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The main determinants of changes in biomass extraction: the decomposition analysis approach

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Abstract

Sustainability is highlighted in renewed European Union (EU) bioeconomy strategy. Sustainable bioeconomy requires improvement in the productivity level of bioresources, which is included in almost all national bioeconomy strategies. However, the aspects of sustainable bioeconomy were analyzed rather scarcely. Therefore, the aim of this paper is to reveal how productivity (or conversely, intensity) level contributes to the changes in biomass extraction in all EU countries. Applying the decomposition of impact (I), population, (P), affluence, (A); and technology (IPAT) approach, the results showed that in separate EU countries and analyzed periods, the changes in biomass extraction were different. During the period of economic growth (2000–2007) and transition (2008–2012), biomass extraction decreased in more than half of all EU countries. The decline of value added in the agriculture sector and/or reduction in biomass intensity level were the main determinants of these changes. Meanwhile, during the bioeconomy strategy period (2013–2018), the reduction in biomass extractions was observed in only six EU countries. During this period, the productivity level of biomass increased and offset the economic and population growth only in Greece, Italy and Malta. Thus, due to advanced technologies in these countries, the economy grew but biomass extraction decreased. Meanwhile, in Estonia, Germany and Poland, despite the reduction in value added in the agriculture sector, the growth of the intensity level of biomass determined the increase in extraction of biomass. Therefore, this study showed that achievement of sustainable bioeconomy principles in the majority of EU countries remains a great challenge, and countries should make all efforts to enhance the productivity level of biomass.

Keywords Sustainable bioeconomy · Efficiency · Biomass · Economic growth · Decomposition analysis · European Union

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1 Introduction

The first bioeconomy strategy, "Innovating for sustainable growth: A bioeconomy for Europe" was presented in 2012 (EU, 2012). Despite the emphasis of sustainable growth, the environmental aspects of a sustainable supply of bioresource were insufficiently addressed there (European Bioeconomy Panel, 2014; Pfau et al., 2014). Thus, in recent years, Koukios et al. (2018) suggested the concept of a "sustainable bioeconomy." The tendencies of sustainable bioeconomy were analyzed by Hansen and Bjørkhaug (2017), Blumberga et al. (2017), Juerges and Hansjürgens (2018) and Antar et al. (2021). Bioeconomy as an economy based on substitute fossil resources with renewable sources as bio-based materials and process could reduce environmental impact and contribute to climate change mitigation. However, developing the bioeconomy, the sustainable and resource-efficient policies is particularly important (Maina, et al., 2017; Urmetzer et al., 2020). In this paper, the compatibility of economy and environmental aspects was considered. Thus, a sustainable bioeconomy covers the efficient production of feed, food, bio-based products and bioenergy products using renewable biological resources. The bioeconomy serves the goals of resource saving and of reducing environmental pollution and is, therefore, in accordance with principles of sustainable development. Since private markets alone fail to serve these goals successfully, the governments are called for to promote the bioeconomy in order to ensure a sustainable development of the economy.

Furthermore, Liobikienė et al. (2020) stated that by focusing on planetary boundaries, the concept of strong sustainability could be implemented. In the renewed bioeconomy strategy (EU, 2018) the sustainable development aspect was particularly highlighted (EU, 2018) and maximized the contribution toward achieving the 2030 Agenda and Sustainable Development Goals.

A large number of authors have analyzed the role of bioeconomy seeking sustainable development goals (Giampietro, 2019; Calicioglu and Bogdanski, 2021; Ramcilovic-Suominen & Pülzl, 2018; Ronzon & Sanjuán, 2020; Urmetzer et al., 2020). Heimann et al. (2019) stated that bioeconomy implementation has the potential to jeopardize the accomplishment of sustainable development. Implementing the renewed bioeconomy strategy, the trade-offs related to Sustainable Development Goals (SDG) such as zero hunger and industry, innovation and infrastructure should be achieved with less pressure on the environment and guarantee SDG targets related to biodiversity, ecosystems and water quality protection (SDG 2, SDG 6, SDG 14 and SDG 15) (Heimann, 2019; Ronzon & Sanjuán, 2020). However, consumption of bioresources is a major concern (Ronzon & Sanjuán, 2020). Due to the fast development of the bioeconomy, the use of bioresources was expected to increase (Vainio et al., 2019) and until 2050 the demand could increase by nearly 50% (Bell et al., 2018; Piotrowski et al. 2015) which would enhance the pressure on the land (Kalt et al., 2016; Liobikienė et al., 2020). Therefore, the implementation of all sustainable development goals requires more than technical solutions (Ronzon & Sanjuán, 2020).

The main condition to implementing a sustainable bioeconomy and Sustainable Development Goals is the interaction of socioeconomic and environmental aspects. The efficiency (or productivity) level perfectly reflects this interaction and reveals the achievement of Sustainable Development Goals (El-Chichakli et al., 2016). Therefore, bioresource productivity is particularly important in implementing a sustainable bioeconomy strategy (Davaney & Henchion, 2018; Scheiterle et al., 2018; Zabaniotou, 2018). In achieving the bioresource efficient EU bioeconomy strategy, the circular bioeconomy concept is considered as well (Kardung et al., 2021; Sharma et al., 2021; Stegmann et al., 2020). However, the current productivity level is still incompatible with circular and sustainable bioeconomy (Angouria-Tsorochidou et al., 2021; Giampietro, 2019). However, there it is still a lack of studies analyzing the changes in biomass productivity on biomass extraction in all EU countries.

The biomass productivity (or efficiency) levels is defined as a ratio of economy outputs and biomass inputs. Thus, the enhancement of biomass productivity reveals economic growth at a faster rate than consumption (or production) of bioresources. In order to reveal whether the changes in productivity level offsets the changes in driving forces as population and economy activities, the IPAT (Impact × Population × Affluent × Technology) approach is applied most often. This approach reveals how population, affluence (or economic development) and technologies contribute to changes in bioresources. This method was vastly applied when analyzing the carbon emissions or energy consumption. The IPAT approach was applied to analyze the determinants of material use as well (Baninla et al., 2020; Chiu et al., 2017; Dong et al., 2017; Huang et al., 2017; Shah et al., 2020; Tian et al., 2017). However, to the best of our knowledge, this analysis was not applied to examine the determinants of biomass extraction. The IPAT approach could present whether the enhancement of technologies (or of productivity level) offsets the economy and population growth. Therefore, by applying the IPAT approach, the aim of this paper was to reveal how productivity (or conversely intensity) level contributes to the changes in biomass extraction in all EU countries. It is a new topic on bioeconomy studies and could contribute to the improvement of sustainable bioeconomy strategy.

2 Literature review

2.1 Development of bioeconomy in EU countries

The renewed bioeconomy strategy in all EU was launched in 2018. The adoption of this strategy is different in each EU country. With growing knowledge and awareness of the finite nature of fossil resources, and the growing climate, environmental, socioeconomic and geopolitical impacts of their exploitation and use, along with their associated risks, the EU and many individual European and other countries have or are currently developing bioeconomy strategies. Until 2020 less than half of all EU countries (Spain, France, Germany, Italy, Latvia, United Kingdom, Austria, Finland, Ireland, the Netherland) have adopted a bioeconomy strategy at the national level. In the residual EU countries, this strategy is under development, or countries have developed other bioeconomy related initiatives.

The EU Bioeconomy Strategy emphasizes that the major opportunity and challenge is sustainable bioeconomy that requires various ecosystem and technological solutions, strategic policies, investments and policies that reward stakeholder innovation, including social entrepreneurship. The European Commission (2019) actively supported and promoted all types of innovations and practices for forestry and bio-based production, sustainable food and farming systems, through a systemic and cross-cutting approach linking actors, territories and value chains. The recent unprecedented COVID-19 crisis has brought to the surface a much wider role that the bioeconomy can have in diversifying supplies for food, feed, and raw materials, contributing to circularity and climate neutrality, while at the same time, creating employment and fostering rural development. New perspectives are needed to foster resilience and smooth the transition to a circular post-COVID-19 economy within the framework of the European Green Deal and the European Recovery Plan, in line with the EU Bioeconomy Strategy objectives. This implies embracing a transformative logic focused on turning the current challenges for local economic resilience into opportunities for diversification through deploying the bioeconomy widely.

Therefore, the successful implementation of sustainable bioeconomy strategy concerns all EU countries. Authors analyzing how countries implement bioeconomy strategy and the potential of bioeconomy development instead one country encompassed all EU countries. A large number of authors explored socioeconomic indicators, such as: output and employment multipliers of the bioeconomy sector, competitiveness effects and the differences among EU countries (Asada & Stern, 2018; Philippidis & Sanjuán-López, 2018; Ronzon & M'Barek, 2018). Other authors (see: Hamelin et al., 2019; Mola-Yudego et al., 2017; Wietschel et al., 2019) encompassing all EU countries analyzed the residual biomass potential or potential of agricultural residues and wood biomass potentials for energy. Schipfer et al. (2017) revealed the biomaterials scenarios for EU-28 countries up to 2050 and respective biomass demand. Scarlat, Dallemand, et al. (2018a, 2018b) and Banja, Jégard, et al. (2019), Banja, Sikkema, et al. (2019) analyzed the biogas development and potential form manure. Banja, Jégard, et al. (2019), Banja, Sikkema, et al. (2019) and Bórawski et al. (2019) explored biomass and biofuels supply for the energy sector in separate EU countries. Liobikienė et al. (2020) showed that the level of land footprint, biocapacity and possibilities of bioeconomy development vary across the EU countries. However, to the best of our knowledge, none of research analyzed the tendencies of sustainable bioeconomy implementation in all EU countries, considering the changes in biomass extraction and the main determinant in applying the IPAT approach.

2.2 Efficiency of bioresource and the IPAT approach

Biomass renewable sources are not "freely" available (as opposed to wind and water) and have a long supply chain from planting, growing, harvesting, pre-treatment, and conversion (Rural Biomass Energy Book, 2020). Authors have acknowledged that the implementation of sustainable bioeconomy requires improvements in the productivity (or efficiency) of the bioresources (Bell et al., 2018; Koukios et al., 2018; Scheiterle et al., 2018), in almost all national bioeconomy strategies. In the literature, authors analyzed only the level of productivity. Brizga et al. (2019) revealed that in Baltic Sea Region countries from 2011 to 2015, the productivity of bioresource changed differently. In Poland, productivity levels increased by 20%. Meanwhile, in Finland, only by 0.3% (Brizga et al., 2019). Liobikienė et al. (2020) showed that considering bioeconomy sector, the land footprint productivity in EU countries differed as well. Therefore, the big challenge remains for policymakers in how to enhance the productivity level. However, it is not only enough to enhance the level of bioresource productivity. The evaluation on how productivity levels contribute to the changes in bioresource extraction is necessary to analyze as well. To the best of our knowledge, this aspect was not analyzed by previous researchers. In order to reveal how productivity level contributes to changes in bioresource extraction, the IPAT approach is suggested.

The IPAT analysis was proposed in the 1970s by Ehrich and widely used to analyze the drivers for energy use, environmental pollution, resource consumption and efficiency (Chiu et al., 2017; Dong et al., 2017; Román-Collado et al., 2018; Tian et al., 2017). Therefore, this method is suitable to analyze the drivers of bioresource extraction as well. IPAT decomposition analysis reveals the contribution of changes in population (P), affluence (A) and technology (T) (or intensity level) to the changes in bioresource extraction. Tian et al. (2017) stated that IPAT decomposition analysis encompasses two aspects of Environmental Kuznets Curve: scale (the population and economic growth) and technique effects, in our case—the reduction in bioresource intensity. Therefore, IPAT analysis shows whether the technologies or efficient enhancement offset the main driving forces of biomass extraction as population and economic growth (Fishman et al., 2015). Furthermore, this analysis is suitable for comparison analysis among countries and could contribute to a basis to spur mutual communication and cooperation among EU countries on the governance of sustainable bioresource extraction and improve the efficiency level (Baninla et al., 2020).

3 Methods and materials

The purpose of this decomposition analysis is to identify and analyze how the changes in biomass domestic extraction (BIO) have been brought about by changes in several independent factors. Biomass is renewable organic material related to crop and animal production, hunting, forestry and logging and fishing and aquaculture activities. In order to evaluate the main determinants, in this study, additive and multiplicative forms of index decomposition analysis were used to generate results from different perspectives. The multiplicative form illustrates the relative aspect for each factor in driving the changes in biomass domestic extraction, as the additive form provides a measure of the magnitude of changes in biomass extraction driven by decomposed factors.

In this paper, applying decomposition analysis, national BIO as an extended Kaya identity (Kaya, 1989) was expressed by the product of three factors:

$$\mathrm{BIO} = \mathrm{POP} \cdot \left(\frac{\mathrm{VAAgr}}{\mathrm{POP}}\right) \cdot \left(\frac{\mathrm{BIO}}{\mathrm{VAAgr}}\right) \tag{1}$$

where BIO is total domestic extraction of biomass in thousand tons, POP represents the total national population, VAAgr is total value added in agriculture in million EUR expressed in constant price. Ratio VAAgr/POP means value added in agriculture sector per capita and ratio BIO/VAAgr means intensity of bioresources.

In multiplicative decomposition, the relative change of aggregate BIO between year 0 (2000) and year t was decomposed by the ratio of each factor, as shown in Eq. (2):

$$\mathrm{BIO}_t^* = \mathrm{POP}_t^* \cdot \left(\frac{\mathrm{VAAgr}_t^*}{\mathrm{POP}_t^*}\right) \cdot \left(\frac{\mathrm{BIO}_t^*}{\mathrm{VAAgr}_t^*}\right), \tag{2}$$

where $\mathrm{BIO}_t^* = \mathrm{BIO}_t/\mathrm{BIO}_0$, $\mathrm{POP}_t^* = \mathrm{POP}_t/\mathrm{POP}_0$, $\mathrm{VAAgr}_t^* = \mathrm{VAAgr}_t/\mathrm{VAAgr}_0$.

In additive decomposition, the absolute change in BIO between year 0 (2000) and year t was decomposed by the difference of each factor, as shown in Eq. (3):

$$\Delta\mathrm{BIO}_t = \Delta\mathrm{POP}_t + \Delta\left(\frac{\mathrm{VAAgr}_t}{\mathrm{POP}_t}\right) + \Delta\left(\frac{\mathrm{BIO}_t}{\mathrm{VAAgr}_t}\right), \tag{3}$$

where $\Delta\mathrm{BIO}_t = \mathrm{BIO}_t - \mathrm{BIO}_0$, $\Delta\mathrm{POP}_t = \mathrm{POP}_t - \mathrm{POP}_0$, $\Delta\left(\mathrm{VAAgr}_t/\mathrm{POP}_t\right) = \mathrm{VAAgr}_t/\mathrm{POP}_t - \mathrm{VAAgr}_0/\mathrm{POP}_0$, $\Delta\left(\mathrm{BIO}_t/\mathrm{VAAgr}_t\right) = \left(\mathrm{BIO}_t/\mathrm{VAAgr}_t\right) - \left(\mathrm{BIO}_0/\mathrm{VAAgr}_0\right)$.

In this study, the biomass domestic extraction was evaluated considering traditional land-use sectors: crop and animal production, hunting and related service activities (A01), forestry and logging (A02), and fishing and aquaculture (A03). The economic indicator as value added in agriculture was also evaluated considering to the same sectors. All data were provided in Eurostat database. In this paper, all EU-28 countries were analyzed. The time period of 2000–2018 was defined as the scope of the bioeconomy. In parallel decomposition analysis was performed dividing this period into: 2000–2007—growth period (period of economic growth and before bioeconomy strategy preparation), 2008–2012—transition period (the period of bioeconomy strategy preparation) and 2013–2018—strategy period (the period after bioeconomy strategy implementation and until its renewal).

4 Results and discussion

4.1 Changes in domestic extraction of biomass and main determinants in all analyzed periods

Results from the additive decomposition analysis in Fig. 1 show that biomass domestic extraction (BIO) in EU-28 countries was fluctuating, but with a growing tendency and increase of 136.8 thousand tones or 8.2% from 2000 to 2018. The main driving forces are population (POP) which increased by 5.2% and value added in agriculture sector per capita (VAAgr/POP) which increased by 4.6%. Meanwhile intensity of bioresources (BIO/VAAgr) at the analyzed period decreased by 1.6%. The reduction in intensity level or growth of biomass productivity was positive tendency. However, in EU-28 the extraction of biomass increased because the growth of biomass productivity level was too slow, and it did not offset the driving forces.

Considering separate EU countries, Table 1 showed that changes in biomass extraction and driving forces between 2000 and 2018 vary among the EU28 countries. The growth of biomass extraction was observed in 20, while a reduction was observed in eight countries. The obtained results demonstrated that the biggest growth of biomass extraction was in Bulgaria (80.5%), Croatia (62.4%) and Romania (60.6%). These countries are the newest EU members and the bioeconomy strategy still is under development stage. Applying the multiplicative decomposition analysis, the main driver for growth of biomass extraction in Bulgaria and Croatia was the intensity of bioresources which increased by 116.3%

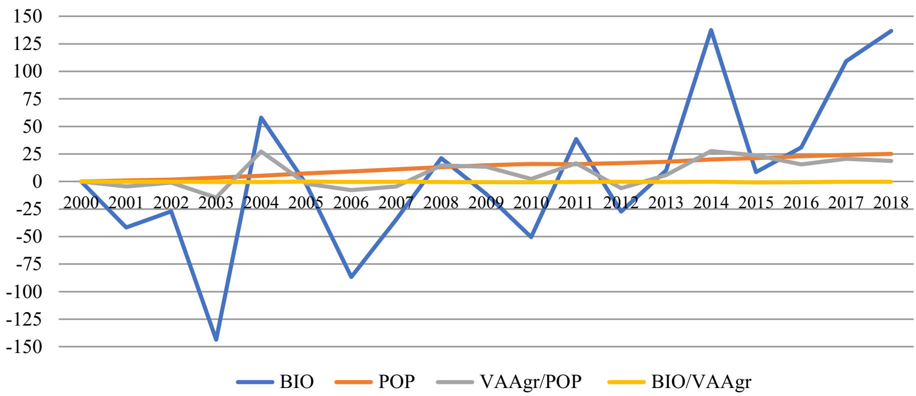

Fig. 1 Additive decomposition analysis of biomass domestic extraction for the time period 2000–2018

Table 1 Changes in biomass domestic extraction and driving forces from 2000 to 2018

	BIO	*POP*	*VAAgr/POP*	*BIO/VAAgr*
Belgium	0.97	1.11	0.91	0.97
Bulgaria	1.81	0.86	0.97	2.16
Czechia	1.10	1.03	1.05	1.01
Denmark	0.93	1.08	0.83	1.04
Germany	1.16	1.01	0.85	1.36
Estonia	1.12	0.94	0.91	1.31
Ireland	0.99	1.28	0.86	0.90
Greece	0.65	1.00	0.92	0.71
Spain	1.04	1.15	1.06	0.85
France	1.01	1.11	1.02	0.90
Croatia	1.62	0.91	0.94	1.89
Italy	0.70	1.06	0.91	0.72
Cyprus	0.84	1.25	0.50	1.34
Latvia	1.09	0.81	1.75	0.77
Lithuania	1.38	0.80	1.35	1.28
Luxembourg	1.13	1.39	0.23	3.59
Hungary	1.30	0.96	1.50	0.90
Malta	0.83	1.22	1.03	0.66
Netherlands	1.11	1.08	1.13	0.91
Austria	1.19	1.10	1.13	0.96
Poland	1.25	0.99	1.13	1.11
Portugal	1.04	1.00	1.06	0.97
Romania	1.61	0.87	1.70	1.08
Slovenia	1.21	1.04	1.27	0.92
Slovakia	1.30	1.01	4.41	0.29
Finland	1.13	1.07	1.21	0.88
Sweden	1.16	1.14	1.17	0.87
United Kingdom	0.98	1.13	0.98	0.89

Green color represents the decreasing, and red color—the increasing factors; color intensity increases gradually as the value of the factor moves away from 1

and 88.9%, respectively, during the analyzed period. In Luxemburg, Germany, Estonia the intensity level of bioresource also increased in high rate. However, the reduction in value added, or population determined that the changes in biomass extraction was negligible in these countries. These tendencies from the perspective of sustainable bioeconomy are not favorable and countries should seek the solutions how to enhance productivity level of biomass. In Romania the main determinant of the growth of the biomass extraction was value added in agriculture sector per capita which increased by 70.3%, while intensity of bioresources growth by 8.4%. Therefore, in Romania the bioeconomy sector is extensively developed but productivity level still did not offset the growth of bioeconomy.

The biggest reduction in domestic biomass extraction in the analyzed period was observed in Greece (35.4%) and Italy (30.1%). In both cases, the main driver was a decrease in intensity of biomass. In Greece, it accounted for 29.4%, and in Italy, it was 27.9%. Furthermore, in these countries, the value added in the agriculture sector also decreased. Therefore, the issue in these countries still exists of whether the extensive bioeconomy sector development will maintain the high productivity level of biomass in order to stabilize the changes in biomass extraction. In Belgium, Ireland and the United Kingdom, the extraction of biomass decreased due to the same reasons: a reduction in value added and intensity level of bioresource. In Denmark and Cyprus, the extraction of biomass decreased only due to the reduction in value added in agriculture sector and developing the bioeconomy sector the biomass extraction can increase in very high rate due to ineffective agriculture sector. Meanwhile, only in Malta did the biomass productivity level offset the growth of agriculture and population and this country the most successfully implemented the sustainable bioeconomy strategy principles during all analyzed period. Furthermore, in Slovakia, the intensity level of biomass decreased the most—by 71%, which slowdown the growth of biomass extraction whereas the economic growth in agriculture sector increased more than four times. This case reveals how important is productivity level particularly when the bioeconomy sector is developed very extensively (Table 1).

4.2 Changes in domestic extraction of biomass and main determinants in the economic growth period (2000–2007)

After the Russian financial crisis, which affected EU countries, fast economic growth was observed in all EU countries. During this period, the bioeconomy sector was not highlighted, but agriculture and the growth of this sector played a serious role. Analyzing the changes in biomass extraction and its determinants between 2000 and 2007 among all EU28 countries, the average decrease in domestic biomass extraction was observed and accounted for 2.1%. According to separate EU countries, in 17 countries, the reduction in biomass extraction occurred, while increase was observed in 11 countries. In Croatia, the growth of biomass extraction was the highest and both intensity of bioresources (+21.2%) and value added in agriculture sector per capita (+16.2%) were the main determinants of this growth. In Slovakia and Sweden, the biomass extraction increased in high rate as well by 17% and 16%, respectively (Table 2). Despite that in these countries the productivity level of biomass increased but it did not offset the fast growth of bioeconomy sector.

Meanwhile, in Greece (−24.4%) and Estonia (−34.8%) the biggest reduction in biomass extraction was observed. In the case of Greece, value added in the agriculture sector per capita was the significant negative driver for the decrease in biomass extraction, and it decreased by 25.0%. Two determinants were significant for Estonia, but their influence was the opposite. The value added in the agriculture sector per capita had a positive effect on extraction of biomass changes (+48.7%). Then, the intensity of bioresources had a negative effect on extraction of biomass changes, and it decreased by 54.2% in this period (Table 2). Therefore, in Estonia during this period, the principles of a sustainable bioeconomy were implemented the most successfully. In Belgium, Denmark, Latvia, Hungary, Malta, the Netherlands, Poland and Slovenia, the productivity level also offset the increase in the agriculture sector.

Table 2 Changes in biomass domestic extraction and driving forces from 2000 to 2007

	BIO	*POP*	*VAAgr/POP*	*BIO/VAAgr*
Belgium	0.99	1.03	1.09	0.88
Bulgaria	0.87	0.92	0.77	1.22
Czechia	1.03	1.00	0.88	1.18
Denmark	0.89	1.02	1.04	0.84
Germany	1.07	1.00	1.08	0.98
Estonia	0.65	0.96	1.49	0.46
Ireland	0.90	1.15	0.69	1.14
Greece	0.76	1.02	0.75	0.98
Spain	0.96	1.11	0.94	0.93
France	0.96	1.05	0.94	0.97
Croatia	1.35	0.96	1.16	1.21
Italy	0.88	1.02	0.92	0.94
Cyprus	1.01	1.10	0.74	1.24
Latvia	0.96	0.93	1.43	0.72
Lithuania	1.13	0.93	1.11	1.09
Luxembourg	1.10	1.10	0.46	2.19
Hungary	0.99	0.98	1.05	0.96
Malta	0.91	1.04	1.46	0.60
Netherlands	0.96	1.03	1.04	0.89
Austria	1.18	1.04	1.05	1.08
Poland	1.05	1.00	1.21	0.87
Portugal	0.92	1.03	0.95	0.94
Romania	0.87	0.94	1.01	0.92
Slovenia	0.96	1.01	1.08	0.88
Slovakia	1.17	1.00	2.44	0.48
Finland	1.05	1.02	1.05	0.98
Sweden	1.16	1.03	1.26	0.90
United Kingdom	0.88	1.04	0.93	0.91

Green color represents the decreasing, and red color—the increasing factors; color intensity increases gradually as the value of the factor moves away from 1

4.3 Changes in domestic extraction of biomass and main determinants in the transition period (2008–2012)

The period of 2008–2012 was considered as bioeconomy strategy preparation also this period encompassed the economic crisis and recovery. Results of changes in extraction of biomass and determinants between 2008 and 2012 among the EU28 countries are shown in Table 3. Therefore, in this period, domestic extraction of biomass in all EU28 countries was almost stable and accounted for 0.4%. The reduction in biomass extraction was observed in 17 countries, while an increase was observed in 11 countries. Comparing with 2000–2007 period in different EU countries the biggest growth of extraction occurred. In transition period in Cyprus, Estonia and Latvia the biomass extractions increased the most by 48.9%, 32% and 28.8%, respectively. Despite that during the economic growth period

Table 3 Changes in biomass domestic extraction and driving forces from 2008 to 2012

	BIO	*POP*	*VAAgr/POP*	*BIO/VAAgr*
Belgium	0.94	1.04	1.02	0.88
Bulgaria	0.98	0.97	0.78	1.30
Czechia	0.96	1.02	1.01	0.93
Denmark	1.05	1.02	1.23	0.84
Germany	1.07	0.98	0.86	1.27
Estonia	1.32	0.99	0.99	1.35
Ireland	0.95	1.03	0.92	1.00
Greece	0.96	1.00	1.19	0.80
Spain	0.86	1.03	0.92	0.91
France	0.97	1.02	0.96	0.99
Croatia	0.80	0.99	0.71	1.14
Italy	0.89	1.01	0.98	0.89
Cyprus	1.49	1.11	0.89	1.51
Latvia	1.29	0.93	1.13	1.22
Lithuania	1.18	0.93	1.21	1.04
Luxembourg	1.02	1.08	1.08	0.87
Hungary	0.70	0.99	0.63	1.12
Malta	0.93	1.02	1.09	0.83
Netherlands	0.99	1.02	1.00	0.97
Austria	0.87	1.01	0.93	0.92
Poland	1.05	1.00	1.03	1.02
Portugal	1.05	1.00	0.98	1.07
Romania	0.90	0.97	0.80	1.17
Slovenia	1.03	1.02	0.89	1.13
Slovakia	0.85	1.01	1.03	0.83
Finland	0.99	1.02	1.03	0.95
Sweden	1.03	1.03	1.00	0.99
United Kingdom	0.93	1.03	0.93	0.97

Green color represents the decreasing, and red color—the increasing factors; color intensity increases gradually as the value of the factor moves away from 1

Estonia was of one of example, while in this period the intensity level increased the most and it determined the increase in biomass extraction. In Cyprus and Latvia, the growth of intensity levels also contributed to the increase in the resource extraction, intensity of biomass increased by 50.6% and 22.5%, respectively. In Lithuania, the growth of extraction was also high—by 18%. However, in this country, the growth of value added in agriculture sector determined this change the most. Furthermore, among EU countries the biggest level of agriculture sector growth was observed in Lithuania and in Denmark. But in Denmark the increase in extraction slow downed one of the biggest declines of biomass intensity level.

The biggest reduction in biomass occurred in Croatia (− 19.9%), and Hungary (− 29.7%). In the period of economic growth, the biomass extraction increased the most in Croatia. In this period in both Croatia and Hungary value added in agriculture sector per capita was the main driver for negative changes in biomass extraction; however, the intensity level increased. Therefore, how important is the biomass productivity level seeking that the growth of bioeconomy sector did not cause huge growth of biomass extraction which could exceed the biomass capacity. Meanwhile in other countries as Belgium, Czechia, Denmark, Greece, Luxemburg, Malta, the Netherlands, Slovakia and Finland, the reduction in biomass intensity offset the population and economic growth and, in these countries, the negligible reduction in biomass extraction was observed. Therefore, before the launched of bioeconomy strategy the principle of sustainable bioeconomy in latter countries was successfully implemented (Table 3).

4.4 Changes in domestic extraction of biomass and main determinants in strategy period (2013–2018)

During the period when EU bioeconomy strategy was launched and implemented from the 2013 to 2018, the average increase in domestic extraction of biomass in all EU28 countries was the highest comparing all analyzed periods and reached 7.6%. Therefore, generally in EU the development of bioeconomy was related to increase in bioresource production, export and consumption. However, the main principle remains that the production and consumption of biomass would be more efficient. Considering separate countries, the growth of biomass extraction was observed in almost all EU countries—22, while decrease occurred only in 6 countries. The biggest growth in extraction level was in Slovenia, Estonia and Romania, respectively, by 25.4%, 24.1% and 21.4%. Value added in agriculture sector per capita was the main driver for growth of biomass extraction in Slovenia (33.1%) and Romania (25.1%). In Estonia despite the sharp decline of value added in agriculture sector (by − 36.8%), increase in intensity of bioresources by 96.4% determined the growth of biomass extraction (Table 4). Therefore, during these two periods (transition and strategy) the sustainable bioeconomy principles was the worst implemented in Estonia. Liobikienė et al. (2019) found that Estonia almost achieved the level of land biocapacity. The highest intensity growth was observed in Poland and Germany as well, and these tendencies are not favorable, considering sustainable bioeconomy principles. Particular Germany where the sustainable aspect was highlighted when the bioeconomy strategy was launched. The growth of biomass extraction was negligible in Germany only due to the reduction in bioeconomy sector.

In Belgium, Denmark, Greece, Italy, Lithuania and Malta, biomass extraction decreased. In Italy (− 10.3%), Lithuania (− 11.1%), and Malta (− 11.6%) the reduction was the highest. The intensity of bioresources was the main driver for Italy and Malta. In Malta, intensity

Table 4 Changes in biomass domestic extraction and driving forces from 2013 to 2018

	BIO	*POP*	*VAAgr/POP*	*BIO/VAAgr*
Belgium	0.99	1.02	0.96	1.01
Bulgaria	1.07	0.97	1.17	0.95
Czechia	1.03	1.01	1.19	0.86
Denmark	0.99	1.03	0.91	1.06
Germany	1.09	1.03	0.75	1.42
Estonia	1.24	1.00	0.63	1.96
Ireland	1.04	1.05	1.30	0.76
Greece	0.94	0.98	1.08	0.89
Spain	1.07	1.00	1.12	0.95
France	1.08	1.02	1.11	0.95
Croatia	1.06	0.96	1.01	1.09
Italy	0.90	1.01	0.99	0.89
Cyprus	1.00	1.00	0.90	1.12
Latvia	1.10	0.96	1.09	1.06
Lithuania	0.89	0.95	0.99	0.95
Luxembourg	1.07	1.12	0.89	1.07
Hungary	1.10	0.99	1.27	0.88
Malta	0.88	1.13	1.03	0.76
Netherlands	1.14	1.02	1.06	1.05
Austria	1.10	1.04	1.12	0.94
Poland	1.17	1.00	0.86	1.36
Portugal	1.06	0.98	1.07	1.01
Romania	1.21	0.98	1.25	0.99
Slovenia	1.25	1.00	1.33	0.94
Slovakia	1.08	1.01	1.16	0.93
Finland	1.07	1.02	1.11	0.94
Sweden	1.01	1.06	0.97	0.99
United Kingdom	1.09	1.04	1.06	0.99

Green color represents the decreasing, and red color—the increasing factors; color intensity increases gradually as the value of the factor moves away from 1

of biomass decreased by 24.0% and in Italy decrease by 10.5%. In Lithuania, there were two negative significant drivers: decrease in population by 5.5% and decrease in intensity of bioresources by 5.0%. From all these countries, only Italy has launched the national bioeconomy strategy (Table 4). Meanwhile, considering other EU countries which have a national bioeconomy strategy, in almost all countries, the intensity of biomass decreased (expect Germany, Latvia and the Netherlands), but it did not offset the other driving forces and biomass extraction increased. Therefore, the growth of productivity level is very important, but it is essential to maintain the stabilization of biomass increase particularly considering that these countries could very quickly exceed the land biocapacity (Liobikienė et al., 2019). Among EU countries only in Greece, Italy and Malta the productivity level offset the driving forces and biomass extraction decreased. Therefore, these countries should further follow the positive tendencies of bioeconomy strategy implementation. Bioeconomy strategies implementation in EU countries can help to address the dilemma of meeting increasing demands for goods and services of a growing and more wealthy population, while at the same time halting the over-exploitation of resources and degradation of ecosystems and biodiversity and also mitigating climate change.

In the literature, both implementing sustainable or circular economy authors provided vast recommendations as potential feedstock for a generation of bio-based products to use food waste or other wastes generated in agriculture sector (Bužinskienė & Miceikienė, 2021; Dahiya et al., 2018; Maina, et al., 2017; Mohan et al., 2019; Singh et al., 2021). The global innovation, technologies and investments in agriculture are also crucial in seeking to enhance the bioresource productivity level (Liobikienė et al., 2019; Wohlgemith et al., 2021). The public acceptance of implementing tools and sustainable use of bioresources is important as well (Woźniak et al., 2021).

Many countries are developing and implementing bioeconomy strategies. While the original emphasis of most of these strategies was on climate protection and on reducing dependency on fossil resources, other sustainability dimensions need to be addressed as well, in particular those spelled out by the Sustainable Development Goals. Therefore, bioeconomy transitions have become integral part of an overall sustainability transition. This requires improvements on the consumption and production side, to avoid excessive demands on bioresources as a result of bioeconomy transitions and the substitution of fossil resources (Hoff et al., 2018).

5 Conclusions

A sustainable bioeconomy covers the efficient production of feed, food, bio-based products and bioenergy products using renewable biological resources. Therefore, implementing sustainable bioeconomy requires improvement in the productivity of the bioresources, which is included almost in all national bioeconomy strategies. The enhancement of biomass productivity is important; however, it is more important to stabilize the growth of biomass which in EU countries is limited. Therefore, the aim of this paper is to reveal how productivity (or conversely intensity) level contributes to the changes in biomass extraction in all EU countries. In order to reveal whether the changes in productivity level offsets the changes in driving forces as population and economy activities the IPAT approach was applied. The time period of 2000–2018 was defined as the scope of the bioeconomy. In parallel decomposition analysis was performed dividing this period into 2000–2007—growth period, 2008–2012—transition period and 2013–2018—strategy period.

The results showed that in separate EU countries during analyzed periods, the changes in biomass extraction were different. During the period of economic growth and transition, biomass extraction decreased in more than half of all EU countries. The decline of value added in the agriculture sector and/or reduction in biomass intensity level were the main determinants of these changes. Meanwhile, during the bioeconomy strategy period (2013–2018), the reduction in biomass extractions was observed in only 6 EU countries. Encompassing all analyzed periods (2000–2018) the growth of biomass extraction was observed in 20, while the reduction was observed in eight countries. The main driving forces as population in EU-28 increased by 5.2% and value added in agriculture sector per capita increased by 4.6%. However, in EU-28 the extraction of biomass increased because that the reduction in biomass intensity level was too slow (1.6%), and it did not offset the driving forces.

Focusing on strategy period (2013–2018) only in Greece, Italy and Malta the productivity level of biomass offset the driving forces—economic and population growth. Meanwhile in Estonia, Germany and Poland despite the reduction in value added in agriculture sector the growth of intensity level of biomass determined the increase in extraction of biomass. Therefore, this study showed that achievement of sustainable bioeconomy principles in major of EU countries remains a great challenge. The increase in biomass productivity is particularly important in order to offset population and economic growth. It requires various ecosystem and technological solutions, strategic policies, investments and policies that reward stakeholder innovation, including social entrepreneurship implementing the sustainable bioeconomy policy in EU. Thus, the authors in future should analyze the sustainability bioeconomy aspects not only in EU countries, but also focus on a broader area. Furthermore, the tools which could enhance the biomass productivity should be deeply explored as well. Future research might focus on the assessment of the prospects of industrial symbiosis, which enables the transformation of the production residues of one company into the resources of another company and thus the supply of energy and the production of other value-added products, from the environmental point of view, as well as on the transformation processes of digital green bioeconomy.

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