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Models for analysing the dependencies between indicators for bioeconomy in the European Union

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ABSTRACT

In the past decade, bioeconomy has become a main field of interest, especially in terms of innovation, as it was often considered a potential solution to several global sustainability issues, such as environmental challenges. Through the conversion of biomass into value-added products for a full reintegration of used renewable biological resources, this sector has played a significant role in the efforts to transfer from petroleum-based economies to bio-based economies. The present article has the objective of developing panel regression models for determining the dependency between some of the main indicators of the bioeconomy development and sustainability for the European Union in the period 2008–2013. One main interesting finding of the study emphasised that higher gas emissions from agriculture are associated positively with higher turnover in the bioeconomy, implying the fact that the development of the bioeconomy is surprisingly not necessarily associated with sustainability. The relevance of the present study lies in the novelty of the subject, as bioeconomy was mainly researched in terms of theoretical knowledge, but less in terms of statistical analysis. Thus, the article offers a comprehensive research regarding the connection of the bioeconomy quantifying indicators and other selected economic influence factors of the European Union.

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1. Introduction

As the need for new models of managing economic systems, industries and environmental challenges increased in the past decade, bioeconomy has received significant attention mainly in regulatory frameworks. The global natural resources are quantitatively finite and the economic development is causing, globally, more consumption. This adds to resource scarcity and increased waste generation, imposing dynamic capabilities as a key factor for adapting business to environmentally challenging turbulences, while the private sector is considered essential for sustainable development

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(Fonseca et al., 2018; Grigorescu et al., 2019; Kareem & Alameer, 2019). As a result, the European Union already implemented measures for the stimulation of private capital allocation for investments decreasing climate change and pollution of the environment, such as green bonds (Hoinaru et al., 2020). The need of managing global issues, such as global warming, the increasing greenhouse gas emissions (Stănilă et al., 2010), but also the need to reduce waste, which is contributing to high polluting levels of sea, soil and air are factors, that stimulated the recent developments in terms of finding renewable sources of energy and innovative strategies to decrease these environmentally harming factors. Entrepreneurial initiatives, the business environment itself through competition and the state's concern for its development and entrepreneurship education are also factors contributing to innovation and new business initiatives (Ajaz Khan et al., 2019; Belas et al., 2020; Janoskova & Kral, 2019; Krisnaresanti et al., 2020; Onea, 2020; Smith, 2020), supporting the development of new economic environmentally friendly organisations, including in the bioeconomy sector. Also, other sectors, especially in the economic field, have become an essential preoccupation, in order to decrease dependency on petroleum or fossil-based resources and waste amounts, to use biomass potential, in order to gain value-added products. Nowadays, the synergy between the global know-how and the local resources are key factors to increase the success chances in any type of economic activity (Bratianu & Anagnoste, 2011). With a turnover of 2.3 trillion Euro and an employment of 18 million people, respectively employing one in 10 European Union workers in 2015, the bioeconomy sector has contributed significantly to the competitiveness of the European Union and to more employment of the workforce in the region (European Commission, 2018a).

According to the European Commission (2015) in 2013 the bioeconomy involved the usage of 1600–2200 million tonnes of biomass in Europe annually, while using agricultural biomass as a main source of input. The same report mentioned that 450–680 million tonnes of biomass produced remain unused in 2013. The need for developing the bioeconomy sector is also supported by the European Union 2020 initiative, namely the 'Innovation Union' as a strategy for an efficient economic development and an environmentally friendly economy of the region. This strategy intends to reach these objectives through research, development and innovation policies, that could contribute to solving current issues in terms of energy efficiency, demographic growth and climate changes.

Bioeconomy has gained many definitions, many authors referring to the general concept of bioeconomy, as the conversion of biomass or renewable biological resources into products and raw materials. According to the European Committee for Standardisation (CEN), bio-based products are defined as 'products wholly or partly derived from biomass, such as plants, trees or animals'. Raw materials are derived from biomass sources for the production of bio-based products, bio-based intermediates and end products, as well as applications of bio-based products. Bioeconomy is considered to contribute as other sources of clean energy to the 17 sustainable development goals, especially adding to goal 7 affordable and clean energy, goal 11 sustainable cities and communities and especially to goal 12 responsible consumption and production in terms of recycling from waste (UN, 2020).

Scarlat et al. (2015) mention the bioeconomy's main focus point is represented by new opportunities for growth in traditional and emerging bio-based sectors, while considering global challenges, resources and environmental constraints. Furthermore, they mention bioeconomy entails the use of biotechnology on a large scale. The authors also state that the bioeconomy is focussed on the usage of renewable raw materials and application of innovations and research and development, as well as of industrial biotechnology in fields such as food, paper and biofuels production.

The main objective of the present paper is to find out how sustainability and life-cycle, as well as deployment of technologies related to the advanced bioeconomy are predicting the size of and transition to the bioeconomy. Thus, the paper refers mainly to a significant sustainability issue in terms of transition to the bioeconomy has developed based on the most recent available data. In addition to Pfau et al. (2014) growth of the bioeconomy is usually associated with increased sustainability, thus, we aimed to find supportive evidence by performing a sustainability and lifecycle assessment in which we analyse organic crop areas, protected biodiversity areas, biomass material flow account and agricultural greenhouse gas emissions. Complementarily to the findings of McCormick and Kautto (2013) on the relevance of technologies deployment in the development of an advanced bioeconomy we analysed a model with the following variables: primary production of biodiesels, biotech patents, research & development in agriculture and recycling bio-waste.

This paper also contributes to scientific literature, as we use three different indicators to estimate the transition of the bioeconomy in the European Union. We use not only the size of the bioeconomy, but also the factor income generated by the production in the bioeconomy and the apparent labour productivity, which is the value added in the bioeconomy per person employed. We state the following hypotheses of the research:

(H1) The development of the bioeconomy is not necessarily associated with sustainability and other lifecycle factors.

(H2) Indicators reflecting a transition to an advanced bioeconomy are positively associated with the growth of the bioeconomy as whole.

Overall, the present research contributes to the scientific inquiries on bioeconomy quantification and relationship to other influence factors that have not been previously studied.

2. Literature review

Bioeconomy has been defined in a variety of ways in the scientific literature; however, all refer to the conversion of biomass or renewable biological resources into products, such as food, bioenergy and bio-based products. For example, as mentioned by the European Commission (2015) the bioeconomy is the production of biomass and the conversion of biomass into value added products, such as food, feed, bio-based intermediates and bioenergy, including the fields of agriculture, forestry, fisheries, food, plus pulp and paper production, as well as parts of chemical, manufacturing bio-based textiles, biotechnological and energy industries, as one can see summarised in Table 1. Saguar et al. (2017) state that the relationship between the bioeconomy and

Table 1. NACE sectors representing bioeconomy activities.

NACE code	Sectors of bioeconomy
A01	Agriculture
A02	Forestry
A03	Fishing and aquaculture
C10, C11, C12	Manufacture of food, beverages and tobacco (C10, C11, C12)
C13, C14	Manufacture of bio-based textiles (C13, C14)
C1, C31	Manufacture of wood products and furniture (C16, C31)
C17	Manufacture of paper
C20, C21, C22	Manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels) (C20, C21, C22)
C2014, C2059	Manufacture of liquid biofuels (Manufacture of bioethanol C2014 and Manufacture of biodiesel C2059)
D3511	Production of electricity

Source: Ronzon and M'Barek (2018).

the principle of circular economic flow is evident, as it allows a circular and sustainable type of industrial economy. Ronzon et al. (2017, 2018) underline that the bioeconomy encompasses all economic activities related to the production and manufacturing of biomass and emphasised a simplified socioeconomic bioeconomy indicators framework, where turnover, labour productivity and especially value added are the main indicators of quantifying the bioeconomy. This emphasises the importance of value added, as it indicates the additional value added to the economy by a sector. Thus, the authors provide three significant socioeconomic indicators of quantifying bioeconomy.

Pfau et al. (2014) mention 'that the rise of the bioeconomy is usually associated with increased sustainability'. Furthermore, a lifecycle approach is needed in the perspective of bioeconomy progress to understand the implications on the environment.

Another study authored by de Besi and McCormick (2015) stated an analytical framework in order to research 12 strategies to promote the transition to a bioeconomy. The authors observed that all studied strategies focussed on the same key priorities for a transition to the bioeconomy. They stated the importance of fostering research and innovation, mainly in biotechnology, promoting cooperation between industry enterprises and research organisations, prioritising the optimised biomass usage through the cascade principle application and by usage of waste residue streams and providing funding support for the development of bio-based activities (de Besi & McCormick, 2015). The conclusion of their study was that securing the sustainable production and usage of biomass may be the most important factor in shaping bioeconomy throughout Europe. It is important to differentiate, that sustainability is not implicitly a result of the bioeconomy, as the latter is based on renewable resources and is not necessarily sustainable, as demonstrated by the use of fossil-based energy in agriculture.

Another important factor for the development of bioeconomy is represented by the deployment of technologies, a main element for a practical implementation of an advanced bioeconomy, while biotechnology is emphasised as a factor contributing next to the bioeconomy in terms of providing solutions to current and future health and resource issues (McCormick & Kautto, 2013). Biotechnology is also referred to by the Organisation for Economic Cooperation and Development (OECD) (2009) as a main factor contributing to solutions for economic and environmental issues, such as: increasing food and fibre production, supply and sustainability, water quality improvement, renewable energy production and its delivery and finally health benefits.

In terms of evaluation of bioeconomy development, sustainability and lifecycle assessment tools are used, such as biodiversity, emissions of particulates, climate impact, resource use, especially in terms of biomass, provide a basis for quantifying bioeconomy (Martin et al., 2018). Furthermore, advanced bioeconomy indicators should be taken into consideration for the quantification of this sector, such as biotechnology patents or research and development.

Saguar et al. (2017) emphasised the connection of the bioeconomy to the circular economy, as the latter is stimulated by the bioeconomy development, this contributing to creating circular types of industrial economies. This is also supported by Viaggi (2018). Sillanpaa and Ncibi (2017) offer another definition of the bioeconomy that encompasses the above mentioned elements, namely that bioeconomy is the global industrial transition of utilising renewable aquatic and terrestrial biomass resources into energy and products for economic, environmental, social and national security benefits in a sustainable way.

Although the bioeconomy is generally linked to sustainability and environmental conservation, several studies have emphasised that this is not necessarily the case. The bioeconomy production is not always sustainable as mentioned by several authors, for example, the bioeconomy production that does not actually decrease greenhouse gas emissions, as expected, or the environmentally damaging effects of bioeconomy production, such as the destruction of natural ecosystems for new production areas, increased eutrophication, pests related to novel crops (Landeweerd et al., 2011; Langeveld et al., 2010; Pfau et al., 2014; Sheppard et al., 2011; Templer & Van der Wielen, 2011). Thus, the development and quantification of bioeconomy and its effects on the economy and environment need to be further researched in terms of positive outcomes.

However, the scientific literature also offers several potential reasons for a transfer to a bio-based economy from a petroleum-based economy, such as employment growth through jobs creation, decreased dependence on traditional sources of energy, more efficient management of natural resources, decrease of greenhouse gas emissions in certain cases (Langeveld et al., 2010). Other authors, such as Calicioglu and Bogdanski also support the theory that a sustainable bioeconomy development should actually support the sustainable development goals, as in supporting food security; ensuring the conservation, protection and enhancement of natural resources; supporting inclusive economic growth; supporting health of communities; ensuring improved efficiency of in resources and biomass usage; promoting sustainable trade and market practices; encouraging sustainable consumption; promoting cooperation and sharing between stakeholders in all relevant domains (Fonseca et al., 2020). Furthermore, bioeconomy monitoring and evaluation can provide opportunities in terms of SDG reporting, in all three dimensions of sustainability, people, planet and profit, while the link between circular economy and bioeconomy in terms of sustainability promotion could be ensured by circular bioeconomy (Kershaw et al., 2021).

3. Methodology

3.1. Indicators of the bioeconomy

In order to ensure a practical approach for the research, we used Eurostat and JRC data for the most recent available period, namely 2008–2015, for bioeconomy turnover, value added at factor costs, labour productivity and number of people employed in these industries, namely the sectors of the bioeconomy as according to the NACE bioeconomy activities classification, which includes the following sectors: agriculture, forestry, fishing and agriculture, manufacture of food, beverages and tobacco, manufacture of bio-based textiles, manufacture of wood products and furniture, manufacture of paper, manufacture of bio-based chemicals, pharmaceuticals, plastics and rubber (excluding biofuels), manufacture of liquid biofuels and production of bioelectricity (Eurostat, JRC, 2018).

Figure 1 shows the main indicators used in this paper to measure the development in the bioeconomy field: average turnover, average value added at factor cost and average labour productivity in the bio-based sectors for the period 2008–2015 for the European Union countries.

The bioeconomy turnover refers to the total revenue generated of all included bio-sectors, while the value added at factor cost is the gross income from operating activities after adjusting for operating subsidies and indirect taxes for all included bio-sectors (Ronzon & M'Barek, 2018). Basically, this is the factor income of all the production activity in the bioeconomy. In order to calculate the apparent labour productivity, which is defined as value added at factor cost divided by the number of persons employed (Eurostat, 2018a). The number of persons employed working in bio-based sectors, as well as persons outside of the unit, who are paid by it, are taken from Eurostat (Ronzon & M'Barek, 2018; JRC, 2018).

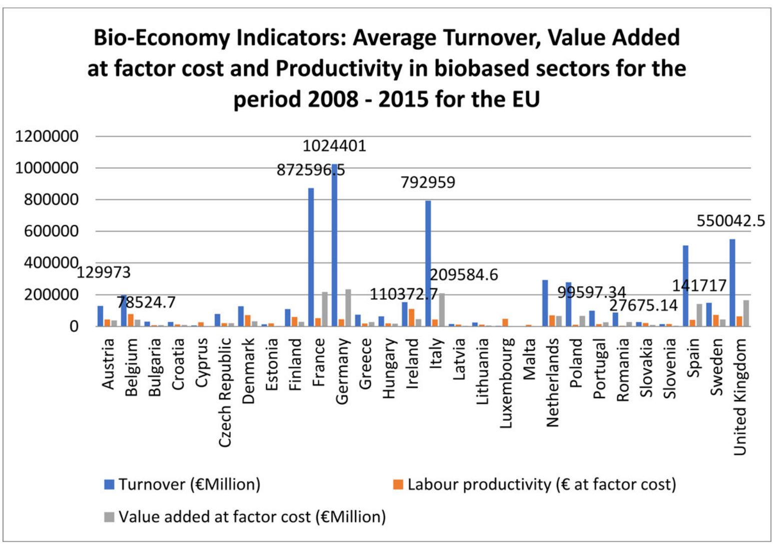

Figure 1. Average turnover, average value added at factor cost and average labour productivity in bio-based sectors in the European Union 2008–2015. Source: Authors' own calculations based on Ronzon et al. (2018) and Eurostat (2018a, 2018b, 2018c) data.

Table 2. Summary statistics: indicators of an advanced bioeconomy, sustainability and lifecycle assessment for the European Union for 2008-2015.

Indicator	*N*	Min	p25	p50	p75	Max	Mean	Unit
Agricultural greenhouse gas emissions	224	64.8	2719.1	7071.1	24752.1	430241.0	30010.2	Thousand tonnes of CO2-equivalent
Primary production of biodiesels	216	0.0	14.8	104.9	278.7	3042.6	329.7	1000 tonnes of oil equivalent
Biotech patents	149	0.2	4.0	27.0	137.1	2805.9	199.5	Number
Organic crop area	112	7.0	55049.5	195182.0	529959.5	11000000.0	720525.0	Hectare
Protected areas for biodiversity	140	316.0	44159.5	87924.5	307009.0	4300000.0	305995.6	km^2
R&D agriculture	166	0.0	0.6	3.5	18.9	215.4	25.1	Million euro
Recycling bio-waste	193	0.0	58.0	310.0	1650.0	38100.0	2400.0	Thousand tonnes

Source: Authors' own research based on Eurostat data (Eurostat, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2018h, 2018i, 2018j, 2018k).

For the estimation models, we used eight variables: agricultural greenhouse gas emissions (thousand tonnes of CO2-equivalent), biodiesels (1000 tonnes of oil equivalent), biotechnology patents as number of patents, hectares of organic crop areas, protected areas for biodiversity (square kilometres), research and development (R&D) for agriculture (million euro), recycling bio-waste (thousand tonnes), as illustrated in Table 2 and the material accounts flow in terms of domestic material consumption biomass (thousand tonnes).

We considered the following factors as lifecycle and sustainability assessment indicators of the bioeconomy: protected areas for diversity, organic crop area, agricultural greenhouse gas emissions, while primary production of biodiesels, biotech patents, research and development in agriculture and recycling bio-waste are advanced bioeconomy indicators. Biomass material flow account is a control variable.

Regarding the definition of the used variables we considered definitions from the sources we used. Domestic material consumption indicates the total amount of material consumed domestically by resident unit and on a country's national economy it can be estimated as direct material input minus physical exports (Eurostat, 2018d). Generally, DMC is additive across countries. Here, the factor refers to domestic material consumption in terms of biomass. We used this indicator as a control variable for the usage of biomass in the economy. In Figure 2, the average biomass material flow accounts in thousand tonnes for European countries is illustrated.

The greenhouse gas emissions for the agriculture sector (in thousand tonnes) and they include greenhouse gas emissions with CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent (Eurostat, 2018e). In the field of bioeconomy, agricultural greenhouse gas emissions are still considered a significant issue, as agriculture produces about 10% of the European Union greenhouse gases and they are still expected to increase to a level of 20% until 2030 (European Commission, 2018b). The organic crop area is in terms of fully converted area in hectares (Eurostat, 2018f). Primary production of biodiesels refers to primary production of the renewable energy by type in 1000 tonnes of oil equivalent (Eurostat, 2018g). Biotechnology patent applications to the European Patent Office (EPO) by priority year as number

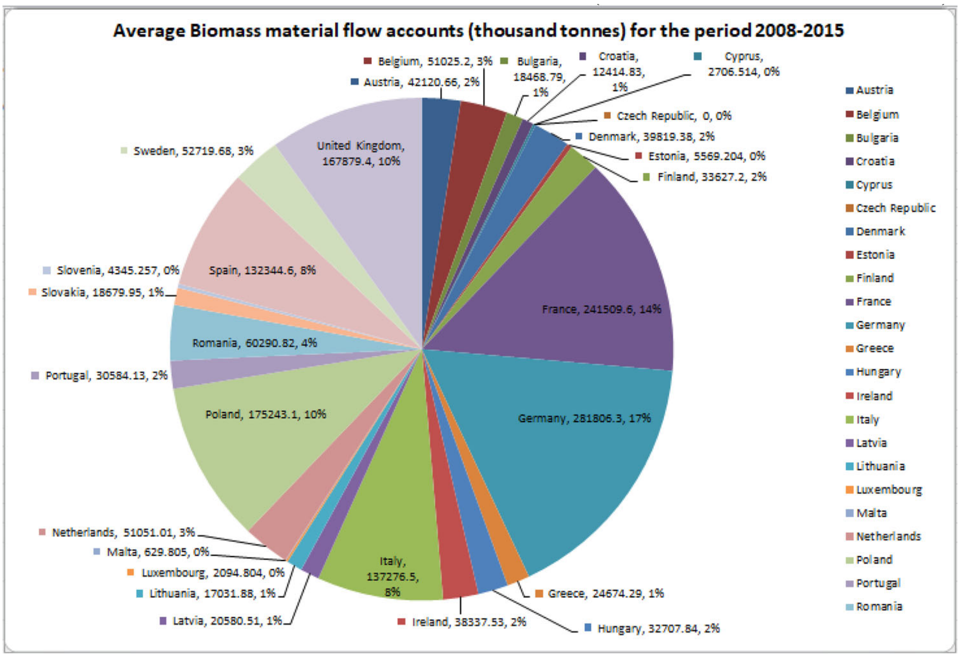

Figure 2. Average biomass material flow accounts (in thousand tonnes) for European Union states between 2008 and 2015. Source: Authors' own calculations based on Eurostat (2018d).

of patent applications (Eurostat, 2018h). Biotechnology patent applications to the EPO by priority year refer to innovative activity within a country's borders that result in patent application to the EPO or in a patent granted by the USPTO in the field of biotechnology, two of the main types being for agriculture, industrial processes as according to Eurostat. Protected areas for biodiversity (habitats directive) are expressed in square kilometres (Eurostat, 2018i). Research and development (RD) in agriculture refers to business expenditure on R&D in agriculture, forestry and fishing in million Euros (Eurostat, 2018j). In order to obtain the total amount of recycling in bio-waste we obtained from Eurostat the recycling bio-waste kg per capita (Eurostat, 2018k) and we multiplied it with the population of the country in the corresponding year (Eurostat, 2018l).

4. Research methods

In the empirical part of the study we estimated three estimation models to predict the effect of indicators of an advanced bioeconomy on bioeconomy indicators. We also predicted the estimated effect of sustainability indicators on the bioeconomy.

The analysis was performed based on the Eurostat data available for the 28 countries of the European Union between the years 2008 and 2013, as for all used indicators the data were available for this period. The main goal of the study was the analysis of countries behaviour for a period of time, respectively 2008–2013 and for this purpose we used a panel data set, formed of an entity (country) and time (per year), which allows to control variables which cannot be observed and contributes to unobserved differences among countries or changes over time. It accounts for individual heterogeneity.

Through the ordinary least square (OLS) and generalised least square (GLS) regression methods implemented, we analysed the effect of more independent variables on three dependent variables, that are indicators of the bioeconomy, namely (bioeconomy) turnover, value added at factor cost and labour productivity at all factor costs. As independent variables in the case of the first model, namely the panel regression for sustainability and lifecycle variables predicting bioeconomy indicators in the EU for the period 2008–2013, we selected: biomass material flow account, protected areas for biodiversity, organic crop area, agricultural greenhouse gas emissions. Firstly, we analysed the impact of these indicators on (bioeconomy) turnover, then on the value added at factor cost and finally on labour productivity at all factor costs.

In the case of the second estimation model, the panel regression for advanced bioeconomy indicators predicting bioeconomy performance in the EU for the period 2008–2013 we analysed the impact of other bioeconomy independent variables on turnover, value added at factor cost and labour productivity. These independent variables were: biomass material flow account, biodiesels, biotechnology patent applications to the EPO by priority year, research & development in agriculture and recycling bio-waste.

Finally, the third model transforms all model variables, including dependent variables logarithmically, so that the variables are approximating a normal distribution with a higher degree.

We also performed a fixed-effects model and a random-effects model. The fixed-effects model is an estimation method by basically using dummy variables for each country (except one) to control differences between entities would lead to equivalent estimated coefficients (β). In a fixed-effects model, it is assumed that the entities have unique characteristics (the countries), that do not change over time. In a random-effects model, it is assumed that unique and time constant characteristics of entities exist, that do not correlate with the explanatory variables. We performed a Durbin–Wu–Hausman in order to determine which of the two models, the fixed-effects model or the random-effects model, is more efficient.

In case of the fixed-effects model, the specifications for example in the case of the model with bioeconomy turnover as dependent variable, the following specifications were used: $TO_{it} = \beta_0 + \beta_1 {*} X_{it} + \beta_2 {*} W_i + u_{it}$, respectively W_i is the unobserved variable that is assumed to be time-invariant (and for which we do not have data), while TO_{it} refers to bioeconomy turnover, X_{it} refers to explanatory variables, the i denotes the cross-section dimension (the country) and t refers to the time-series dimension (the year), u_{it} is the error term. Furthermore, for the value added at factor cost a similar function was applied only that in this case the value added at factor cost was the dependent variable, $VA_{it} = \beta_0 + \beta_1 {*} X_{it} + \beta_2 {*} W_i + u_{it}$, where VA_{it} is the abbreviation for the dependent variable, value added at factor cost. The third dependent variable taken into consideration was the labour productivity, thus the function, is $LP_{it} = \beta_0 + \beta_1 {*} X_{it} + \beta_2 {*} W_i + u_{it}$, where LP_{it} is the abbreviation for labour productivity, as in Stock and Watson (2008).

Alternatively, in the case of the random-effects model a GLS estimation method is used, for example in this paper in the case of the bioeconomy turnover dependent variable model, the following specification is used (Stock & Watson, 2008): $TO_{it} = \beta_0 + \beta_1 {}^* X_{it} + \alpha + \varepsilon_{it} + u_{it}$, where α is the intercept for all countries and ε_{it} is the within entity (country) error and u_{it}, is the between entity (country error). The same function was applied for value added at factor cost and labour productivity as dependent variables. The assumption of this type of model is that there is no correlation between the entity error and the explanatory variables. In order to determine which of these two models is more efficient from the statistical point of view we implemented the Durbin–Wu–Hausman test (Hausman test), which verifies whether there is any correlation between unique errors between entities named as u_{it} in the formula and the explanatory variables, for which we have the following hypothesis: $H0 = \mathrm{Cov}(\alpha_{it}, X_{it}) = 0$, $H1 = \mathrm{Cov}(\alpha_{it}, X_{it})\ 6 = 0$, where Cov stands for covariance. After the Hausman test, the H0 is accepted or rejected. The fixed-effects model is statistically more efficient if the H0 is rejected.

For the random-effects model, a Wald test has been applied and for the fixed-effects model an *F*-test has been applied to test whether the coefficients jointly are not significantly different from zero.

5. Findings and analysis

The biomass material flow account is used as a control variable for the amount of biomass consumed in the total economy, namely as a raw indicator for bioeconomy. Model 1 from Table 3 shows how the sustainability and lifecycle assessment variables are associated with the turnover of the bioeconomy in the European Union countries for the period 2008–2013. As expected, the coefficients indicate that the usage of the material biomass flow has a positive association with turnover. Protected areas for biodiversity have a small negative effect on the turnover in the bioeconomy sector. The opposite holds for the estimated coefficient of organic crop area, which contributes positively to the size of the turnover of the bioeconomy sector. The size of the bioeconomy is also positively associated with the agricultural greenhouse gas emissions, thus, higher gas emissions from agriculture are associated with higher turnover in the bioeconomy. In addition, we applied the Durbin–Wu–Hausman test and the Wald test to evaluate the statistical model.

The Durbin–Wu–Hausman test indicates that the random-effects model is a more efficient estimation in this case. Individual effects of the panels (countries) are uncorrelated with the independent variables in the case of random-effects model.

In Table 3, model 2 represents an estimation model, which has the value added at factor cost as the dependent variable, which is the gross income from operating activities after adjusting for operating subsidies and indirect taxes, compared to model 1 (with dependent Turnover) the coefficients are smaller, but no changes in directions (signs) have occurred, which indicates that the selection of our model variables is robust.

Furthermore, models 3 and 4 of Table 3 present the same estimation model but with different dependent variables namely labour productivity at all factor costs, respectively apparent labour productivity. In contrast to turnover or value added at factor cost, this variable has a unit of euro per capita, which leads to extremely small

Table 3. Panel regression for sustainability and lifecycle assessment variables predicting bioeconomy indicators in the EU for the period 2008–2013.

	(1)	(2)	(3)	(4)
Dependent variable	Turnover	Value added at factor cost	Labour productivity at all factor costs	Aparent labour productivity at all factor costs
Independent variables				
Biomass material flow account	1.523***	0.241*	−0.000000204	−0.000000206
	(0.382)	(0.102)	(0.000000135)	(0.000000137)
Protected areas for biodiversity	−0.402***	−0.0900***	2.30e − 08	2.37e − 08
	(0.0938)	(0.0251)	(3.31e − 08)	(3.36e − 08)
Organic crop area	0.217***	0.0634***	−1.37e − 08	−1.39e − 08
	(0.0320)	(0.00858)	(1.13e − 08)	(1.15e − 08)
Agricultural greenhouse gas emissions	7.297***	2.081***	0.00000126*	0.00000127*
	(1.449)	(0.388)	(0.000000511)	(0.000000520)
_cons	−5047.5	181.1	0.0344***	0.0344***
	(10935.7)	(2930.0)	(0.00386)	(0.00391)
N	108	108	108	108
R^2 (overall)	92.79	91.64	11.14	11.2
Hausman	0.03	0.01	1095.91****	
	(0.9999)	(1.0000)	(0.0000)	
Wald	1324.99***	1128.86***	12.91*	
	(0.000)	(0.000)	(0.0117)	
F				3.16*
				(0.0172)
FE/RE (fixed effects/ random effects)	RE	RE	RE	FE

Source: Authors' own calculations.
Standard errors in parentheses
*$p < .05$.
*$p < .01$.
***$p < .001$.

coefficients. Aside from the coefficient of agricultural greenhouse gas emissions all the signs of the coefficients are opposite from the ones in models 1 and 2. The amount of area destined for organic crop is negatively associated with labour productivity at all factor costs. This is economically relevant, because production of organic crop is more labour-intensive compared to the production of non-organic crop, which uses more fossil-based resources and especially more insecticides. The coefficient of the variable protected areas for biodiversity is not statistically different from zero, while it has a negative association with turnover and the value added at factor costs, the two latter ones providing a measure of the size of the bioeconomy (not per capita). Model 3 shows the results of the Durbin–Wu–Hausman test to be significant with $p < .001$, which evaluates into consistent inefficient. Model 4 presents a fixed-effects model to control for unobserved effects within the panel, which results in coefficients not being significantly changed. This indicates that there was no omitted variable bias.

For Table 4, we estimated a stylised model to predict the effect of technologies deployed related to the advanced bioeconomy on the size and efficiency of all the bio-based sectors in the economy. Model 1 presents an estimation model with bioeconomy turnover as a dependent variable and biomass material flow, respectively

Table 4. Panel regression for advanced bioeconomy indicators predicting bioeconomy size and performance in the EU for the period 2008–2015.

Dependent variable	(1) Turnover	(2) Value added at factor cost	(3) Labour productivity at all factor costs	(4) Apparent labour productivity at all factor costs
Independent variables				
Biomass material flow account	1.427***	0.418***	−6.48e − 08	−5.95e − 08
	(0.197)	(0.0526)	(6.09e − 08)	(6.15e − 08)
Primary production of biodiesels	41.15	−11.23	−0.0000329***	−0.0000350***
	(30.15)	(8.043)	(0.00000930)	(0.00000954)
Biotech patents	−688.0***	−200.3***	0.0000913*	0.000112**
	(123.3)	(32.90)	(0.0000380)	(0.0000409)
R&D agriculture	140.9	48.33	0.000239**	0.000232*
	(282.6)	(75.41)	(0.0000872)	(0.0000881)
Recycling bio-waste	11.7	24	3.67e − 6	2.66e − 6
	(9.56)	(2.55)	(2.95)	(3.07)
_cons	13718.1	4852.7	0.0319***	0.0319***
	(10401.9)	(2775.3)	(0.00321)	(0.00323)
N	92	92	92	92
R^2 (overall)	95.91	94.86	33.31	0.351
Hausman	4.99	1.09	2.11	
	(0.2881)	(0.8966)	(0.7158)	
Wald	1827.65	1586.98		
	(0.0000)	(0.0000)		
F				8.87
FE/RE (fixed effects/ random effects)	RE	RE	RE	(0.0000) FE

Source: Authors' own calculations.
Standard errors in parentheses.
*$p < .05$.
**$p < .01$.
***$p < .001$.

the amount of biomass consumed in the economy as a control variable. The four indicators which are added, namely primary production of biodiesels, the number of biotech patents, Euros spent of R&D in the agricultural sector and recycling of bio-waste are indicators of technologies employed in the transition to an advanced bio-economy. In an advanced bioeconomy, biomass is not only used for food and other traditional uses, such as the production of wooden furniture products and clothing, but also used in bio-based intermediates, such as functional polymers, bio composites, biodegradable products or biofuels (e.g., biodiesel and bio-kerosene). The primary production of biodiesels in our model has no significant association with the bioeconomy turnover, while the amount of biotech patents is negatively associated with turnover (although in Model 2 it is less negatively associated with value added at factor cost). R&D expenditure on agriculture is positively associated with the size of bio-economy turnover, but the coefficient is not statistically significant. Finally, the amount of total recycling bio-waste is positively associated with bioeconomy turnover, namely more recycling predicts a higher bioeconomy turnover.

The Wald test shows that coefficients are jointly significantly different from zero and the Durbin–Wu–Hausman test rejects the theory that fixed-effects model would be more efficient. For example, the random-effects model can be interpreted as follows: the coefficient represents the average effect of the variable recycling bio-waste on the dependent variable; bioeconomy turnover, when the variable recycling bio-waste changes across time (years) and between countries by one unit (Baltagi, 2008), the coefficient includes both the within-panel and between-panel effects.

In Table 4, Model 2 presents a different dependent variable, namely value added at factor cost. The estimated coefficients have the same signs, but are smaller compared to Model 1, except that the sign of the coefficient for the primary production of biodiesels is negative. An increase in the primary production of biodiesel, is associated with lower value creation, in the bioeconomy at factor cost but with a higher total turnover in Model 1.

In Table 4, Models 3 and 4 present the estimation model with the dependent variable labour productivity at factor cost. Model 3 presents the primary production of biodiesel, which is associated negatively with labour productivity, while the amount of biotech patents is positively associated with this dependent variable. The amount of biotech patents is associated with a high labour productivity, which fits the economic theory of intense knowledge-based industries, while the use of biodiesels is often related to industries with lower productivity and less knowledge-based, such as farming or transportation. Model 4 of Table 4 presents a fixed-effects model, without significant changes, except that the coefficient of biotech patents is smaller. The coefficient of the number of biotech patents has been decreased, which could have been caused by reducing the omitted variable bias.

5.1. Logarithmic transformation of variables

In Table 5, we present our final estimation models. Every model variable, including dependent variables has been logarithmically transformed, so that the variables are approximating a normal distribution with a higher degree. Due to the high skewness of the involved variables and the non-linear relationship between the dependent variable and the independent variables, a logarithmic transformation of both, makes the relationship between dependent and independent variable more linear. This is advisable because OLS assumptions imply that the error term should be normally distributed. Models 1 and 2 of Table 5 present the estimation model with the sustainability and lifecycle assessment variables. Models 3 and 4 present a model with the variables indicating a transition to the advanced bioeconomy. In the estimation models, we did not include labour productivity as a dependent, although the previous estimation models are illustrative for the effect on the overall productivity on an employee level, the coefficients are too small. While comparing the results with the non-log estimation results of Table 4 (Models 1 and 2) and Table 3 (Models 1 and 2) the signs and relative size of the coefficients mostly do not differ, only for the variables biotech patents and R&D for agriculture, which shows that our estimation models are relatively robust.

In Table 5, Models 1 and 2 indicate significant results that the amount of greenhouse gasses emitted, are positively associated with the size and value creation of the bio-based sectors, which supports the hypothesis that a transition to the bioeconomy is not necessarily sustainable. The other estimation results are not statistically

Table 5. Logarithmic transformation of variables: estimating a log–log model with random-effects.

Dependent variable	(1) Turnover	(2) Value added at factor cost	(3) Turnover for a transition to advanced bioeconomy	(4) Value added at factor costs for a transition to advanced bioeconomy
Independent variables				
Biomass material flow account	0.496***	0.447***	0.639***	0.663***
	(0.111)	(0.114)	(0.0511)	(0.0553)
Protected areas for biodiversity	−0.133	−0.0747		
	(0.0728)	(0.0747)		
Organic crop area	0.0614	0.0415		
	(0.0474)	(0.0486)		
Agricultural greenhouse gas emissions	0.661***	0.643***		
	(0.101)	(0.104)		
Primary production of biodiesels			0.00513	−0.0220
			(0.0310)	(0.0335)
Biotech patents			0.118***	0.0882**
			(0.0259)	(0.0280)
R&D agriculture			−0.00627	−0.0224
			(0.0228)	(0.0246)
Recycling bio-waste			0.199***	0.222***
			(0.0360)	(0.0389)
_cons	1.111***	0.0514	0.573	−1.200
	(0.303)	(0.311)	(0.586)	(0.633)
N	112	112	82	82
R^2	96.06	95.60	96.76	95.90
Wald	2605.82	2326.57	2270.20	2270.22
	(0.0000)	(0.0000)	(0.00000)	(0.0000)

Source: Authors' own calculations.
Standard errors in parentheses.
*$p < .05$.
**$p < .01$.
***$p < .001$.

significant, namely that the variable protected area for biodiversity, is positively associated with both turnover and value at factor cost supports our hypothesis as well. On the contrary, the organic crop area is negatively associated with the development of the bioeconomy. This can be explained by the fact that the supply of biological, eco-friendly products has been increased significantly but the production per unit of land has been lower than conventional (non-organic) agriculture.

In Models 3 and 4 of Table 5, the number of biotech patents contribute positively for both turnover and value added at factor cost, while R&D at Agriculture contribute negatively (non-significantly). The positive association between both biotech patents and the recycling of bio-waste and (higher) turnover in the bioeconomy and value added at factor cost obtained imply that the biotechnology field is a significant growth factor. Both factors contribute through the creation of innovative products and services in the bio-based sectors, which supports our hypothesis that the transition to an advanced bioeconomy is positively associated with the overall development of the bioeconomy. The other estimation results are not significant, namely that the primary production of biodiesels and recycling of bio-waste is positively associated with the turnover of the bioeconomy while R&D in agriculture is negatively associated with both turnover as value added at factor cost.

The log–log model will not only lead to more efficient estimators, but also leads to a more understandable and useful way of interpreting the coefficients. If one of the dependent variables changes by 1% the coefficient indicates the expected percentage change of the independent variable. In economics this coefficient of the log variable is commonly referred as an elasticity (Stock & Watson, 2008). For example, a 1% increase in agricultural greenhouse gas emissions is associated with a 0.661% increase in turnover of the bio-based sectors.

6. Conclusions

The transition to an advanced and sustainable bio-based economy has become imperative in the current economic, social and environmental context. This type of transition requires two different approaches, namely a sustainable approach and a transition to a more advanced bioeconomy.

In this paper, we researched two hypotheses, which were based on qualitative findings, namely that the development of the bioeconomy is not necessarily associated with sustainability and other lifecycle factors. Also indicators reflecting a transition to an advanced bioeconomy are positively associated with the growth of the bioeconomy as whole; both hypotheses are supported by our research.

A key finding of this paper is that agricultural greenhouse gas emissions contribute positively for bioeconomy turnover and value added at factors cost, which implies that when the size of the bioeconomy is increasing, the amount of agricultural greenhouse gas emissions are also increasing. This emphasises that bioeconomy as an economic system is not necessarily fully sustainable. Our research confirms quantitatively the findings of other authors, such as Pfau et al. (2014), Landeweerd et al. (2011) and Langeveld et al. (2010), who emphasise that a transition to a bioeconomy is not necessarily sustainable.

Another finding of the study is that the number of biotech patents contributes positively for both turnover and value added at factor cost, implying that biotech patents are positively associated with more production and creation of economic value in the bioeconomy. The finding also confirms quantitatively the study of De Besi and McCormick (2015), that research and development in the field of biotechnology is a key area in developing the advanced bioeconomy.

Our findings imply that European economic policies should be focussed on sustainability and on a transition to an advanced bioeconomy. By developing and providing the right framework, these factors will not represent a negative influence on the bioeconomy, but will be a stimulus to create this sector. Our quantitative research of different variables and their dependencies in the bioeconomy significantly to the current research, while introducing a measurement for the development and growth of the bio-based sectors based on sectors encompassing the bioeconomy. Further research is required for the transition to a sustainable and advanced bioeconomy, but this study can serve as a basis for future research. Bioeconomy factors will develop and others will emerge, as well as other statistical approaches, that could decompose the effects differently.

A main objective for future research could be to analyse future models of bioeconomy developments, as the transition to the bio-based economy is still in the beginning phase and new indicators quantifying this sector are expected to emerge in order to broaden this sector of bioeconomy.

Disclosure statement

No potential conflict of interest was reported by the authors.

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