Economic and environmental implications of a target for bioplastics consumption: A CGE analysis

S. Haddad[1]; N. Escobar[2]; W. Britz[1]

1: Institute for Food and Resource Economics, Economic Modeling of Agricultural Systems Group, Germany, 2: Institute for Food and Resource Economics, Chair of Economics of Sustainable Land Use and Bioeconomy, Germany

Corresponding author email: neus.escobar@ilr.uni-bonn.de

Abstract:

Private and public initiatives worldwide encourage a shift towards more sustainable production and consumption patterns, including bioplastics. These are, however, essentially produced from food crops. Given the manifold support schemes for the promotion of bioenergy, bioplastic producers also claim for targeted policies. This can further increase competition for biomass globally, with unintended consequences for food prices and the environment. A comprehensive analysis of the effects of a 5% target for bioplastic consumption is presented based on Computable General Equilibrium (CGE) linked to environmental indicators. Both "fossil-based plastics" and "bioplastics" are implemented in the GTAP 9 database. Two scenarios are defined: scenario 1 increases consumption taxes on "fossil-based plastics" while scenario 2 decreases them for "bioplastics". Although both generate an expansion of the sector, the tax performs better in economic and also environmental terms, partially due to the substitution for oilseeds in the major producing regions, which even generates afforestation in carbon-rich areas. Only the target in scenario 1 generates an increase in GDP per CO2-eq. saved at global scale. The study shows the usefulness of CGE models as a tool to analyze cost-effectiveness of Bioeconomy-related policies, provided that emerging bio-based sectors and novel technologies are adequately implemented.

Acknowledgement: This research has been funded by the German Federal Ministry of Education and Research within the project STRIVE (Sustainable Trade and Innovation Transfer in the Bioeconomy). More information at: www.strive-bioecon.de

JEL Codes: O38, Q24

#1444

IAAE

Economic and environmental implications of a target for bioplastics consumption: A CGE analysis

Abstract

Private and public initiatives worldwide encourage a shift towards more sustainable production and consumption patterns, including bioplastics. These are, however, essentially produced from food crops. Given the manifold support schemes for the promotion of bioenergy, bioplastic producers also claim for targeted policies. This can further increase competition for biomass globally, with unintended consequences for food prices and the environment. A comprehensive analysis of the effects of a 5% target for bioplastic consumption is presented based on Computable General Equilibrium (CGE) linked to environmental indicators. Both "fossil-based plastics" and "bioplastics" are implemented in the GTAP 9 database. Two scenarios are defined: scenario 1 increases consumption taxes on "fossil-based plastics" while scenario 2 decreases them for "bioplastics". Although both generate an expansion of the sector, the tax performs better in economic and also environmental terms, partially due to the substitution for oilseeds in the major producing regions, which even generates afforestation in carbon-rich areas. Only the target in scenario 1 generates an increase in GDP per CO_2-eq. saved at global scale. The study shows the usefulness of CGE models as a tool to analyze cost-effectiveness of Bioeconomy-related policies, provided that emerging bio-based sectors and novel technologies are adequately implemented.

1. Introduction

Plastics are highly demanded by many economic sectors across the economy due to their interesting qualities in terms of versatility and durability, and also relatively low production costs. Indeed, global plastic production has been growing exponentially and it is expected to reach up to 1.2 billion tonnes annually in 2050 (EC 2017). Plastics –also called polymers- are made from polymerization of resins, most of them being based on carbon and hence considered organic chemicals. However, in conventional plastics, carbon ultimately comes from heavy crude oil; thus, their production is linked to fossil resource depletion and climate change. It is estimated that 90% of plastics are produced from fossil fuel feedstock and production gives rise to approximately 400 million tonnes of greenhouse gas (GHG) emissions per year globally. If current trends continue, by 2050, the plastic sector could be responsible for 20% of global oil consumption and 15% of the global annual CO_2 emissions (EC 2017). Non-biodegradability or long durability of conventional plastics generates additional environmental problems after end-of-life as plastic debris pollutes the oceans, as well as natural terrestrial and freshwater ecosystems. The majority of fossil-based plastics are indeed not biodegradable, namely polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polyolefins such as polyethylene (PE) or polypropylene (PP).

The disadvantages of conventional plastic explain the growing interest for polymers based on biologic renewable resources, i.e. biomass, hereinafter called *biopolymers* or simply *bioplastics*. However, these can also be either biodegradable or not. The global production capacity of bioplastics has been increased from 1.5 to 1.9 million tonnes in the period 2012-2015, and is forecasted to reach 6.7 million tonnes in 2018 (Rivero et al. 2016). Still, this barely represents 1% of total production of plastics, and mostly corresponds to non-biodegradable bioplastics that allow for direct substitution of the most common fossil-based plastics, i.e. bio-polyethylene (bio-PE) and bio polyethylene terephthalate (bio-PET). Although these will still dominate the market in the medium term, the share of bio-based and biodegradable plastics (e.g. polylactic acid –PLA-, polyhydroxy alkonates –PHA- or polyhydroxy butarate –PHB-) is meant to increase to up to 2.5% of the total plastic production by 2020 (European Bioplastics 2016), mainly for packaging. China-Korea, the United States (US), the European Union (EU) and Brazil are currently the leading bioplastic producers, although further capacity increases are still expected in the Asian-Pacific region (European Bioplastics 2016). Future market developments will depend on international trade, new conversion technologies for feedstock diversification, and not at least policies. While a diversity of schemes and instruments exists, the support for bioplastics has been very limited (OECD 2013). Bioplastic producers worldwide increasingly demand targeted policies in the framework of a circular economy, pointing to the various large-scale support initiatives to renewables, including biomass-based ones such as biofuel or biogas.

The main feedstocks currently used for bioplastic production differ depending on the region, but are all conventional food crops, while second generation technologies are not yet implemented on a commercial scale. Hence, increased bioplastic production is expected to put additional pressures on limited resources such as land and water. The amount of the impact clearly hinges on biomass conversion efficiencies and future market penetration (Posen et al. 2017), which depends in turn on the technical substitution potentials in the industry, production costs for both conventional and bioplastics, and policy instruments. Some authors focus on the GHG performance relative to the fossil counterpart by means of Life Cycle Assessments, on a case-by-case basis (Groot and Borén 2010; Philp et al. 2013; Tsiropoulos et al. 2015). However, a comprehensive evaluation of the environmental impacts of an increase in biomass consumption for material uses at global scale is lacking. These include land use change (LUC), both direct and indirect (dLUC and iLUC, respectively), which contribute to global warming by changing carbon stocks. While dLUC is the direct land conversion to grow, in this case, bioplastic feedstock, iLUC refers to the successive adjustments in land use for other crops, forestry and grasslands due to price changes. In particular, iLUC has been subject to much scrutiny in the case of biofuels, frequently by means of Computable General Equilibrium (CGE) models since iLUC is market-mediated (Lambin and Meyfroidt 2011). The advantage of CGE analysis is that it consistently captures the inter-sectoral and factor market linkages in the whole economy and endogenously models land use intensification and LUC (Wicke et al. 2014). Commercial bioplastics are, however, not represented in the latest version of the widespread GTAP database (Aguiar et al. 2016), which basically serves as the basis for all global CGE studies. To the best of our knowledge, only Lee (2016) made an attempt to implement "bioplastics" as a sector in GTAP 8 (Narayanan et al. 2012), built on 2007 data. The author applies a recursive-dynamic approach with a focus on the economic effects in key Asian countries, hence neglecting global environmental effects. In view of this gap, our study has three main objectives: a) to quantify the land use implications and greenhouse gas (GHG) emissions of expanded bioplastic consumption at global scale; b) to evaluate economic vs. environmental trade-offs of enforcing bioplastic targets in leading producing regions; and c) to improve both the GTAP 9 database (Aguiar et al. 2016) and CGEBox (Britz 2017) by introducing conventional and bioplastics as additional sectors for further assessment of the sustainability of bioplastic-related policies in the Bioeconomy.

2. Methods

2.1. Model

This study takes the standard GTAP model (Hertel 1997) as the starting point, as implemented in CGEBox (Britz 2017). This is a comparative-static, multi-regional CGE model with global scope that assumes perfect competitive markets and constant returns to scale in all sectors. Drawing on neo-classical microeconomic theory, it assumes rational, fully informed decision making by aggregate firms, factor suppliers and consumers. Bi-lateral trade flows are depicted by the Armington approach, which implies that goods produced in different regions are imperfect substitutes for each other. Depending on their production technology and resource constraints, firms choose the best combination of domestic and imported input factors to maximize profits; consumers purchase goods under their money budgets to maximize utility. After a shock, prices and quantities adjust endogenously to clear all markets, i.e. demand is equal to supply at global, country, and industry level both for commodities and primary factors. Policies are in the standard model depicted by *ad-valorem* taxes and subsidies.

In addition to the standard GTAP model, various extensions available with CGEBox are employed in our study, namely: GTAP-Agr (Keeney and Hertel 2005) to better represent the characteristics of the agricultural sector; GTAP-E (Burniaux and Truong 2002) to incorporate substitution between energy sources in the production nest and calculate CO_2 emissions from the combustion of fossil fuels in value-added; GTAP-AEZ (Lee 2005) to capture competition for land between uses at the level of agroenvironmental zone (AEZ) and quantify CO_2 emissions from LUC, when coupled to carbon stock data from Aguiar et al. (2016). Non-CO_2 emissions from agricultural activities are also quantified according to Aguiar et al. (2016). As combined, these features allow for a comprehensive evaluation of the effects of increased market shares of bioplastics across all the economic sectors, in order to analyze global spillover effects including LUC and GHG emissions.

2.2. Baseline data

The study departs from the GTAP 9 database (Aguiar et al. 2016), which depicts the world economy in 2011. For the present analysis, a spatial aggregation to 35 regions has been applied, while keeping the full industry detail of 57 sectors. Despite this relatively high sectoral resolution, neither the "conventional" fossil-based plastic nor the emerging bio-based plastic sectors are explicitly captured. Hence, the database needs to expanded to include these two industries, by following a "top-down" approach as proposed by Lee (2016). This consist of breaking down the chemical sector into two sub-sectors, namely "plastics" and "rest of chemicals"; the former is further broken down into "fossil-based plastics" and "bio-based plastics". The disaggregation is carried out by using the split utility comprised in CGEBox (Britz 2017), using output and feedstock cost shares for the leading producing regions, namely, the US, the EU, China and Brazil.

These shares are calculated as follows. Firstly, the share of the plastic sector relative to overall chemical production in the original database is estimated based on output values for the year 2013 (Lee 2016; PlasticsEurope 2015). Secondly, the share of bioplastic production relative to total plastics is calculated from installed production capacities in the year 2013 (Shen et al. 2009). The following assumptions have been taken to map feedstocks and regions, given the diversity of biopolymer families and the limited data availability for being a strategic market segment. Data suggest that Brazil is currently focused on bio-PE, although PHB is also produced in small amounts, both from sugarcane; the EU utilizes mainly wheat for thermoplastic starch (TPS) blends, although other coarse grains may be employed if intermediate demand for bioplastic production increases; China relies on corn and other cereals for the production of both PLA and PHB, while the US mainly uses domestic corn for the same purposes. Output shares of the three new sectors are calculated following Eq. 1 – 3, by using calculated output values, by taking bioplastic prices from OECD (2013) and 2013 crop prices from FAO (2017). Only first generation biopolymers, i.e. derived from annual crops, are considered, while second generation ones, based on lignocellulosic feedstocks, are excluded from the analysis as there are not implemented in commercial industries.

$$biop(r) = \frac{output(r,biop)}{output(r,plas)} \times \frac{output(r,plas)}{output(r,chem)} \quad \text{(eq. 1)}$$

$$plas(r) = \frac{output(r,plas)}{output(r,chem)} \quad \text{(eq. 2)}$$

$$otherchem(r) = 1 - plas(r) \quad \text{(eq. 3)}$$

Where biop(r) refers to the output share of bioplastics in each producing region (being zero in non-producing ones); plas(r) is the output share of total plastics; and otherchem(r) is the share of other chemicals, all of them relative to total production of chemicals. Calculated output shares are shown in Table 1. As a rule of thumb, it has been assumed that the fossil plastic sector represent 20% of the chemical sector in all the countries. After all these adjustments, the contribution of the four regions under study to the world's overall plastic output in our baseline, including both fossil-based and bio-based plastics, is shown in Figure 1.

Table 1. Calculated output shares (%) for total plastics and bioplastics.

	US	Brazil	China	EU28
Share of total plastics in the chemical industry	18.21	16.78	19.50	15.89
Share of bioplastics in the plastic industry	1.01	2.38	0.10	0.09
Share of bioplastics in the chemical industry	0.18	0.40	0.02	0.02

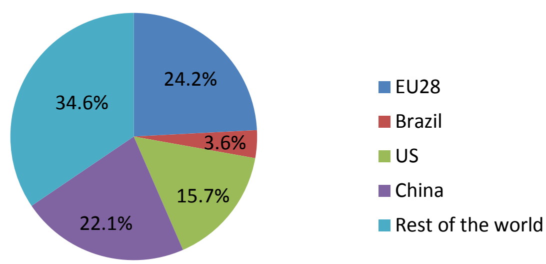

Figure 1. Regions' output shares (in values) in the overall plastic market, after implementing fossil-based plastics and bioplastics in GTAP 9.

Modifications in the cost structure of these two industries are then necessary in order to capture differences between the production technologies of the newly created sectors. While the fossil-based plastic sector employs crude oil, assumed equal to the extent it is used in the parent chemical sector, the bio-based plastic sector is shifting to biologic raw material, i.e. crop biomass. The share of agricultural feedstock relative to overall production costs in the aforementioned focus regions has been updated based on technical conversion efficiencies from IfBB (2016) and the same price information, depending on the bioplastic type. When a region produces more than one type, average feedstock prices and quantities are weighted by production capacities for the different bioplastic families in order to obtain a single cost share for a hypothetic aggregated biopolymer. The split utility ensures that the global Social Accounting Matrix (SAM) derived from GTAP 9 remains balanced to maintain the equilibrium conditions in all the markets in the CGE context. It also guarantees that the newly generated entries for the three new sectors exhaust exactly the original SAM entries for the total chemical sector, including bi-lateral trade flows.

As a result, a new database with 59 sectors is obtained, completely consistent with the original one, which serves as a benchmark for the experiments proposed in section 2.3. Some adjustments are still made in the underlying GTAP structure in order to: a) introduce land as a primary production factor in the production technology of the bioplastic sector, since it is not considered in the chemical sector, and

b) allow for substitution between plastics and bioplastics in intermediate demand. The latter clearly constitutes an improvement relative to the study of Lee (2016). A composite commodity “fossil-based plastics and bioplastics” is introduced in the CES demand structure of firms for intermediate inputs. A substitution elasticity of 5 is initially introduced, although the influence of this assumption will be further assessed through sensitivity analysis. The production nest is modified accordingly and shown in Figure 2.

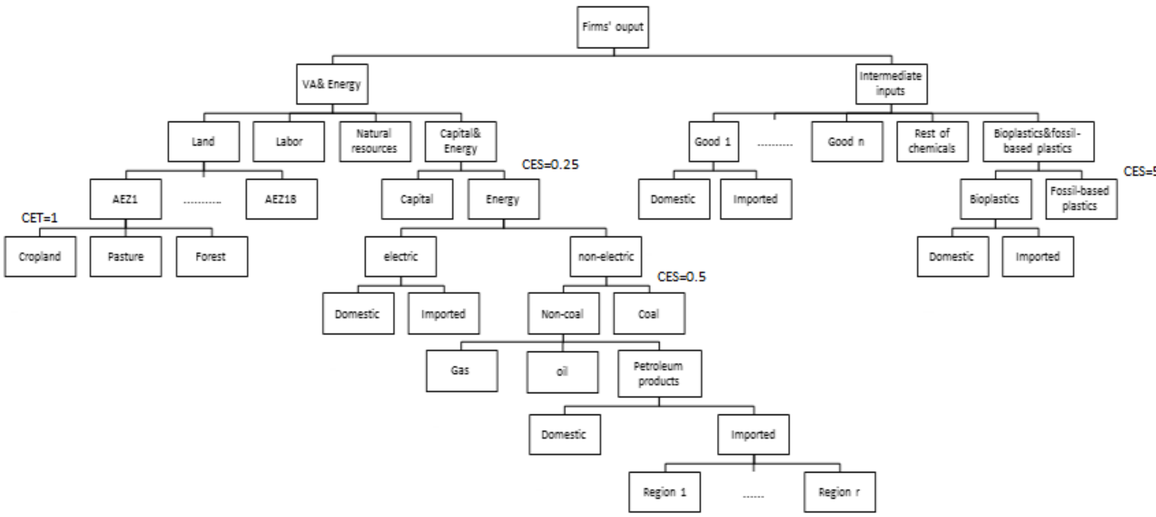

Figure 2. Improved nested production structure.

2.3. Scenarios

The experiment consists of a 5% target for bioplastics in the aforementioned regions simultaneously, relative to overall plastic consumption. This is a conservative assumption, according to the current state of technology (Morone et al. 2017), although other studies point to substitution potentials between 10-50% in 2050 (Schipfer et al. 2017). To this aim, the aggregated Armington demand for bioplastics is fixed, while consumption taxes resp. subsidies are endogenously adjusted by the model to reach the fixed targets. Two alternative scenarios are defined: scenario 1 increases consumption taxes on “fossil-based plastics” while scenario 2 decreases them for “bioplastics”, which can translate into a subsidy to consumption.

3. Results

Results for scenarios 1 and 2 are interpreted across the following sub-sections in terms of % changes relative to the generated benchmark.

3.1. Market effects

The target implies a drastic expansion of the bioplastic sector such that total output increases globally by 1250% in scenario 1 and 1300% in scenario 2, as shown in Table 2. The effect is greater in China and the EU, which account for the largest share of the total plastic market (Figure 1), while the share of bioplastics in the baseline is much lower than in Brazil and the US (Table 1). The bioplastic production in the US and Brazil reacts stronger to the tax on the substitute in scenario 1, compared to subsidizing its production in scenario 2; the opposite is true for China and the EU. This is also linked to the cost structure in each country and differential feedstock prices in the world market after the shock: both China and the EU employ wheat and other cereals, highly demanded for other uses, while corn and sugarcane are more readily available in the US and Brazil, respectively. This can be also explained by the fact that corn and sugarcane were already used in the chemical sector of these two countries in the original database, reflecting ethanol production in the year 2011; hence, a shrinkage in the fossil-based plastic sector frees up feedstock resources for bioplastic production in the US and Brazil.

The expansion in bioplastics comes at the cost of the fossil-based plastic sector's output, as defined in the shock. Specifically, it is reduced on average by 9.25% in scenario 1 and 1.85% in scenario 2. The differences can be firstly explained by changes in the average price levels for plastics as an aggregate. A tax on conventional plastics increases the costs of the aggregate and tends to reduce overall plastic demand and hence production. Secondly, given the assumed somewhat limited substitution (elasticity = 5) between the two types of plastics, stronger price effects are necessary to yield the targeted level of bioplastics used. Consequently, the effect of a tax in consumption of conventional plastics is much stronger, especially in the US (-15.37%), the EU (-13.85%) and Brazil (-11.04%). In scenario 1, only the contraction in China is smaller than the world average (-2.27%), given the size of its total chemical industry, which is the greatest as compared to the other countries (Figure 1). The subsidy in scenario 2 generates a decrease in the production of fossil-based plastics in the range of 2-4% in the four analyzed regions as the average price for plastics increases.

The effects of the target on the intermediate demand for crops in the bioplastic industry are similar in the two scenarios, although some differences can be observed, in tune with the relative expansion of the sector. There is a greater demand for feedstock in the US and Brazil and a lower demand in China and the EU under scenario 1. This is ultimately driven by price effects in the international market, which are shown in Table 3 and discussed below.

Table 2. Supply and demand effects in the sectors directly affected by the shock, as a % change relative to the baseline.

	Scenario 1					**Scenario 2**				
	World	US	Brazil	China	EU28	World	US	Brazil	China	EU28
Total output										
Bioplastics	1246.4	590.7	257.3	5330.9	4329.2	1303.1	483.5	227.8	5581.4	5399.0
Fossil-based plastics	-9.25	-15.37	-11.04	-2.27	-13.85	-1.85	-3.37	-4.06	-2.62	-1.97
Intermediate demand for crops in the bioplastic sector										
Sugar	278.4	-	257.3	-	-	250.0	-	227.8	-	-
Wheat	4360.3	-	-	5330.9	4328.6	5404.6	-	-	5881.4	5398.8
Cereal grains (inc. corn)	1486.8	590.7	-	5330.5	4329.3	1483.0	483.5	-	5881.2	5399.0

The production costs of bioplastics in the tax scenario 1 increases by 1.93%, 2.52% and 0.26% in the US, Brazil and the EU, respectively, but they decrease in China by 1.31%, hence in the world as a whole. This is due to the target on total demand, which drives up or down production costs subject to feedback effects across input markets. As overall production of conventional plastics is reduced substantially in scenario 1, the impact on the production costs for bioplastics depends mainly on the price developments of inputs used both in conventional and non-conventional plastics, as well as for agricultural feedstocks only employed in bioplastics. The reduction in the output of conventional plastics translates into a push to other sectors that use the same primary factors; this effect is greater in scenario 1 and especially in China. Scenario 1 reduces non-biomass input costs for bioplastics enough to decrease overall production costs. Note that the tax is levied on consumption, i.e. it needs to offset these cost savings, hence additionally shifts the demand composition of plastics towards the target level for bioplastics. In scenario 2, with a subsidy on the consumption of bioplastics, production costs per unit increase between 0.06% and 0.56% in the four regions, with the highest increase for China.

Prices of all agricultural feedstocks are increasing with the shock, especially under scenario 1 which generates the strongest effects in both the sugar and corn markets. Brazilian sugar and US corn are traded internationally and consumed in many sectors worldwide, with the two countries representing a significant share of the global supply. Thus, feedback effects throughout agricultural markets are greater with the tax on conventional plastics consumption, which generates larger increases in overall bioplastic output in these two regions. The world market price of sugar is 2.33% higher relative to the baseline, while the price for other cereal grains (which comprises corn) increases by 4.47% in scenario 1. In scenario 2, world market prices increase less than 1% for all the key crops. The larger increase (0.83%) is observed for cereal grains, which are increasingly consumed in the Chinese bioplastic sector, given the limited availability of wheat; the domestic price of cereal grains in China increases by 3.15%.

Table 3. Effects on primary factor prices and production costs of conventional plastics and bioplastics, and the associated feedstocks, as a % change relative to the baseline.

	Scenario 1					**Scenario 2**				
	World	US	Brazil	China	EU28	World	US	Brazil	China	EU28
Bioplastics	-0.08	1.93	2.52	-1.31	0.26	-0.37	0.08	0.20	0.56	0.06
Fossil-based plastics	-0.08	1.50	2.02	-3.07	-1.16	0.02	-0.01	0.09	0.03	-0.02
Sugar	2.33	-	3.68	-	-	0.10	-	0.38	-	-
Wheat	3.96	-	-	4.45	6.37	0.24	-	-	0.40	0.67
Cereal grains (inc. corn)	4.47	4.42	-	6.89	7.54	0.83	0.52	-	3.15	0.57
Capital	-0.14	1.69	2.06	-8.08	-3.22	-0.02	-0.01	0.13	-0.01	-0.04
Unskilled labor	-0.45	1.81	2.62	-7.33	-3.84	0.02	-	0.18	0.09	0.04
Skilled labor	0.27	1.73	2.09	-7.51	-2.77	-0.02	-	0.10	-0.03	-0.04
Land	4.26	4.72	2.73	5.20	5.05	0.77	1.04	0.88	1.89	1.23

Changes in primary factor prices, also shown in Table 3, are also greater in scenario 1, reflecting overall high production levels of plastics. Overall, both skilled and unskilled labor become more expensive in the US and Brazil, and cheaper in China and the EU, in scenario 1. There is also higher capital use in the corn and sugarcane agricultural sectors of the US and Brazil, which drives higher prices, while the price of capital drops in China and the EU. The implications in scenario 2 are much smaller, which leads to the conclusion that the effects of a tax on the consumption of bioplastics are smaller across the whole economy, relative to a tax on the consumption of fossil-based plastics. In this case, only unskilled labor becomes more expensive, especially in Brazil. Land prices are all increasing, by 4.26% in scenario 1 and 0.77% in scenario 2, with the greater effects in China and the EU where competition for agricultural land between uses is stronger and there is less room for deforestation.

3.2. Economic effects

The economic implications of these changes can be seen in Table 4. There is a substantial GDP drop in scenario 1 (-0.25% at the world level), especially in China (-0.44%) and the EU (-0.82%); the global decrease is about 0.03% in scenario 2, being also the greatest in China (-0.11%) and the EU (-0.06%). This highlights the higher potential for a tax on conventional plastics consumption to generate negative income effects.

Table 4. Economic effects in terms of GDP and GDP per capita.

	Scenario 1					**Scenario 2**				
	World	US	Brazil	China	EU28	World	US	Brazil	China	EU28
Total Real GDP (billion $)	71,303.5	15,522.7	2,476.0	7,289.5	17,522.2	71,458.1	15,531.8	2,476.3	7,314.1	17,656.4
GDP per capita ($)	10,252.0	49,818.9	12,572.9	5,423.2	34,508.6	10,274.2	49,848.1	12,574.2	5,441.5	34,772.8
% change relative to benchmark	-0.25	-0.07	-0.03	-0.44	-0.82	-0.03	-0.02	-0.02	-0.11	-0.06

3.3. Environmental effects

Environmental implications of the target are analyzed in terms of changes in land area extension, i.e. LUC, and GHG emissions, including CO_2 emissions from LUC, non-CO_2 emissions, i.e. N_2O and CH_4 from agriculture, and CO_2 emissions from energy consumption in the industry. GHG results can be taken as the total life cycle emissions of the entire economy for the reference year, since they ultimately include emissions embodied in the value added, all in terms of CO_2-eq.

3.3.1. Land use changes

As a consequence of the market effects described in section 3.1, overall agricultural land expands by 0.08% in scenario 1 and 0.03% in scenario 2, at the cost of both managed forest and pasture. The decreases in these land categories are much smaller in scenario 2 though; only 0.03% in the two uses relative to 0.15% and 0.20% in forest and pasture, respectively, in scenario 1. Changes in land cover per AEZ are shown in Figures 3-5. Specifically, Figure 3 captures changes in cropland area in scenario 1 (a) and scenario 2 (b), relative to the baseline with no target on bioplastic consumption; Figure 4 (a,b) captures changes in forest area, while Figure 5 (a,b) focuses on pasture land.

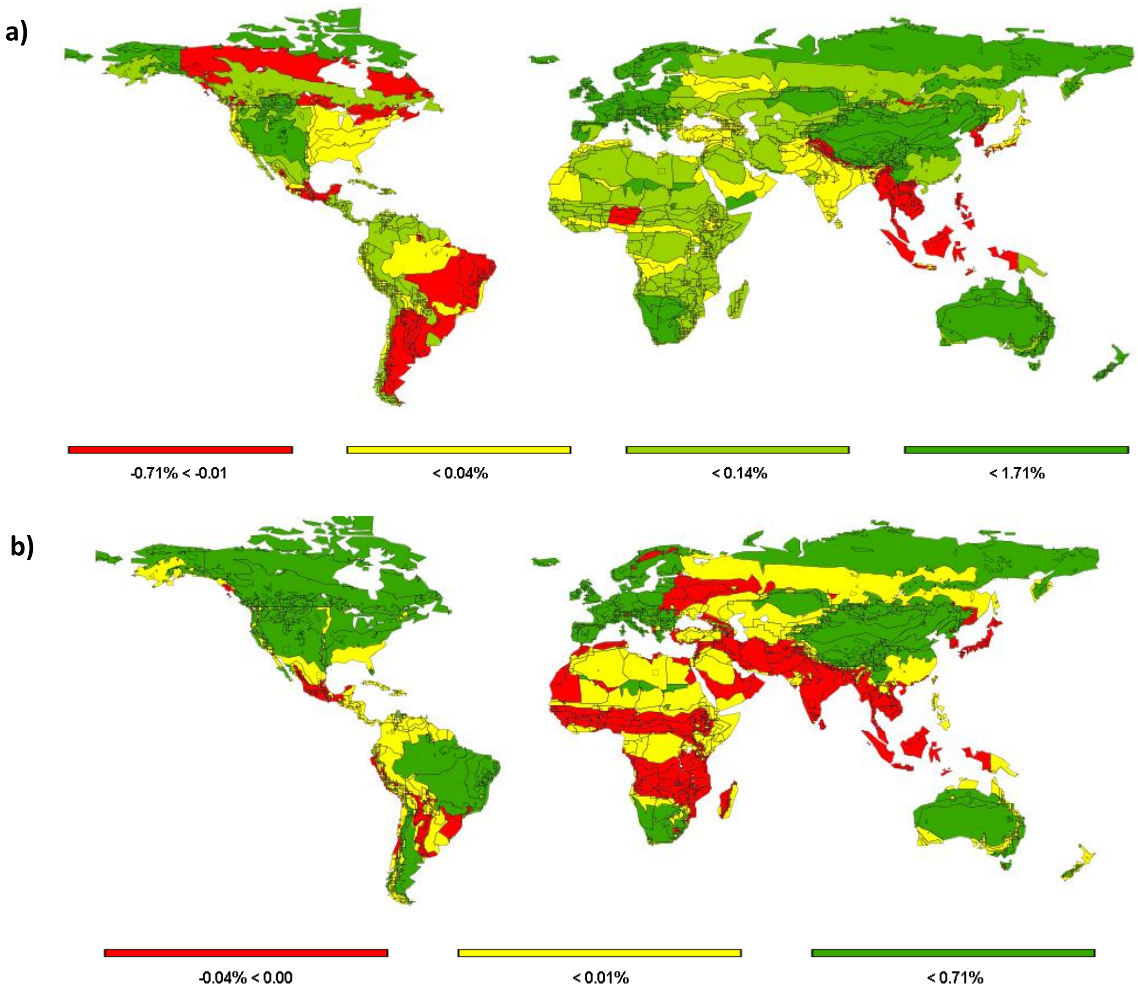

Figure 3. Changes in cropland extension in scenario 1 (a) and scenario 2 (b).

Scenario 1 points to an expansion in cropland between 0.14% and 1.71% in most of the EU countries, most of China and surroundings, Australia, West of the US, Southern African countries and Northern Russia; while an area contraction up to 0.71% is observed in specific AEZs of Canada, Brazil, Argentina and Southeast Asia (Figure 3a). This is due to the fact that coarse grains for bioplastic production are expanding at the expense of oilseeds. The picture in Figure 3b is slightly different, with cropland area increasing in the EU, China and Australia, but to a lower extent (between 0.01% and 0.71%) and also in most of Brazil, Argentina and the US. Other countries of Sub-Saharan Africa, the Middle East and India are, on the contrary, subject to a decrease in cropland. As mentioned in section 3.1, the bioplastic target affects agricultural markets to a smaller extent when it implies a subsidy on bioplastic consumption.

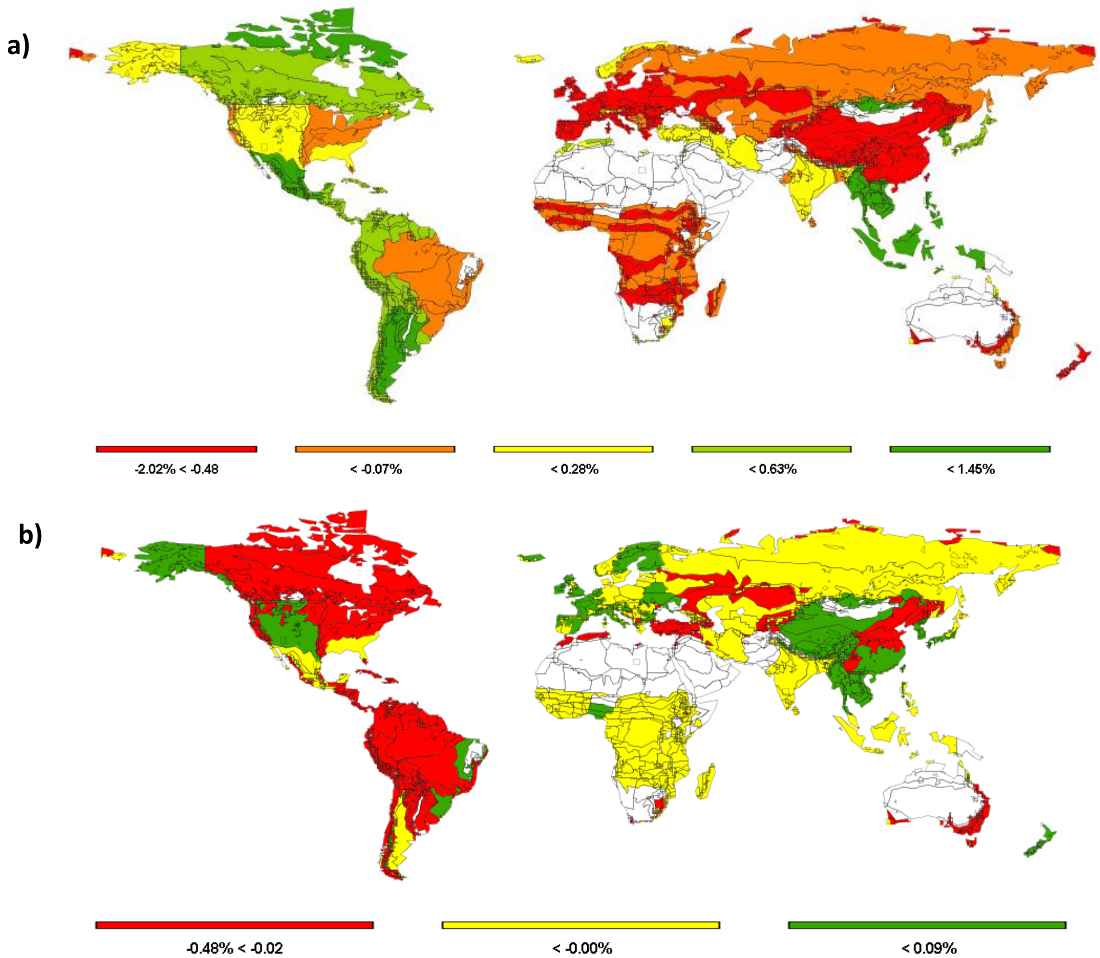

Figure 4. Changes in forest area extension in scenario 1 (a) and scenario 2 (b).

As for the forest area, the two scenarios deliver very different results. Scenario 1 points to an expansion in the area diverted to managed forest mainly in Canada, Southeast Asia, and Latin America, between 0.28% and 1.45% (Figure 4a); possibly due to the decrease in the total production of oilseeds in these regions. On the contrary, forest decreases between 0.07% and 2.02% in a larger extension of Eurasia, Sub-Saharan Africa and also the US Corn Belt and Brazil. These are essentially the regions supplying feedstock for bioplastic production. In scenario 2 (Figure 4b), forest decreases up to 0.48% in large areas of the whole American continent, including Brazil and the US Corn Belt, while there is a small afforestation across Eurasia and Sub-Saharan Africa. Pastureland is clearly shrinking in North America, Africa and Australia in the two scenarios, although differences are also detected for South America, mainly Brazil, the EU and China. In Figure 5a, pastureland expands in both Brazil and Argentina up to 1.32%, while decreases between 0.01% and 0.58% in Figure 5b. This is again due to the effects of the bioplastic target on oilseeds production, which also propagate through the livestock sector. In Brazil, oilseed production decreases by 1.02% in scenario 1 while increases by 11.49% in scenario 2, at the expense of pasture. In the EU, oilseed production is decreasing by 5.4% in scenario 1, hence pastureland is affected to a lower extent than it is in scenario 2, in which overall oilseed production increases slightly (0.01%).

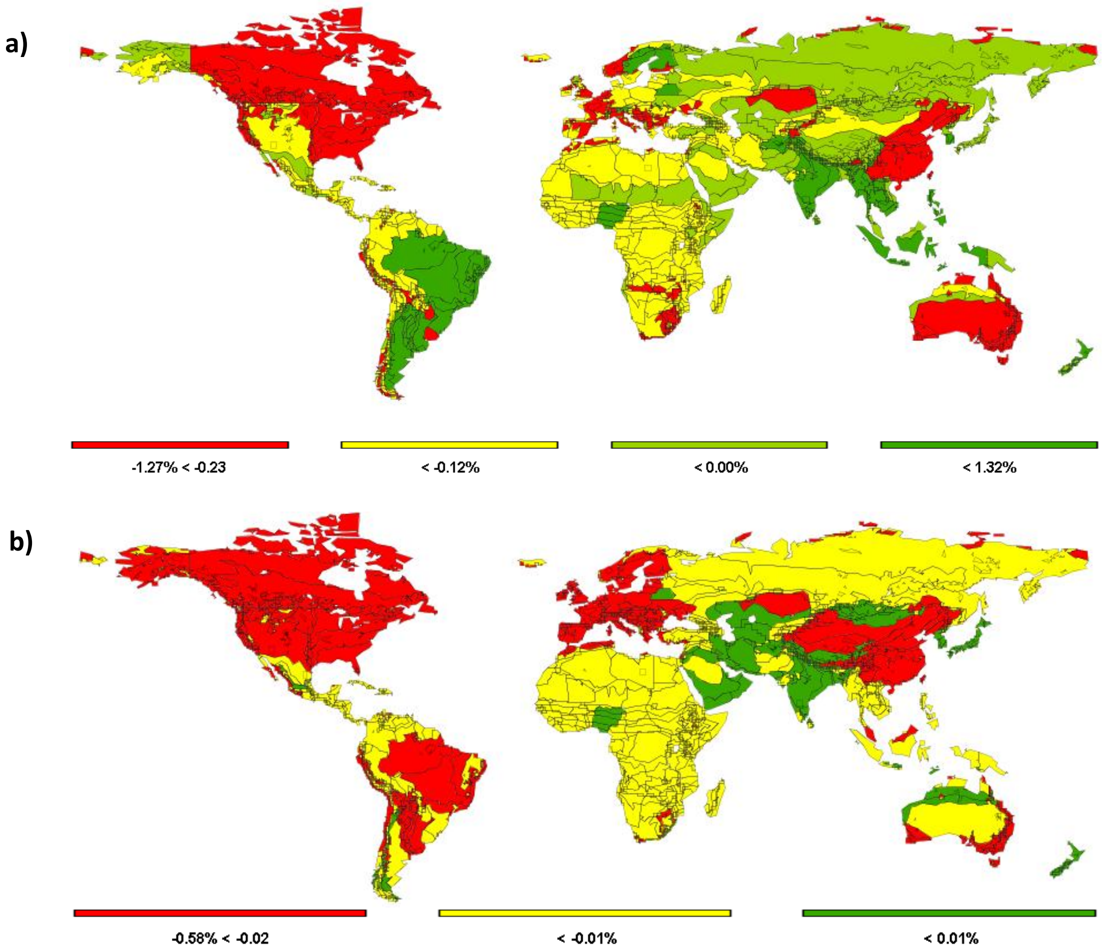

Figure 5. Changes in pastureland extension in scenario 1 (a) and scenario 2 (b).

3.3.2. Greenhouse gas emissions

In the baseline, the four regions under study account for around 55% of the global GHG emissions, expressed as CO_2-eq. As can be observed in Table 5, both CO_2 and non-CO_2 emissions decrease in scenario 1, while a small increase is detected in scenario 2, relative to the baseline. The regions that generate the highest reduction in scenario 1 are China (-2.9%) and the EU (-4.1%), mainly in terms of non-CO_2 emissions from agriculture, as shown in Figure 6. This means that there is a reduction in the input intensity, while also emissions from energy and LUC are decreasing in these two regions (-1.5% in total) and also in the rest of the world (-0.35%). On the contrary, an increase in emissions from fertilizer application can be observed in the US (0.11%). In scenario 2, all the regions together, including the rest of the world, are increasing non-CO_2 emissions by 1.36%, while the increase in CO_2 emissions is slightly positive (+0.17%). This indicates that only the implementation of the target by means of a tax on fossil-based plastic consumption (scenario 1) is effective in reducing overall GHG, when also LUC is taken into account.

Table 5. Greenhouse gas (GHG) emissions captured by the model, in Mt of CO_2-eq.

	Baseline		Scenario 1		Scenario 2	
	CO2 emissions	non-CO2 emissions	CO2 emissions	non-CO2 emissions	CO2 emissions	non-CO2 emissions
China	6370.22	947.44	6342.19	920.33	6375.12	949.66
US	4705.74	193.56	4700.7	193.78	4705.54	194.59
Brazil	308.12	65.63	307.82	65.49	308.15	65.77
EU28	2906.14	329.84	2876.58	316.35	2909.2	331.05
Rest of the world	11102.72	1783.35	11086.37	1795.27	11100.74	1783.55
Total	25392.94	3319.82	25313.66	3291.22	25398.75	3324.62

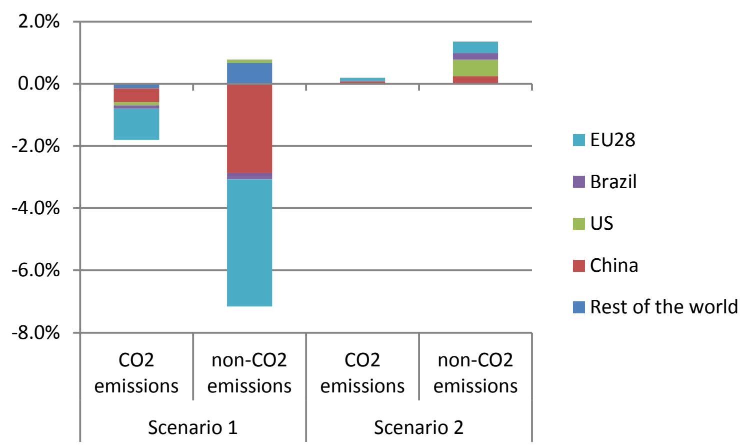

Figure 6. Changes in total greenhouse gas (GHG) emissions, as a % change relative to the baseline.

4. Discussion

Results from section 3 allow for the economic vs. environmental trade-offs of enforcing bioplastic targets in leading producing regions to be assessed in terms of cost-effectiveness to decrease global GHG emissions. Specifically, the ratio of the change in real GDP (billion $) to the change in GHG (Mt of CO_2-eq.) is calculated. It must be emphasized that the latter account for all the emissions generated by all the economic sectors through a) energy consumption in the production of goods and services, b) emissions from fertilizer application, and c) changes in land carbon stocks. The ratio is estimated at +1.63 in scenario 1 and -2.02 in scenario 2, both in billion $ per Mt CO_2-eq. This means that the target on bioplastic consumption only generates an increase in GDP per Mt of CO-eq. saved when enforced by means of a tax on conventional plastics.

As happens in all modeling exercises, outcomes are ultimately influenced by model assumptions. In this case, the substitution elasticity between plastics and bioplastics can play a crucial role in both economic and environmental outcomes, to be further evaluated by means of a sensitivity analysis. The substitution elasticity should capture real substitution potentials of specific bioplastics for the fossil-based equivalent. These depend, in turn, on the use biopolymers are diverted to in the industry (e.g. packaging, automotive, equipment, machinery). Different substitution potentials could also be assumed for each country, depending on the bioplastic family that prevails in the market. Furthermore, new capacities and technologies are expected to emerge in these and other regions in the short- and medium-term; this would imply additional efforts in order to improve the benchmark based on real world production data. Also, refining the cost shares in the conventional and non-conventional plastic sectors would help to better reflect future market effects driven by the consumption of intermediate inputs, i.e. biomass vs. crude oil.

Different types of bioplastics can lead to different impacts at the end-of-life depending on their biodegradability and recyclability properties. Further disaggregation of the newly implemented bioplastic sector would be desirable for a more thorough analysis of these effects in the context of more efficient production systems. Finally, as observed for biofuels, increasing targets on bioplastics can lead to increased footprints, including land, in countries not necessarily implementing the policy. It must be recalled that the present exercise simulates a conservative target, while authors point to much larger market substitution (Schipfer et al. 2017); for instance, up to 85% in the EU market. This would deliver greater spillover environmental effects due to international trade.

5. Conclusions

A 5% target for the increase in consumption of bioplastics in leading producing regions, i.e. the US, the EU, China and Brazil, has been analyzed by means of the broadly used CGE model GTAP. To this aim, the database underlying GTAP 9 has been modified by disaggregating two new sectors from the original chemical sector, namely “fossil-based plastics” and “bioplastics”. This entails an important contribution since it is based on real production capacities. Two different policy instruments have been endogenously determined in scenarios 1 and 2 in order for the target to be reached. Although both the tax on conventional plastics consumption (scenario 1) and the subsidy on bioplastics consumption (scenario 2) clearly generate an expansion of the sector, the tax performs better in economic and also environmental terms. This is partially due to the substitution for oilseeds in the major producing regions, which even generates afforestation in carbon-rich AEZs. The cost-effectiveness of the target has been ultimately calculated as the ratio of the change in income to the change in environmental impact, in this case, GHG. Only scenario 1 delivers a positive ratio, implying an increase in real GDP (billion $) per Mt of CO_2-eq. reduced at global scale. The present study shows the usefulness of CGE models as a tool to analyze cost-effectiveness of Bioeconomy related policies, provided that emerging bio-based sectors and novel technologies are adequately implemented. Improvements in conversion efficiencies, but also development of new pathways using diversified sources could alter the picture, greatly influenced by international trade of agricultural commodities.

Acknowledgements

This research has been funded by the German Federal Ministry of Education and Research within the project STRIVE (Sustainable Trade and Innovation Transfer in the Bioeconomy). More information at: www.strive-bioecon.de

References

Aguiar, A.; Narayanan, B.; McDougall, R. (2016): An Overview of the GTAP 9 Data Base. In JGEA 1 (1), pp. 181–208. DOI: 10.21642/JGEA.010103AF.

Britz, W. (2017): CGEBox – a flexible and modular toolkit for CGE modelling with a GUI. Institute for Food and Resource Economics (ILR). Bonn (Germany). Available online at http://www.ilr.uni-bonn.de/em/rsrch/cgebox/cgebox_GUI.pdf.

Burniaux, J. M.; Truong, T. (2002): GTAP-E: An Energy-Environmental Version of the GTAP Model. Center for Global Trade Analysis, Purdue University. West Lafayatte, IN (United States). Available online at https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=923.

EC (2017): European Commission. Strategy on Plastics in a Circular Economy. Brussels (Belgium). Available online at http://ec.europa.eu/smart-regulation/roadmaps/docs/plan_2016_39_plastic_strategy_en.pdf, checked on 5/8/2017.

European Bioplastics (2016): Global bioplastics production capacities continue to grow despite low oil price. Stronger political support needed to realise full potential of bio-based materials in Europe. Available online at http://www.european-bioplastics.org/market-data-update-2016/.

FAO (2017): Food and Agriculture Organization of the United Nations. FAOstat. Prices. Available online at http://www.fao.org/faostat.

Groot, W. J.; Borén, T. (2010): Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand. In Int J Life Cycle Assess 15 (9), pp. 970–984. DOI: 10.1007/s11367-010-0225-y.

Hertel, T. W. (1997): Global Trade Analysis: Modeling and Applications: Cambridge University Press.

IfBB (2016): Biopolymers facts and statistics 2016. Institute for Bioplastics and Biocomposites. With assistance of Fakultät II Maschinenbau un Bioverfahrenstechnik. Edited by Hochschule Hannover. Available online at http://ifbb.wp.hs-hannover.de/wp-content/uploads/2015/11/IfBB-Biopolymers-facts-and-statistics-edition-2-2015-e-version.pdf, checked on 4/27/2017.

Keeney, R.; Hertel, T. W. (2005): GTAP-AGR: A Framework for Assessing the Implications of Multilateral Changes in Agricultural Policies. Center for Global Trade Analysis, Purdue University. West Lafayatte, IN (United States). Available online at https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1869.

Lambin, E. F.; Meyfroidt, P. (2011): Global land use change, economic globalization, and the looming land scarcity. In Proceedings of the National Academy of Sciences of the United States of America 108 (9), pp. 3465–3472. DOI: 10.1073/pnas.1100480108.

Lee, D. H. (2016): Bio-based economies in Asia. Economic analysis of development of bio-based industry in China, India, Japan, Korea, Malaysia and Taiwan. In International Journal of Hydrogen Energy 41 (7), pp. 4333–4346. DOI: 10.1016/j.ijhydene.2015.10.048.

Lee, H. L. (2005): The GTAP Land Use Data Base and the GTAPE-AEZ Model: Incorporating Agro-Ecologically Zoned Land Use Data and Land-based Greenhouse Gases Emissions into the GTAP Framework. Center for Global Trade Analysis, Purdue University. West Lafayatte, IN (United States). Available online at https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1839.

Morone, P.; Papendiek, F.; Tartiu, V. E. (2017): Food waste reduction and valorisation // Food Waste Reduction and Valorisation. New York NY: Springer Berlin Heidelberg; Springer International Publishing.

Narayanan, B.; Aguiar, A.; McDougall, R. (2012): Global Trade, Assistance, and Production: The GTAP 8 Data Base. Edited by B. Narayanan, A. Aguiar, R. McDougall. Center for Global Trade Analysis, Purdue University. West Lafayatte, IN (United States).

OECD (2013): Policies for Bioplastics in the Context of a Bioeconomy. Available online at http://www.oecd-ilibrary.org/science-and-technology/policies-for-bioplastics-in-the-context-of-a-bioeconomy_5k3xpf9rrw6d-en, checked on 4/21/2017.

Philp, J. C.; Ritchie, R. J.; Guy, K. (2013): Biobased plastics in a bioeconomy. In Trends in biotechnology 31 (2), pp. 65–67. DOI: 10.1016/j.tibtech.2012.11.009.

PlasticsEurope (2015): Plastics – the Facts 2014/2015. An analysis of European plastics production, demand and waste data. PlasticsEurope. Brussels, Belgium. Available online at http://www.plasticseurope.org/Document/plastics---the-facts-2015.aspx, checked on 4/20/2017.

Posen, I. D.; Jaramillo, P.; Landis, A. E.; Griffin, W. M. (2017): Greenhouse gas mitigation for U.S. plastics production: energy first, feedstocks later. In Environ. Res. Lett. 12 (3), p. 34024. DOI: 10.1088/1748-9326/aa60a7.

Rivero, C. P.; Hu, Y.; Kwan, T. H.; Webb, C.; Theodoropoulos, C.; Daoud, W.; Lin, C.S.K. (2016): Bioplastics From Solid Waste. In Jonathan W. C. Wong, R. D. Tyagi, Ashok Pandey (Eds.): Current developments in biotechnology and bioengineering. Solid waste management. Amsterdam: Elsevier, pp. 1–26.

Schipfer, F.; Kranzl, L.; Leclère, D.; Sylvain, L.; Forsell, N.; Valin, H. (2017): Advanced biomaterials scenarios for the EU28 up to 2050 and their respective biomass demand. In Biomass and Bioenergy 96, pp. 19–27. DOI: 10.1016/j.biombioe.2016.11.002.

Shen, L.; Haufe, J.; Patel, M. K. (2009): Product overview and market projection of emerging bio-based plastics. University of Utrech. Utrech (Netherlands). Available online at https://www.uu.nl/sites/default/files/copernicus_probip2009_final_june_2009_revised_in_november_09.pdf.

Tsiropoulos, I.; Faaij, A. P. C.; Lundquist, L.; Schenker, U.; Briois, J. F.; Patel, M. K. (2015): Life cycle impact assessment of bio-based plastics from sugarcane ethanol. In Journal of Cleaner Production 90, pp. 114–127. DOI: 10.1016/j.jclepro.2014.11.071.

Wicke, B.; Verweij, P.; van Meijl, H.; van Vuuren, D. P.; Faaij, A. P. C. (2014): Indirect land use change. Review of existing models and strategies for mitigation. In Biofuels 3 (1), pp. 87–100. DOI: 10.4155/bfs.11.154.