127	246	96				64	2084
Demand [10^4 t]	791	246	220	167	107	66	64	

Source: Own creation, 2024

My results highlight the importance of optimising the transportation process in the case of agricultural products from Ukraine to the global markets. In this process, the share of railways is essential because this way of transport is much more effective from the point of view of energy and the environment. That's why the rapid construction of a large-scale transfer point on the Romanian-Ukrainian border can be considered an important step for increasing the efficiency and environmental friendliness of transportation. Due to the longevity of military hostilities, we must not calculate the re-opening of the Black Sea ports for foreign trade activities. This situation underlines the importance of strengthening the Romanian and Bulgarian railway and sea transport capabilities. The market structure of Ukraine is concentrated mainly on states situated in the Middle East and on the northern coast of Africa. These ports can be much faster and cheaper and with much lesser environmental pollution than ports in the northern part of Germany. The analysis of dual values of optimal solutions supports this thesis. The further development of the land and sea transport infrastructure of Port Constanta would be an important step in the direction of decreasing the environmental burden. The development of ports in the Adriatic Sea is a specific problem. Port of Piraeus is influenced by Chinese investors, so here, the possibilities of realisation of the EU policy would be rather difficult. Rijeka has favourable possibilities for development, but the train connections of this port are relatively amortised. Koper has been developing rather rapidly, but it cannot receive large-scale ships, that's why there is a transfer of cargo at Malta. The Port of Trieste [Trst] is developing rapidly, and the Hungarian government has bought a 100 million Euro ownership in it. This offers the possibility of a Cop-Záhony-Trieste.

The participation of the Polish ports in foreign trade of agricultural products of Ukraine is an important question because if it is more efficient to send the agricultural products from the northern part of Ukraine to Polish ports, this would be a more efficient way of transportation, than the additional, 400-700 km long land transportation to the German ports.

Policy implications

Results of the calculations highlight that the closing of the trade on the Black Sea port caused considerable additional losses for the European logistical systems. If the hostilities continue and there is no possibility to re-establish the Black Sea transport, there is a need to re-construct the logistical system of transporting various goods from Ukraine to the world market. This will be a long-range, complex process. The most important steps of development can be summarised as follows:

1. Further development of and enlargement of modern terminals on the border of Ukraine and the member states of the EU.
2. Modernisation of the railway and land-based transport systems of the East-Central European states.

Long-range tasks:

1. Development of the port infrastructure on the Balcanic countries, especially in Croatia, Romania and Bulgaria.
2. It would be highly important the development of modern logistical centres in Ukraine for the promotion of export of agricultural products

3. In case of development of Ukrainian railway connections, it should be considered the building of special lines on European standards for the more smoother export of Ukrainian goods to Europeans states
4. The increasing of the level of processing of various goods would be an important contribution to the decreasing of transportation demand. Nowadays, Ukraine is the largest exporter of sunflower seed, but if there were a possibility to increase the share of sunflower oil, this could decrease the transport demand by 55%.

There are some inherent limitations of the analysis. The most important of these are as follows: (1) The study does not analyse the problems of transportation of goods in territory of Ukraine, (2) the analysis of various inland waterways into the international trade (e.g. Danube-Rheine-Maine channel) is a further possibility of decreasing of the environmental burden, (3) the linear programming is just one possibility for analysis of transportation processes. Dynamic, agent-based models could further increase of the accuracy of calculations.

5.5. Poppins' case study

In Europe, one of the Visegrad countries, the Czech Republic, is the main producer of Papaver somniferum (poppy). Looking beyond Europe, two other nations stand out as "superpowers" in poppy seed cultivation: Afghanistan and Myanmar. In Afghanistan, 224,000 hectares of land are used for poppy cultivation, while in Myanmar, the area amounts to 29,500 hectares (OECONOMUS ECONOMIC RESEARCH FOUNDATION, 2024; PROCHÁZKA & SMUTKA, 2012), and both are leaders in opium production. In the last 2-3 years, opium production has also increased in Southeast Asia (UNODC, 2023).

Based on the National Chamber of Agriculture (NAK) map, the land dedicated to poppy farming in Hungary had risen from 9 thousand hectares to over 12 thousand hectares in the past decade, indicating that the area for various poppy types had nearly doubled since 2004 when the country joined the EU. The main reason contributing to this growth is the highly versatile utilisation of poppies as a raw material for food products, pharmaceuticals, and the flower industry. In the EU, poppy cultivation has strict regulations. Specifically, it is permitted to grow for personal use on plots smaller than 500m^2 using low alkaloid varieties containing less than 0.06%. Cultivation on larger plots or planting high alkaloid varieties for medicinal purposes necessitates obtaining a license (NAK, 2024)

Generally, poppy is cultivated for its opium and oilseed content. Poppy seeds are mainly used for their oil (NERGIZ AND ÖTLES, 1994; BOZAN AND TEMELLI, 2003; MUSA ÖZCAN & ATALAY, 2006), and the seeds are a good source of energy in our daily lives. Poppy seeds hold 50% oil, and the Indian ones have high levels of oleic and linoleic acids (SINGH ET AL., 1990). According to BOTANICAL FORMULATIONS (2021), poppy seed oil has many multilateral uses in food preparation and can be used for salads, cooking and for desserts as flavouring. It contains a lot of healthy benefits; phytonutrients boost the immune system and improve blood flow, are rich in omega 3 and 6 fatty acids, and it is also good for daily heart and brain operation and keep under control the digestive and the nervous systems. Furthermore, the elevated amounts of zinc, manganese, and copper found in poppy seed oil help manage sugar levels in individuals with type 2 diabetes, facilitate the digestion of nutrients, and enhance the repair of cells and tissues within the body.

In 2024, I was one of the lucky ones who was able to participate in the preparation and working meetings of an investment in poppy cultivation. As poppy is a product that really belongs to the bioeconomy (food & pharmaceutical industry), I was extremely happy about the opportunity. The case study below was written for a real company that did not contribute to the publication of its name in the study, so it will be referred to here as Poppins. The study's main questions were: *If the company were to set up a poppy processing unit, how economical would it be, and how long* *would it take to recoup the capital invested?* I will analyse only 5 years to see what will happen during this time at the company.

The Poppins planned to cultivate 300 hectares of land in Somogy county, which they plan to use to grow different varieties of poppy. Below, I present the 5-year production plan of Poppins. Its accounting balance sheet is not fully presented due to lack of space.

Table 25. Poppins' 5-year production plan

Production plan										
Product	**Production quantity (t)**	**Production price (thousand HUF/kg)**	**Income (thousand HUF/t)**	**Raw material demand for 1 unit**	**Raw material costs for one unit of production**	**Raw material costs (thousand HUF/t)**	**Contracted services**	**Oother service activities**	**Wages and salaries (thousand HUF)**	**Special operating costs and charges (thousand HUF/t)**
1st year of production										
White poppy	200	0.663	132.6		0.45	90				14
Unwashed blue poppy	1800	0.465	837		0.3	567				126
Washed blue poppy	1700	0.558	948.6		0.4	714				204
Poppy sowing-seed	7	17.05	119.35		5	35				14
Poppy seed box	2400	0.382	916.8		0.3	720				168
total			2954.35			2126			0	526
2nd year of production										
White poppy	300	0.663	198.9		0.45	135				21
Unwashed blue poppy	1600	0.465	744		0.3	504				112
Washed blue poppy	1900	0.558	1060.2		0.4	798				228
Poppy sowing-seed	7	17.05	119.35		5	35				14
Ground poppy seeds	100	0.8	80		0.4	40				10
Poppy seed box	2400	0.382	916.8		0.3	720				168
total			3119.25			2232			0	553
3rd year of production										
White poppy	400	0.663	265.2		0.45	180				28
Unwashed blue poppy	1400	0.465	651		0.3	441				98
Washed blue poppy	2100	0.558	1171.8		0.4	882				252
Poppy sowing-seed	7	17.05	119.35		5	35				14
Ground poppy seeds	200	0.8	160		0.4	80				20
Poppy seed box	2400	0.382	916.8		0.3	720				168
total			3284.15			2338			0	580
4th year of production										
White poppy	200	0.663	132.6		0.45	90				14
Unwashed blue poppy	1200	0.465	558		0.3	378				84
Washed blue poppy	2300	0.558	1283.4		0.4	966				276
Poppy sowing-seed	7	17.05	119.35		5	35				14
Ground poppy seeds	300	0.8	240		0.4	120				30
Poppy seed box	2400	0.382	916.8		0.3	720				168
total			3250.15			2309			0	586

5th year of production										
White poppy	500	0.663	331.5		0.45	225				35
Unwashed blue poppy	1000	0.465	465		0.3	315				70
Washed blue poppy	2500	0.558	1395		0.4	1050				300
Poppy sowing-seed	7	17.05	119.35		5	35				14
Ground poppy seeds	400	0.8	320		0.4	160				40
Poppy seed box	2400	0.382	916.8		0.3	720				168
total			3547.65			2505			0	627

Source: Own creation, 2024

Table 25 shows that in the first year, the company focused on only five products (White poppy, Unwashed blue poppy, Washed blue poppy, Poppy sowing seed and Poppy seed box) to start its operations. The total cost of the investment is 294 000 000 HUF, which, according to the data, could be recouped in the first year, but due to the fixed costs and the construction of the assets, the company ends the first year with a loss. There is no dividend or full return this year, as all the resources are needed for the machine under construction. In the second year, the poppy grinding machine will be available, and a new product, ground poppy, will be introduced. This additional product brings the company a little more income (31193 thousand HUF), but the costs incurred make the company loss-making even in the second year. As at the beginning, Poppins still does not plan to employ its own workers but instead uses temporary employment agencies to employ as many people as are needed for the season. From this period onwards, the share of material costs in the company's life becomes increasingly important (c. 72%). It can be seen that the financial and asset investment (despite depreciation and other costs) starts to generate a real return and profit from the third year onwards, the revenues can no longer only cover the basic costs, Poppins' liquidity increases and it can pay dividends to the owners of the company on its profits. By the end of the fifth year, the equity, both invested capital and assets, have been recouped, and the profit and dividend amounts are increasing steadily year on year. **Thus, it can be said that over the five years, the investment pays off and generates a profit, even with constant depreciation and other costs.** Poppins is recommended to replace/replace the poppy milling machine after 15-20 years at the latest due to technological upgrading and depreciation.

6. CONCLUSIONS AND RECOMMENDATIONS

Climate change and its side effects significantly determine the quality and quantity of biological material. It is well documented that the increase of the products in the bioeconomy is of central importance in the development of the economies in a sustainable way. From this follows, that the increase of the bioeconomy will be an efficient contribution to sustainable development. In the *Literature* survey *chapter* of the thesis, I have compiled a general conceptual framework of factors forming the bioeconomy and, at the same time, contributing to the realisation of the Sustainable Development Goals of the UN. Plus, as an addition, I have added a short outlook to the bioeconomy's future with AI features.

My thesis is based on seven research questions.

The first research question (hereinafter RQ) was how can be characterised the European Bioeconomy in the context of the global bioeconomy system. During my analysis, it became clear that there are some countries that play a huge role in the European bioeconomy. The Nordic bioeconomy emphasises sustainability through biomass utilisation and circular solutions. Finland's bioeconomy, valued at €29 billion in 2022, is driven by forestry and innovation. Norway, with its extensive coastline, focuses on the "blue bioeconomy", aiming for marine bioresources to contribute up to 10% of the national economy by 2030. Denmark, strong in biomass potential, invests in biogas production and bio-based materials. Sweden, a leader in sustainable forestry, aims for carbon neutrality by 2045. Looking a little further south, Italy also plays an important role. The Italian bioeconomy, a significant contributor to the national economy, experienced a 2.2% growth in 2023, employing 2 million people and producing 10% of the total value added. The sector's strength is evident in the 808 innovative start-ups, primarily focused on R&D and the agri-food sector, which accounts for over 63% of the bioeconomy. Italy leads in product and process innovations within the food industry, showcasing its technological prowess despite its smaller size compared to European counterparts. The data clearly shows that other European countries need to take further action, make political decisions, and develop strategies to ensure that the bioeconomy plays a more significant role at the national level.

The second research question was whether the logistical planning system could decrease the environmental burden in the bioeconomy supply chain. I worked in the logistics and supply chain sector for almost 15 years, and I was a witness to logistics innovations. But for the bioeconomy, this aspect is really important as the continuous environmental burden is one of today's biggest problems. Using the right and (preferably) environmentally friendly mode of transport is important for all actors in the supply chain. It is also important to mention here the policies for the respect of the different food safety rules (FAO/WHO, 2001). The development of bio-based economies demands an extremely high level of flow of materials from one physical place to another. This fact highlights the importance of complex logistical systems. In my dissertation, a case study has been used to prove this research question. One of the most significant challenges before the European logistical systems has been the supply of the traditional markets of Ukraine under the conditions of blocking the classic export channels of Ukraine. The results show that rail is the most optimal mode of transport in terms of environmental impact and energy under current conditions. If hostilities continue, a complex, long-term process of re-establishing alternative transport routes is needed.

However, this analysis had limitations, including a lack of analysis of Ukrainian goods transportation and the potential of inland waterways in international trade. Linear programming is just one of the analysis methods, with dynamic models potentially increasing accuracy.

The third RQ was the characterisation of the bioeconomy in the context of the CEE countries and Hungary. For this analysis, I used the OECD input-output tables to find the connections between the sectors and the countries. I examined nine sectors' connections with one another, and I found that (1) most of the EU countries have strong connections between the agriculture and pharmaceutical industries, and only a few (e.g. Romania) have weak ones. Leontief's inverse calculation shows limited impact of agricultural demand on pharmaceuticals across countries. Ghosh's inverse results indicate a larger impact of agricultural supply on pharmaceuticals in Germany and Spain. I have also created cross-country analyses, but the calculations did not show a strong effect on the Hungarian pharmaceutical industry.

Furthermore, (2) agriculture impacts the food industry evidently. Any changes in agriculture immediately affect the food industry. It's noteworthy that among the countries analysed, only Germany's agricultural sector influences the Hungarian food industry, whereas Austria and Poland have minimal or no effect. This connection is intriguing in itself, especially since earlier cross-country examinations of agriculture and pharmaceuticals revealed either no relationship or a weak one.

(3) I examined agriculture's link to the motor industry and its use of agricultural inputs in car production. The original data from the OECD indicates a significant correlation in some nations; however, after computing the Leontief inverse, only three nations (CZE, LVA, and ESP) exhibited a strong relationship on the demand side. On examining the supply side using the Ghosh inverse, it appears that only the Czech Republic demonstrates an impact of agricultural supply

changes on the automotive sector. There was no observable correlation among the selected cross-countries.

(4) I checked the connection between the wood and paper industries, too. The correlation is evident, as OECD data also reveals a strong relationship between these two sectors in nearly all countries, with the exception of IRL, CYP, and MLT. However, when I applied the Leontief inverse, I discovered that only about half of the 27 European countries—17 in total—display a similar close relationship. In my cross-country analysis, I found that the timber industries in other countries do not influence the demand for the Hungarian paper industry.

(5) Climate change, pollutants, and disappearing species impact aquatic fauna, affecting the food industry. I thought it was important to look at the link between fisheries and the food industry because, although it sounds obvious, the results do not fully support it. Four EU countries show little link between fisheries and the food industry. Market response to surplus demand is limited to five countries, while supply-side response is limited to three countries. This raises further questions, as fishing is essentially a supply-driven industry. And I would like to underline that the cross-country analyses indicate that fishing activities in certain Nordic countries do not affect the Hungarian food industry hardly at all. This raises the question of whether this observation is limited to the three EU Nordic countries examined or if it also extends to Norway, which, despite not being an EU member, boasts the largest fishing economy, as highlighted earlier in the study. Further investigation into this matter is something I intend to pursue in the future.

(6) The next sectors were pharmaceuticals and food, which I analysed. I deemed it crucial to assess these in this sequence because the various vitamins that belong to the pharmaceutical sector are dietary supplements and play a role in our everyday lives. For this reason, I found it vital to explore how shifts in the pharmaceutical sector influence the food industry and whether any connection exists. The connection was clear based on OECD data; however, when I analysed the demand data, it became evident that only three nations' (BEL, IRL, SVN) food sectors responded to fluctuations in the pharmaceutical sector. A cross-country analysis indicates that there was nearly no correlation between these industries in the three countries examined.

(7) In today's world, we frequently encounter discussions surrounding various forms of pollution, deserts, and landfills where textiles and plastics gather. Given the harmful impact of plastic proliferation and the rise of fast fashion on the environment, I was interested in exploring whether there exists a connection between the textile and plastics industries and, if so, what kind of connection it is. The basic input-output data indicated a strong correlation between both industries across a significant number of countries (23), while the Leontief index of demand changes demonstrates that the plastics and rubber sectors respond to fluctuations in the textile industry in only seven nations. In the cross-country evaluation, the calculation did not show any

relationship between the analysed countries. I suppose to analyse this relationship in depth in other aspects because as DARIA et al. (2020) highlighted in their article, that the biotextiles, derived from plant and animal fibres, offer a sustainable alternative to synthetic materials. While their properties and processing require further standardisation, their environmental benefits and cost-effectiveness make them a promising option for widespread use.

The fourth and fifth RQ focused on the effects of the bioeconomy of export structure and its potential role in the Visegrad countries. V4 countries have different pathways to a sustainable bioeconomy, but all are members of the BIOEAST Initiative. During their analysis, I found that particularly agriculture and food show high backwards and forward linkages, which indicate their significant role in boosting economies. These countries and their economies are rather similar, characterised by a high level of resemblance from the point of view of agroecological potential, but the various pathways of development have led to a rather diversified landscape in the economic structure. The share of sectors producing or processing biological products varies across V4 countries, with Poland having the highest and Czechia the lowest. I assume that, mainly due to its size, it has more arable land than the other V4 countries and. ŁĄCKA et al. (2020) came to a similar conclusion in their study. The value-added production of these sectors also shows differences in the contribution of biological materials. Increasing demand for bioeconomy products within the region can lead to substantial increases in demand across various sectors, highlighting the potential for economic growth through international trade. The comparative analysis of these structures could be highly important and informative for the outlining of perspectives and limits of bioeconomy systems. The analysis I conducted regarding the backwards and forward linkages yields substantial implications for the formulation of economic policy. The principal findings are as follows:

1. The concept of the bioeconomy suggests that this sector is fundamentally dependent on the utilisation of local agro-ecological resources. This dependence is pivotal as it facilitates the valorisation of natural assets, thereby precluding the relocation of production capacities predicated on biomaterials.

2. The agriculture and forestry sectors that produce biomass, along with those parts of the national economy that process these products, directly and significantly contribute to economic growth. They generate a demand that is above average due to multiplicative and accelerative effects. This is important because:

a. Demand for bioeconomy products is less susceptible to unpredictable market fluctuations (for instance, during the COVID-19 pandemic, food demand remained stable, in contrast to sectors like tourism).

b. Most bioeconomy products are consumed domestically, which means that voluntary trade restrictions from current or potential partners (such as “trade wars”) will affect the market to a relatively lesser extent.

c. These factors suggest that the bioeconomy can play a more substantial role in overall economic stimulation compared to sectors that have received attention from policymakers in recent decades (such as motor vehicle production or manufacturing of computers and other electronic devices).

3. While overproduction can be managed in a free or well-regulated market economy, agriculture faces a constant threat of surplus due to unpredictable natural production conditions. The Ghoshian indices of bioeconomy suggest that overproduction of agricultural goods may lead to significant structural issues within national economies. Consequently, we must anticipate an increasing frequency of local product shortages and surpluses due to global climate change, necessitating targeted development of economic, organisational, and physical infrastructures for crisis management in such situations.

4. There is a need to enhance the range of non-food applications for biomass to convert this raw material into products with higher added value. Although using biomass for energy production significantly contributes to the practical achievement of the United Nations’ Sustainable Development Goals, the value-added in this case is relatively low. Efforts should be made to better integrate and utilise biological materials in sectors where their application has strong traditions (such as textiles or pharmaceuticals) or to explore new uses for biomaterials (like substituting plastic with biodegradable materials).

5. To take full advantage of economies of scale and scope, geographic proximity and similarities can foster economic collaboration among V4 countries in the development of joint bioeconomy-related projects.

6. The considerable differences between various V4 states from the point of view of intensity of their participation in the international value chain of bioeconomy products highlight the importance of searching for ways to overstep the cheap raw material producers' position.

The agricultural and food industries play a crucial role in boosting the overall economy, particularly in Hungary, compared to numerous other economic sectors.

The sixth RQ investigated the stability of the agricultural raw material base in Hungary. In my dissertation, I referred to production structures as portfolios because I treated them as financial investments. I observed the financial yield-risk characteristics of nine crops. Maize and sunflowers provide significant yields but involve risks that are significantly higher than optimal. The yields of rapeseed, soybeans, and wheat are accompanied by a slightly lower level of risk. Potatoes, oats, and rice provide low yields but involve a relatively low level of risk. If we accept the optimisation proposal, it seems advisable to focus on increasing the area under sunflower cultivation. In addition, I compared three different objectives: (1) maximising revenue, (2) minimising portfolio variance, and (3) maximising average yield per expected tail loss unit. The results show that maize can provide high yields, but the income-generating capacity of the product is relatively low.

And the last, **seventh RQ** closely linked to my first RQ. I wanted to know if the computer-based methods and simulation systems could aid economic planning for the non-food use of biological materials. Computer-based tools are growing rapidly to characterise the environmental footprints of transport activities. Nowadays, most logistics service providers offer different, sometimes specialised, transport options. However, in the case study, I did not have the opportunity to request a quote for the transport of non-food biological material from the Ukraine (e.g. DHL) without a special contract. As this is now an area under geopolitical pressure, I had to solve the problem myself. That's how I found COPERT, Versit+, EcoCalc and finally EcoTransIT, where I can calculate online what would be the emission of global freight transport of the shipment. With the calculation, information and the screenshot evidence of the detailed information available on the EcoTransIT website regarding environmental impact, the research question and hypothesis have been proven in my dissertation.

Based on the results summarised in my thesis, numerous policy implications can be considered. The most important of these are as follows:

1. There is an increasing need for the development of complex water management systems in decades of global warming and climate change. This is a necessary precondition for the enhancement of resilience of the agricultural production basis of bioeconomies.
2. A priority should be given to bioeconomy-based production in the development of various policy planning phases and in the process of implication of long-range as well as operative plans and subsidy allocation concepts.

3. On the level of the EU and national planning, the "grossraum" approach should be applied, offering a wider range of international cooperation based on the utilisation of absolute and comparative advantages.
4. The development of bioeconomic systems must not be considered separately from another parts of the economy. That is why infrastructural investments are essential for the utilisation of the potential of the bioeconomy.

7. NEW SCIENTIFIC RESULTS

Based on the previously mentioned research questions, a rather complex set of hypotheses. I have created a table to show them and their evaluation. It is summarised in Table 26.

Table 26. Hypotheses and their evaluation

Hypotheses	Evaluation	
H1: The European bioeconomy system plays an above-average role in the acceleration and multiplication of economic development, even in the most developed states.	The hypothesis was proven	✓
H2: The combination of modern methods of logistical planning can efficiently decrease the environmental burden caused by the transportation of products of bioeconomy.	The hypothesis was partly proven	✓
H3: The East-Central European countries can be characterised by a relatively developed agriculture, which is why the role of the bioeconomy is highly important in the national economies. The bioeconomy systems are extremely complex and open ones, which is why they can exercise a positive effect on general economic development based on their accelerative and multiplicative effects.	The hypothesis was proven	✓
H4: There are intense cooperation and collaboration among the bioeconomy subsectors among V4 countries based on geographical proximity and utilisation of possibilities of the optimal division of work.	The hypothesis was rejected	✗
H5: Based on their historical traditions, the non-food use of agricultural products is widely applied, e.g. in pharmaceutical or textile industries.	The hypothesis was rejected	✗
H6: The adverse consequences of climate change exercise a negative effect on the stability of the income–generating capacity of the Hungarian bioeconomic system, but portfolio optimisation is a suitable method for finding the optimal land use solution structure. There is a feasible possibility to find an optimal balance between the production value and risk in setting up the portfolio of agricultural production systems.	The hypothesis was proven	✓

H7: The non-food use of agricultural products can be an important driver of economic development, especially in the less favoured areas of Hungary.	The hypothesis was proven	✓

Source: Own creation, 2025

My research can be summarised in four scientific, novel results.

1. My current work was the first which applied the modern methods of portfolio optimisation for the determination of the optimal structure of agricultural production of a given country.
2. To the best of my knowledge, I was the first to offer a complex analysis of the bioeconomy system of the V4 countries, highlighting the importance of international cooperation.
3. In the framework of my thesis, I have highlighted the lack and potential importance of the division of labour among the various V4 countries.
4. I was the first to prove the integration of economic and ecological aspects into logistical decision-making in case of a logistical crisis situation, based on the integration of modern decision-supporting and optimisation systems.

8. SUMMARY

One of the main motivations for writing my doctoral thesis was the changes in agriculture and the economy. Another was to be able to spend the rest of my life working on a subject that is important to me. Bioeconomy has myriad links to the sectors, and there is a growing role for related technological developments such as AI. My thesis focused on the intricate optimisation of the bioeconomy system since the bioeconomy is gaining importance at both the regional and global scales. Its significance is undeniable, as the global crisis regarding available raw materials (such as feedstock) stands as one of humanity's major challenges.

Bioeconomy is a relatively new concept which is at the centre of international academic attention. Its importance and novelty are in approach, focussing on the usage of biological materials for human nutrition and other fields of application, from the textile industry to pharmaceutics. The importance of this concept is based on two pillars: on one hand, it became obvious that the application of materials of non-biological origin (e.g. plastics) has considerable limitations (e.g. limited resources on raw materials for production of chemical products) as well as the problems with deposition of non-renewable materials, applied for production of packaging and another industrial products.

Analysing the hypotheses (what I presented in Table 26) and their level of acceptance/rejection, it is obvious that the adverse consequences of global climate change will considerably influence the Hungarian economy, but the modern methods of operations research offer a favourable possibility to minimise these losses.

The position of bioeconomy in V4 countries is rather contradictory because, on the one hand- the share of non-bioeconomy sectors is relatively high, but our results show the important role of this cluster of sectors in economic development, which is much higher than the share of these sectors in the GDP. This characteristic feature of the sector is the high level of openness both in in-and output terms, that’s why the sector can play an important role in the development of economies. This characteristic feature is especially significant at the time of writing my thesis when it became obvious that the global and European auto industry is not capable of creating considerable economic development and is not suitable to stabilise these economies in times of recession.

I have analysed the connections between seven sectors in the CEE countries and Hungary using OECD input-output tables. The findings revealed varying degrees of impact between sectors, with some showing strong connections while others exhibited minimal or no effect. My work also highlighted the need for further investigation into certain relationships, such as the influence of fishing activities on the Hungarian food industry and the connection between the textile and plastics industries.

Contrary to the general-held opinion, the share of the bioeconomy has decreased considerably in the long run because, e.g. the European textile industry has been shrinking, and the majority of raw materials are not agricultural products anymore. Increasing the use of these materials of bioeconomy could considerably contribute to the general economic development.

My results have proven that there is a need for the general development of the international division of labour among various V4 countries based on the absolute and comparative advantages of these countries. This is a key point for further development.

My outcomes highlighted the importance of the complex optimisation of modern logistical systems, which is essential for further environmentally conscious development. My case studies have proven that from the point of view of microeconomic feasibility, the bioeconomy and the non-food use of agricultural raw materials can be an important income–generating factor, contributing to the general and regional economic development.

APPENDICES

A1. BIBLIOGRAPHY

1. AGRIBUSINESSUKRAINE (2022): Agribusiness of Ukraine during the war. https://agribusinessinukraine.com/the-infographics-report-ukrainian-agribusiness-2022-eng/
(Accessed: 2024.12.12)
2. AGROALNEXT (2023): Evaluación de la biomasa potencial en España a nivel provincial. Informe metodológico y resultados. https://www.agroalnext.es/descargas/evaluacion-de-biomasa-potencial-en-espana-a-nivel-provincial/
(Accessed: 2024.12.24)
3. ALBERT, R., BARABÁSI, A - L. (2002): Statistical mechanics of complex networks. Rev. Mod. Phys. 74, 47. DOI: https://doi.org/10.1126/science.1165821
4. ALBRECHT, S., GOTTSCHICK, M., SCHORLING, M., STINT, S. (2012): Bio-economy at a crossroads. Way forward to sustainable production and consumption or industrialization of biomass? GAIA – Ecological Perspectives for Science and Society, Vol. 21, No. 1, 33-37.
5. AN, P., QU, S., YU, K., & XU, M. (2024): Mapping analytical methods between input–output economics and network science. Journal of Industrial Ecology, 28, 648–679. Doi: https://doi.org/10.1111/jiec.13493
6. AN, Q., AN, H., WANG, L., GAO, X., & LV, N. (2015): Analysis of embodied exergy flow between Chinese industries based on network theory. Ecological Modelling, 318, 26-35. DOI: https://doi.org/10.1016/j.ecolmodel.2015.01.020
7. ARASTO, A., ASIKAIEN, A. KAUKOVIRTA A. (2021): Finnish bioeconomy on the global product market in 2035. https://www.vttresearch.com/sites/default/files/2021-02/Bioeconomy-products-2035-whitepaper-VTT-Luke.pdf?t
8. ATTENBOROUGH, D. (2020): Egy élet a bolygónkon. Budapest, Park Könyvkiadó.
9. AVRĂMESCU, T. C. (2020): The Current State of Bioeconomy in Romania. "Ovidius" University Annals, Economic Sciences Series. Volume XX, Issue 1/2020. https://stec.univ-ovidius.ro/html/anale/RO/2020/Section%202/2.pdf
10. AWS (2025): 30MHz Builds a Smart Agriculture Solution for Indoor Farms and Greenhouses on AWS. Agriculture Customer Stories. https://aws.amazon.com/solutions/case-studies/agriculture-customer-stories/
(Accessed: 2025.02.28)
11. BAI, A., DURKÓ, E., TAR, K., TÓTH, J. B., LÁZÁR, I., KAPOCSKA, L., KIRCSI, A., BARTÓK, B., VASS, R., PÉNZES, J., & TÓTH, T. (2015): Social and economic possibilities for the energy utilization of fitomass in the valley of the river Hernád. *Renewable Energy*, *85*, 777-789. https://doi.org/10.1016/j.renene.2015.06.069
12. BAKSHI, B.R. (2022): Interdisciplinary open lecture and seminar for researchers and PhD students. Place: Hungarian Univeristy of Agriculture and Life Sciences, Gödöllő, 2022.04.27.
13. BARABÁSI A - L. AND ALBERT, R. (1999): Emergence of Scaling in Random Networks. Science 286, 509-512. DOI: https://doi.org/10.1126/science.286.5439.509
14. BARABÁSI, A - L. (2024): A hálózatok tudománya. Budapest, Open Books.
15. BARTLETT, J. (2024): Fast fashion goes to die in the world's largest fog desert. The scale is breathtaking. https://www.nationalgeographic.com/environment/article/chile-fashion-

pollution
(Acessed: 2025.02.19)
16. BASK, A. & RAJAHONKA, M. (2017): The role of environmental sustainability in the freight transport mode choice: A systematic literature review with focus on the EU. International Journal of Physical Distribution & Logistics Management, 47, 560-602. DOI: https://doi.org/10.1108/IJPDLM-03-2017-0127
17. BECK-O'BRIEN, M., BRINGEZU, S., BANSE, M., BARRELET, J., BEZAMA, A., BÖSCH, B., BRÜNING, S., BÜHRLEN, B., CABEZAS, A., CYFFKA, K. F., DZENE, I., FEHRENBACH, H., GORDILLO VERA, F., HELANDER, H., HENKE, J., HENNENBERG, K., HINZ, R., IOST, S., JORDAN, M., KILIAN, D., KÖPPEN, S., KYNAST, E., LUTZ, C., MEYER, C., PEREIRA, S., PFEIFFER, M., PHUNTSHO, POZO INOFUENTES, P., REISS, T., REUSCHEL, S., RICHTER, S., SCHALDACH, R., SCHEFFLER, M., SCHOMBERG, A., SCHÜNGEL, J., SCHWEINLE, J., THRÄN, D., WANG, M., WEIMAR, H., WIEGMANN, K., WIJESINGHA, J., WILSKE, B., WYDRA, S., ZEUG, W., ZINKE, C. (2024): Monitoring the German Bioeconomy: Status, performance, trends and implications for sustainable development. Published by the Center for Environmental Systems Research (CESR), - University of Kassel, Kassel, DOI: https://doi.org/10.17170/kobra-2024111510679
18. BELL, J., PAULA, L., DODD, T., NÉMETH, SZ., NANOU, C., MEGA, V., CAMPOS, P. (2017): EU ambition to build the world's leading bioeconomy—Uncertain times demand innovative and sustainable solutions. New Biotechnology. Vol 40, pp. 25-30. DOI: https://doi.org/10.1016/j.nbt.2017.06.010
19. BERKOWICZ, R., WINTHER, M. & KETZEL, M. (2006): Traffic pollution modelling and emission data. Environmental Modelling & Software, 21, 454-460.DOI: https://doi.org/10.1016/j.envsoft.2004.06.013
20. BERNERS – LEE, M. (2020): Nincs B bolygó. Kézikönyv a sorsdöntő évekhez. Pallas Athéné Könyvkiadó Kft.
21. BIO BASED INDUSTRIES CONSORTIUM (2021): Mapping Portugal's bio-based potential. Country report. https://biconsortium.eu/sites/biconsortium.eu/files/publications/BIC-Country-Report-Portugal-2021.pdf
(Accessed: 2024.12.24)
22. BIOEAST INITIATIVE (2024). https://bioeast.eu/vision-objectives/
(Accessed: 2024.12.24)
23. BIOECONOMY IN GERMANY – BACKGROUND. https://biooekonomie.de/en/bioeconomy-germany-background
(Accessed: 2024.11.12)
24. BORGATTI, S.P., MEHRA, A., BRASS, D.J., LABIANCA, G. (2009): Network analysis in the social sciences. Science 323, 892–895. DOI: https://doi.org/10.1126/science.1165821
25. BOSMAN, R., & ROTMANS, J. (2016): Transition Governance towards a Bioeconomy: A Comparison of Finland and The Netherlands. *Sustainability*, *8*(10), 1017. DOI: https://doi.org/10.3390/su8101017
26. BOTANICAL FORMULATIONS (2021): Poppy seed oil. https://www.botanicalformulations.com/oil-monographs/poppy-seed-oil
(Accessed: 2025.01.28)

27. BOZAN, B., & TEMELLI, F. (2003): Extraction of Poppy Seed Oil Using Supercritical CO2. Journal of Food Science, 68(2), 422-426. DOI: https://doi.org/10.1111/j.1365-2621.2003.tb05688.x
28. BRIZGA, J., MICEIKIENĖ, A., LIOBIKIENĖ, G. (2019): Environmental aspects of the implementation of bioeconomy in the Baltic sea region: an input-output approach. J. Clean. Prod. 240, 1–10. DOI: https://doi.org/10.1016/j.jclepro.2019.118238
29. BROWN, A. J., LIND, H., & BOWERS, J. (1967): THE ' GREEN PAPER ' ON THE DEVELOPMENT AREAS. National Institute Economic Review, 40, 26–33. http://www.jstor.org/stable/23874174
30. BRUCKNER, M., HÄYHÄ, T., GILJUM, S., MAUS, V., FISCHER, G., TRAMBEREND, S. AND BÖRNER, J. (2019): Quantifying the global cropland footprint of the European Union's non-food bioeconomy. Environ. Res. Lett. 14 045011. DOI: https://doi.org/10.1088/1748-9326/ab07f5
31. BUESO, Y.F., TANGNEY, M., (2017): Synthetic biology in the driving seat of the bioeconomy. Trends Biotechnol. 35, 373–378. DOI: http://doi.org/10.1016/j.tibtech.2017.02.002
32. BUGGE, M. M. - HANSEN, T. - KLITKOU, A. (2016): What is the bioeconomy? A review of the literature. Sustainability, 8(7), 1–22. DOI: https://doi.org/10.3390/su8070691
33. CALICIOGLU, Ö. AND BOGDANSKI, A. (2021): Linking the bioeconomy to the 2030 sustainable development agenda: can SDG indicators be used to monitor progress towards a sustainable bioeconomy? New Biotechnology. Volume 61, 25 March 2021, Pages 40-49. DOI: https://doi.org/10.1016/j.nbt.2020.10.010
34. CAPASSO, M., & KLITKOU, A. (2020): Socioeconomic Indicators to Monitor Norway's Bioeconomy in Transition. Sustainability, 12(8), 3173. DOI: https://doi.org/10.3390/su12083173
35. CARREZ, D., VAN LEEUWEN, P. (2015): Bioeconomy: circular by nature. The European Files (38), 34–35. http://europeanfiles.eu/wp-content/uploads/issues/2015-september-38.pdf
36. CARVALHO, V. M. (2012): Input-output networks: A survey. A report for the European Commission under the CRISIS consortium agreement. https://cordis.europa.eu/docs/projects/cnect/1/288501/080/deliverables/001-CRISISD31InputOutput.pdf
(Accessed: 2024.12.26)
37. CHOVANCOVÁ, J., LITAVCOVÁ, E. & SHEVCHENKO, T. (2021): Assessment of the relationship between economic growth, energy consumption, CO2 emissions and renewable energy sources in the V4 countries. Journal of Management and Business: Research and Practice, 13(2). DOI: https://doi.org/10.54933/jmbrp-2021-13-2-3
38. CISMAȘ, L. M., BĂLAN, E. M., ZELDEA, C. G., IORDAN, M., & CISMAȘ, C. M. (2023): Agriculture and the Bioeconomy: A Socioeconomic Analysis of Central and Eastern European Countries. Sustainability, 15(22), 16082. DOI: https://doi.org/10.3390/su152216082
39. ÇOBAN, M. N., BIÇEN, Ö. F., NASSANI, A. A., & ANSER, M. K. (2025): Exploring the effects of global value chain participation, technological eco-innovation and natural resource rents on environmental quality in the EU-14. Scientific Reports, 15(1), 17572. DOI: https://doi.org/10.1038/s41598-025-01569-z

40. COLEN, L., MELO, P., ABDUL-SALAM, Y., ROBERTS, D., MARY, S., PALOMA, S. G. Y. (2018): Income elasticities for food, calories and nutrients across Africa: A meta-analysis. Food Policy. Vol 77, 116-132.
41. CONFENTE, I., SCARPI, D., & RUSSO, I. (2020): Marketing a new generation of bio-plastics products for a circular economy: The role of green self-identity, self-congruity, and perceived value. Journal of Business Research, 112, 431-439. DOI: https://doi.org/10.1016/j.jbusres.2019.10.030
42. CRESCENZI, P., D'ANGELO, G., SEVERINI, L., VELAJ, Y. (2016): Greedily improving our own closeness centrality in a network. ACM Trans. Knowl. Discov. Data (TKDD) 11, 1–32. DOI: https://doi.org/10.1145/2953882
43. CREUTZIG, FELIX, ET AL. (2015): Bioenergy and climate change mitigation: an assessment. Gcb Bioenergy 7 (5), 916–944. DOI: https://doi.org/10.1111/gcbb.12205
44. CRISTÓBAL, J.R.S. (2008): Is Agriculture a Key Sector in the European Economies? . Outlook on Agriculture 37(1): pp.31-35.
45. CSAJBÓK, J., PEPÓ, P., & KUTASY, E. (2020): Photosynthetic and Agronomic Traits of Winter Barley (Hordeum vulgare L.) Varieties. Agronomy, 10(12), 1999. DOI: https://doi.org/10.3390/agronomy10121999
46. CSERMELY, P. (2004): Strong links are important, but weak links stabilize them. Trends in Biochemical Sciences. 29, 331-334. DOI: https://doi.org/10.1016/j.tibs.2004.05.004
47. DAIOGLOU, V., DOELMAN, J.C., WICKE, B., FAAIJ, A., P. VAN VUUREN, D. (2019): Integrated assessment of biomass supply and demand in climate change mitigation scenarios. Global Environmental Change journal 54. DOI: https://doi.org/10.1016/j.gloenvcha.2018.11.012
48. DARIA, M., KRZYSZTOF, L., & JAKUB, M. (2020): Characteristics of biodegradable textiles used in environmental engineering: A comprehensive review. Journal of Cleaner Production, 268, 122129. DOI: https://doi.org/10.1016/j.jclepro.2020.122129
49. DAYSTAR, J.; HANDFIELD, R.; GOLDEN, J.S.; MCCONNELL, E.; MORRISON, B.; ROBINSON, R.; KANAOKA, K. (2018): An Economic Impact Analysis of the U.S. Biobased Products Industry. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2018.pdf
50. DEEPAK, BANSAL, S., THAKUR, A., SINGH, S., BAKSHI, M., BANSAAL, S. (2019): Changes in crop physiology under drought stress: A review. Journal of Pharmacognosy and Phytochemistry. Vol 8 (4) pp. 1251-1253.
51. DET KONGELIGE NORSKE VIDENSKABERS SELSKAB (DKNVS) OG NORGES TEKNISKE VITENSKAPSAKADEMI (NTVA) (2012): Verdiskaping basert på produktive hav i 2050. https://www.regjeringen.no/globalassets/upload/fkd/vedlegg/rapporter/2012/verdiskaping-rapport-010812.pdf
(Accessed: 2024.06.12)
52. DEVANEY, L., HENCHION, M. (2018): Consensus, caveats and conditions: international learnings for bioeconomy: development. J. Clean. Prod. 174, 1400–1411. DOI: https://doi.org/10.1016/j.jclepro.2017.11.047
53. DIAKOSAVVAS, D. & FREZAL, C. (2019): "Bio-economy and the sustainability of the agriculture and food system: Opportunities and policy challenges", OECD Food, Agriculture

and Fisheries Papers, No. 136, OECD Publishing, Paris, DOI: https://doi.org/10.1787/d0ad045d-en
54. DIDOVETS, I., KRYSANOVA, V., HATTERMANN, F. F., LÓPEZ, M. D. R. R., SNIZHKO, S. & SCHMIED, H. M. (2020): Climate change impact on water availability of main river basins in Ukraine. Journal of Hydrology: Regional Studies, 32, 100761. DOI: https://doi.org/10.1016/j.ejrh.2020.100761
55. DIMA, A. M., TANTAU, A., & MAASSEN, M. A. (2022): Models for analysing the dependencies between indicators for bioeconomy in the European Union. Economic Research-Ekonomska Istraživanja, 35(1), 3533–3550. DOI: https://doi.org/10.1080/1331677X.2021.1997623
56. DOBRESCU, E., GAFTEA, V., & SCUTARU, C. (2010): Using the Leontief matrix to estimate the impact of investments upon the global output. Romanian Journal of Economic Forecasting, 13(2), 176-187.
57. DUPONT-INGLIS, J., BORG, A. (2018): Destination bioeconomy – the path towards a smarter, more sustainable future. New. Biotechnology. Vol 40, 140–143. DOI: https://doi.org/10.1016/j.nbt.2017.05.010
58. DUQUE-ACEVEDO, M., BELMONTE-URENA, L.J., CORTÉS-GARCÍA, F.J., CAMACHO-FERRE, F., (2020): Agricultural waste: review of the evolution, approaches and perspectives on alternative uses. Glob. Ecol. Conserv. 22. DOI: https://doi.org/10.1016/j.gecco.2020. e00902
59. ECOTRANSIT WORLD (2024). https://www.ecotransit.org/en/ (Accessed: 2024.12.13)
60. EcoTransIT World Initiative (2022): Ecological transport information tool for worldwide transports. Methodology and data update 2022. https://www.ecotransit.org/wp-content/uploads/20220908_Methodology_Report_Update_2022.pdf
(Accessed: 2024.12.12)
61. EFKEN J., DIRKSMEYER W., KREINS P., KNECHT M. (2016): Measuring the importance of the bioeconomy in Germany: concept and illustration. NJAS Wagening. J. Life Sci. 2016;77:9–17. DOI: https://doi.org/10.1016/j.njas.2016.03.008
62. EGENOLF, V., & BRINGEZU, S. (2019): Conceptualization of an Indicator System for Assessing the Sustainability of the Bioeconomy. Sustainability, 11(2), 443. DOI: https://doi.org/10.3390/su11020443
63. ELHEDDAD, M. – BENJASAK, C. – DELJAVAN, R. – ALHARTHI, M. – ALMABROK, J. M. (2020): The effect of the Fourth Industrial Revolution on the environment: The relationship between electronic finance and pollution in OECD countries. Technological Forecasting & Social Change, DOI: https://doi.org/10.1016/j.techfore.2020.120485
64. EMONTS-HOLLEY, T., ROSS, A., SWALES, K. (2020): Estimating induced effects in IO impact analysis: variation in the methods for calculating the Type II Leontief multipliers. Econ. Syst. Res. 1–17. DOI: https://doi.org/10.1080/09535314.2020.183774
65. ENRIQUEZ, J. (1998): Genomics and the World's Economy, Science Magazine, vol. 281, no. 5379, pp. 925-926. DOI: https://doi.org/10.1126/science.281.5379.925
66. ERIKSSON, D., BRINCH-PEDERSEN, H., CHAWADE, A., HOLME, I. B., HVOSLEF-EIDE, A. K., RITALA, A., TEERI, T. H., & THORSTENSEN, T. (2018): Scandinavian perspectives on plant gene technology: Applications, policies and progress. Physiologia Plantarum, 162(2), 219-238. DOI: https://doi.org/10.1111/ppl.12661

67. ESCOBAR, N. – LAIBACH, N. (2021): Sustainability check for bio-based technologies: A review of process-based and life cycle approaches. Renewable and Sustainable Energy Reviews. Vol 135 110213. DOI: https://doi.org/10.1016/j.rser.2020.110213
68. EUROPEAN ASSOCIATION FOR BIOINDUSTRIES (EUROPABIO): Building a Bio-based Economy for Europe in 2020; European Association for Bioindustries: Brussels, Belgium, 2011.
69. EUROPEAN COMMISSION (2012a): Directorate-general for research and innovation. Innovating for sustainable growth: a bioeconomy for Europe. Publications Office. DOI: https://data.europa.eu/doi/10.2777/6462
70. EUROPEAN COMMISSION (2012b): Innovating for sustainable growth: A bioeconomy for Europe. Brussels: European Commission, http://ec.europa.eu/research/bioeconomy/pdf/official-strategy_en.pdf (Accessed: 2022.01.17.)
71. EUROPEAN COMMISSION (2018a): A sustainable bioeconomy for Europe: Strengthening the connection between economy, society and the environment. Updated Bioeconomy Strategy. Brussels: European Commission, https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf (Accessed:2022.01.10)
72. EUROPEAN COMMISSION (2018b): The position of the bioeconomy in the Netherlands. https://knowledge4policy.ec.europa.eu/sites/default/files/NL%20BE%20Position%20Paper_en.pdf (Accessed: 2024.12.23)
73. EUROPEAN COMMISSION (2021): Hungary AI Strategy Report. https://ai-watch.ec.europa.eu/countries/hungary/hungary-ai-strategy-report_en (Accessed: 2025.02.28)
74. EUROPEAN COMMISSION (2023): Biomass https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomass_en#biomass-in-the-renewable-energy-directive (Accessed: 2023.12.20)
75. EUROPEAN COMMISSION (2024): European innovation scoreboard 2024. https://projects.research-and-innovation.ec.europa.eu/en/statistics/performance-indicators/european-innovation-scoreboard/eis-2024#/eis/countries/PT (Accessed: 2024.12.24)
76. EUROSTAT (2023): Biomass https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Biomass (Accessed: 2023.12.21)
77. EUROSTAT (2024): Database https://ec.europa.eu/eurostat/data/database (Accessed: 2024.12.12)
78. FAO/WHO (2001): Codex Alimentarius. Joint FAO/WHO Food Standards Programme. https://www.fao.org/uploads/media/Codex_2001_food_labelling.pdf (Accessed: 2025.03.01)
79. FAOSTAT (2024): Crops and livestock products https://www.fao.org/faostat/en/#data/QCL (Accessed: 2024.12.12)

80. FARCAS, A. C., GALANAKIS, C.M., SOCACIU, C., POP, O. L., TIBULCA, D., PAUCEAN, A., JIMBOREAN, M.A., FOGARASI, M., SALANTA, L.C., TOFANA, M., SOCACI S. A. (2020): Food Security during the Pandemic and the Importance of the Bioeconomy in the New Era. Sustainability 2021, 13, 150. DOI: https://dx.doi.org/10.3390/su13010150
81. FAVA, J. A. – DENISON, R. – JONES, B. – CURRAN, M. A. – VIGON, B. – SELKE, S. – BARNUM, I. (EDS.) (1990): 'A technical framework for life-cycle Assessments' Report of the workshop organised by the Society of Environmental Toxilogy and Chemistry, Smugglers Notch, Vermont, 18-23 August, 1990. Published in 1991. pp. 134
82. FAVA, F., GARDOSSI, L., BRIGIDI, P., MORONE, P., CAROSI, D. A., & LENZI, A. (2021): The bioeconomy in Italy and the new national strategy for a more competitive and sustainable country. New Biotechnology, 61, 124-136. DOI: https://doi.org/10.1016/j.nbt.2020.11.009
83. FEMENIA, F. (2019): A meta-analysis of the price and income elasticities of food demand. German Journal of Agricultural Economics. Vol 68, (670-2022-357), 77-98.
84. FINLAY, M.R. (2003): Old Efforts at New Uses: A Brief History of Chemurgy and the American Search for Biobased Materials. Journal of Industrial Ecology, 7: 33-46. DOI: https://doi.org/10.1162/108819803323059389
85. FISCHER, J. - MANNING, A.D. - STEFFEN, W. - ROSE, D.B. - DANIELL, K. - FELTON, A. - GARNETT, S. - GILNA, B. - HEINSOHN, R. - LINDENMAYER, D.B. - MACDONALD, B. - MILLS, F. - NEWELL, B. - REID, J. - ROBIN, L. - SHERREN, K. - WADE, A. (2007): Mind the sustainability gap. TRENDS in Ecology and Evolution. Vol. 22, No. 12. DOI: https://doi.org/10.1016/j.tree.2007.08.016
86. FOGARASSY, CS., HORVÁTH, B. (2018): Körkörös ellátási láncok. Lépések a fenntarthatóság felé, Vol. 72, No. 2, p. 4-5. https://kovet.hu/wp-content/uploads/2018/09/lepesek_72.pdf
87. FOOD DRINK EUROPE (2022): Data and Trends of the European Food and Drink Industry https://www.fooddrinkeurope.eu/resource/data-trends-of-the-european-food-and-drink-industry-2021/
(Accessed: 2022.03.07)
88. FRISVOLD, G.B., MOSS, S.M., HODGSON, A., MAXON, M.E., (2021): Understanding the US Bioeconomy: a new definition and landscape. Sustainability 13, 1–24. DOI: https://doi.org/10.3390/su13041627
89. FU, R., JIN, G., CHEN, J., YE, Y., (2021): The effects of poverty alleviation investment on carbon emissions in China based on the multiregional input–output model. Technol. Forecast. Soc. Change 162, 120344. DOI: https://doi.org/10.1016/j.techfore.2020.120344
90. FUELS EUROPE (2022): CO2 Emissions Trend by Sector in the EU (1990-2016) https://www.fuelseurope.eu/interactive-graph/co2-emissions-trend-by-sector-in-the-eu/
(Accessed: 2022.03.06)
91. GABINETE DE PLANEAMENTO, POLÍTICAS E ADMINISTRAÇÃO GERAL (GPP) (2021): Bioeconomia 2030. https://www.gpp.pt/images/Destaques/Noticia/Bioeconomia/BioEconomia-RelatorioPrincipal-Visualizacao.pdf
(Accessed: 2024.12.24)

92. GALANAKIS, C. M., BRUNORI, G., CHIARAMONTI, D., MATTHEWS, R., PANOUTSOU, C. AND FRITSCHE, U. R. (2022): Bioeconomy and green recovery in a post-COVID-19 era. Science of The Total Environment. 808, 152180. DOI: https://doi.org/10.1016/j.scitotenv.2021.152180
93. GARCÍA MOLINOS, J., BURROWS, M. T., & POLOCZANSKA, E. S. (2017): Ocean currents modify the coupling between climate change and biogeographical shifts. Scientific Reports, 7(1), 1-9. DOI: https://doi.org/10.1038/s41598-017-01309-y
94. GATTO, F., & RE, I. (2021): Circular Bioeconomy Business Models to Overcome the Valley of Death. A Systematic Statistical Analysis of Studies and Projects in Emerging Bio-Based Technologies and Trends Linked to the SME Instrument Support. Sustainability, 13(4), 1899. DOI: https://doi.org/10.3390/su13041899
95. GAWEL, E., PANNICKE, N. AND HAGEMANN, N. (2019): A path transition towards a bioeconomy-The crucial role of sustainability. Sustainability 2019, 11(11), 3005. DOI: https://doi.org/10.3390/su11113005
96. GHIL, M., LUCARINI, V. (2020): The physics of climate variability and climate change. Rev. Mod. Phys. 92, 035002. DOI: https://doi.org/10.1103/RevModPhys.92.035002
97. GLOBAL BIOECONOMY SUMMIT (2018): Innovation in the Global Bioeconomy for Sustainable and Inclusive Transformation and Wellbeing. https://gbs2020.net/wp-content/uploads/2021/10/GBS_2018_Report_web.pdf
(Accessed: 2025.01.30)
98. GMK CENTER (2023): RAILWAY GATEWAY TO THE WORLD: WHAT IS THE STATE OF FREIGHT TRANSPORTATION BETWEEN UKRAINE AND POLAND. https://gmk.center/en/posts/railway-gateway-to-the-world-what-is-the-state-of-freight-transportation-between-ukraine-and-poland/
(Accessed:2024.12.12)
99. GOLDSMITH, E. (1972): Blueprint for Survival. Penguin
100. GONÇALVES, M., FREIRE, F., & GARCIA, R. (2021): Material flow analysis of forest biomass in Portugal to support a circular bioeconomy. Resources, Conservation and Recycling, 169, 105507. DOI: https://doi.org/10.1016/j.resconrec.2021.105507
101. GOYAL, R. & STEINBACH, S. (2023): Agricultural commodity markets in the wake of the black sea grain initiative. Economics Letters, 231, 111297. DOI: https://doi.org/10.1016/j.econlet.2023.1112
102. HA, N. H. P., & TRINH, B. (2018): Vietnam economic structure change based on Vietnam input-output tables 2012 and 2016. Theoretical Economics Letters, 8(4), 699-708.
103. HANNON, B. (1973): The structure of ecosystems. *Journal of Theoretical Biology*, *41*(3), 535-546. DOI: https://doi.org/10.1016/0022-5193(73)90060-X
104. HARARI, Y.N. (2015): Sapiens – Az emberiség rövid története. Animus Kiadó, Budapest.
105. HASEGAWA, T., FUJIMORI, S., HAVLÍK, P., VALIN, H., BODIRSKY, B. L., DOELMAN, J. C., FELLMANN, T., KYLE, P., KOOPMAN, J. F., LOTZE-CAMPEN, H. (2018): Risk of increased food insecurity under stringent global climate change mitigation policy. Nature Climate Change. Vol 8, (8), 699-703. DOI: https://doi.org/10.1038/s41558-018-0230-x
106. HEIJMAN, W. & SCHEPMAN, T. (2018): Measuring the Size of the Dutch Bio-Economy. Visegrad Journal on Bioeconomy and Sustainable Development. 7. 67-72. DOI: https://doi.org/10.2478/vjbsd-2018-0013

107. HELDAK, M., KUCHER, A., STACHERZAK, A. & KUCHER, L. (2019): Structural transformations in agriculture in Poland and Ukraine: towards economic sustainability. Journal of Environmental Management and Tourism, 9, 1827-1841. DOI: https://doi.org/10.1016/j.econlet.2023.111297
108. HEWINGS, G. J. D. (1985): Regional Input-Output Analysis. Reprint. Edited by Grant Ian Thrall. WVU Research Repository, 2020.
109. HOW THE BIOECONOMY CONTRIBUTES TO THE EUROPEAN GREEN DEAL (2022) https://www.bioeconomyalliance.eu/wp-content/uploads/2023/10/EUBA-report-How-the-Bioeconomy-contributes-to-the-European-Green-Deal_0.pdf
110. HRICOVA, R. (2022): The current status of East Slovakian transshipment points and the possibilities of their further development. Acta Logistica, 9, 379-386. DOI: https://doi.org/10.22306/al.v9i4.328
111. HUANG, X. (2010): What Is Portfolio Analysis. Studies in Fuzziness and Soft Computing. DOI: https://doi.org/10.1007/978-3-642-11214-0_1
112. HURMEKOSKI, E., SMYTH, C. E., STERN, T., VERKERK, P. J. AND ASADA, R. (2021): Substitution impacts of wood use at the market level: a systematic review. Environ. Res. Lett. 16 123004. DOI: https://doi.org/10.1088/1748-9326/ac386f
113. INFOGRAPHIE - LA BIOÉCONOMIE, UNE APPROCHE NOUVELLE POUR DES SOLUTIONS DURABLES. https://agriculture.gouv.fr/infographie-la-bioeconomie-une-approche-nouvelle-pour-des-solutions-durables
(Accessed: 2024.12.23)
114. INOUE, H., & TODO, Y. (2019): Firm-level propagation of shocks through supply-chain networks. Nature Sustainability, 2(9), 841-847. DOI: https://doi.org/10.1038/s41893-019-0351-x
115. INTERNATIONAL ADVISORY COUNCIL ON GLOBAL BIOECONOMY (2020): Global Bioeconomy Policy Report (IV): A decade of bioeconomy policy development around the world. https://gbs2020.net/wp-content/uploads/2020/11/GBS-2020_Global-Bioeconomy-Policy-Report_IV_web.pdf
(Accessed: 2025.01.30)
116. INTERREG (2020): Chain reactions. Thematic brief bioeconomy. Big data – artificial intelligence. https://bioeconomy.sk/en/wp-content/uploads/sites/2/2021/01/Thematic-brief-Big-Data-AI-in-Bioeconomy.pdf
(Accessed: 2025.02.28)
117. INTESA SANPAOLO (2024): La Bioeconomia in Europa. 10◦ Rapporto. https://group.intesasanpaolo.com/content/dam/portalgroup/repository-documenti/research/it/bioeconomia/2024/La%20Bioeconomia%20in%20Europa%20giugno%202024.pdf
(Accessed: 2024.12.23)
118. ISARD, W., & ANSELIN, L. (1982): Integration of Multiregional Models for Policy Analysis. Environment and Planning A. DOI: https://doi.org/10.1068/a140359
119. ISSUES IN SCIENCE AND TECHNOLOGY (2023): Regulations for the Bioeconomy. https://issues.org/maxon-regulating-bioeconomy-forum/
(Accessed: 2025.02.28)

120. JÁMBOR, A. – TÖRÖK, Á. (2012): Az agrár-közgazdaságtan és a bioökonómia: A 28. Nemzetközi Agrárközgazdasági Konferencia tapasztalatai. Budapest, Gazdálkodás, 56.évf., 5.szám.
121. JANDER, W., WYDRA, S., WACKERBAUER, J., GRUNDMANN, P., & PIOTROWSKI, S. (2020): Monitoring Bioeconomy Transitions with Economic–Environmental and Innovation Indicators: Addressing Data Gaps in the Short Term. Sustainability, 12(11), 4683. DOI: https://doi.org/10.3390/su12114683
122. JANOSOV, M. (2023): Data. Így hálóznak be az adataid. Budapest, Open Books.
123. JANSSEN, S. – ITTERSUM, M. K. (2007): Assessing farm innovations and responses to policies: A review of bio-economic farm models. Agricultural Systems. Vol 94, No. 3, pp. 622-636
124. JAROSCH, L., ZEUG, W., BEZAMA, A., FINKBEINER, M., & THRÄN, D. (2020): A Regional Socio-Economic Life Cycle Assessment of a Bioeconomy Value Chain. Sustainability, 12(3), 1259. DOI: https://doi.org/10.3390/su12031259
125. JUMA, C., KONDE, V., UNCTAD (2002): The new bioeconomy : industrial and environmental biotechnology in developing countries : Ad Hoc Expert Group Meeting, Palais des Nations, Geneva, 15-16 November 2001.
126. KAGAWA, S., SUH, S., HUBACEK, K., WIEDMANN, T., NANSAI, K., & MINX, J. (2015): CO2 emission clusters within global supply chain networks: Implications for climate change mitigation. Global Environmental Change, 35, 486-496. DOI: https://doi.org/10.1016/j.gloenvcha.2015.04.003
127. KARAMETOU, P., & CONSTANTINE, A. (2010): The causal nexus between social capital and local development in mountain rural Greece. International Journal of Social Inquiry, Volume 3 Number 1 2010 pp. 29-66.
128. KARVONEN, J., HALDER, P., KANGAS, J., LESKINEN, P. (2017): Indicators and tools for assessing sustainability impacts of the forest bioeconomy. For. Ecosyst. 4, 1–20. DOI: https://doi.org/10.1186/s40663-017-0089-8
129. KHAN, J., JOHANSSON, B., & HILDINGSSON, R. (2021): Strategies for greening the economy in three Nordic countries. Environmental Policy and Governance, 31(6), 592-604. DOI: https://doi.org/10.1002/eet.1967
130. KIRCHER, M. (2019): Bioeconomy: Markets, Implications, and Investment Opportunities. Economies. Vol 7, 73.DOI: https://doi.org/10.3390/economies7030073
131. KLEINSCHMIT, D. - LINDSTAD, B. H. - THORSEN, B. J. - TOPPINEN, A. - ROOS, A. - BAARDSEN, S. (2014): Shades of green: A social scientific view on bioeconomy in the forest sector. Scandinavian Journal of Forest Research, Vol. 29., No. 4, pp. 402–410. DOI: https://doi.org/10.1080/02827581.2014.921722
132. KRYSHTAL, H. (2023): Role of Logistics in the Development of Agriculture of Ukraine in the War Conditions. Science and innovation, 19, 73–82-73–82. DOI: https://doi.org/10.15407/scine19.02.073
133. KULISIC, B., HORVATINČIĆ, K., OPLANIC, M., POHAJDA, I., RADIĆ, T., ŠIMEK, Ž., TIŠMA, S., VUKOVARAC, L. (2021): Positioning the Croatian linear bioeconomy towards sustainable and circular bioeconomy. https://ec.europa.eu/programmes/erasmus-plus/project-result-content/a06e1f76-3688-4547-9835-0b889403a518/POSITIONING_THE_CROATIAN_LINEAR_BIOECONOMY_TOWARDS_SUSTAINABLE_AND_CIRCULAR_BIOECONOMY.pdf

134. KUNS, B., VISSER, O. & WÄSTFELT, A. (2016): The stock market and the steppe: The challenges faced by stock-market financed, Nordic farming ventures in Russia and Ukraine. Journal of Rural Studies, 45, 199-217. DOI: https://doi.org/10.1016/j.jrurstud.2016.03.009
135. ŁĄCKA, I., MYSZCZYSZYN, J., GOŁĄB, S., BĘDZIK, B., SUPROŃ, B. (2020): Correlation between the Level of Economic Growth and Foreign Trade: The Case of the V4 Countries. European Research Studies Journal, Volume XXIII, Issue 3, 657-678. DOI: https://doi.org/10.35808/ersj/1661
136. LAHR, M.L. (1993): A review of the literature supporting the hybrid approach to constructing regional input–output models. Econ. Syst. Res. 5, 277–293. DOI: https://doi.org/10.1080/09535319300000023
137. LANDRIGAN ET AL. (2017): The Lancet Commission on pollution and health. The Lancet Commission. DOI: http://dx.doi.org/10.1016/S0140-6736(17)32345-0
138. LANGEVELD, J. W. A., MEESTERS, K. P. H., BREURE, M. S. (2016): The biobased economy and the bioeconomy in the Netherlands. Biomass research report 1601. https://www.rvo.nl/sites/default/files/2016/03/Netherlands%20position%20biobased%20economy_FBR%20Biomass%20Research%202016_0.pdf (Accessed: 2024. 12.23)
139. LASARTE LÓPEZ, J., PIOTROWSKI, S., M'BAREK, R., CARUS, M., TAMOŠIŪNAS, S. (2022): Jobs and wealth in the EU bioeconomy / JRC - Bioeconomics. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/7d7d5481-2d02-4b36-8e79-697b04fa4278
140. LAZORCAKOVA, E., DRIES, L., PEERLINGS, J., & POKRIVCAK, J. (2022): Potential of the bioeconomy in Visegrad countries: An input-output approach. Biomass and Bioenergy, 158, 106366. DOI: https://doi.org/10.1016/j.biombioe.2022.106366
141. LEBEDEVAS, S., DAILYDKA, S., JASTREMSKAS, V. & RAPALIS, P. (2017): Research of energy efficiency and reduction of environmental pollution in freight rail transportation. Transport, 32, 291-301. DOI: https://doi.org/10.3846/16484142.2016.1230888
142. LEBRETON, L., SLAT, B., FERRARI, F. ET AL. (2018): Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Sci Rep 8, 4666 DOI: https://doi.org/10.1038/s41598-018-22939-w
143. LEHOCZKI, B. (2022): Semi-periphery regionalisms in a changing world order: the case of Mercosur and Visegrad Group. Third World Quarterly, 43(4), 779-796. DOI: https://doi.org/10.1080/01436597.2021.2024757
144. LEHTONEN, O., OKKONEN, L. (2013): Regional socio-economic impacts of decentralised bioeconomy: a case of Suutela wooden village, Finland. Environ. Dev. Sustain. 15, 245-256. DOI: https://doi.org/10.1007/s10668-012-9372-6
145. LEONTIEF, W. W., STROUT, A. (1963): Multiregional input-output analysis, in structural interdependence and economic development. In: Structural Interdependence and Economic Development. Palgrave Macmillan, pp. 119–150. DOI: https://doi.org/10.1007/978-1-349-81634-7_8
146. LEONTIEF, W.W. (1941): The Structure of the American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis. Harvard University Press, Cambridge, MA.
147. LEVIDOW, L. - BIRCH, K. - PAPAIOANNOU, T. (2013): Divergent paradigms of European agro-food innovation: The knowledge-based bio-economy (KBBE) as an R&D

agenda. Science, Technology & Human Values, Vol. 38., No. 1, pp. 94–125. DOI: https://doi.org/10.1177/0162243912438143
148. LEWANDOWSKI, I. – GAUDET, N. – LASK, J. - MAIER, J. - TCHOUGA B. - VARGAS-CARPINTERO, R. (2018): Bioeconomy. Shaping the Transition to a Sustainable, Biobased Economy. Switzerland, Springer. DOI: https://doi.org/10.1007/978-3-319-68152-8
149. LI, Z., SUN, L., GENG, Y., DONG, H., REN, J., LIU, Z., TIAN, X., YABAR, H., HIGANO, Y. (2017): Examining industrial structure changes and corresponding carbon emission reduction effect by combining input-output analysis and social network analysis: a comparison study of China and Japan. J. Clean. Prod. 162, 61–70. DOI: https://doi.org/10.1016/j.jclepro.2017.05.200
150. LIOBIKIENE, G., CHEN, X., STREIMIKIENE, D., BALEZENTIS, T. (2020): The trends in bioeconomy development in the European Union: Exploiting capacity and productivity measures based on the land footprint approach. Land Use Policy. Vol 91, 104375. DOI: https://doi.org/10.1016/j.landusepol.2019.104375
151. LOKKO, Y., HEIJDE, M., SCHEBESTA, K., SCHOLTÈSA, P., VAN MONTAGU, M., GIACCA, M. (2018): Biotechnology and the bioeconomy—towards inclusive and sustainable industrial development. New. Biotechnology. 40, 5–10. DOI: https://doi.org/10.1016/j.nbt.2017.06.005
152. LUATHEP, P., SUMALEE, A., LAM, W. H., LI, Z.-C. & LO, H. K. (2011): Global optimization method for mixed transportation network design problem: a mixed-integer linear programming approach. Transportation Research Part B: Methodological, 45, 808-827. DOI: https://doi.org/10.1016/j.trb.2011.02.002
153. LUSSER, M., SANCHEZ LOPEZ, J., LANDA, L., AVRAAMIDES, M., MOTOLA, V., ZIKA, E., ET AL. (2018): Joint survey on bioeconomy policy developments in different countries. https://task42.ieabioenergy.com/wp-content/uploads/sites/10/2018/06/JRC112081_joint_survey_report_final.pdf (Accessed: 2025.01.30)
154. LUSTIGOVÁ, L., KUSKOVA, P. (2006): Ecological footprint in the organic farming system. ZEMEDELSKA EKONOMIKA-PRAHA. Vol 52, (11), 503.
155. MACIEJCZAK, M., HOFREITER, K., (2013): How to define bioeconomy. Rocz. Nauk. SERIA 15, 243–248. http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.ekon-element000171343951
156. MAINAR-CAUSAPÉ, A.J., PHILIPPIDIS, G., SANJUÁN-LÓPEZ, A.I. (2021): Constructing an open access economy-wide database for bioeconomy impact assessment in the European Union member states. Econ. Syst. Res. Vol 33, No. 2, 133-156. DOI: https://doi.org/10.1080/09535314.2020.1785848
157. MAKSYMIV, Y., YAKUBIV, V., PYLYPIV, N., HRYHORUK, I., PIATNYCHUK, I. AND POPADYNETS N (2021): Strategic challenges for sustainable governance of the bioeconomy: preventing conflict between SDGs. Sustainability 2021, 13(15), 8308, DOI: https://doi.org/10.3390/su13158308
158. MALUCK, J., & DONNER, R. V. (2015): A Network of Networks Perspective on Global Trade. PLOS ONE, 10(7), e0133310. DOI: https://doi.org/10.1371/journal.pone.0133310
159. MARSDEN, T. (2012): Towards a real sustainable agri-food security and food policy: Beyond the ecological fallacies? Political Quarterly, Vol. 83, No. 1, pp. 139–145.

160. MARX, K. (1867): Capital: A critique of political economy. Volume 1, Part 1: The process of capitalist production. New York, NY: Cosimo.
161. MCCORMICK, K., - KAUTTO, N. (2013): The bioeconomy in Europe: An overview. Sustainability, 5(6), 2589–2608. DOI: https://doi.org/10.3390/su5062589
162. MCNERNEY, J., FATH, B. D., & SILVERBERG, G. (2013): Network structure of inter-industry flows. *Physica A: Statistical Mechanics and its Applications*, *392*(24), 6427-6441. DOI: https://doi.org/10.1016/j.physa.2013.07.063
163. MEADOWS, D. H. – MEADOWS, D. L. – RANDERS, J. – BEHRENS, W. W. (1972): The limits to growth. p. 9
164. MILLER, R.E. & BLAIR, P.D (2009): Input-Output analysis. Foundations and Extensions. http://digamo.free.fr/io2009.pdf
(Accessed: 2023.12.12)
165. MINISTRY OF ECONOMIC AFFAIRS AND EMPLOYMENT OF FINLAND (2023) https://tem.fi/en/bioeconomy?t
(Accessed: 2023.12.22)
166. MIRON, D. (2023): Micro and Macroeconomic Impact of the EU Energy Policy. Amfiteatru Economic Journal, 25, 294-303.DOI: https://doi.org/10.24818/EA/2023/63/294
167. MORRISON, B. – GOLDEN, J. S. (2015): An Empirical Analysis of the Industrial Bioeconomy: Implications for Renewable Resources and the Environment. Bioresurces, Vol 10, No 3. DOI: https://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/6947
168. MOSES, L. N. (1955): The stability of interregional trading patterns and input-output analysis. The American Economic Review, 45:803–832.
169. MUNKHOLM, K. F. (2024): AI and Bioeconomy in China: A Comprehensive Analysis. https://www.linkedin.com/pulse/ai-bioeconomy-china-comprehensive-analysis-kjeld-friis-munkholm-孟可和-sqvtf
(Accessed: 2025.02.28)
170. MUSA ÖZCAN, M., & ATALAY, ÇIGDEM. (2006): Determination of seed and oil properties of some poppy (Papaver somniferum L.) varieties. Grasas Y Aceites, 57(2), 169–174. DOI: https://doi.org/10.3989/gya.2006.v57.i2.33
171. NEMZETI AGRÁRGAZDASÁGI KAMARA (NAK) (2024): Ízletes desszertek mellett számos gyógyszerünk alapanyaga a mák. https://www.nak.hu/sajto/sajtokozlemenyek/108060-izletes-desszertek-mellett-szamos-gyogyszerunk-alapanyaga-a-mak
(Accessed: 2025.01.28)
172. NERGIZ, C., ÖTLES¸, S. (1993): Chemical composition of Nigella sativa L. Seeds. Food Chemistry. 48 (1993) No. 3, pp. 259-261.
173. NOCERA, S., TONIN, S. & CAVALLARO, F. (2015): The economic impact of greenhouse gas abatement through a meta-analysis: Valuation, consequences and implications in terms of transport policy. Transport Policy, 37, 31-43
174. NORDIC STATISTICS DATABASE/BIOECONOMY. https://www.nordicstatistics.org/areas/bioeconomy/
(Accessed: 2024.11.23)
175. NORWEGIAN MINISTRY OF TRADE, INDUSTRY AND FISHERIES (2019): Blue Opportunities. The Norwegian Government's updated ocean strategy.

https://www.regjeringen.no/globalassets/departementene/nfd/dokumenter/strategier/w-0026-e-blue-opportunities_uu.pdf

176. O'CONNOR, E., EVERS, N. & VEGA, A. (2023). Port capacity planning–A strategic management perspective. Marine Policy, 150, 105537. DOI: https://doi.org/10.1016/j.marpol.2023.105537
177. OECD (2009): The Bioeconomy to 2030: Designing a Policy Agenda, OECD Publishing, Paris. https://doi.org/10.1787/9789264056886-en
178. OECD (2016): Inter-Country Input-Output tables. https://www.oecd.org/en/data/datasets/inter-country-input-output-tables.html
179. OECD (2021): Inter-Country Input-Output tables. https://www.oecd.org/en/data/datasets/inter-country-input-output-tables.html
180. OECD (2023): Towards a National Circular Economy Strategy for Hungary, OECD Publishing, Paris. https://doi.org/10.1787/1178c379-en
181. OECONOMUS RESEARCH FOUNDATION (2024): Where poppy doesn't go in poppy seed rolls – Myanmar is the world's leading opium producer. https://www.oeconomus.hu/en/oecoglobus/where-poppy-doesnt-go-in-poppy-seed-rolls-myanmar-is-the-worlds-leading-opium-producer/ (Accessed: 2025.01.28)
182. OKUYAMA, Y., HEWINGS, G.J., SONIS, M., ISRAILEVICH, P.R. (2002): An economic analysis of biproportional properties in an input-output system. J. Reg. Sci. 42, 361–387. DOI: https://doi.org/10.1111/1467-9787.00263
183. OLÁH, J., POPP, J., DULEBA, S., KISS, A., LAKNER, Z. (2021): Positioning Bio-Based Energy Systems in a Hypercomplex Decision Space—A Case Study. Energies 2021,14, 4366. DOI: https://doi.org/10.3390/en14144366
184. OLS, C. AND BONTEMPS, J-D. (2021): Pure and even-aged forestry of fast-growing conifers under climate change: on the need for a silvicultural paradigm shift. Environ. Res. Lett. 16 024030. DOI: https://doi.org/10.1088/1748-9326/abd6a7
185. ONE THIRD OF THE BIOECONOMY'S VALUE ADDED COMES FROM THE FOREST SECTOR (2023). https://www.luke.fi/en/news/one-third-of-the-bioeconomys-value-added-comes-from-the-forest-sector?t (Accessed: 2023.12.23)
186. OPSAHL, T., AGNEESSENS, F., & SKVORETZ, J. (2010): Node centrality in weighted networks: Generalizing degree and shortest paths. Social Networks, 32(3), 245-251. DOI: https://doi.org/10.1016/j.socnet.2010.03.006
187. PARK, J. (2007): The supply-driven input-output model: A reinterpretation and extension. Cell, 213, 550-9979.
188. PFAU, S. F. - HAGENS, J. E. - DANKBAAR, B. - SMITS, A. J. M. (2014): Visions of sustainability in bioeconomy research. Sustainability, Vol. 6, No.3, pp. 1222–1249. DOI: https://doi.org/10.3390/su6031222
189. PHILIPPIDIS, G., SANJUÁN LÓPEZ, A.I., FERRARI, E., M'BAREK, R. (2014): Employing social accounting matrix multipliers to profile the bioeconomy in the EU member states: is there a structural pattern? Span. J. Agric. Res. 12, 913–926. http://hdl.handle.net/10532/2773

190. PHILLIPS, A. (1955): The tableau Economique as a simple Leontief model. Q. J. Econ. 69, 137–144. DOI: https://doi.org/10.2307/1884854
191. PHILP, J. AND WINICKOFF, D. (2019): "Innovation ecosystems in the bioeconomy", OECD Science, Technology and Industry Policy Papers, No. 76, OECD Publishing, Paris, DOI: https://doi.org/10.1787/e2e3d8a1-en
192. PHILP, J., (2018): The bioeconomy, the challenge of the century for policy makers. New Biotechnology. Vol 40, 11–19. https://doi.org/10.1016/j.nbt.2017.04.004
193. PLEYM, I., SVORKEN, M., & KVALVIK, I. (2021): The Norwegian Bioeconomy Strategy and the Way Forward for Blue Growth. Arctic Review on Law and Politics, 12, 238–244. DOI: https://doi.org/10.23865/arctic.v12.3341
194. POLENSKE, K. R. (1974): MULTIREGIONAL INTERACTIONS BETWEEN ENERGY AND TRANSPORTATION. Applications. 1. https://researchrepository.wvu.edu/rri_ioapplication/1 (Accessed: 2024.12.25)
195. PORC, O., HARK, N., CARUS, M., DR. CARREZ, D. (2024): European Bioeconomy in Figures 2014-2021. https://biconsortium.eu/sites/biconsortium.eu/files/publications/European%20Bioeconomy%20in%20Figures%202014%20-%202021_1.pdf
196. PROCHÁZKA, P. & SMUTKA, L. (2012): Czech Republic as an Important Producer of Poppy Seed. AGRIS on-line Papers in Economics and Informatics, Czech University of Life Sciences Prague, Faculty of Economics and Management, vol. 4(2), pages 1-13, June. DOI: https://doi.org/10.22004/ag.econ.131361
197. PROESTOU, M., SCHULZ, N. & FEINDT, P.H. (2024): A global analysis of bioeconomy visions in governmental bioeconomy strategies. Ambio 53, 376–388 DOI: https://doi.org/10.1007/s13280-023-01958-6
198. PROTEINS FOR THE FUTURE. RECOMMENDATIONS FROM THE DANISH BIOECONOMY PANEL. https://stateofgreen.com/en/news/proteins-for-the-future/?t (Accessed: 2023.04.02.)
199. PÜLZL, H. - KLEINSCHMIT, D. - ARTS, B. (2014): Bioeconomy: An emerging metadiscourse affecting forest discourses? Scandinavian Journal of Forest Research, Vol. 29, No. 4, pp. 386–393. DOI: https://doi.org/10.1080/02827581.2014.920044
200. PUTTKAMMER, J., GRETHE, H. (2015): The Public Debate on Biofuels in Germany: Who Drives the Discourse? German Journal of Agricultural Economics, 2015, Vol. 64, Issue 04. DOI: https://doi.org/10.22004/ag.econ.270184
201. R PROGRAM – PACKAGE 'IOANALYSIS'- WADE – SARMIENTO BARBIERI(2021) https://cran.r-project.org/web/packages/ioanalysis/ioanalysis.pdf (Accessed: 2021.07.22)
202. RÁCZ, GY. (2013): The Congress of Visegrád in 1335: Diplomacy and Representation. Hungarian historical review: new series of acta historica academiae scientiarium hungaricae, 2 (2). pp. 261-287.
203. REFSGAARD, K., KULL, M., SLÄTMO, E., & MEIJER, M. W. (2021): Bioeconomy – A driver for regional development in the Nordic countries. New Biotechnology, 60, 130-137. DOI: https://doi.org/10.1016/j.nbt.2020.10.001
204. RÉGION GRAND EST (2020): Une ambition : faire du Grand Est un leader européen de la bioéconomie. https://www.bioeconomie-grandest.fr/wp-content/uploads/2020/06/1588-la-

strategie-bioeconomie_8p.pdf
(Accessed: 2024.12.23)

205. ROBERT, N., GIUNTOLI, J., ARAUJO, R., AVRAAMIDES, M., BALZI, E., BARREDO, J. I., BARUTH, B., BECKER, W., BORZACCHIELLO, M. T., BULGHERONI, C., CAMIA, A., FIORE, G., FOLLADOR, M., GURRIA, P., LA NOTTE, A., LUSSER, M., MARELLI, L., M'BAREK, R., PARISI, C., PHILIPPIDIS, G., RONZON, T., SALA, S., LOPEZ, J. S., MUBAREKA, S. (2020): Development of a bioeconomy monitoring framework for the European Union: An integrative and collaborative approach. New Biotechnology, 59, 10-19. DOI: https://doi.org/10.1016/j.nbt.2020.06.001
206. ROBOCK, A., MU, M., VINNIKOV, K., TROFIMOVA, I. V. & ADAMENKO, T. I. (2005): Forty-five years of observed soil moisture in the Ukraine: No summer desiccation (yet). Geophysical Research Letters, 32. DOI: https://doi.org/10.1029/2004GL021914
207. ROGELJ, J., ET AL. (2018): Mitigation pathways compatible with 1.5°C in the context of sustainable development. In: Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. (Eds.), Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Ed. T. Waterfield. IPCC.
208. ROGERS, J. D., & BOZEMAN, B. (2001): "Knowledge Value Alliances": An Alternative to the R&D Project Focus in Evaluation. Science, Technology, & Human Values. DOI: https://doi.org/10.1177/016224390102600102
209. ROJEK, K. (2023): Factors affecting the international competitiveness of polish economy system in 2004-2019. Competitiveness Review: An International Business Journal, 33(2), 483-502. DOI: https://doi.org/10.1108/CR-05-2021-0079
210. ROMANIAN TERMINAL OPENS TO STREAMLINE UKRAINIAN GRAIN EXPORTS (2024). Railway Gazette. https://www.railwaygazette.com/freight/romanian-terminal-opens-to-streamline-ukrainian-grain-exports/66781.article
(Accessed: 2024.12.24)
211. RONZON, T., & M'BAREK, R. (2018): Socioeconomic Indicators to Monitor the EU's Bioeconomy in Transition. Sustainability, 10(6), 1745. DOI: https://doi.org/10.3390/su10061745
212. RONZON, T., PIOTROWSKI, S., M'BAREK, R., CARUS, M., TAMOŠIŪNAS, S. (2018): Jobs and wealth in the EU bioeconomy/JRC-Bioeconomics. http://data.europa.eu/89h/7d7d5481-2d02-4b36-8e79-697b04fa4278
213. ROSE, STEVEN K., KRIEGLER, E., BIBAS, R., CALVIN, K., POPP, A., P. VAN VUUREN, D., WEYAN, J. (2013): Bioenergy in energy transformation and climate management. Clim. Change 123 (3–4), 477–493. https://link.springer.com/article/10.1007/s10584-013-0965-3
214. RUHNAU, B. (2000): Eigenvector-centrality — A node-centrality? *Social Networks*, *22*(4), 357-365. DOI: https://doi.org/10.1016/S0378-8733(00)00031-9
215. SAREWITZ, D., & PIELKE, R. A. (2007): The neglected heart of science policy: Reconciling supply of and demand for science. Environmental Science & Policy, 10(1), 5-16. DOI: https://doi.org/10.1016/j.envsci.2006.10.001

216. SARKIS, J. – DOU, Y. (2018): Green Supply Chain Management. A Concise Introduction. USA, Routledge, p.14
217. SCHMIDT, A. (2016): Friends forever? The Role of the Visegrad Group and European Integration. Politics in Central Europe, 12, 113 - 140. DOI: https://doi.org/10.1515/pce-2016-0019
218. SCORDATO, L., BUGGE, M. M., HANSEN, T., TANNER, A., & WICKEN, O. (2022): Walking the talk? Innovation policy approaches to unleash the transformative potentials of the Nordic bioeconomy. Science and Public Policy, 49(2), 324-346. DOI: https://doi.org/10.1093/scipol/scab083
219. SGROI, F. (2022): The circular economy for resilience of the agricultural landscape and promotion of the sustainable agriculture and food systems. Journal of Agriculture and Food Research, 8, 100307. DOI: https://doi.org/10.1016/j.jafr.2022.100307
220. SHARPE, W. F. (1963): A Simplified Model for Portfolio Analysis. Management Science, 9(2), 277–293. http://www.jstor.org/stable/2627407
221. SHEPPARD, A.W., RAGHU, S., BEGLEY, C., GENOVESI, P., DE BARRO, P., TASKER, A., ROBERTS, B. (2011): Biosecurity as an integral part of the new bioeconomy: A path to a more sustainable future. Curr. Opin. Environ. Sustain. 2011, 3, 105–111.
222. SHERIDAN, KATHRYN (2016): Making the bioeconomy circular: the biobased industries' next goal? Ind. Biotechnol. 12 (6), 339–340. https://doi.org/10.1089/ind.2016.29057.ksh
223. SHISHIDO, S., NOBUKUNI, M., KAWAMURA, K., AKITA, T., FURUKAWA, S. (2000): An international comparison of Leontief input-output coefficients and its application to structural growth patterns. Econ. Syst. Res. 12, 45–64. DOI: https://doi.org/10.1080/095353100111272
224. SHUAI, C., YU, L., CHEN, X., ZHAO, B., QU, S., ZHU, J., LIU, J., MILLER, S. A., XU, M. (2021): Principal indicators to monitor sustainable development goals. Environ. Res. Lett. 16 124015 https://doi.org/10.1088/1748-9326/ac3697
225. SIJTSEMA, S. J., ONWEZEN, M. C., REINDERS, M. J., DAGEVOS, H., PARTANEN, A., & MEEUSEN, M. (2016): Consumer perception of bio-based products—An exploratory study in 5 European countries. NJAS: Wageningen Journal of Life Sciences, 77(1), 61–69. DOI: https://doi.org/10.1016/j.njas.2016.03.007
226. SILLANPÄÄ, M. – NCIBI, C. (2017): A Sustainable Bioeconomy. The Green Industrial Revolution. Switzerland, Springer. DOI: https://doi.org/10.1007/978-3-319-55637-6
227. SILVA, S. G. M. (2021): The Economic Performance of bioeconomy. The Case of EU 27. UNIVERSIDADE CATÓLICA PORTUGUESA. https://repositorio.ucp.pt/handle/10400.14/36110&ved=2ahUKEwiH5eSX3b2KAxWB_rsIHT6BLkEQFnoECBYQAQ&usg=AOvVaw3uO9oeB30TjjeBFGdVaQNN
228. SINGH, S. P., KHANRA, K. R, DIXIT, B. S., SRIVASTAVA, S. N. (1990): Fatty acid composition of opium poppy (Popover somniferum L.) seed oil. Indian Journal of Agricultural Sciences. 1990, 60, No. 1, pp. 358-359.
229. SOCACIU, C. (2014): Bioeconomy and Green Economy: European Strategies, Action Plans and Impact on Life Quality. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology. Vol 71, No. 1. DOI: https://doi.org/10.15835/buasvmcn-fst:10121

230. SONIS, M., HEWINGS, G.J., GUO, J. (1996): Sources of structural change in input– output systems: a field of influence approach. Econ. Syst. Res. 8, 15–32. DOI: https://doi.org/10.1080/09535319600000002
231. SPANOS, K.A.; SKOUTERI, A.; GAITANIS, D.; PETRAKIS, P.V.; MELIADIS, I.; MICHOPOULOS, P.; SOLOMOU, A.; KOULELIS, P.; AVRAMIDOU, E.V. (2021): Forests of Greece, Their Multiple Functions and Uses, Sustainable Management and Biodiversity Conservation in the Face of Climate Change. Open J. Ecol. 2021, 11, 374–406. DOI: https://doi.org/10.4236/oje.2021.114026
232. STEBELSKY, I. (1985): Agriculture of the Soviet Union and Eastern Europe. Journal of Geography, 84, 264-272. DOI: https://doi.org/10.1080/00221348508979400
233. STEELE, D. B. (1969): Regional multipliers in Great Britain. Oxford Economic Papers, 21:268–292.
234. STEENGE, A.E. (2004): Social Cost in the Leontief Environmental Model: Rules and Limits to Policy. In Wassily Leontief and Input-Output Economics, edited by E. Dietzenbacher and M.L. Lahr. Cambridge: Cambridge University Press.
235. STEINBACH, S. & YILDIRIM, Y. (2024): Agricultural commodity market response to Russia's withdrawal from the grain deal. Journal of Agricultural Economics, 75, 1004-1016. DOI: https://doi.org/10.1016/j.econlet.2023.111297
236. SWEDEN'S CLIMATE GOALS. https://www.krisinformation.se/en/hazards-and-risks/climate-change/swedens-climate-goals
(Accessed: 2024.01.23)
237. SWOT ANALYSIS – GREECE (2024). https://www.biogov.net/region/greece/
(Accessed: 2024.12.24)
238. SZAJNER, P., SZCZEPANIAK, I. & ŁOPACIUK, W. (2024): An assessment of the production potential and food self-sufficiency of Ukraine against the background of the European Union and Poland. Sustainability, 16, 7735. DOI: https://doi.org/10.3390/su16177735
239. TANG, Y., LI, M., WANG, J., PAN, Y., & WU, F. (2014): CytoNCA: A cytoscape plugin for centrality analysis and evaluation of protein interaction networks. Biosystems, 127, 67-72. DOI: https://doi.org/10.1016/j.biosystems.2014.11.005
240. TERCEÑO GÓMEZ, A. (2023): Análisis de los Sectores Claves de la Bioeconomía en España. https://racef.es/archivos/discursos/web_racef_terceno_261_23_1_compressed.pdf
(Accessed: 2024.12.24)
241. THE BIOECONOMY. https://www.bioinnovation.se/en/om-bioekonomi-begrepp-och-fakta/?t
(Accessed: 2024.11.10)
242. THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION (2018): Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. https://eur-lex.europa.eu/eli/dir/2018/2001/oj
(Accessed: 2024.05.16)
243. THE FEDERAL GOVERNMENT (2020): National Bioeconomy Strategy. Summary. Bundesministerium für Bildung und Forschung/ Federal Ministry of Education and Research (BMBF) Division "Sustainable Economy; Bio-Economy". https://www.bioeconomy-international.de/lw_resource/datapool/_items/item_169/summary_bioeconomy_strategy.pd

f
(Accessed: 2024.11.12)
244. THEIL, H., GOSH, R. (1980): A comparison of shift-share and the RAS adjustment. Reg. Sci. Urban Econ. 10, 175–180. DOI: https://doi.org/10.1016/0166-0462(80)90024-1
245. TÖBBEN, J. R., DISTELKAMP, M., STÖVER, B., REUSCHEL, S., AHMANN, L., & LUTZ, C. (2022): Global Land Use Impacts of Bioeconomy: An Econometric Input–Output Approach. Sustainability, 14(4), 1976. DOI: https://doi.org/10.3390/su14041976
246. TRENBERTH, K. E., FASULLO, J. T., & SHEPHERD, T. G. (2015): Attribution of climate extreme events. Nature Climate Change, 5(8), 725-730. DOI: https://doi.org/10.1038/nclimate2657
247. TRIGO, E., CHAVARRIA, H., PRAY, C., SMYTH, S. J., TORROBA, A., WESSELER, J., ZILBERMAN, D., & MARTINEZ, J. (2023): The Bioeconomy and Food Systems Transformation. Sustainability, 15(7), 6101. DOI: https://doi.org/10.3390/su15076101
248. UIC (2024): Railway statistics synopsis. https://uic.org/IMG/pdf/railway_statistics_synopsis_2024web_1866037339.pdf
(Accessed: 2024.12.15)
249. UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS (2022) https://www.undp.org/sustainable-development-goals?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=EAIaIQobChMIyMnH6bOE-AIVlo5oCR0HAQn_EAAYAiAAEgJ49PD_BwE
(Accessed: 2022.05.12)
250. UNODC (2023): Southeast Asia Opium Survey 2023. Cultivation, Production, and Implications.
https://www.unodc.org/roseap/uploads/documents/Publications/2023/Southeast_Asia_Opium_Survey_2023.pdf
(Accessed: 2025.01.28)
251. USDA (2024): Ukraine Grain Transportation. https://www.ams.usda.gov/sites/default/files/media/UkraineJune2024.pdf
(Accessed: 2024.12.13)
252. VAN MEIJL, H., HAVLIK, P., LOTZE-CAMPEN, H., STEHFEST, E., WITZKE, P., DOMÍNGUEZ, I. P., BODIRSKY, B. L., VAN DIJK, M., DOELMAN, J., FELLMANN, T. (2018): Comparing impacts of climate change and mitigation on global agriculture by 2050. Environmental Research Letters. Vol 13, (6), 064021.
253. VÁSÁRY, V., & SZABÓ, D. (2018): Characteristics of sustainable bioeconomy in the CEE macro-region. Central European Review of Economics & Finance, 27(5), 5-26.
254. VENKATRAMANAN, V. – SHAH, S. – PRASAD, R. (2021): Sustainable Bioeconomy. Pathways to Sustainable Development Goals. Singapore, Springer. DOI: https://doi.org/10.1007/978-981-15-7321-7
255. VESPIGNANI, A. (2020): A jóslás algoritmusa. Budapest, Libri Könyvkiadó.
256. VIVIEN, F-D., NIEDDU, M., BEFORT, N., DEBREF, R. AND GIAMPIETRO, M. (2019): The hijacking of the bioeconomy. Ecological Economics, 159, 189-197. DOI: https://doi.org/10.1016/j.ecolecon.2019.01.027

257. WALLACE, M.L. & RAFOLS, I. (2015): Research Portfolio Analysis in Science Policy: Moving from Financial Returns to Societal Benefits. Minerva 53, 89–115. DOI: https://doi.org/10.1007/s11024-015-9271-8
258. WANG, H.G. (2004): A brief discussion on “bioeconomy”. Life Science Instruments 2(3), 40-44. https://www.cnki.net/KCMS/detail/detail.aspx?dbname=cjfd2004&filename=sbky200403020&dbcode=cjfq
259. WANG, J., LI, M., WANG, H., PAN, Y. (2012): Identification of Essential Proteins Based on Edge Clustering Coefficient, in IEEE/ACM Transactions on Computational Biology and Bioinformatics, vol. 9, no. 4, pp. 1070-1080, July-Aug. 2012, DOI: https://doi.org/10.1109/TCBB.2011.147
260. WANG, Q., ZHOU, Q., LIN, J., GUO, S., SHE, Y., & QU, S. (2024): Risk assessment of power outages to inter-regional supply chain networks in China. Applied Energy, 353, 122100. DOI: https://doi.org/10.1016/j.apenergy.2023.122100
261. WEINSCHENCK, G. (1986): Der ökonomische oder der ökologische Weg [The economic or the ecologic way?]. Ger. J. Agric. Econ. Agrarwirtsch. Vol 35, pp.321–327.
262. WENZ, L., & LEVERMANN, A. (2016): Enhanced economic connectivity to foster heat stress–related losses. Science Advances. DOI: https://doi.org/1501026
263. WESSELER, J., & VON BRAUN, J. (2017): Measuring the bioeconomy: Economics and policies. Annual Review of Resource Economics, 9, 275–298. DOI: https://doi.org/10.1146/annurev-resource-100516-053701
264. WIELD, D. (2013): Bioeconomy and the global economy: Industrial policies and bioinnovation. Technology Analysis & Strategic Management, Vol. 25, No.10, pp. 1209–1221. DOI: https://doi.org/10.1080/09537325.2013.843664
265. WIKIPEDIA (2024): Rail Map Ukraine. https://en.m.wikipedia.org/wiki/File:Rail_Map_Ukraine.png (Accessed: 2024.12.15)
266. WILSON, A. (1970): Entropy in urban and regional modelling. Routledge Revival (2012)
267. WORLD BANK GROUP (2024): Sri Lanka Development Update 2024. https://www.worldbank.org/en/country/srilanka/publication/sri-lanka-development-update-2024 (Accessed: 2024.12.24)
268. WORLD ECONOMIC FORUM (2022): This visual breaks down the economic crisis in Sri Lanka. https://www.weforum.org/stories/2022/07/economic-politics-debt-protest-crisis-sri-lanka/ (Accessed: 2022.07.21.)
269. WORLD ECONOMIC FORUM (2024a): Accelerating the tech-driven bioeconomy. Insight report. https://www3.weforum.org/docs/WEF_Accelerating_the_Tech_Driven_Bioeconomy_2024.pdf (Accessed: 2025.02.28)
270. WORLD ECONOMIC FORUM (2024b): How countries are redefining their bioeconomy for the future. https://www.weforum.org/stories/2024/05/countries-redefining-bioeconomy-for-the-future/ (Accessed: 2025.02.28)

271. WOŹNIAK, E., & TWARDOWSKI, T. (2018): The bioeconomy in Poland within the context of the European Union. New Biotechnology, 40, 96-102. https://doi.org/10.1016/j.nbt.2017.06.003
272. WYDRA, S. (2020): Measuring innovation in the bioeconomy—Conceptual discussion and empirical experiences. Technology in Society. Volume 61, May 2020, 101242. DOI: https://doi.org/10.1016/j.techsoc.2020.101242
273. XU, D., LIU, G., LI, H., MENG, F., CHEN, Y., AGOSTINHO, F., ALMEIDA, C. M., & GIANNETTI, B. F. (2023): High-frequency sectoral carbon and environmental analysis based on monthly input-output tables compilation during 2018–2021. IScience, 26(11), 108045. DOI: https://doi.org/10.1016/j.isci.2023.108045
274. XU, M., ALLENBY, B., & CRITTENDEN, J. C. (2011): Interconnectedness and resilience of the U.S. economy. Advances in Complex Systems, 14(5), 649-672. DOI: https://doi.org/10.1142/S0219525911003335
275. XU, M., DAIGGER, G.T., XI, C., LIU, J., QU, J., ALVAREZ, P.J., BISWAS, P., CHEN, Y., DOLINOY, D., FAN, Y., GAO, H.O., HAO, J., HE, H., KAMMEN, D.M., LEMOS, M.C., LIU, F., LOVE, N.G., LU, Y., MAUZERALL, D.L., MILLER, S.A., OUYANG, Z., OVERPECK, J.T., PENG, W., RAMASWAMI, A., REN, Z., WANG, A., WU, B., WU, Y., ZHANG, J., ZHENG, C., ZHU, B., ZHU, T., CHEN, W-Q., LIU, G., QU, S., WANG, C., WANG, Y., YU, X., ZHANG, C., ZHANG, H. (2021): U.S.–China Collaboration is Vital to Global Plans for a Healthy Environment and Sustainable Development. Environmental Science & Technology. 2021, 55 (14), 9622-9626. DOI: https://doi.org/10.1021/acs.est.0c08750
276. YEVJEVICH, V. (1995): Effects of area and time horizons in comprehensive and integrated water resources management. Water Science and Technology. Vol. 31, No. 8, pp. 19-25
277. YUSTIAWAN, Y., MAHARANI, W., & GOZALI, A. A. (2014): Degree Centrality for Social Network with Opsahl Method. Procedia Computer Science, 59, 419-426. DOI: https://doi.org/10.1016/j.procs.2015.07.559
278. ZIEGLER, S. (2014): Environmental Impacts in the Liner Shipping Industry. In: Information Technology in Environmental Engineering: The Hapag-Lloyd Online tool EcoCalc Reveals Emissions Arising from Container Transportation (Funk, B., Niemeyer, P. and Gòmez, J. M. (eds)). Berlin, Heidelberg: Springer Berlin Heidelberg: 223–228. DOI: https://doi.org/10.1007/978-3-642-36011-4_19

A2. LIST OF FIGURES

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