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Assessing the Potentials of Bioeconomy Sectors in Poland Employing Input-Output Modeling

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Abstract: Bioeconomy emerges under major current global challenges, both environmental and economic, that are related to the existence and use of bio-based resources; in this context, policy stakeholders and scientists seek and propose potential solutions. Bioeconomy is among the discussed strategies with the potential to offer solutions. In this framework, bioeconomy's importance increased over the last several years, thus it is essential to identify and monitor its role and significance in an economy and assess its potentials and intersectoral relationships. In this framework, the current study, through a general equilibrium analysis, aims to identify the sectors that are related to the bioeconomy and assess their potential in the Polish economy as such quantitative studies do not exist in the literature for Poland. For doing so, an Input-Output model was built, identifying initially the bioeconomy sectors and, afterwards, estimating their linkage coefficients in order to capture their direct and indirect impacts on the Polish economy. Results indicate that the fully bio-based sectors, such as the agriculture and food sectors, have higher potentials to induce knock-on effects in the economy than the mixed bio-based sectors. Thus, the current study's results can offer important information to policy makers for decision making, such as in the case of planning development in any mixed bio-based sectors, such as biofuels or biogas.

Keywords: bioeconomy; bio-based sectors; Input-Output; linkage analysis

1. Introduction

Current global challenges related to the existence and use of bio-based resources, such as food, feed, chemicals and energy demand, induced various policy stakeholders and scientists to deal with these problems. In this context, bioeconomy is among the issues that are discussed with potentials to propose solutions and, thus, attracts the interest of the scientific community.

On 13th February 2012, the European Commission introduced a strategy, "Innovating for Sustainable Growth: A Bioeconomy for Europe" [1]. This strategy proposed a concise way to address the ecological, environmental, energy, food supply and natural resource challenges that the world is facing. The ultimate goal that was set up in 2012 was to obtain a strong bioeconomy that could assist European economies to live within their limits. The sustainable production and utilization of biological resources led to the production of more from less, including waste reuse. At the same time, it allows for limiting the negative impacts on the environment and reducing the dependency on fossil resources, thus controlling climate change. For satisfying the increasing needs of the population globally, along with the depletion of scarce resources, environmental problems and climate change, the current status of production, consumption, processing, storage, recycling and the disposal of biological resources has to change [1]. The "Review of the 2012 European Bioeconomy Strategy" reveals the opportunities that bioeconomy offers. As a matter of fact, the importance of bioeconomy Strategy coordination is increasingly recognized by many European Union (EU) Member States and regions [2]. Various studies and manuals appeared in the literature either explaining the role of bioeconomy or assessing its potentials, mainly through foresight studies, to confront related problems and offer solutions [1,3–6]. As bioeconomy appeared to offer solutions, its importance has increased in recent years, thus it is essential to identify and monitor its role in an economy and assess its potential impact through intersectoral transaction relationships.

Bioeconomy identifies with activities that produce, process or use biological resources mainly arising from agriculture, forestry, fisheries and aquaculture, the food industry, chemicals, cosmetics, paper and textile industries as well as the energy sector [1]. Although measuring bioeconomy is a daunting task, various recent efforts recognizing the importance of the bioeconomy have attempted to do so at country level [7,8] and at the European level [9]. Apart from sectors producing biomass that are considered to fully belong to the bioeconomy, there are many other sectors where the bio-based component is obvious, however its share needs to be estimated. A systematic approach to quantifying the bioeconomy is developed in the Joint Research Center (JRC) in Seville. The understanding and quantification of bioeconomy at the sectoral level enables economists to assess intersectoral transactions that are relevant to the development of bio-based activities and exogenously injected funds and estimate direct and indirect economy-wide impacts.

The EU, through a number of policies that are additional to those directly concerning bioeconomy, such as Common Agricultural Policy (CAP), Common Fisheries Policy (CFP) and other policies related to the sectors that are in the production of biomass, aims to stimulate the knowledge and actions towards supporting and strengthening bioeconomy. Such actions are implemented at the national level, such as the national observatories for bioeconomy, in the EU countries Among the latest studies that examined bioeconomy in Poland is the one of Wozniak and Twardowski [10]. Poland, in spite of being among the EU countries with great potential in the production and use of biomass, has not yet adequately examined the importance and potentials of its bioeconomy sector, at least not through a general equilibrium modeling framework.

Thus, the identification of the bioeconomy sectors and the assessment of their presumable impacts for the Polish economy are the two main issues that are examined in the current study. The identification and construction of the bioeconomy sectors in the available symmetric Polish Input-Output (I-O) table is done first and, then, the sectors are studied in order to identify their dynamics and economy-wide effects. In this context, the current study for the Polish economy aims to provide such information. Although, it should be mentioned that the current study focuses mainly on the economic dimension of the bioeconomy sectors through the modeling procedure and does not take into account the environmental issues. Results will provide valuable information to relevant stakeholders about the potentials of the bioeconomy sectors and if it is worth developing them further. Policy makers shall be assisted with valuable information for decision making regarding the support and development of bioeconomy's related sectors, mainly mixed bio-based. This is offered through the identification and assessment of their potentials in terms of output or employment support in the economy by the case specific Input-Output model.

2. The Polish Bioeconomy in a European Context

A systematic approach for quantifying the bioeconomy and estimating socioeconomic indicators to monitor the EU's bioeconomy is developed by JRC in Seville [7,11]. According to their monitoring methodology, bioeconomy is defined by accounting the production and manufacture of biomass of 16 sectors of economic activity as classified by the Statistical Classification of Economic Activities in the EU (NACE). A number of them are considered fully bio-based and the rest partially or mixed bio-based. The production of biomass is covered in section A by the agriculture, forestry and fishing sectors.

The manufacture of biomass is operated by sectors from section C and, specifically, by food products, tobacco products, leather and leather products, wood and wooden products, paper and paper products and also mixed sectors with bio-based share, such as the manufacture of textiles, wearing apparel, chemical and chemical products, pharmaceutical products, rubber and plastic products and furniture. Section D comprises of the production of electricity from which the production of bio-based electricity is estimated [9].

In the study named "European Bioeconomy in Figures 2008–2015", using Eurostat data as a primary source [12], an assessment of the turnover and employment of the European bioeconomy for the year 2015 was made. The analysis shows that within these years, the turnover of total bioeconomy in the EU-28 increased continuously from €2.09 trillion to €2.29 trillion. About half of this increase comes from the food sector, a quarter of the turnover comes from agriculture and forestry, while the last quarter is produced by bio-based industries (chemicals and plastics, pharmaceuticals, paper, forestry, textiles, biofuels and bioenergy). The employment in the bioeconomy sectors has changed since 2008 from 21.4 million to 18.5 million, especially due to the agricultural sector share reduction. When only the industrial sectors were analyzed, the total employment amounted to 3.7 million jobs in 2015 [12].

In Poland, the situation of monitoring bioeconomy in the same detail is not found, despite the fact that some studies present the status of bioeconomy [10,13–15]; information and data about the relationships and transactions among the production sectors of the economy have not been explored yet. The challenge that the current study aims to address is the identification and construction of these bioeconomy sectors in the available symmetric Polish I-O table in order to study their importance and impacts in the national economy.

In Poland, issues related to the development of bioeconomy are included in three strategies which are part of the implementation of the Strategy for the Development of the Country [10]. The study of Wozniak and Twardowski focuses mainly on the development of three areas: (1) a competitive and innovative economy; (2) an effective and robust state and (3) the demonstration of the differences in the development of the regions. Although there is no official strategy that is dedicated to the bioeconomy, there are items that are related to individual sectors that are featured in the country's Smart Specialization Strategy, which is created along five areas: (a) health society, (b) agro-food, (c) forestry-timber and environmental bioeconomy, (d) sustainable energy, (e) natural resources and waste management and innovative technologies and industrial processes. Besides the ongoing research on the national strategy for the bioeconomy development, there are some studies on assessing the regional development of bioeconomy. The research conducted by Skorwider-Namiotko has shown that in particular areas, there are some substantial features that may contribute to the development of bioeconomy [13]. According to the bio-based Industries Consortium report (2017), regions play an important role in the development of the bio-based economy in Europe as they can support the development of (regional) innovative value chains. Additionally, regions have the ability to play a key role in attracting investments and projects benefited from the European Structural and Investment Funds (ESIF) or the European Agricultural Fund for Rural Development (EAFRD), for creating jobs, economic growth and new opportunities.

According to the recent study of Ronzon et al. [9] in the JRC, Poland belongs to a group of countries with below EU average turnover per person employed in bioeconomy; though, it is above the EU average in employment shares in biomass producing sectors. This study demonstrates that agriculture is the largest employment sector, of which is particularly well developed in Poland ($\geq$ 65% of the bioeconomy labour force). Other important bioeconomy sectors supporting employment where Poland is a leader or above the average are: forestry (highest employment in the EU); wood products and furniture (also highest employment); food, beverages and tobacco; bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels); bio-based textiles and paper production. Regarding the turnover and value added at factor cost, the sectors that Poland is above the average compared to the EU are: agriculture, forestry, food, beverage and tobacco, liquid biofuels, paper production and wood products and furniture.

Poland, compared to other EU members, has a strong potential in the production of raw materials which are the base for bioeconomy. According to the Central Statistical Office, Poland has great potential in producing biomass that is defined as organic, non-fossil materials of biological origin that can be used as biogenic feedstock in food supply, other products and biomass for generating heat or electricity. Moreover, Poland is one of the leaders in the EU in terms of agricultural land use, as 18.8 million hectares are used as agricultural land; additionally, forested area covers nearly 30% of the country and is equal to 9.4 million hectares. The calculated quantity of biomass production in Poland is equal to 165 million metric tonnes, which constitutes about 10% of the total EU volume; this amount places Poland after Germany and France. As mentioned, the cultivated land and forested area are also significant sources for biomass production; unfortunately, this production is characterized by small value added and low profitability. The Polish bioeconomy is based on the traditional sectors such as agriculture, forestry and the food industry.

According to the research of Wicki and Wicka [14], the global production volume in the Polish bioeconomy in 2014 amounted to around €82 billion, which is 10% of the total production of the Polish economy. In the same period (2013), the EU averages of bioeconomy amount to €2.1 trillion in turnover and more than 17 million jobs. The agro-food sector is dominated by large groups (both national and foreign) increasingly focusing on exports, whereas forestry is largely based on state-owned and feeds pulp and paper and furniture industries. It is worth mentioning that Poland is the fourth largest world exporter of furniture. Chemical and pharmaceutical industries have a sizeable role in the country's economy, with the latter witnessing a growth of more than 60% in the last 10 years.

Woźniak and Twardowski [10] concluded in their study that the EU has been directed towards bioeconomy during the recent years. Generally, the concept of bioeconomy lacks recognition in many countries in the EU, including Poland; moreover, the opportunities offered are not well known. Thus, the development of the bioeconomy concept that combines different fields of knowledge should induce positive socio-economic impacts and recognize the regions that are pioneers in research and development and innovation diffusion.

3. Materials and Methods

3.1. Input-Output Model

Input-Output analysis was introduced initially in the literature by the work of Leontief [16]. The original interindustry model, through time, has been extended and applied in many scientific areas, mainly due to its simplicity and the important information that it can reveal through a general equilibrium analysis. The extended model is used to examine issues such as energy related problems, environmental issues such as pollution impact analysis, issues related to specific sectors such as bioeconomy sectors, agro-food sectors etc. The basic I-O model is expressed through a system of linear equations, one for each sector of economic activity, by presenting the interindustry transactions, sales and purchases to the other sectors of the economy.

Despite the wide use and applications of the model, its theoretical base is limited by some basic assumptions; the well-known I-O restricted assumptions [16] that the methodology is criticized (e.g., linearity, fixed technology coefficients). Although, when the restrictive assumptions are taken into account in the analysis, the model is unique in its type and is widely used as an analytical tool by scientists and policy makers.

The I-O system is based on the compilation of the transaction matrix that records the sales and purchases among the sectors of the economy under examination. The row entries of the transaction matrix represent the sales of each sector to all others, while the column entries represent the purchases of each sector from all others. The transaction matrix along with the final demand quadrant and the final payments quadrant form the symmetric I-O table. The symmetric table is the one that is used for analysis purposes and is compiled by the statistical services of each country. As such, full survey tables are published every 10 years with intermediate updates.

The representation of the I-O system in mathematical form [16,17] is based on three matrices: the first and basic one is the transactions matrix that is mentioned above. Following basic matrix manipulations, the second matrix, the direct requirements, is calculated so that it reports the direct I-O coefficients. Finally, the Leontief inverse is the third matrix of the system that is calculated using the direct requirements.

The abovementioned model is the so-called demand driven and is used extensively in the literature compared to the supply-driven; a detailed presentation of the above demand driven model can be found among others in [16,17]. The calculation of the Leontief inverse offers the ability to extend further the modeling procedure in I-O analysis by calculating various I-O linkage coefficients that reveal the potentials of each sector in an economy. Among the most known linkage coefficients are the I-O multipliers which are estimated in terms of employment, total gross output and household income. I-O multipliers reveal the economy wide needs of an economy in terms of output, employment and income in order to satisfy an exogenous change (e.g., an increase in final demand). These linkage coefficients indicate the potentials of each sector and its capacity to induce knock-on effects in the economy. Multipliers provide an adequate tool that can assess with relative accuracy the impacts of any exogenous final demand change in the economy's income, output and employment levels. A detailed analysis for the calculation of the I-O multipliers is presented in Miller and Blair and Loizou et al. [16,17].

Such linkage coefficients are calculated in the current study in order to examine and assess the potentials of the bioeconomy sectors in the Polish economy. A step further, in the current analysis, includes the calculation of the I-O elasticities which were developed by Mattas and Shrestha [18] that also examine the potentials of the sectors of an economy in terms of gross output, employment and household income. Elasticities were developed by taking into account the relative size of every sector's final demand compared to its output, an issue that is not captured by the multipliers. As elasticities are expressed in relative terms, they measure the total percentage change in the economy's output caused by a monetary unit change in the final demand of a sector. In the same manner, the household income and employment elasticities are also expressed; they measure the percentage change in the economy's household income and employment due to a percentage change in the final demand of a sector.

3.2. Augmented I-O Table by Means of Disaggregation

A tool that can identify, with relevant accuracy, the significance, interlinkages and impacts of one or more sectors (such as bioeconomy) in an economy, as mentioned, is Input-Output (I-O) analysis; a case study for Ireland can be found in Grealis and O'Donoghue [19]. I-O and general equilibrium models offer a number of advantages compared to partial equilibrium analysis models. I-O models have the ability to examine the economy-wide effects of a sector and assess direct and indirect impacts due to exogenous changes. Thus, in order to examine the potential evolution and the role of bioeconomy in the Polish context, it is proposed to use I-O analysis. In order to do that, the mixed bioeconomy sectors, as they do not appear as separate sectors in the published I-O table, are identified and created to weigh their importance separately and assess their direct and indirect impacts in the economy. I-O modeling is among the models that were used to estimate the impacts of bioeconomy [20] and especially bioenergy projects or environmental problems on an economy [17,21,22].

The identification and construction of the bioeconomy sectors in the Polish I-O table is the first challenge of the current study, while the second challenge aims at the assessment of their potentials and impacts in the whole economy through a linkage analysis. Following I-O analysis principles, the examination of a sector(s) significance requires its existence in the I-O table. The non-existence of a sector requires its identification and creation as a separate one in the I-O table. In other words, a process of disaggregation is implemented; such as it is the case in the current study, the bioeconomy sectors are identified. Techniques that are used in the literature to identify sectors are employed with the assistance of the collection of primary and secondary (superior) data when considered necessary [16,23–25].

As soon as the bioeconomy sector(s) are identified and constructed, the new augmented I-O table forms a tool that can provide valuable information for the importance of the bioeconomy development in the Polish economy. Using the I-O table and forming a model, the direct importance and interlinkages with other sectors in the economy can be quantified. Moreover, the I-O model has the ability to capture the indirect impacts throughout the whole economy (economy-wide impacts). This is done mainly through the calculation of the Leontief matrix and the various linkage coefficients, I-O multipliers [16] and I-O elasticities [18]. The calculation of the well-known I-O multipliers offers the ability to the user to identify the importance of investment projects or policy support measures to develop certain activities (biogas, biorefineries) in the economy under examination and assess the impacts (direct and indirect) on all other sectors of the economy in terms of output, household income and employment. Such information may prove valuable for policy decisions and strategies for examining and monitoring bioeconomy within an economy.

3.3. Model Data Requirements

In the current analysis, the latest published (2010) national symmetric I-O table for the Polish economy was used. The national symmetric I-O table scheme that was employed in the current analysis consisted of 77 sectors of economic activity. As mentioned above, for the examination of the bioeconomy in the Polish economy, the mixed bio-sectors had to be created in the available I-O table. Table 1 presents the 18 bio-based sectors from which nine are fully bio-based and included in the I-O table and the rest are mixed bio-based and created in order to become separate sectors to examine their potentials. Utilizing data and information provided by a specific publication of the JRC [9] and paying attention to methodological issues pointed out, the mixed bio-based sectors were created (Table 1). The final classification scheme of the I-O table that was used in the current analysis, after the aggregation of some non-important and small sectors and the creation of the mixed bio-based sectors, consists of 79 sectors of economic activity. The last two columns of Table 1 indicate the shares of the mixed bio-based sectors for the EU-28 and the Polish economy. For example, in the case of textiles, the share of bio-based textiles in the EU-28 is 27.04%, while this share in Poland is much lower (13.16%). As it can be seen, the shares of all other sectors are more or less similar, except for biodiesel and bioethanol which are higher in the Polish economy (sectors 201 and 2059, respectively). These pieces of information for the mixed bio-based sectors were used next in the analysis to disaggregate and define the sectors in the I-O Polish model. Specifically, the shares of the mixed bio-based sectors were used initially to subtract the transactions from the original sectors in the I-O table and create the new (mixed bio-based) sectors. The primary creation of these sectors was, in turn, adjusted utilizing information and superior data from experts regarding the transactions of the new sectors. This information concerning the transactions of each new sector with the rest of the economy (column and row transactions) was used to adjust their initial identification [25].

Table 1. Bioeconomy sectors in Poland with shares of bio-mixed sectors.

Number	Nace	Sector	EU-28 (%)	Poland (%)
1	01	Agriculture		
2	02	Forestry		
3	03	Fisheries (sea, aquaculture)		
4	10	Food Products		
5	11	Beverages		
6	12	Tobacco		
7	(%) 13	Bio-based textiles	27.04	13.16
8	(%) 14	Bio-based Wearing apparel	40.98	41.90
9	15	Leather and related products		
10	16	Wood products		
11	(%) 31	Bio-based Furniture	43.68	44.74
12	17	Paper and paper products		
13	(%) 20	Bio-based chemical (excl. biofuels)	7.65	2.91
14	(%) 21	Bio-based pharmaceuticals	49.31	49.37
15	(%) 22	Bio-based plastics and rubber	4.62	6.13
16	(%) 2014	Bioethanol	3.61	41.67

Table 1. *Cont.*

Number	Nace	Sector	EU-28 (%)	Poland (%)
17	(%) 2059	Biodiesel	10.01	65.75
18	(%) 3511	Bio-based electricity	4.72	6.02

Source: https://datam.jrc.ec.europa.eu/datam/mashup/BIOECONOMICS/index.html and [9].

For the calculation of the corresponding employment linkages, compatible sectoral employment data were used for the 79 sectors of the I-O table, which were provided by Polish statistics [26,27]. Although, for some sectors, an underestimation of the exact employment level exists in the data because the Polish statistics report data only for business establishments that employ more than eight persons. Thus, sectors including a number of small companies (under eight persons) are not correctly accounted for; most often figures related to labour are seriously underestimated. For this purpose, additional employment data were used for sectors such as agriculture, the food sector etc., in order to account for the employees of small companies.

The final scheme of the Polish I-O table with 79 sectors from which 18 concern bioeconomy offers valuable information as it reveals the direct transactions of each sector with all the others in the economy. That is, sales of every sector to intermediate and final demand sectors (rows) and the purchases of inputs from intermediate and primary sectors (columns). Although, in order to identify the indirect importance and interrelationships of each sector, a modeling procedure is necessary; the calculation of the Leontief inverse and the I-O linkage coefficients can offer this information. Next, in the current analysis, the I-O multipliers [16] and the I-O elasticities [18], in terms of gross output, employment and household income, are estimated and presented. This is done in order to discover the key sectors of the economy and examine the capacity of the bioeconomy sectors, both mixed and fully bio-based. The estimated linkages reveal the ability of each sector to stimulate the whole economy's gross output, household income and employment due to an exogenous change in the final demand (e.g., investments, exports or consumption) of a sector.

4. Results

Interesting results were revealed through the linkage analysis regarding the potentials of the bioeconomy sectors. Initially the multipliers (Table 2) for the bioeconomy sectors of the Polish economy were calculated, while next to each multiplier its rank is shown compared to the 79 sectors of the model. In terms of output potentials, the bioeconomy sectors perform satisfactorily; most of them rank relatively high, indicating that through any exogenous fund inflows, higher economy wide impacts will be generated. This means that policies aiming to strengthen bioeconomy in the Polish economy will indirectly support the local economy as many other sectors will have to produce in order to satisfy the indirect needs of the bioeconomy sectors.

As it can be seen, the Food sector is the one with the largest output multiplier (2.33); this means that for every euro increase in the final demand of the food sector, the economy's total output will be increased by 2.33 euro due to the direct and indirect linkage relations of the sector. Beverages rank in second place (2.28), while agriculture ranks in the 16th and wood products rank 10th. Observing the estimated output multipliers, it can be concluded that the pure bioeconomy sectors have higher multipliers compared to the mixed bio-based sectors. Thus, the power of the pure bioeconomy sectors to push forward the economy in terms of output is much higher than the power of the mixed bioeconomy sectors. For example, the bio-based chemicals sectors rank 50th, with an output multiplier of 1.63; this means that for every monetary unit increase in the final demand of the bio-based chemicals sector, an additional 0.63 monetary units of output will be generated in the economy by all sectors. An explanation of this outcome might be the current small-scale level of development of the mixed bioeconomy sectors (e.g., biofuels, biochemicals, etc.).

In terms of employment, more or less the same sectors have the highest multipliers (type I), namely, tobacco, beverages, food products and wood products, which actually are very high. For example, every person that is employed in the food sector will create, in total, 4.8 jobs in the whole economy to cover the direct and indirect employment needs of the food sector; this is a high multiplier and the economy's employment will be supported significantly. Income multipliers (type I) indicate an increase in the economy's household income for every monetary unit increase in the income of a sector. In the case of agriculture, an increase of a million euros of its income will induce directly and indirectly a total increase of the income of the economy by €2.8 million. Food products, beverages, paper products and bio-based chemicals are also among the sectors that have the potential to support the economy's household income.

Table 2. Input-Output Multipliers of the bioeconomy sectors (Output, Employment and Income).

Number	Sector	OM	R	EM (Type I)	R	IM Type I)	R
1	Agriculture	2.0080	16	1.358	65	2.831	6
2	Forestry	1.8179	37	1.464	58	1.556	56
3	Fisheries	1.1711	79	1.127	78	1.619	54
4	Food products	2.3326	1	4.806	6	2.676	8
5	Beverages	2.2822	2	5.327	3	2.833	5
6	Tobacco	1.6308	54	5.533	2	1.710	46
7	Bio-based textiles	1.5691	62	1.519	51	1.742	43
8	Bio-based wearing apparel	1.4080	74	1.4080	74	1.377	65
9	Leather and related products	1.4787	68	1.4787	68	1.623	53
10	Wood products	2.1490	10	2.1490	10	2.489	11
11	Bio-based furniture	2.1768	7	1.659	46	1.902	33
12	Paper and paper products	1.9201	28	2.563	20	2.624	9
13	Bio-based chemical	1.6313	50	1.204	71	2.455	14
14	Bio-based pharmaceuticals	1.3853	76	2.228	24	1.945	29
15	Bio-based plastics and rubber	1.9288	26	1.910	33	2.108	23
16	Bioethanol	1.6313	49	1.145	77	2.455	13
17	Biodiesel	1.6313	52	1.145	76	2.455	16
18	Bio-based electricity	1.9362	23	2.808	13	2.068	26

OM = Output Multipliers; EM = Employment Multiplies; IM = Income Multipliers; R = Rank.

It is worth mentioning that apart from type I employment and income multipliers, simple employment and income multipliers (or total effects) were calculated that indicate the potentials of any sector to support the economy's employment and income due to a monetary increase in final demand. In this case, simple income multipliers are relatively low for the bioeconomy sectors, while in the case of bioeconomy's employment, multipliers are higher. This indicates that any exogenous fund that inflows to the bioeconomy sectors have high direct and indirect impacts on the rest sectors of the economy; thus, a policy that supports bioeconomy will simultaneously support the overall employment level of the economy.

I-O elasticities (Table 3) also measure the potentials of each sector through their direct and indirect linkage interrelations in an economy, although they additionally take into consideration the size of the final demand of each sector. The food sector presents very high elasticities, as in the case of multipliers; its importance is high in terms of output (0.077) as well as in terms of employment (0.108) and income (0.068). An exogenous increase in the final demand of the food sector by 1% will induce an increase in the whole economy's output by 0.077%. This increase concerns all sectors of the economy and not only the food sector; thus, the importance and the potential of the food sector to generate economic activity in the Polish economy can be seen. The mixed bio-based sectors present more or less the same structure as in the case of multipliers and have relatively low output elasticities; this is logical as their final demand value is very small. The situation becomes better in the case of employment and income elasticities in which a higher ranking is observed.

Table 3. Input-Output Elasticities of the bioeconomy sectors (Output, Employment and Income).

Number	Sector	OE	R	EE	R	IE	R
1	Agriculture	0.023	13	0.016	31	0.034	10
2	Forestry	0.001	65	0.002	70	0.002	72
3	Fisheries	0.000	77	0.000	78	0.002	73
4	Food products	0.077	2	0.108	2	0.068	4
5	Beverages	0.010	26	0.081	4	0.034	9
6	Tobacco	0.004	51	0.112	1	0.017	29
7	Bio-based textiles	0.001	69	0.005	61	0.009	57
8	Bio-based wearing apparel	0.004	50	0.008	53	0.009	53
9	Leather and related products	0.003	56	0.011	48	0.013	41
10	Wood products	0.008	32	0.012	45	0.015	35
11	Bio-based furniture	0.007	33	0.013	39	0.019	27
12	Paper and paper products	0.007	35	0.013	40	0.014	38
13	Bio-based chemical	0.001	70	0.002	68	0.013	40
14	Bio-based pharmaceuticals	0.005	43	0.018	29	0.015	37
15	Bio-based plastics and rubber	0.001	67	0.007	55	0.009	52
16	Bioethanol	0.000	79	0.001	72	0.013	43
17	Biodiesel	0.000	76	0.001	71	0.013	42
18	Bio-based electricity	0.000	74	0.015	33	0.009	55

OE = Output Elasticities; EE = Employment Elasticities; IE = Income Elasticities; R = Rank.

In order to have a general view of the most important and promising sectors with the potential to stimulate knock-on effects in the Polish economy, in terms of output, the sectors with the highest output multipliers and elasticities are presented in Table 4. The food sector ranks first in multipliers and second in elasticities; no other bioeconomy sector is among those with the highest multipliers. As shown above in Tables 2 and 3, bioeconomy sectors rank high in terms of employment and income. Constructions, furniture and sectors from services are the ones with the highest output multipliers; constructions is also the sector with the highest output elasticity.

Table 4. Sectors with the highest Output Multipliers (OM) and Output Elasticities (OE).

Sectors	OM	R	Sectors	OE	R
Food Products	2.3326	1	Constructions	0.113	1
Beverages	2.2822	2	Food products	0.077	2
Constructions	2.2441	3	Motor vehicles	0.064	3
Travel agency	2.2165	4	Real estate	0.055	4
Gambling, sporting services	2.2039	5	Retail trade	0.054	5
Furniture	2.1768	6	Public administration	0.041	6

5. Discussion and Conclusions

The growing concern for issues regarding the environment, efficient management of resources, dependence reduction from fossil fuels, food waste management, sustainability etc. lead to the development of strategies such as bioeconomy. The support and enhancement of such strategies, and in the current case of bioeconomy, monitoring and assessment of its potentials in an economy, is required. Such a tool to examine the potentials of the bioeconomy sectors was developed in the current study for the Polish economy by employing I-O techniques. In the framework of general equilibrium analysis, an I-O model was developed to capture the dynamics and potentials of bioeconomy through linkage analysis. Although, it should be mentioned that the current study is mainly concentrated on examining the economic sustainability of bioeconomy and not the issues related to the environmental sustainability of bioeconomy in Poland, as that is not the aim of the study.

The first challenge and task of the study was to define the bioeconomy sectors, as the mixed bio-based sectors are not classified as separate sectors in the available published symmetric I-O table that was used. In doing so, disaggregation techniques were applied and 18 bioeconomy sectors in total

(Table 1), both mixed and fully bio-based, were defined in the I-O table. Half of them (nine) were fully bio-based sectors and the other nine were mixed bio-based sectors (Table 1). The mixed bio-based sectors (biochemical, biofuels, pharmaceuticals etc.) are relatively small in size (output) compared to the fully bio-based sectors, such as agriculture, the food sector etc.

The next aim was to assess the potentials of the bioeconomy sector and all others (of the 79 in total) of the classification scheme of the I-O model. This was done by initially calculating the Leontief inverse and then a number of linkage coefficients in terms of output, employment and income that could be used to define the potentials of each sector and calculate the creation of corresponding economy-wide impacts. The model and its outcomes are expected to provide useful information to concerned stakeholders, in particular to policy makers, in order to monitor bioeconomy and help them define which of the bio-based sectors have the potential to support the economy more efficiently.

The calculated multipliers and elasticities indicated the potential of each of the 79 sectors of the model in terms of output, employment and household income. Specifically, among those, bioeconomy sectors ranked high, therefore it is reasonable to assume that they have the potential to induce knock-on effects in the Polish economy. The food sector, the beverages sector and agriculture have high multipliers in terms of output and employment as well as in terms of household income. Wood products, bio-based furniture, tobacco, bio-based electricity, paper products and bio-based chemicals are also important in terms of employment or income. Similar results can be found in the studies of JRC [9,11,28], which were mentioned above, mainly indicating the potential of the fully bio-based sectors compared to the mixed bio-based sectors.

The situation is more or less the same in the case of I-O elasticities, though not the same bio-based sectors have high elasticities. The food sector, agriculture and beverages are among those that rank high. On the other hand, the mixed bio-based sectors rank low; an explanation of this situation might be the small size of final demand of the mixed bio-based sectors.

Thus, any policies aiming to support bioeconomy sectors and, at the same time, expecting to induce economy-wide impacts in the economy in terms of output, employment and income should select the sectors mentioned above with high linkage coefficients. These sectors will cause important indirect impacts on the economy through any exogenous fund inflows (e.g., investments). It is worth mentioning that the I-O model has the ability to identify with accuracy the sectors that the indirect impacts will come from. Policy makers and relevant stakeholders, with the calculated I-O linkages, have a tool to direct their plans and investments in the Polish economy; ex-ante policy or investment decisions as well as strategies regarding bioeconomy enhancement can be supported by such a relatively accurate guide. Further research is in progress, although it requires detailed survey information to extend this analysis at the regional level, especially for Polish regions that actively promote bioeconomy in the context of smart specialization strategies.

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