The Thesis of the PhD dissertation

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Role of bioeconomy towards the realisation of Sustainable Development Goals

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1. RESEARCH’S BACKGROUND AND GOALS

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 complex optimisation of the bioeconomy system 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). There is a lot of overlap between the bioeconomy and the UN's long-term sustainability goals, which have been illustrated in Table 1.

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

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.**

*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.

2. METHODOLOGY

2.1. Portfolio analysis

Analysing these portfolios aids in determining if the organisation's efforts align with its strategic objectives and often includes benchmarking. The term has a strong background in corporate finance, referring to strategies for managing collections of securities (SHARPE, 1963). According to HUANG (2010), 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. In my work, I calculate the portfolio results with R Studio, a free web program.

2.2. Input-output analysis

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 $d = 0$.

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. 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:

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

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):

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

2.3. Optimisation of the logistical system

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 CO_2 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.

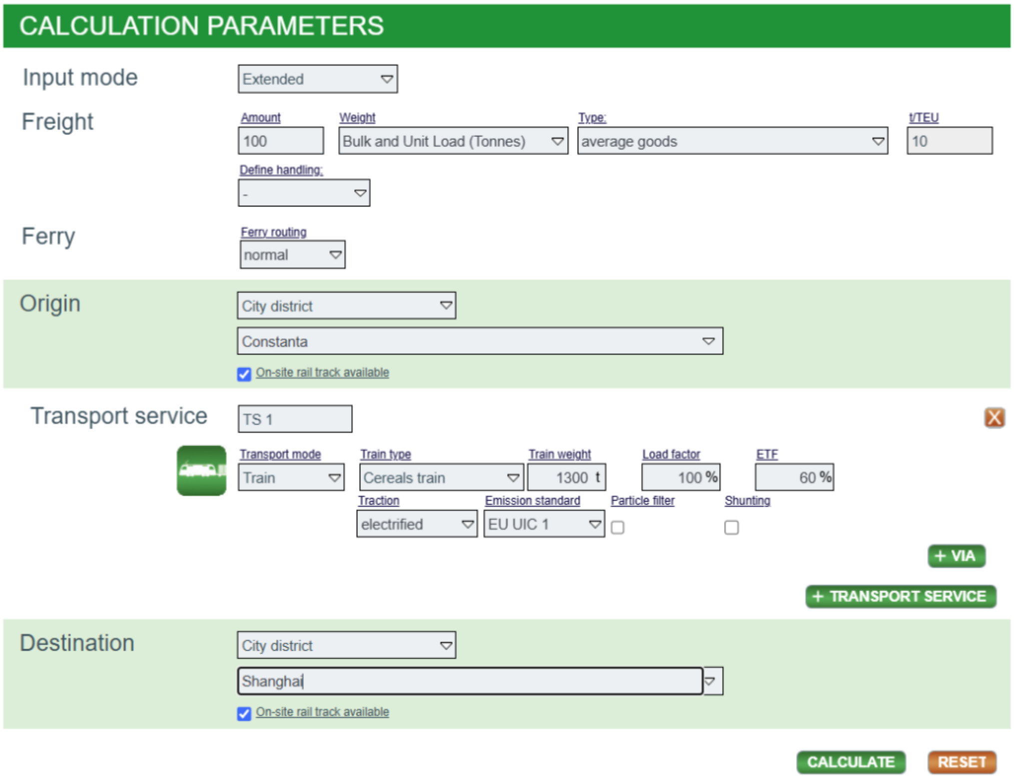

Figure 1. The calculator surface of the Ecotransit system

Source: Own screenshot from EcoTransIT, 2024

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

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

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.

3. RESULTS AND THEIR DISCUSSION

3.1. The Era of Drought

In the context of my dissertation, I have chosen the effect of drought on the raw material basis of bioeconomy. 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 on example of wheat production (Fig. 2).

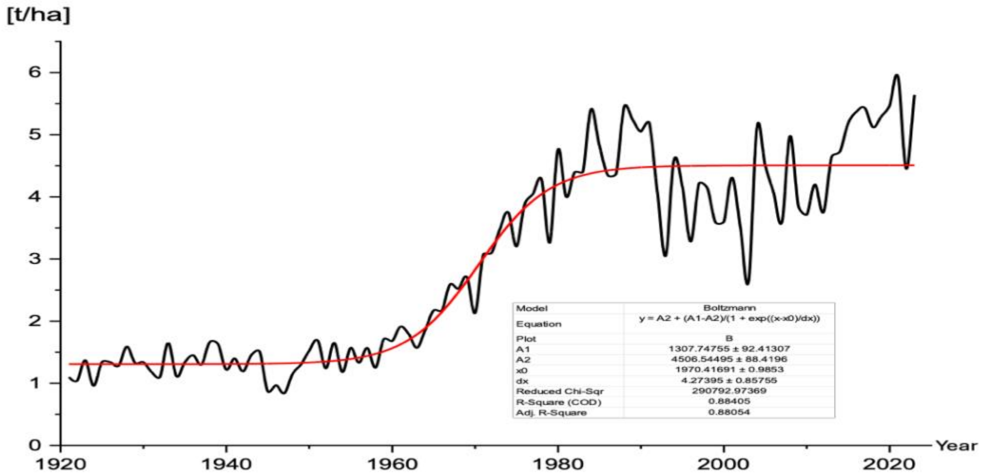

Figure 2. Changes in the wheat average yield and approximation with Boltzman function (1920-2023)

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

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 3.

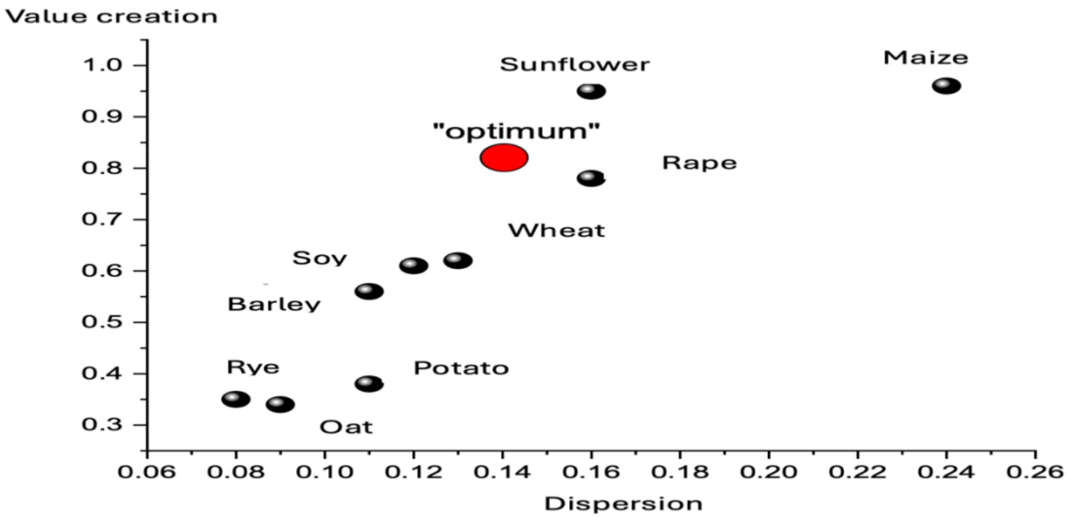

Figure 3. Financial return-risk characteristics of the crops under consideration

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.

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 cops, the rape has an important role in the income stabilisation. Results of the calculation of optimal land use structure are presented in Figure 4.

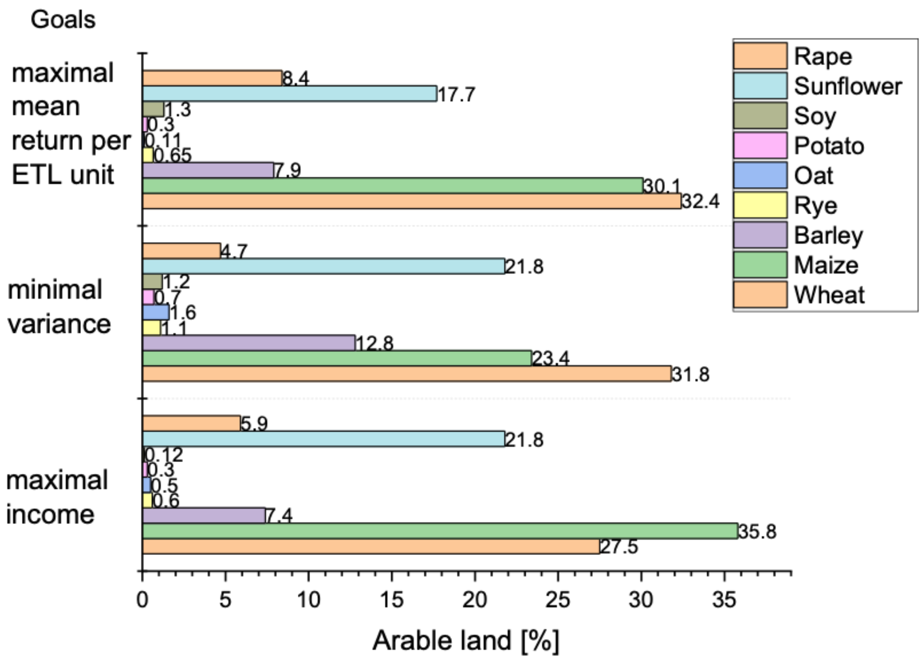

Figure 4. Optimal structure of arable land utilisation (the numbers indicate the share of various plants, in per cent)

Source: Own creation, 2025

3.2. Bioeconomy in the Visegrad countries

The economic structure of 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). 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%.

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 pharmaceutics 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-ecologic 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.

Values of the Leontief index were relatively low in the case of foreign countries. 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 bioeconomy in the V4 countries in Table 2.

Table 2. 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

An examination of inter-sectoral trade flows within the V4 countries uncovers a notable pattern: most trade between sectors takes place within the same country. The distribution of these flows is strongly right-skewed and can be accurately modelled using a gamma or Weibull distribution. This suggests that most sectors are closely linked to only a limited number of other sectors. Network analysis further reveals that the V4's economic structure consists of four distinct sub-clusters, each aligned with a specific nation-state. This highlights that intrastate sectoral connections are much stronger than those across national borders. Figure 5 depicts the most important value flows among bioeconomy sectors.

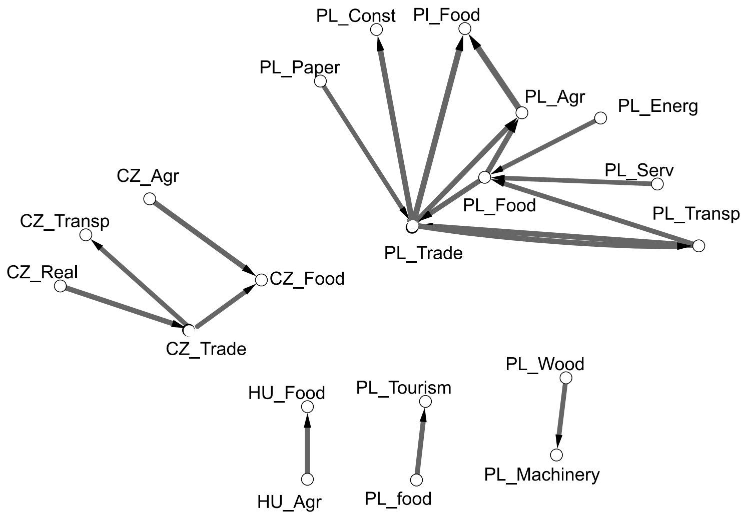

Figure 5. The most important value flows among the bioeconomy-related sectors of the V4 countries

Source: Own creation, 2025

3.3. 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).

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 in the economy and how it affects the other parts of the industry. I selected nine from the industries, which I analysed if 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.

In the tables, the left part shows the original input-output data from OECD report (OECD, 2021), the centre presents the Leontief-inverse result, and the right side of the table shows the Ghoshian inverse (the latter was examined for the agriculture and fishing sectors only). Due to the space limitation, I selected only 1 to illustrate.

1. **Agriculture – Pharmaceuticals**

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 3, 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.

Table 3. 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

3.4. 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's favourable agricultural conditions, including vast arable land and high-quality soil, have positioned it as a major global exporter of agricultural products. However, the ongoing Russian conflict has disrupted transportation routes, particularly maritime exports through the Black Sea, necessitating a shift towards alternative land-based transportation methods, but it also has limitations. Despite the challenges posed by the war, Ukraine's relatively developed land-based transportation sector offers potential solutions to meet the increased demand for agricultural exports. The aim of this chapter was to analyse how can the transportation problems solved with eco-friendly solutions. In the first phase of the research, I have determined the GHG emission values between the transfer stations and ports. As an example of my research, in Table 4 I present the output of the linear optimisation for the determination of the optimal division of labour among various ports.

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

Ports	Jakarta	Alexandria	Izmir	Karachi	Kenitra	Chittagong	Aden
Hamburg							
Constanta	281		154			35	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

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. 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 European 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.

4. 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.

5. 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 6.

Table 6. Hypotheses and their evaluation

Hypotheses	Evaluation	
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	✓
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	✓
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	✓
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	✗

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	✗
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	✓
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 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 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.

6. PUBLICATION LIST

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