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Environmental aspects of the implementation of bioeconomy in the Baltic Sea Region: An input-output approach

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ABSTRACT

Bioeconomy is one of the main aspects of the Baltic Sea Region (BRS) Programme. However, at the national level, bioeconomy strategies are still under development in several countries. As environmental aspects are particularly important to ensure the sustainability of bioeconomy, the aim of this paper is to analyse changes in consumption- and production-based bio-resource, land and water footprints for the period of 2011–2015 and couple them with economic indicators, to assess the efficiency of bioeconomy in the BSR countries. The results show significant differences in consumption- and production-based bio-resource, land and water footprints among the BSR countries; these differences are not linked to the existence of bioeconomy strategies in these countries. Taking into account a sustainable level of bio-resource, cropland and water use commitments, countries should develop their bioeconomy giving due consideration to the sustainability of resource use, whereas in all the BSR countries these targets are significantly exceeded. The analysis of the efficiency of bioeconomy also revealed significant differences in bio-resource productivity and land and water intensity among countries. From a sustainable development perspective, we can positively see that in all the BSR countries, bio-resource productivity increased and water footprint intensity reduced. The most positive changes were observed in Poland. Meanwhile, in Estonia and Finland, the increase in land footprint during the study period was observed. Thus, these countries should pay particular attention to efficiency improvements in forest and agricultural sectors. This study contributes to setting targets for bioeconomy policy in the BSR and reveals the main tendencies and challenges of the implementation of bioeconomy.

1. Introduction

Bioeconomy is defined as economy which comprises all economic activities related to the use of biological products and processes (Loiseau et al., 2016; Cristóbal et al., 2016; McKormick and Kautto, 2013; Ramcilovic-Suominen and Pülzl, 2018; Golembiewski et al., 2015; Sasson and Malpica, 2018; Dietz et al., 2018; Ingrao et al., 2018; Näyhä, 2019). A number of scholars have argued that bioeconomy contributes to the promotion of renewable resources, climate change mitigation, it could also facilitate food security, accelerate economic growth and job creation (EC, 2012; Woźniak and Twardowski, 2018; Balezentis et al., 2019; Aguilar et al., 2018; Budzinski et al., 2017; D'Amato et al., 2017; Bell et al., 2018; Besi and McCormick, 2015; Devaney and Henchion, 2018; Ingrao et al., 2018). Thus, bioeconomy is one of the main aspects of green growth and sustainable development (D'Amato et al., 2017; Loiseau et al., 2016; Pitkänen et al., 2016).

In the European Union (EU), the first bioeconomy strategy "Innovating for Sustainable Growth: A Bioeconomy for Europe" (EU, 2012) was launched in 2012. However, experts stated that environmental aspects, particularly the sustainable supply of biomass, were not sufficiently addressed in this strategy (European Bioeconomy Panel, 2014). Therefore, the EU bioeconomy strategy was renewed in 2018 (EU, 2018), which maximises its contribution towards the 2030 Agenda and its Sustainable Development Goals as well as the Paris Climate Agreement and highlights the importance of a sustainable and circular bioeconomy. In turn, many EU regions and countries have developed or are preparing national

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bioeconomy strategies (Ladu and Blind, 2017). The Baltic Sea Region (BSR) is not an exception. The Baltic Sea Strategy concludes that the Baltic Sea Region has the potential to become one of the world's leading regions in green growth and sustainable development. The region has well-developed infrastructure, technological and environmental knowledge and a large concentration of biomass.

Sustainable bioeconomy is one of the policy areas of the BSR strategy. Such global challenges as climate change, soil and ecosystem degradation, which are becoming even more difficult to address as the global population is growing, are emphasized both in the BSR strategy and in the EU's new bioeconomy strategy for sustainable EU (2018), which serves as the basis for the implementation of the BSR strategy. One of the goals of sustainable bioeconomy is to stop soil degradation and restore degraded ecosystems. Another goal is sustainable management of natural resources, which can be achieved by taking timely actions aimed at avoiding ecosystem degradation as well as restoring and strengthening ecosystem functions. This should help to ensure a better provision of food and water and considerably improve the capacity to adapt to climate change and mitigate it. Moreover, the maintenance and productivity of sea, ocean, forest, and soil ecosystem health depend on biodiversity. To implement the abovementioned goals, it is necessary to improve the capacities of surveillance and forecasting of the condition of natural resources. This requires reliable and comparable information about the environmental impact and its application to environmental measures, if their environmental benefit has been proven. The data shall be obtained and used on the basis of the Product Environmental Footprint method.

For bioeconomy to be sustainable, it is necessary to assess how it may influence the planet's ecological capacity and to be able to measure this effect. Environmental footprint is one of the key indicators. It must be assessed in order to identify measures to help mitigate the environmental impact, assess and preserve biodiversity and cultivate the most diverse ecosystem services in the development of bioeconomy. The BRS provides for the surveillance of biodiversity, the condition of ecosystems, degraded land areas and areas which might be affected by climate change (such as areas affected by desertification), with the aim of restoring land and sea ecosystems. The BSR strategy also contributes to the European Commission's (EU) measure of the implementation of the European internationally agreed surveillance system in order to perform the surveillance of progress in the development of sustainable and circular bioeconomy in Europe and to use the resulting data as the basis in the related policy areas. The accumulated knowledge will be used in the issuance of non-binding recommendations on the development of bioeconomy within safe ecological limits.

The Nordic Council of Ministers is a coordinator for bioeconomy in EU's BSR strategy. The Nordic political priorities on bioeconomy are presented in the Nordic bioeconomy programme document (2018), the vision of which is based on four pillars: competitive bio-based industries, sustainable resource management, resilient and diverse ecosystems and inclusive economic development. In order to reach this vision, the bioeconomy programme defines 15 action points under three thematic areas: innovate (supporting research, innovation and human capital), accelerate (policies and market development) and network (forging new and stronger connections). Several BSR countries (Germany, Latvia and Finland) have adopted their national bioeconomy strategies. Sweden, Poland and Denmark have developed other policy initiatives dedicated to bioeconomy. Meanwhile, in Lithuania and Estonia, such strategies are under development.

The review of bioeconomy strategies in the BSR countries demonstrates that the focus of these strategies in each of the countries differs. Latvia's bioeconomy strategy (2018) pays most of the attention to social and economic aspects, i.e. the increase of the value-added of bioeconomy products, employment rate and exports. Strategic goals of The Finnish bioeconomy strategy (2014) include a competitive operating environment for bioeconomy, new bioeconomy business, a strong bioeconomy competence base as well as the accessibility and sustainability of biomasses. Thus, in addition to social and economic aspects, the Finnish bioeconomy strategy also encompasses an environmental aspect as the precondition for the sustainability of biomass. In its bioeconomy strategy, Germany particularly highlights an environmental aspect and pursues the vision of a natural, circular and sustainable bio-based economy (2013). Swedish Research and Innovation Strategy for a Bio-based Economy (2012) also emphasizes that bioeconomy is based on a sustainable production of biomass to enable an increased use within a number of different sectors of society and increased added value for biomass materials, concomitant with a reduction in energy consumption and recovery of nutrients and energy as additional endproducts. The objective is to optimize the value and contribution of ecosystem services of the economy, or in other words, to increase efficiency.

Furthermore, environmental aspects are critically important for the sustainability of bioeconomy. Increasing demand for biomass as a part of the development of bioeconomy is expected to create biomass scarcity (Borgström, 2018). Particularly, it concerns the EU, where a local biomass supply is limited (Sleenhoff et al., 2015; Aguilar et al., 2018; Hennig et al., 2016). Biomass supplies are not endless as it takes time for supplies to regrow. Thus, a steep increase in the consumption of unsustainable biomass could hinder the implementation of bioeconomy (Scarlat et al., 2015; Levidow et al., 2012; Bezama, 2016; Hildebrandt et al., 2018). Moreover, the sustainable use of biomass and the consideration of ecological limits and planetary boundaries are particularly necessary for the implementation of sustainable bioeconomy (Koukios et al., 2018).

In literature, environmental aspects of the consumption and potential of biomass have been rather extensively analysed (Woźniak and Twardowski, 2018; Scarlat et al., 2015; Kalt et al., 2016; Bentsen and Felby, 2012; Searle and Malins, 2015; Stecher et al., 2013; Batidzirai et al., 2012; Seidenberger et al., 2008; Schueler et al., 2016). Recently, Egenolf and Bringezu (2019) have highlighted the importance of environmental footprints in monitoring the sustainability of bioeconomy. It is land footprint approach that has been vastly applied (Hubacek and Feng, 2016; Schaffartzik et al., 2015; Bruckner et al., 2015; O'Brien et al., 2014a,b, 2015; 2017; Kastner et al., 2014; Arto et al., 2012; Weinzettel et al., 2014; Tukker et al., 2014). Meanwhile, water footprint has been analysed rather scarcely, only by Rogers et al. (2016), Richard et al. (2019) and Xu et al. (2018). Considering material footprint, bioresources in particular, only Scarlat et al. (2015) explored the usage of bio-resources in different economic sectors in the EU. Kalt et al. (2016) analysed the use of biomass in Austria. Budzinski et al. (2017) evaluated the use of forest biomass in German bioeconomy. In this study, in order to understand the environmental consequences of the implementation of bioeconomy in the BSR, we encompassed all three types of footprints: land, water and material. Furthermore, production- and consumption-based footprints were evaluated in order to reveal not only production-related bioeconomy impacts but also the consumption level for which countries are also responsible. To the best of our knowledge, these indicators have not yet been analysed in the BSR countries.

When seeking the sustainability of bioeconomy, it is not enough to evaluate changes in the usage of bio-resources, land and water. Sustainable bioeconomy should take into account not only environmental aspects but also the socio-economic dimension. At the same time, Bracco et al. (2018) state that measuring only socioeconomic indicators might also provide an incomplete picture.

Thus, we suggested analysing the economic and environmental interaction of bioeconomy by looking at eco-efficiency, which can also be used to measure the economic development and its contributions to the sustainable development goals (El-Chichakli et al., 2016). Schutte (2018), Scheiterle et al. (2018), Egelyng et al. (2018), Devaney and Henchion (2018) and Zabaniotou (2018) state that sustainable bioeconomy should focus on the efficiency of natural resources and that biomass conversion must retain a high efficiency. The inefficient use of biomass constraints the effectiveness of bioeconomy policies (Maes and Van Passel, 2019). However, the ecoefficiency of bioeconomy has been scarcely analysed.

In light of the above discussion, the aim of this paper is to evaluate the environmental sustainability of bioeconomy in the BSR countries in the period of 2011–2015, by calculating and analysing land, water and material (bio-resource) footprints as the main environmental indicators of bioeconomy (Hertel et al., 2013; O'Brien et al., 2015, 2017), coupling them with economic indicators in order to evaluate eco-efficiency of these economies.

2. Methodology

In this study, we evaluated the most important indicators for assessing the sustainability of bioeconomy (Egenolf and Bringezu, 2019), particularly looking at production- and consumption-based material, land and water footprints.

For the analysis of material footprint, we used biological raw material consumption (RMC) indicator, covering the domestic consumption of biotic raw materials, e.g. agricultural, forest and aquatic raw materials used in the whole life-cycle of the product or services, including food, feed as well as biomass used for the production of material and energy. The indicator under discussion is one of the most important indicators of bioeconomy because bio-resources are the most fundamental of all the material flows as they are providing food for life on Earth and are virtually irreplaceable (Weisz et al., 2006).

Land footprint encompasses the main resources of biomass (cropland, pastures, and forests). This indicator has been defined as the land area used to produce the goods and services dedicated to satisfying the domestic final demand of a country (territory) regardless where this land was actually used (O'Brien et al., 2017). In the present paper, the land footprint was allocated to the four land-use types: cropland, forest land, pastures and other land.

Water footprint covers green and blue water used in the bioeconomy. The blue water footprint refers to the amount of surface and groundwater consumed, but the green water footprint is composed of the quantities of precipitation water released into the atmosphere by the evapotranspiration of the plant and the evaporation of the soil during the growing period (or lifetime) of a crop (Egenolf and Bringezu, 2019; Hoekstra, 2017).

We calculated these footprints on the basis of environmentally extended multi-regional input-output (MRIO) analysis, using data from EXIOBASE 3.7. Database (Stadler et al., 2018) covering 48 countries and regions and 165 industries for each of them for the years 2011–2015. Environmentally extended MRIO modelling has already been widely used in many studies to inform discussions in global material, land and water use policies (Galli et al., 2013; Giljum et al., 2015; Lenzen et al., 2013; Steen-Olsen et al., 2012; Wiedmann et al., 2015). This approach allows us to determine the direct and indirect material, land and water footprints associated with the final consumption within a country. We followed this approach in the present study as it has the advantage of the full coverage for all economic activities (O'Brien et al., 2017).

To calculate material, land and water footprints, we used the open-source input-output (IO) analysis tool - *pymrio* (https://github.com/konstantinstadler/pymrio) and Python programming language. The footprint results were calculated on the basis of classic Leontief demand-style modelling (Leontief, 1986), using the following equation:

$$L = (I\text{-}A)^{-1} \quad (1)$$

where, A is the inter-industry coefficient matrix and I - the identity matrix of A, and L is the Leontief inverse or total requirements matrix ($(I\text{-}A)^{-1}$) capturing direct and indirect economic inputs to satisfy one unit of the final demand in monetary value.

To move from monetary to biophysical units and calculate the total (direct and indirect) consumption-based land, water and material footprints (D_{cba}), we first extended the MRIO framework with a matrix of the direct sectoral land (km^2/million EUR), water (million m^3/million EUR) and material (1000 t/million EUR) input intensity coefficients (e), and calculated consumption-based impact intensity matrix E:

$$E = e(I\text{-}A)^{-1} = eL \quad (2)$$

The total D_{cba} were then calculated from the IO accounts by multiplying the matrix E, which incorporates direct and indirect footprints per unit of output, by the matrix of the total final demand on products and services in that particular year (y):

$$D_{cba} = Ey \quad (3)$$

The total production-based footprints (D_{pba}) where calculated summing up a row vector of sectoral land, water and material input coefficients (F) and the impacts associated with the final demand (G) (if existant):

$$D_{pba} = F + G \quad (4)$$

To measure the efficiency with which ecological resources are used to satisfy human needs, we used the following eco-efficiency indicators: the bio-resource productivity according to formula (5) and the intensity of land and water footprint expressed in formulas (6) and (7). All the eco-efficiency indicators were calculated for both production- and consumption-based footprints.

$$\text{Bio-resource productivity} = GDP_{PPS} \ / \ \text{Material footprint (MF)} \quad (5)$$

where GDP in euros is expressed in Purchasing Power Standard (PPS) provided by Eurostat and material footprint (1000 t).

$$\text{Land intensity} = \text{Land footprint (LF)} \ / \ GDP_{PPS} \quad (6)$$

$$\text{Water intensity} = \text{Water footprint (WF)} \ / \ GDP_{PPS} \quad (7)$$

In this study, we focused on nine BSR countries (Finland (FI), Sweden (SE), Denmark (DK), Germany (DE), Poland (PL), Lithuania (LT), Latvia (LV) and Estonia (EE)) which are at different stages of the development of their national bioeconomy strategies.

3. Research results and discussion

3.1. Material footprint (MF)

Our results demonstrated that bioeconomy is an important consumer of biotic resources in all the BSR countries. In 2015, bioeconomy was responsible for the consumption of 76% of fishery resources, 64% of fodder crops, 59% of forest resources, 44% of crop residues, 43% of grazing resources and 36% of primary crops. However, the share of bioeconomy in the consumption of abiotic resources is not significant – bioeconomy is only responsible for the consumption of 5% of fossil fuel, 4% of non-metallic minerals and 4% of metal ores.

Analyzing consumption-based bio-resource footprint, in 2015, the biggest per capita biotic resource footprint in the BSR was in Finland and Sweden, 9.8 and 8.3 t/cap respectively (see Fig. 1). This could be explained by the relatively high forest resource footprints in both countries. Furthermore, Weisz et al. (2006) explain high biomass consumption in Sweden and Finland by a low population density (25 and 18 persons per km^2 respectively) in these countries. When compared to 2011, in Finland, the consumption-based bio-resource footprint decreased, but in Sweden, it slightly increased by 0.3%. The lowest biotic resource footprint was in Poland and Estonia – 3.5 and 4.5 t/cap respectively. Despite the fact that Estonia and Latvia have a similar population density (30 persons per km^2) to the Scandinavian countries, their consumption-based biotic resource footprints are significantly lower. However, between 2011 and 2015, the growth in consumption-based bio-resource footprint was observed in all the Baltic States.

Taking into account the sustainable level of the total resource consumption estimated to be below 10 t/cap in 2050 (Laakso and Lettenmeier, 2016) or 70% reduction in per capita resource consumption compared to 2008 (Bringezu and Schütz, 2014; O'Brien et al., 2013, 2014a,b), all the BSR countries should develop bioeconomy strategies aiming for a significant decrease in the biotic resource consumption and improved efficiency. Thus, in the future, the main question of how to implement a bioeconomy strategy and enhance the substitution of non-renewable materials with renewable ones at the same time reducing material consumption.

Furthermore, considering the share of bio-resource in the total RMC, bio-resources account for more than one-fifth of the total consumption-based RMC in all the BSR countries. In 2011, the lowest share of the consumption of bio-resources was observed in Poland (21%), whereas in Latvia and Lithuania the share was the highest, i.e. 31%. In 2015, the situation changed: in Estonia the share of bio-resources in the consumption-based material footprint decreased to only 19%. It might be due to the fact that in Estonia the bioeconomy strategy is still under development and the government has no particular commitments to increase bioeconomy activities. Meanwhile, in 2015, the biggest share of bio-resources (34%) was observed in Finland, i.e. 2% increase compared to 2011. In Germany and Sweden, where the bioeconomy strategy was already adopted in 2012, the share of bio-resources in RMC decreased in 2015 compared to 2011. Thus, in these countries, the implementation of bioeconomy strategies did not lead to increased consumption of biotic resources.

There are even greater differences in terms of the share of production-based RMC among the BSR countries. From Fig. 2 we can see that Germany and Poland have the lowest per capita footprints, whereas in Latvia and Finland – the highest. Furthermore, almost in all the BSR countries (except Sweden), the production-based bio-resource consumption increased in 2015 compared to 2011. The biggest changes were observed in Latvia and Estonia, where this variable increased by 22% and 23% respectively.

Lithuanian and Latvian economies are much more reliant on the production of bio-resources than other countries around the Baltic Sea as biotic resources account for more than half of the production-based RMC. Furthermore, in Latvia, the share of production-based bio-resources had the highest increase between 2011 and 2015. This result can be explained by the fact that the share of agricultural land in Latvia and Lithuania is 30% and 47% respectively of all the land use. While other BSR countries have more diversified economies in terms of resource input. The smallest share of production-based bio-resources in RMC was observed in Poland, but also in Sweden and Germany, the share of bio-resources was low. Moreover, when comparing 2011 and 2015, the biggest drop in the share of the consumption of production-based bio-resources was in Sweden. Thus, despite the implementation of bioeconomy strategy, the consumption of biotic resources in Sweden stabilized, but it did not really help to minimize the consumption of other types of resources.

As illustrated in Table 1, in 2015, biotic resources embedded in the production was significantly bigger (by the factor 0.61 and 0.56 respectively) in Estonia and Latvia than resources embedded in the consumption, thus, these countries are net exporters of biological resources. Therefore, Estonia and Latvia should pay more attention to the development of higher value-added bioeconomy activities at the national level. In Lithuania and Poland, the highest share of the produced biotic resources was consumed domestically. Meanwhile, in other BSR countries (Germany, Denmark, Finland and Sweden), the use of consumption-based resources was higher; particularly, in the case of Germany this ratio was almost two times higher than that of the use of production-based resources. Therefore, these countries are recipients and depend on the export of bio-resources from other countries. For this reason, they should pay particular attention to the reduction of the consumption of bio-resources, the enhancement of efficiency and development of domestic production capacities.

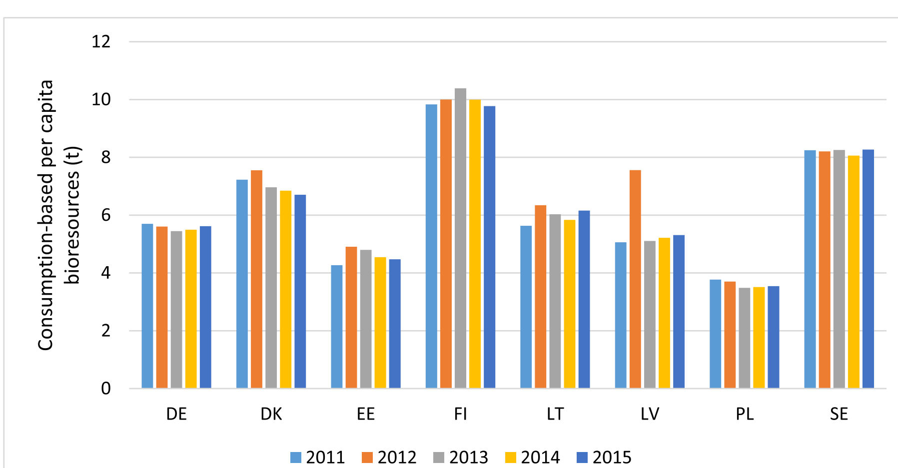

Fig. 1. Changes in the consumption-based per capita bio-resource footprint in the BRS countries from 2011 to 2015.

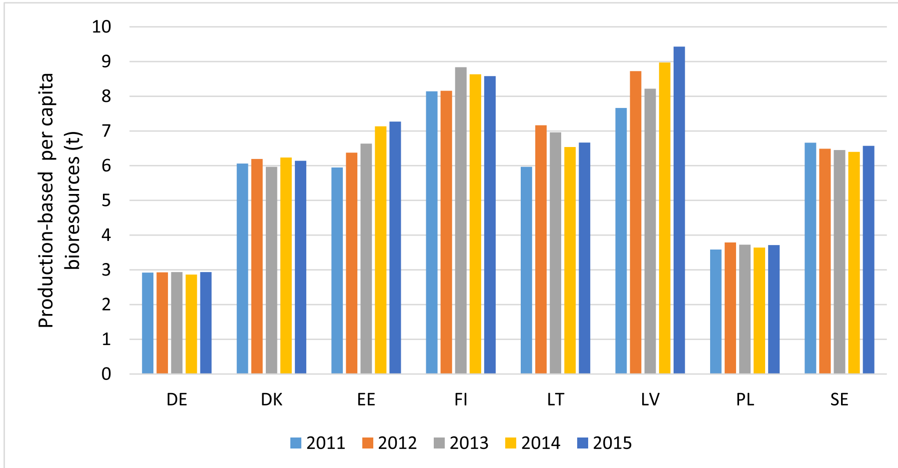

Fig. 2. Changes in the production-based per capita bio-resource footprint in the BRS countries from 2011 to 2015.

Table 1
The comparison of consumption and production-based RMC in 2015, million t.

	DE	DK	EE	FI	LT	LV	PL	SE
Consumption footprint	456.0	38.0	5.9	53.4	18.0	10.6	134.7	80.6
Production footprint	238.3	34.7	9.6	47.0	19.5	18.7	141.1	64.1
Consumption vs production footprints	1.91	1.09	0.61	1.14	0.92	0.56	0.95	1.26

3.2. Land footprint (LF)

The biggest consumption and production-based land footprint is associated with forest land, followed by cropland and pastures. Only in the case of Denmark, it is cropland and not forest that is the biggest land footprint category. This can be explained by the fact that Denmark places a high emphasis on livestock farming, which has high biological resource intensity. Germany, as the biggest economy, accounts for 48% of all the consumption-based and 46% of the production-based land footprint of the BSR in 2015.

Finland and Sweden are leaders in the consumption-based land footprint, but Poland has the lowest footprint. When analyzing changes in the consumption-based land footprint, it can be observed that in all the BSR countries (expect Latvia), land footprint slightly decreased from 2011 to 2015, Poland demonstrating the steepest decrease, i.e. by 15.3% (Fig. 3, left side). As far as the production-based land footprint is concerned, only in three BSR countries (Lithuania, Poland and Sweden) the reduction was observed from 2011 to 2015. Meanwhile, in Estonia, the growth of the footprint was the highest (by 33%) from 2011 to 2015 and almost reached Finland's level. Differences among the countries are significant: in Germany, the per-capita production-based land footprint is almost 10 times lower than in Estonia and Finland (Fig. 3, right side).

Table 2 demonstrates that the production-based land footprint in Germany, Denmark, Finland and Poland exceeds the land footprint embedded in the consumption, but three Baltic States are much more self-sufficient in terms of the land use. However, in the case of Estonia, the production-based land footprint is even bigger than the whole territory of the country. It could be explained by the fact that in Estonia, a significant part of the land-intensive national production is exported. However, consumption-based land footprints are significantly smaller. Thus, instead of the developing bioeconomy at the national level, Estonia is a donor of biotic resources to other countries. However, Germany and Denmark are consuming more land resources than their national territory could support; therefore, their consumption patterns are dependent on other countries.

Finland has the highest consumption- and production-based per capita land footprint. This is mostly due to the significant forest land footprint in Finland (0.043 km^2 per capita in 2015), which is 3.5 times above the average in the region. The second most

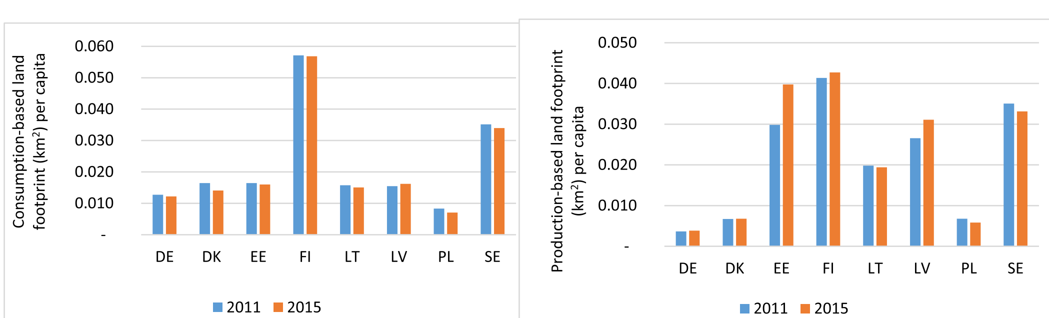

Fig. 3. Changes in the consumption-based (on the left) and production-based land footprint (on the right) in 2011 and 2015.

Table 2
Land footprint embedded in the consumption and production of the Baltic Sea countries in 2015 (th. km^2).

	DE	DK	EE	FI	LT	LV	PL	SE
Consumption footprint	990.7	79.6	21.0	310.9	43.9	32.1	267.6	331.2
Production footprint	311.3	38.4	52.3	233.7	56.7	61.8	221.5	322.9
Territory of the country	357.4	43.1	45.2	338.4	65.3	64.6	312.7	450.3
Consumption footprint/Territory	277%	185%	47%	92%	67%	50%	86%	74%
Production footprint/Territory	87%	89%	116%	69%	87%	96%	71%	72%

important footprint is the cropland footprint, but there are no such differences among the countries. For what concerns the production-based per capita land footprint, there is a bigger diversity, but for all the countries (except Denmark), forest land is responsible for the biggest per capita land footprints (see Fig. 4). Some authors (Bringezu et al., 2012, 2014; O'Brien et al., 2014a,b) suggest the sustainable land footprint target to be reached by 2030 to be at 0.002 km^2 cropland per capita. For all the countries around the Baltic Sea, cropland consumption land footprint is significantly above this target – from 0.0025 km^2 in Poland to 0.0052 km^2 in Finland. Unfortunately, to the best of our knowledge, there are no studies suggesting the total sustainable land footprint targets.

3.3. Water footprint (WF)

In the case of the water footprint, Germany stands out as a dominant economy in the region – it alone is responsible for 56% of the production-based and 66% of the consumption-based water footprint in the BSR. Green water is the biggest contributor to the water footprint, on average making up to 91% of the consumption-based and 97% of the production-based water footprint. The blue water footprint is significantly lower. In all the countries, except for Lithuania and Latvia, the consumption-based water footprint is bigger than the production-based water footprint. In Sweden, the difference is more than 5 times, in Finland, more than 3 times, but in Germany two times (see Table 3).

The global annual water footprint is currently averaging at 1400 m^3 per capita and, taking into account the growing world population, the sustainable per capita water footprint level in the future should not exceed 1000 m^3 (Hoekstra, 2017). Despite the decrease of consumption-based water footprint from 2011 to 2015 in all the BSR countries (Fig. 5 left side), currently, it is Poland that is closest to this target with 1280 m^3 per capita. The highest consumption-based per capita water footprint was observed in Germany and Denmark, where it is more than two times above the sustainable level – 2250 and 2130 m^3 per capita respectively.

During the analysed period, the production-based water footprint increased in the BSR countries, where the level of the footprint was the biggest (Lithuania, Denmark, Latvia and Estonia). Meanwhile, in Finland and Sweden, the level of the water footprint was the lowest and the reduction from 2011 to 2015 was observed (Fig. 5 right side).

3.4. The eco-efficiency of bioeconomy in the BSR countries

Resource productivity shows how much value-added can be generated per ton of the material used. In this paper, we looked specifically at the bio-resource productivity. Results indicate that it has been increasing in all the countries around the BSR. However, there are significant differences among countries. The lowest productivity was observed in Finland, Lithuania and Latvia. The year 2012 stands out for Latvia with a significant productivity loss. This can be explained by a significant increase in the consumption of primary crop, specifically palm kernel oil, in that particular year. FAO State data shows that imports of palm kernel oil increased from 56 tons in 2011 to 173 tons in 2012 and then dropped to 105 tons in 2013 (FAO Stat, 2019). Meanwhile, the highest bio-resource productivity was observed in Germany, Denmark and Poland, with the highest growth in the latter country. In Poland, bio-resource productivity increased by 20% (Fig. 6) between 2011 and 2015. This way Poland is demonstrating significant progress in the sustainability of its bioeconomy. Meanwhile, in Finland, in the same time-period the productivity of bio-resource increased the least, only by 0.3%. Thus, despite the fact that a lot of attention in the bioeconomy strategy is paid to the environmental aspect, as the sustainability of biomass use, the policymakers face a great challenge to enhance necessary social and technical innovations throughout the supply chain to ensure the necessary increase in bio-resource productivity and decrease in the total material throughput.

When comparing land intensity (km^2/GDP), we can identify three groups of countries: Estonia and Latvia stand out with the highest land intensity; Sweden, Finland and Lithuania have a

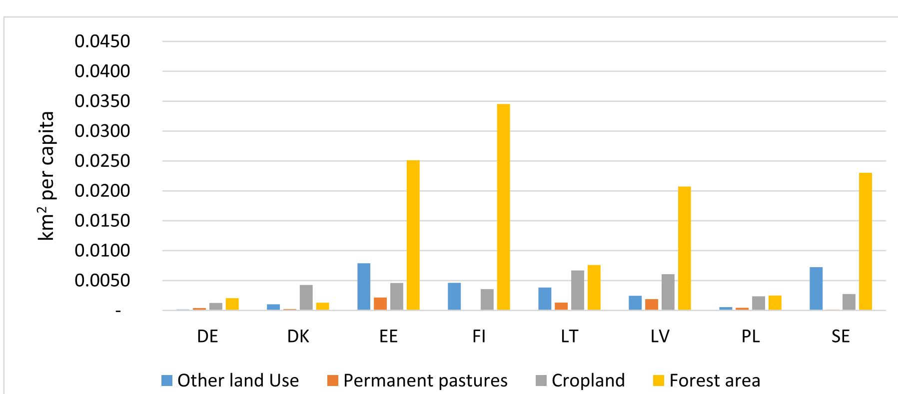

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Fig. 4. The production-based per capita land footprint (km^2 per capita) in 2015.

Table 3
The water footprint embedded in the consumption and production of the Baltic Sea countries in 2015 (mil. m^3).

	DE	DK	EE	FI	LT	LV	PL	SE
Consumption	182819	12040	2184	8865	5185	2942	48680	16297
Production	88826	9506	1691	2920	5439	3186	43380	3139
Consumption/Production	206%	127%	129%	304%	95%	92%	112%	519%

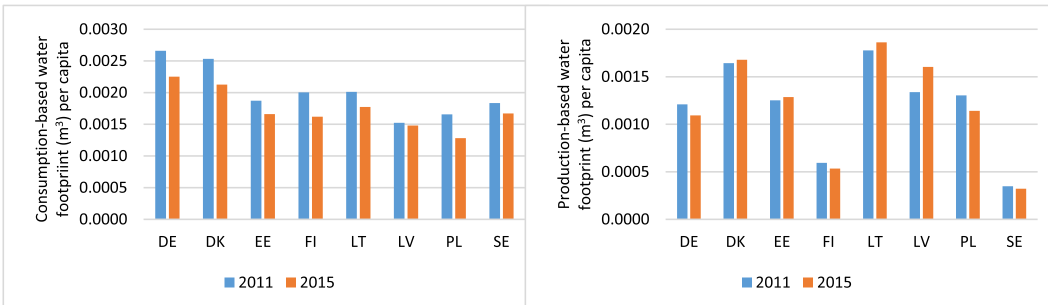

Fig. 5. Changes in the consumption-based (on the left) and production-based water footprint (on the right) in 2011 and 2015.

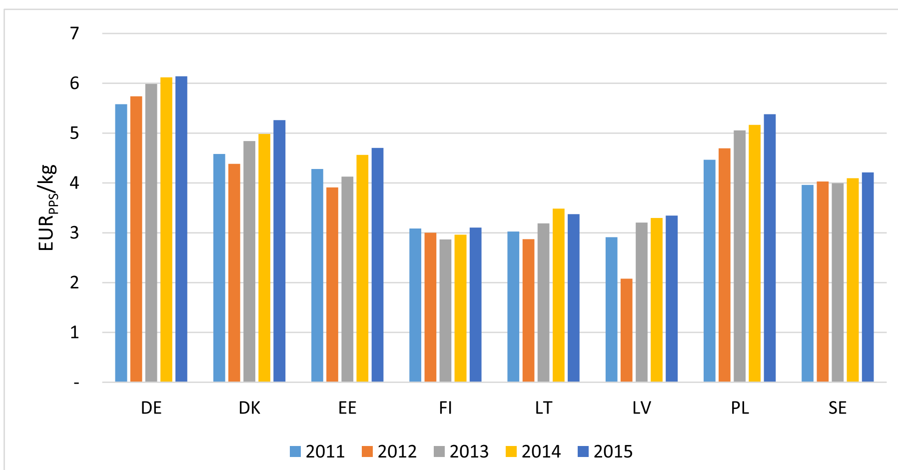

Fig. 6. Bio-resource productivity (GDP in EUR_{PPS}/DMC) from 2011 to 2015.

medium intensity; whereas Germany, Denmark and Poland have the lowest intensity (Fig. 7). The highest standard deviation is for the forest land footprint. Our results on biotic resource production across the countries of the BSR reveal that countries with the lowest per capita DMC have the most intensive land-use systems, associated with comparatively high environmental pressures

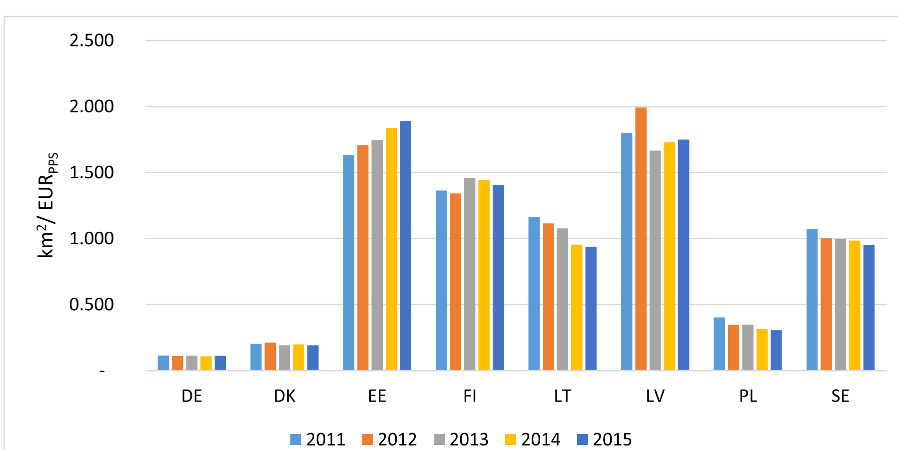

Fig. 7. Land footprint intensity (Land use/GDP in EUR_{PPS}) from 2011 to 2015.

(measured e.g. in terms of fertilizer application). Countries with the highest values of per capita DMC of biomass show the lowest values of biomass DMC per km^2. For example, Finland's and Sweden's DMC of biomass amounts to 198–201 t of biomass per km^2 of the land footprint. The extraction of biomass in these countries is already in the order of magnitude of their natural bio-productivity. Therefore, this result can be explained by a low level of fertility and ineffective agriculture policy.

When analyzing the changes in land footprint intensity, the biggest reduction was observed in Poland (by 24%). Thus, it can be stated that Poland successfully achieved the efficiency of bioeconomy targets. Furthermore, considering the territory of the country, Poland has the biggest potential to develop bioeconomy and it does it most effectively. However, in Estonia and Finland, the increase in land footprint intensity was observed during the analysed period (Fig. 8). Estonia's production-based land footprint exceeded the territory of the country (Table 3), thus, in this country, particular attention should be paid to the enhancement of the efficiency of the land use.

The results in Fig. 8 show that water footprint intensity decreased in all the countries around the Baltic Sea. The biggest reduction from 2011 to 2015 was observed in Poland (22%), but the smallest in Latvia (0.5%). The biggest production-based water intensity was in Lithuania and Latvia; however, the lowest one was observed in Finland and Sweden. Thus, despite the high level of production-based bio-resource and land footprint level, the water usage in these countries is rather efficient.

4. Conclusions and policy implication

In recent years, the BSR has paid particular attention to bioeconomy and prepared its development vision. In the implementation of bioeconomy, environmental aspects play the most important role, whereas despite the fact that biomass is a renewable resource, unsustainable use of biomass could hinder the implementation of bioeconomy and destabilize ecological foundation. Thus, the aim of this paper was to compare bio-resource, land and water footprints in the countries of the BSR, couple these footprints with economic indicators and assess the ecoefficiency of bioeconomy, which is particularly important when seeking sustainable bioeconomy.

The results show that there are significant differences among the BSR countries in terms of the share of consumption- and production-based bio-resources in total RMC. Despite the fact that Germany and Sweden are the first countries from the region adopting their national bioeconomy strategies, the share of consumption- and production-based bio-resources in RMC in 2015 was lower in these countries compared to other BSR countries and it decreased in comparison to 2011. Therefore, in order to ensure the sustainability of bioeconomy, countries should focus more on how to ensure the development of bioeconomy and the substitution of non-renewable resources with sustainably managed renewable resources and come up with the specific targets in this regard. Furthermore, the policymakers should intensify the development of sustainable bioenergy, which also contributes to the mitigation and adaptation of climate change, the conservation of biological resources and other sustainability aspects.

The production-based bio-resource footprint between 2011 and 2015 grew in all the BSR countries, whereas, in the same period of time, the consumption-based bio-resource footprint grew only in the Baltic States. From all the BSR countries, Germany, Denmark, Finland and Sweden are recipients and depend on the imports of bio-resources from other countries. Taking into account the fact that the BSR countries are exceeding the sustainable level of resource consumption, the countries should develop bioeconomy strategies aiming at more sustainable resource consumption and also take into account international trade flows in order to ensure they deal with the possible resource leakage, when more intensive bioresources are directly and indirectly (embedded) imported from other countries. Furthermore, the setting of the upper biomass consumption levels should be included in these strategies. One way to deal with these limits is to apply the trade permission system or Cap and Trade schemes, which are flexible environmental regulations and are used to deal with the greenhouse gas emissions.

Finland and Sweden remain the leaders in the consumption- and production-based land footprint. In all the BSR countries (expect Latvia), the consumption-based land footprint decreased from 2011 to 2015. Meanwhile, the production-based land footprint decreased only in Lithuania, Poland and Sweden. Considering the territory of the country, Estonia's production-based land footprint is even bigger than the whole territory of the country, thus, a significant part of the land-intensive national production is exported. However, Germany and Denmark consumed more land resources than their territories could support; therefore, their consumption patterns are dependent on other countries. Furthermore, unfortunately, in all the BSR countries, the land footprint is significantly above the sustainable land footprint target. Therefore, the BSR bioeconomy strategies should aim at the enhancement of the productivity of the land use and consider implementing measures to respect planetary boundaries and the capacity of ecosystem

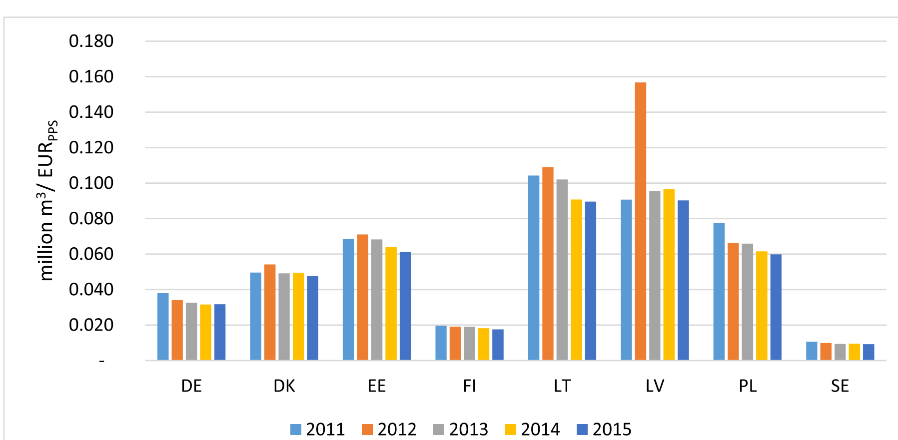

Fig. 8. Water footprint intensity (Water use/GDP in EUR$_{PPS}$) from 2011 to 2015.

services.

All the BSR countries experienced a reduction in the consumption-based water footprint; however, the sustainable water use target was not reached in any of the BSR countries. In Germany and Denmark, this target was exceeded more than 2 times in 2015, whereas during the analysed period, the production-based water footprint increased in the BSR countries already demonstrating high water footprint. Therefore, policymakers should also promote the efficiency of water usage in the bioeconomy sector.

The analysis of the eco-efficiency of bioeconomy revealed significant differences in the bio-resource productivity, land and water intensity among the countries. From the sustainable development perspective, the increase in bio-resource productivity and the decrease in water footprint intensity in all the BSR countries are evaluated positively. The most positive changes were observed in Poland. Thus, Poland, compared to the rest of the BSR, was more successful in ensuring high eco-efficiency of its bioeconomy. However, it was in Estonia and Finland that the increase in land footprint intensity was observed during the analysed period, which is an unsustainable trend. Thus, when implementing bioeconomy and seeking sustainable development, the countries primarily set an objective to achieve a higher level of efficiency in biomass, land and water footprints. These targets should be included in the bioeconomy strategies and the policymakers should seek the implementation of sustainable bioeconomy by promoting social innovations and technological development.

BSR countries are demonstrating bigger progress in reducing consumption-based bioeconomy footprint but production-based footprints, with some exceptions, during the study period have been increasing. However, further research is needed to better understand the trends of bioeconomy footprints and drivers behind them. They should be further studied using decomposition analyses and expending the study period.

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