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Bioeconomy and SDGs: Does the Bioeconomy Support the Achievement of the SDGs?

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Earth's Future



RESEARCH ARTICLE

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Key Points:

- The effects of bioeconomy activities on the Sustainable Development Goals are assessed for synergies and inferences
- Without binding regulations on sustainability, the bioeconomy has the potential to jeopardize the achievement of the SDGs
- Assumptions for the substitutability of targets and the valuing of trade-offs are shown to be crucial factors

Supporting Information:

- Supporting Information S1
- Data Set S1

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Bioeconomy and SDGs: Does the Bioeconomy Support the Achievement of the SDGs?

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Abstract This paper evaluates how bioeconomy activities, stated in the concepts of the European Union, Organisation for Economic Co-operation and Development, and the German government, potentially affect the targets of the Sustainable Development Goals (SDGs). The aim of the bioeconomy is to substitute the use of fossil resources by renewable resources, while the SDGs set targets for a holistic sustainable global development. A literature-based influence analysis on empirical studies is employed to derive three bioeconomy scenarios (business as usual, bioeconomy, and sustainable bioeconomy) and to quantify their effects on the individual SDG targets. It is shown that the bioeconomy scenario has positive as well as negative effects on the SDG targets. While targets for cleaner industrial production are strongly supported, socioeconomic targets are subject to mixed effects and environmental targets significantly hurt. This paper outlines which SDGs need special attention when implementing a bioeconomy according to the above-mentioned concepts. The results add to the debate on SDG trade-offs and on the substitutability of SDG targets. Without regulations, policies, and investments ensuring sustainability, or in case the substitutability of SDG targets is not allowed, the bioeconomy concepts have the potential to jeopardize the achievement of several SDGs. In contrast, the sustainable bioeconomy scenario assumes strong sustainability measures that reveal the extensive potential of the bioeconomy to support the achievement of the SDGs.

Plain Language Summary This research analyses if the actions planned in the bioeconomy concepts of the OECD, EU and German government support the achievement of the Sustainable Development Goals (SDGs) formulated by the United Nations. The SDGs consist of 17 goals covering nearly all aspects for a sustainable global development, like poverty reduction or marine ecosystem protection. In contrast to the unique SDGs, there are several bioeconomy concepts which are formulated individually by countries and international organizations, defined according to their political agendas. On the baseline all bioeconomy concepts have the common target to substitute fossil resources by renewable resources. However, the implementation of the bioeconomy concepts by several economic powerful countries will have large effects on the global development. This study analyses how those effects will potentially affect the achievement SDGs. The challenge thereby is to account for the multidimensionality of the bioeconomy concepts and the SDGs. The results of this research shall enable policymakers and researchers to identify critical bioeconomy SDG relations, in order to conduct further research on these critical aspects, and to adjust the implementation of the bioeconomy so that it does not constrict the achievement of the SDGs.

1. Introduction

Mankind is still unsustainably consuming natural resources and services, beyond rates at which these resources can reproduce, regrow, and regenerate, exerting thereby increasing pressures on climate, ecosystems, habitats, and biodiversity (Global Footprint Network, 2016). Yet the role of the environment and natural resources for development, wealth, and particularly poverty reduction has remained poorly acknowledged in national and international policy designs so far (Griggs et al., 2013). A tipping or even turning point toward the design of more sustainable national and international policies could be the 2030 Agenda for Sustainable Development. These Sustainable Development Goals (SDGs) have been adopted by the United Nations General Assembly in September 2015 and consist of 17 goals containing 169 specific targets (United Nations, 2015).

The global SDG framework has not been implemented into a white spot of the global policy landscape but interacts with various existing regulations and initiatives at the regional, national, and supranational levels. One prominent example for an already existing regulatory framework relates to the development and

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intensification of the bioeconomy. In contrast to the unique SDGs, there are several bioeconomy concepts that are formulated individually by countries and international organizations, defined according to their political agendas (Food and Agriculture Organization [FAO], 2016; Staffas et al., 2013). The German government defines its bioeconomy concept “as a sustainable bio-based economy oriented on the natural life-cycle of materials which can provide us with high quality products from natural resources and sufficient healthy food to satisfy the global demand” (Bundesministerium für Bildung und Forschung [BMBF], 2010, p. 3). According to the European Union (EU) “the bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy” (European Commission, 2012, p.5), whereas the Organisation for Economic Co-operation and Development (OECD, 2009, p. 22) thinks of a bioeconomy “as a world where biotechnology contributes to a significant share of economic output.” Notably, sustainability is addressed in the concept papers of the EU and the German government, while the OECD strongly considers the bioeconomy as a driver for economic growth. However, even in the concepts of the EU and Germany, the commitment to ensure sustainability of the bioeconomy remains vague, raising the highly relevant research question to which extend exiting bioeconomy policy frameworks are in line with the achievement of the SDGs. Here we present a literature-based scenario analysis to approach this question and to assess to which extent the bioeconomy concepts of the EU (European Commission, 2012), the OECD (2009), and the German government (BMBF, 2010; Bundesministerium für Ernährung und Landwirtschaft (BMEL), 2014) support the achievements of the SDGs, identifying meanwhile key requirements to make bioeconomy development sustainable.

The sustainability of bioeconomy policies has been already discussed in the literature (Birch et al., 2010; Global Bioeconomy Summit [GBS], 2015; Juerges & Hansjürgens, 2016; Pfau et al., 2014; Sheppard et al., 2011; Smolker, 2008). These studies and reports mainly criticize that measure and strategies ensuring sustainability are missing in most of the bioeconomy concepts. The final report of the GBS (2015) distinguishes between bioeconomy and sustainable bioeconomy. The authors argue that for achieving a sustainable bioeconomy, the planet’s natural capital needs to be improved and that besides technological also social innovations are crucial (GBS, 2015). This statement underlines that measuring the effects of the transition toward bioeconomy requires particular evaluation over *their* sustainability, especially regarding social and ecological implications. Moreover, while imagining a society based on renewable resources, it is important to remember that renewable resources like biomass must be given the time and opportunity to renew; thus, they must be managed sustainable (Zilberman et al., 2013). Pfau et al. (2014) argue that the bioeconomy concepts are not already sustainable by default. They emphasize that the main goals are rather the reduction of the dependence on fossil resources, followed by reducing greenhouse gases emissions and the carbon footprint. Policymakers anticipate the increasing price and environmental risks of resource extraction, as well as the dependence on potentially geopolitical unstable regions, where the remaining resources are predominantly located (Pfau et al., 2014). Thus, from their point of view the primary motivation for establishing a bioeconomy is political and economic and then environmental. While the final report of the GBS already acknowledges the potential of the bioeconomy to support the achievement of some SDGs, the other studies analyze the sustainability of bioeconomy policies in general, using different sustainability concepts and definitions.

Accordingly, this paper goes beyond these studies by directly analyzing the relationship between bioeconomy policies and the SDGs, which, in turn, provide the first global political approval of sustainable development. Most closely related to this study is the work of El-Chichakli et al. (2016). They briefly describe which SDGs might be positively affected by the bioeconomy and provide policy recommendations for supportive measures. However, the policy recommendation only scratches on the surface of the bioeconomy SDG relation and is not based on a systematic literature research. This study analyses the magnitude and relevance of the effects from bioeconomy activities on SDG targets and indicates which effects strongly support or jeopardize the achievement of the SDGs. It adds to the literature by identifying the most negative and positive effects of a bioeconomy and delivers a foundation for discussions on the sustainability of the bioeconomy as well as for optimizing the bioeconomy concepts to minimize their negative effects on SDG targets. Thus, the results of this work can be used as a guideline for policymakers to concentrate their efforts on the most important issues that may emerge from implementing the bioeconomy concepts.

The just mentioned bioeconomy activities are measures that are conducted to achieve the aims of the bioeconomy, according to the respective concepts of institutions and governments. Considering the aims, the

bioeconomy concepts and SDGs are overlapping in some aspects, and some aims of the bioeconomy activities are complementary or even identical to SDG targets. However, the bioeconomy activities can enable as well as hinder the achievement of SDG targets, especially by triggering trade-offs with SDG targets whose aspects are not considered in the bioeconomy concepts. In order to evaluate if the bioeconomy activities support or contradict the SDGs, each level of activities needs to be considered. As an example, consider the three connected aspects: increased biomass production (*aim*), farm productivity (*aim*), and use of marginal land (*activity*). Increased biomass production can have income and job market effects, while increased farm productivity may have, among others, income and environmental effects, and the use of marginal land can have negative effects for the local population and biodiversity. Thus, all three aspects are complementary but affect different SDGs. Moreover, the use of marginal land is only one of many possible activities to achieve the aim of increased biomass production, and the effects on the SDG targets from other activities may differ significantly. An important asset of this study is that it takes into account various activities for each major aim of the bioeconomy concepts and evaluates their potential effect on the respective SDGs.

A literature-based scenario analyses is employed, because econometric approaches and computable general equilibrium models are unable to cover such a wide range of dimensions that must be considered to draw a holistic picture of the bioeconomy effects on the SDGs. Up to now, comparable quantitative evaluations capture only a limited number of dimensions, concentrating on, for example, food security, productivity and land use change (Delzeit et al., 2018), or water (Howarth, 2008), or changes in biodiversity (Sheppard et al., 2011). To provide a multidimensional overview on the different affected SDGs, this study bundles the results of quantitative evaluations dealing with the respective dimension of the SDGs. Such a holistic approach, in terms of SDG dimensions, has not yet been conducted by econometric or computable general equilibrium approaches due to missing data as well as due to the complexity of the required multidimensional models. However, this study delivers a summary of the potential effects and can be used as a foundation for the selection of dimensions and the design of scenarios for future quantitative analyses.

This paper is structured as follows. Section 2 explains the literature-based scenario analysis where we use the bioeconomy definition of the German government, the EU, and the OECD to define our scenario space. Section 3 presents the results, discussing for the SDGs 1 to 3, 6 to 9, and 12 to 15 the interaction with the bioeconomy and the implication of the different bioeconomy policy scenarios. Section 4 brings about the discussion and the conclusion.

2. Method

This ex ante evaluation is based on a review of scientific literature. The bioeconomy concepts are not yet fully implemented, and data on effects of bioeconomy activities are not available. However, several measures that are considered to be used for the bioeconomy have been implemented individually, and research on the effects of these measures already exists. Furthermore, scholars, governments, and international organization have published their anticipation of effects from bioeconomy activities (BMBF, 2010; BMEL, 2014; Deininger, 2013; European Commission, 2012; FAO, 2016; GBS, 2015; Levidow et al., 2012; Zilberman et al., 2013). Since this paper does not claim to judge on the probability that those expectations occur, all well-grounded expectations are included. The literature review collects papers with information on effects resulting from potential bioeconomy activities on aspects that are considered in the SDG targets. However, in rare cases the evidence for the same measure differs, which may have various reasons, such as different study design, study area, or estimation techniques. One study may find a significant evidence for an effect and another does not. Since only high-level papers are included, it is assumed that the evidences in the papers are valid. Only if a majority of the high-level papers make strong arguments rejecting the evidence for an effect, the effect is excluded.

For the literature-based influence analysis, the scientific search engine *Web of Science* is employed. A list of search words can be found in the supporting information. Among the identified articles, articles from journals ranked at least in the second quartile of their Journal Citation Reports categories were selected for the review of influences. In addition, articles and reports cited within these initially selected articles were also consulted. Table 1 provides an overview on the literature consulted for the evaluation of the bioeconomy considering the respective SDGs.

To examine the effects of bioeconomy activities on the SDGs, one needs to acknowledge which SDGs are relevant. This way, based on the literature review it is possible to analyze which targets of the various SDG

Table 1
Literature used for evaluation by SDGs

| SDG | Literature |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SDG 1 | Cotula et al. (2008); Landis et al. (2008); OECD (2009); Varshney et al. (2011); EU (2012); McMichael (2012); Tschardt et al. (2012); Deininger (2013); Hertel et al. (2013); Swinnen and Riera (2013); BMEL (2014); |
| SDG 2 | Moschini and Lapan (1997); Johns and Eyzaguirre (2007); Cotula et al. (2008); Danielsen et al. (2009); Landis et al. (2008); Smolker (2008); OECD (2009); Stein (2010); Tilman et al. (2009); Blakeney (2011); Meenakshi et al. (2010); Banward (2011); Chappell & LaValle (2011); Varshney et al. (2011); Sheppard et al. (2011); EU (2012); McMichael (2012); Tschardt et al. (2012); Deininger (2013); Hertel et al. (2013); Swinnen and Riera (2013); BMEL (2014); Lewandowski (2015); Juerges and Hansjürgens (2016) |
| SDG 3 | Alavanja et al. (2004); Kamel & Hoppin (2004); McCauley et al. (2006); OECD (2009); Jamaludin et al. (2013); BMEL (2014); Global Bioeconomy Summit (2015); Rojas Fabro et al. (2015); Wongsanit et al. (2015); & Larsen and Noack (2017) |
| SDG 6 | OECD (2009); Robertson and Vitousek (2009); Smaller and Mann (2009); Cotula (2011); Gheewala et al. (2011); Moraes et al. (2011); Raghu et al. (2011); EU (2012); Deininger (2013); Rosegrant et al. (2013); Zilberman et al. (2013); BMEL (2014) |
| SDG 7 | OECD (2008); OECD (2009); EU (2012); BMEL (2014); Bruckner et al. (2014) |
| SDG 8 | Grossman & Krueger (1995); Stern (2004); Cotula et al. (2008); Deininger (2013); OECD (2009); EU (2012); McMichael (2012); BMEL (2014) |
| SDG 9 | Cotula et al. (2008); Deininger (2013); OECD (2009); EU (2012); BMEL (2014) |
| SDG 12 | OECD (2009); Giljum et al. (2011); EU (2012); Galli et al. (2012); BMEL (2014); Hoekstra and Wiedmann (2014) |
| SDG 13 | Danielsen et al. (2009); Fargione et al. (2008); Searchinger et al. (2008); Kim et al. (2009); OECD (2009); Varshney et al. (2011); EU (2012); BMEL (2014); UN (2015) |
| SDG 14 | Beman et al. (2005); Howarth (2008); OECD (2009); Robertson and Vitousek (2009); EU (2012); BMEL (2014) |
| SDG 15 | Beman et al. (2005); Cotula et al. (2008); Howarth (2008); OECD (2009); Robertson and Vitousek (2009); Banward (2011); Ferdinands et al. (2011); Raghu et al. (2011); Sheppard et al. (2011); Chappell and LaValle (2011); EU (2012); Deininger (2013); Hertel et al. (2013); BMEL (2014); Lewandowski (2015); Juerges and Hansjürgens (2016) |

are potentially affected by the actions and plans stated in the concepts of EU, OECD, and the German government. Based on this analysis, the goals 1 to 3, 6 to 9, and 12 to 15 were identified to be influenced by bioeconomy activities (Figure 1). The goals *No Poverty*, *Zero Hunger*, and *Decent Work and Economic Growth* (SDGs 1, 2, and 8, respectively) are affected by the socioeconomic outcomes of the bioeconomy. The bioeconomy affects the job market, the agricultural commodity market, and agricultural activities in general. Therefore, employment, food security, and poverty need to be considered, as reflected by these three goals. The goal *Good Health and Well-Being* (SDG 3) is, among others, affected by investments into biotechnology research promoted by the bioeconomy concepts. According to the OECD, in 2009 about 80% of biotechnology research investments by private and public sector went to health applications (OECD, 2009). *Clean Water and Sanitation*, *Climate Action*, *Life below Water*, and *Life on Land* (SDGs 6, 13, 14, and 15, respectively) are affected by the ecological dimensions of the bioeconomy. They capture the effects of industry and agriculture on water, the atmosphere, the oceans, and land. Finally, the SDGs *Affordable and Clean Energy*, *Industry, Innovation and Infrastructure*, and *Responsible Consumption and Production* (SDGs 7, 9, and 12, respectively) reflect the bioeconomic production of goods and energy, relating in turn to the sustainable use of global resources in general. Summarized, the SDG bioeconomy relations can be bundled into three groups, with a socioeconomic, ecological, and industrial and economic dimension, whereby health is sorted to the socioeconomic dimension.

2.1. Quantification Method

For the quantification of the potential bioeconomy effects on SDGs, two major challenges must be addressed: (i) The magnitude of the effects on the SDGs is highly sensitive and depends on how the bioeconomy is implemented, and (ii) the weak definition of *bioeconomy measures* makes it very difficult to evaluate their outcomes. As an example, the EU states that “The goal is to provide agriculture and forestry with the required knowledge and tools to support productive, resource-efficient and resilient systems that supply food, feed and other bio-based raw-materials without compromising ecosystems services, while supporting the development of incentives and policies for thriving rural livelihoods” (European Commission, 2012, p. 19). The statement declares ambitious goals but remains silent on how to achieve them. There are various applicable modern agricultural techniques, like sustainable intensification, conservation agriculture, or precision agriculture,

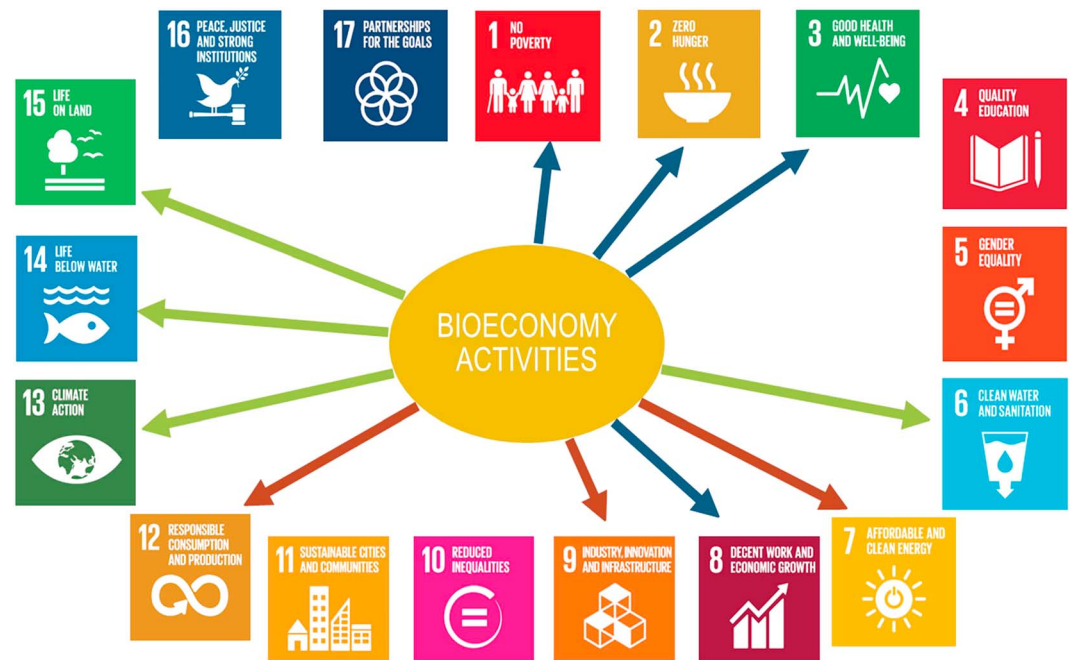


Figure 1. Sustainable Development Goals affected by bioeconomy activities. Blue arrow: socioeconomic targets; green arrow: ecological targets; red arrow: clean industry and economic targets.

each having its advantages and disadvantages. To evaluate the potential effect of the bioeconomy on the SDGs, the outcomes of all those possible approaches must be considered in course of this analysis.

Thus, since there are different possibilities for an implementation of a bioeconomy, three scenarios are employed. Scenario 1 describes the business as usual (BAU) without any implementation of the bioeconomy concepts. The demand for biomass would only grow according to population growth and anticipated preference changes through increased incomes. Also, investments into biotechnology, cleaner industries, environmental protection, and climate change mitigation remain to have a constant share of total investments.

The bioeconomy (BE) scenario is based on the concepts of the EU and OECD (European Commission, 2012; OECD, 2009). In terms of biomass, demand would increase much stronger than in the BAU scenario, but no further sustainability measures are employed. As a result, in the BE scenario, both positive and negative effects of biomass demand become more intense compared to the BAU scenario. Therefore, in line with the bioeconomy concepts, investments into biotechnology, cleaner industries, and climate change mitigation are strongly promoted and supported.

The sustainable bioeconomy (SBE) scenario is similar to the BE scenario, but sustainability measures and regulations are additionally implemented, which particularly dampen the negative effects of increased biomass demand. Some sustainability aims are taken from the concept of the German government (BMEL, 2014), but since this concept is still neglecting serious issues, further sustainability aims and measures from the literature review are considered. It needs to be noted that the sustainable bioeconomy draws an idealized sustainable world in which global regulations and measures ensuring the sustainability of the bioeconomy activities would be in place.

To evaluate the potential effect of the three scenarios on the SDGs, the following steps are taken:

1. Determine the *base value*. The effects of the bioeconomy activities are taken from the literature and matched to the respective targets of the SDGs. Those effects receive a base value denoting the relevancy of them for the SDG targets. The classification of the base values is illustrated in Figure 2. The scale is related to the work of Nilsson et al. (2016).
2. Determine the *scenario value*. The second dimension accounts for the magnitude of the effect in each of the three scenarios. Thereby, the magnitude of this scenario value takes an integer between 0 (no effect) and 3 (strong effect). The scale is selected due to the possibility to assign a different nonzero level to each

| | | | |
|---------------------|---------------------|-----------------|---------------------|
| -2 Contradicting | -1 Counteracting | +1 Promoting | +2 Complementary |
|---------------------|---------------------|-----------------|---------------------|

Figure 2. Base values. The base value reflects the relevancy of an effect on specific Sustainable Development Goal (SDG) targets. The assignment of the value to the effect is based on the literature and the wording of the SDGs. If the effect is directly mentioned in a target or can be matched perfectly, it gets one of the extreme base values. The values in the middle are assigned to effects which are related to the SDG but only weakly or indirect. Sensitivity analyses are conducted showing that this approach is robust.

of the scenarios. Further, it is important to note that an effect can be related to multiple targets, and one target can be subject to multiple positive and negative effects.

Equations (1) and (2) describe the calculation of the effect score for one SDG (E_{sg}) by adding the average positive and average negative effect for this specific SDG. Equation (3) calculates impact factor over all SDGs. The equations are as follows:

$$E_{vsg} = \frac{1}{N_{vsg}} \sum \text{Base value}_{i,vsg} * \text{Scenario value}_{i,vsg} \quad \text{for } v = \{p, c\}, \quad (1)$$

$$E_{sg} = E_{psg} + E_{csg}, \quad (2)$$

$$E_s = \sum_{g=1}^N E_{psg} + \sum_{g=1}^N E_{csg}, \quad (3)$$

where i indicates the effect; p denotes a positive effect; c , a negative effect; s , the scenario; and g , the respective SDG. One of the core principles of the SDGs is equal weighting of all SDGs (UN, 2015). This principle does not allow the weighting of the mean, and consequently, by adding up the average effects of the SDGs in equation (3), each SDG is weighted the same in the overall evaluation. However, the data in the supporting information allow the reader to assign weights to the SDG targets and produce alternative results.

When assigning the scenario and base values, taking the arithmetic mean increases the robustness of the evaluation to subjectivity and assumption errors. Compared to sums or sum of squares, adding and dropping an effect or changing the values brings only comparable small variations if the number of included values is sufficient large. The arithmetic mean is preferred to the geometric mean because the numeric range is the same for each effect, and the focus is on absolute changes not changes in rates. Since the base value and the scenario value are ordinal data, the usual recommended measure are quantiles, such as the median. For ordinal data, quantiles have the advantage that they can be interpreted by categories. However, in this evaluation the effect score is not interpreted categorical but is an indicator for the tendency of the aggregated effect of the bioeconomy. For this purpose the mean has shown to be more practical than the median, since the median tends to neglect extreme values that are relevant for this evaluation. As a result, this can lead to dubious conclusions. To demonstrate this point, two alternative calculations employing the median as measure can be found in the data set.

Calculating and adding the average positive and average negative effects, as in equations (1) and (2), also bears two shortcomings. First, one strong effect becomes extenuated by including many weak effects when calculating the averages in equation (1). This is a high-priced trade-off for the sake of robustness. Second, if the number of positive and negative effects per SDG is neglected when calculating the effect score in equation (2), we have a domination of strong effects. One strong positive (negative) effect can dominate many weak negative (positive) effects. This condition describes the imperfect substitution elasticities of the effects. An example that demonstrates their existence is that groundwater depletion can only be combatted by more efficient farming techniques to a certain degree. In case the groundwater is totally depleted, even the most efficient farming technique would not be applicable and helpful anymore. Thus, the strong negative effect cannot be equalized by many positive effects from efficient farm management.

For this evaluation several sensitivity analyses have been conducted. An alternative approach is accounting for the number of positive and number of negative effects per SDG. In principle, considering the number of effects is highly relevant because it provides valuable information on how strong the SDG is affected. Bioeconomy activities can affect one SDG through several channels, which should be respected when evaluating their impact.

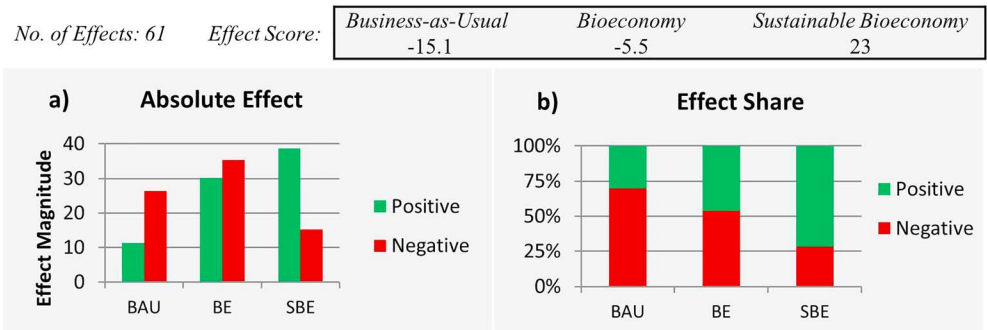


Figure 3. Analysis aggregated over all relevant Sustainable Development Goals. The score of the negative effects is multiplied by -1 and thus showing a positive value. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE.

For the alternative approach equations (1) and (2) are substituted by equation (4). If the number of positive effect and the number of negative effect are the same, or close together if large, then the results between the first and the alternative approach are very similar and only differ in scale.

$$I_{sgw} = \frac{1}{N_{sg}} \sum \text{Base value}_{i,esg} * \text{Scenario value}_{i,esg} \quad \text{for } e = p = c \quad (4)$$

The difference between the first and the alternative approach is exemplified at the end of the results section. Furthermore, the calculation of the evaluation, including the sensitivity analyses, can be found in the data set. This table lists the score for each effect and scenario, as well as the source of the information and the assumptions made for each effect and scenario.

3. Results: Bioeconomy and the SDGs

This section presents the results of the analysis and is structured as follows. The first part explains the aggregated results and provides an overview over all affected SDGs. The second part shows three different outcomes for individual SDGs. SDG 8 delivers an example for a positive case, SDG 15 exemplifies a negative case, and SDG 1 demonstrates mixed effects and represents the results for the majority of the evaluated SDGs. For further information, the results on the other individual SDGs are discussed in the supporting information, and the detailed calculations of the effect scores can be taken from the data set. Finally, the outcomes of the sensitivity analysis applying the second evaluation approach are described.

3.1. Aggregated Results

Figure 3a demonstrates that the BE scenario has increased positive as well as increased negative effects compared to BAU scenario, and the effect score increases from -15.1 (BAU) to -5.5 (BE). Thus, the overall impact of the BE scenario on the SDGs is still negative, but the share of positive effects significantly increases, as visualized by Figure 3b. However, the BE scenario can only be considered superior if we allow for the substitution of effects. This means that the increased negative effects can be outbalanced by the stronger increased positive effects. Without substitution the BE scenario would be worse, since in this case only the change in the negative effects, or the change in positive effects if the negative effects are equal, would count. Figure 4 is mapping the individual SDGs. When substitution is allowed (Figure 4a), compared to the BAU scenario, the BE scenario is only the worse option for SDGs 13 to 15. Without substitution the BE scenario is worse for seven SDGs (Figure 4b).

Separating the results into a socioeconomic, an industrial and economic, and an ecological dimension, as displayed in Figure 5, provides a very good impression of the areas where the most conflicts are. While the industrial dimension of the SDGs is strongly supported by the bioeconomy, the socioeconomic component shows mixed results. The net effect of the BE scenario is positive, but the increase of the negative effects show that substitution must be allowed to draw this conclusion. Finally, the ecological dimension can be strongly violated if sustainability is not respected. The dimension-wise evaluation mirrors the primary aims of the considered bioeconomy concepts, which are mainly concentrating economic factors, like resource efficiency,

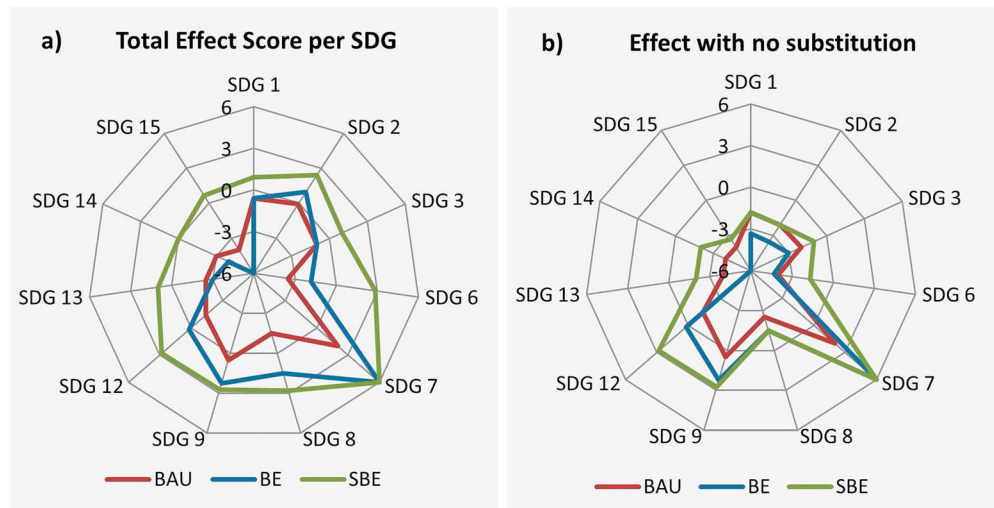


Figure 4. Scores of the individual SDGs. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE; SDGs = Sustainable Development Goals.

productivity, and competitiveness, which are to a large share reflected by the clean industry and economic dimension. Also, the strong motivation to reuse waste and residual materials for energy production has a large positive impact on those SDGs. Therefore, going through the concepts, socioeconomic and ecological aspects seem to be rather subordinate.

For the substitution of fossil resources by natural resources the global agricultural output has to be increased. Therefore, it is intuitive that many interactions between the bioeconomy and SDGs are similar to interactions between industrial agriculture and SDGs, which mainly affect the socioeconomic and ecological SDGs. The bioeconomy concepts of OECD, EU, and the German government differ in their

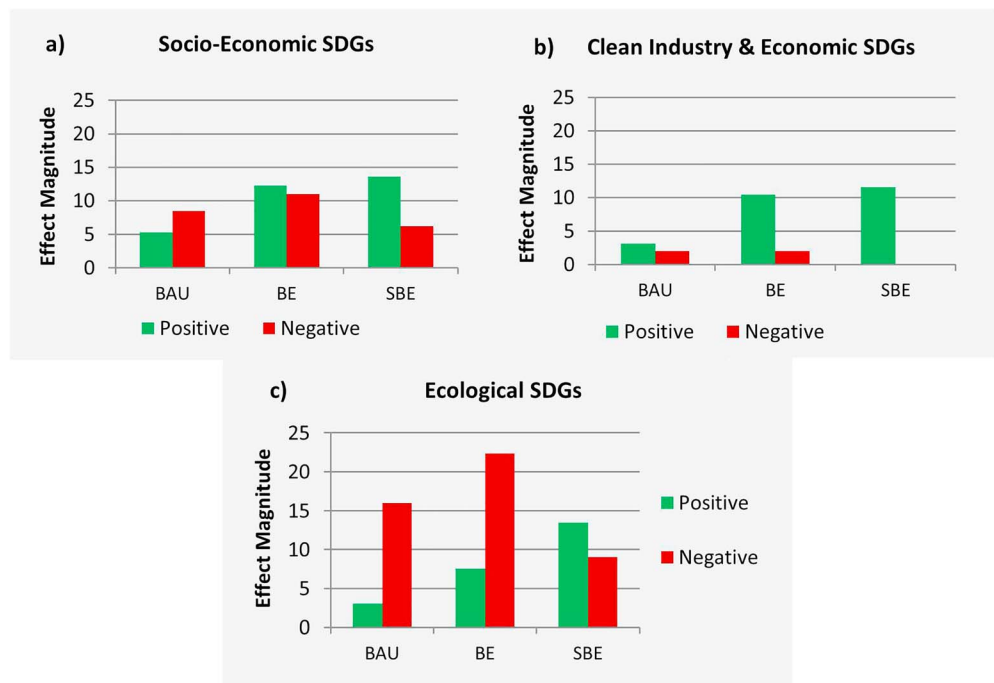


Figure 5. SDGs aggregated by dimension. The score of the negative effects is multiplied by -1 and thus showing a positive value. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE; SDGs = Sustainable Development Goals.

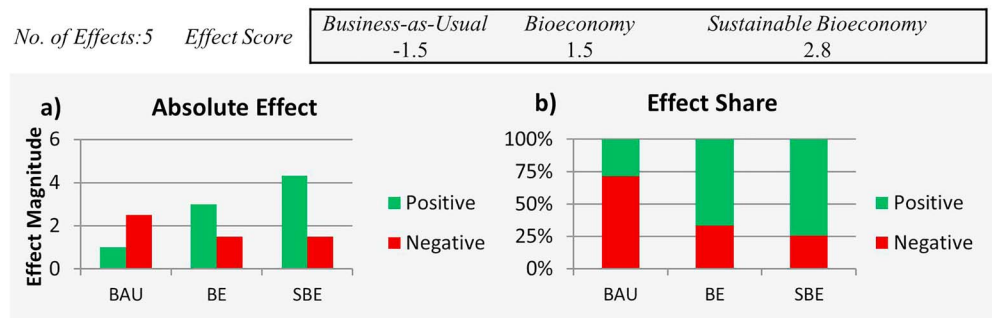


Figure 6. Sustainable Development Goal 8. The score of the negative effects is multiplied by -1 and thus showing a positive value. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE.

approach addressing potential emerging problems. The OECD and the EU consider biotechnological innovations as driver of the bioeconomy and simultaneously as the solution for bioeconomy inherent problems (European Commission, 2012; OECD, 2009). However, this approach has several shortcomings and neglects important issues, which are addressed in the evaluation of the individual SDGs. The German government recognizes and stresses negative effects that cannot be solved by biotechnology. This includes issues on property rights, exploitation rights, biodiversity, and distributional aspects (BMEL, 2014). While accounting for such factors would make the bioeconomy sustainable, the concept of the German government does not deliver solutions or binding regulations yet. Therefore, their bioeconomy concept is located between the BE and the SBE scenario.

3.2. Three Cases

3.2.1. Improvement: SDG 8 Decent Work and Economic Growth

Figure 6 shows that for SDG 8 the BE scenario is unambiguously positive compared to the business as usual scenario. Economic development is a main target of the bioeconomy concepts of the OECD, EU, and Germany. With investments into new technologies and value-added production, skilled labor jobs are assumed to be created. The FAO estimates that in 2013 all sectors of the bioeconomy in the EU already generated about 18.3 million jobs with an annual turnover of 2.1 trillion EURO (FAO, 2016). The difference between the bioeconomy and the sustainable bioeconomy is only caused by stronger efforts to decouple economic growth from environmental degradation in a sustainable bioeconomy. The negative effects are the same for both scenarios and explained below.

There is some criticism questioning if the cultivation of industrialized monocultures actually can provide new jobs at all. For some biomass crops, labor participation per hectare in industrialized monocultures is much lower than in traditional small-holder cultivation. Deiningger (2013) states that the cultivation of herbicide-tolerant and pest-resistant crops requires less steps in the production processes and significantly reduces the labor intensity of production. This provides a trade-off between efficiency and labor intensity. If those farmers who lose their jobs, through mechanization and efficient low labor share techniques, do not find new off-farm employment opportunities, for example, in the value-added production, this can lead to further poverty and migration into urban areas (Cotula et al., 2008; Deiningger, 2013).

Thus, the effect on this goal considering developing countries in both bioeconomy scenarios is rather unclear. On the one hand, it is expected that new value-added production possibilities also emerge in those countries (BMEL, 2014; Scarlat et al., 2015). On the other, the bioeconomy concepts of the OECD, EU, and Germany predominantly target investments into technology, new production opportunities, and high-skilled labor for their own regions. The bioeconomy concepts cannot be considered as development support program for job creation in developing countries in the first instance. This is also the case in the SBE scenario. However, the German government recognizes that "it must be ensured that the robustly-increasing demand for renewable resources also supports the development-policy objectives in developing countries and emerging economies" (BMEL, 2014, p. 9).

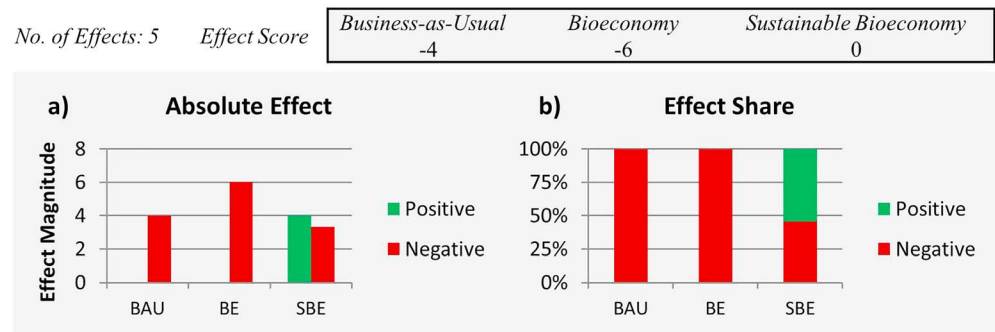


Figure 7. Sustainable Development Goal 15. The score of the negative effects is multiplied by -1 and thus showing a positive value. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE.

3.2.2. Deterioration: SDG 15 Life on Land

SDG 15 is an extreme case, since there are no positive effects for the BAU and BE scenario, as shown in Figure 7. The effect score reveals that the BE scenario has the strongest negative impact, for following reason. While, for example, the EU states that the goal of the bioeconomy is to use bio-based raw materials without compromising ecosystems, SDG 15 emphasizes that ecosystems need to be restored. Restoration is however not in the focus of the bioeconomy documents (European Commission, 2012; OECD, 2009). Similar affected is the SDG target considering afforestation and restoration of degraded forests. The bioeconomy concepts recognize trees as a highly valuable biomass resource, in particular for lignin-cellulosic applications like biofuels. The bioeconomy criteria to only use sustainable managed forests promotes the afforestation for commercial use in some regions as well as allows for the deforestation in other regions (BMEL, 2014; European Commission, 2012). Considering this, in addition to incentives to clear forest for cropland in order to satisfy the increasing biomass demand (Deininger, 2013; Henders et al., 2015), the BE scenario cannot be considered supportive for this SDG target. The SBE scenario therefore fulfills the SDG target 15.2 by promoting the substantially increase of afforestation and reforestation globally (UN, 2015), while taking local factors and ecological requirements into account.

Furthermore, the increased demand for biomass, and thus the increased demand and price for land, may incentivize to unlock new agricultural areas and thereby harm ecosystem services as well as biodiversity (Deininger, 2013). Biodiversity can also be reduced by the extensive cultivation of potential invasive hybrid and genetically modified organism crops, which may suppress local varieties and contradict target 15.8 (Ferdinands et al., 2011; Sheppard et al., 2011). Moreover, overutilization of land can lead to land degradation and desertification in the worst case (Smolker, 2008). Juerges and Hansjürgens (2016) argue that in the transition toward a bioeconomy the increasing demand for biomass might set incentives to manage soils with a short-term time perspective, while causing negative effects for soil quality in the long term. They conclude, since short-term costs and benefits of decisions regarding the use of soils often differ from long-term costs and benefits of building up soils, the challenge of managing trade-offs and spillovers over time is increasingly essential in the governance of the transition process.

Since the above-mentioned problems are already well known from the developments in the last decades, a bioeconomy without strong emphasize on sustainability will probably foster, or in the best case maintain, the problems. However, still the SBE scenario can have severe negative effects on SDG 15. While afforestation, land degradation, and restoration of ecosystems would be addressed, issues from land expansion and invasive crops remain adherent. Thus, the net effect of the SBE scenario is neutral for the achievement of SDG 15.

3.2.3. Upscaling Effect: SDG 1 No Poverty

The effects of the BE scenario on SDG 1 represent the outcome for most of the other SDGs. While in absolute terms the positive and negative effects of the BE scenario increase compared to the BAU scenario, the relative share of the negative effects decreases. Nevertheless, looking at the negative effects in Figure 8a, they increase by 54% from the BAU scenario to the BE scenario.

The potential negative effects of the bioeconomy on poverty are the same as of industrial agriculture and the biomass production for biofuels. The increased demand for land can lead to land grabbing, displacements, unequal distribution of land considering soil quality, and loss of communal land. Furthermore, the switch

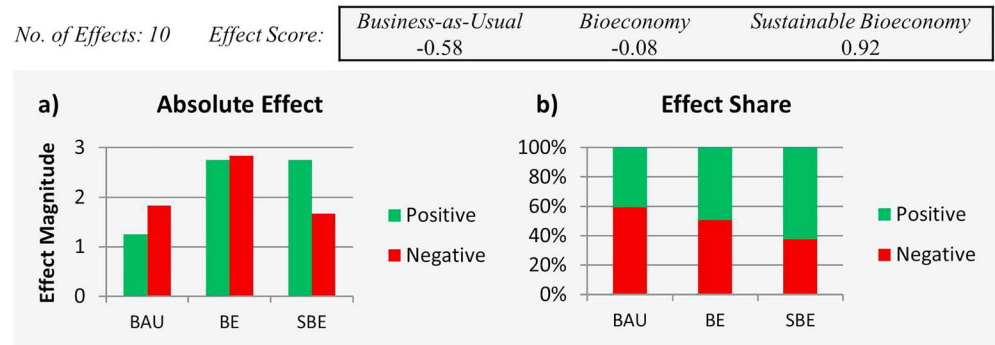


Figure 8. Sustainable Development Goal 1. The score of the negative effects is multiplied by -1 and thus showing a positive value. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE.

of farmers from food crops toward biomass production for industrial purposes increases their dependencies on international agricultural commodity prices (Cotula et al., 2008).

However, bioeconomy activities can also help to reduce poverty through two channels. On the one hand, increasing demand for agricultural goods can lead to higher prices and thus higher income of farmers (Cotula et al., 2008). The EU estimates an increase in world food demand of 70% by 2050 and a further steep increase in the demand of biomass for industrial purposes (European Commission, 2012). On the other, producing goods for a bioeconomy may provide new opportunities for value-added industries in developed as well as developing countries (BMEL, 2014; GBS, 2015; Scarlat et al., 2015). Hence, off-farm employments could emerge and help to alleviate poverty.

The SBE scenario assumes that the local population in biomass producing areas is not excluded from the profits of increased biomass production, and regulations hindering displacements and land grabbing are in place. However, the assumed increased production of intensive cash crops, which require a lower labor share than traditional agriculture (Deininger, 2013), and the higher dependency on global agricultural commodity markets (Cotula et al., 2008), lead to the result that in absolute numbers, Figure 8b, the negative effects of the sustainable bioeconomy are not lower than in the BAU scenario. Nevertheless, the ratio of positive and negative effects strongly improves, demonstrating that with sustainability measures, the bioeconomy has the potential to support the achievement of SDG 1 targets.

3.3. Sensitivity Analysis

Considering the aggregated effect over all SDGs, the results are robust and accounting for the number of effects in the evaluation does not really make a difference. In approach 1, the BE scenario would support the SDGs with 46% of its total effect on the SDGs, while according to approach 2, 48% of the impact is positive. This demonstrates the robustness of this evaluation, as with both measures the overall share of positive effects is only varying by two percentage points. These and further statistics as well as robustness checks are provided in the data set.

Stronger differences between approaches 1 and 2 can be found when looking at some individual SDGs, where the number of positive and negative effects strongly differ. SDG 2 provides a very good example to demonstrate differences between the two approaches, as shown in Figure 9. For this SDG the number of negative effects is much larger than of the positive effects, but the base and scenario values of the negative effects are comparably low. This leads to a domination of the positive effects in approach 1. However, when accounting for the quantity of positive and negative effects in approach 2, the results change significantly and the negative effects now dominate for all scenarios.

Subjectivity can become a factor when accounting for the number of effects. The issue is demonstrated on the positive effect "Productivity and efficiency increases of farm management techniques." On the one hand, productivity and efficiency can be considered as complementary and being the result of the same activities and efforts. In other words, when you increase productivity you simultaneously improve efficiency to a certain degree, and vice versa. On the other, one can argue that productivity and efficiency are complementary but still two individual attributes and thus should be considered as two effects. In this case the sum of

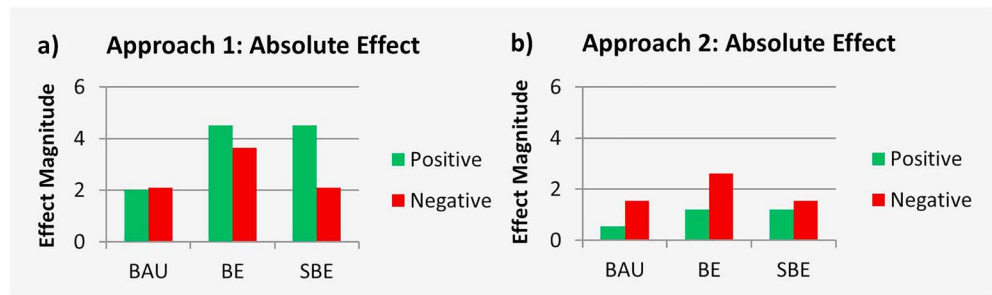


Figure 9. Absolute effects on Sustainable Development Goal 2 for approach 1 and approach 2. The score of the negative effects is multiplied by -1 and thus showing a positive value. BAU = business as usual; BE = bioeconomy; SBE = sustainable BE.

positive effects on SDG 2 would increase by about 30% due to the high base and scenario value of this effect. Here also the reason for taking averages becomes visible, as the average positive effect would only increase by 15%, thus making this approach more robust to changes in the computation base.

Furthermore, as already mentioned in the method section, accounting for the number of effects promotes that a large number of weak effects can compensate a small number of strong effects. This condition has been already exemplified by the means of groundwater depletion in the approach section above.

4. Discussion

To evaluate the results of this study, two questions need to be answered. First, does the BE scenario support the achievement of the SDGs in general, and second, can the BE scenario be regarded as an improvement to reach the SDGs compared to the situation today? Both questions are dependent on the discussion on trade-offs within the SDG concept. For the first question, assumptions on the weighting of SDG targets are relevant, and the answer to second question is conditional on the applied concept of substitutability within the SDG targets.

Assuming that a scenario can only be considered supportive if at least more than 50% of its effects are positive, the answer to the first question is straightforward. In both evaluation approaches, the BE scenario tightly misses this target, and only the SBE scenario fulfills that criteria. However, this conclusion neglects the problem of not weighting SDG targets. Maybe the positive affected SDG targets have in reality more impact on the global well-being than the negative affected ones. As already mentioned above, the SDG framework does not allow the weighting of targets (UN, 2015), and thus this research follows this rule. Nevertheless, the data in the data set provides a framework for policymakers and researchers to assign weights according to their own assumptions. Differences in the results can be used for a discussion on the practical use of the SDG targets.

Answering the second question is more complicated. Under both measurement approaches the score for the negative and positive effects in the BE scenario increase compared to the BAU scenario, while the share of positive effects increases stronger. As a result, the BE scenario can only be considered superior if substitution between positive and negative effects is allowed. The question to policymakers is whether it is reasonable to strongly increase the negative impacts on SDG targets for the sake of stronger positive impacts. Especially, if there are inequalities in the distribution of the profits. The conceptual nonsubstitutability of the SDGs and the ideal of a strong sustainability rather disapprove this assumption (Rickels et al., 2016; UN, 2015). However, Rickels et al. (2016) note that strictly applying the nonsubstitutability might hinder the application of effective policies. They argue that the specification of substitution possibility cannot solely be based on scientific reasoning but requires normative judgment and decision (Rickels et al., 2016, p. 265). The findings of this research support this statement, recommending that trade-offs from bioeconomy activities need to be ferret out and evaluated on an individual basis.

Compared to the BE scenario, the SBE scenario shows much more improvement. Thereby, the positive effects of the sustainable bioeconomy on land, the oceans, water, and resource use are dominating. The negative effects can be to some degree considered as the inherent trade-offs of the SDGs, which are also

highlighted by Pradhan et al. (2017). Supporting one SDG can have unavoidable negative effects on another SDG (Pradhan et al., 2017), and this is also true if the sustainable bioeconomy is used as an approach to fulfill the targets. However, the superiority of the sustainable bioeconomy is caused by the strong assumptions made, and it would be appropriate to have some reasonable skepticism. The SBE scenario builds on innovations that are not yet cost competitive and in different stages of development. Furthermore, it assumes that matters of international cooperation and regulation are addressed to avoid issues like negative spillovers to other countries or cost advantages of countries that are defaulting from sustainability regulations. This requires strong efforts negotiating agreements and regulations on an international and intergovernmental scale and thus depends on the political will in the respective countries.

5. Conclusion

In a nutshell, the results of this study are in line with the recent studies on bioeconomy concepts and their sustainability in general. Without additional measures and efforts, the sustainability of the existing concepts is not assured. Furthermore, global socioeconomic and ecological effects need special attention. As a net importer of natural resources, such as land, Germany, and the EU have an increased responsibility to implement sustainability criteria for their bioeconomy activities. Through global trade and production spillover effects, their bioeconomy activities do not only affect their own regions but countries all over the world (BMEL, 2014).

Focusing on the SDGs, this analysis demonstrates that the road on which we are going today will leave most of their targets unfulfilled. Also, an unsustainable bioeconomy is certainly not the best solution. Without regulations, policies and investments ensuring sustainability, or in case the increased positive effect of bioeconomy activities cannot outbalance the increased negative effect, the bioeconomy has the potential to rather restrain than support the achievement of the SDGs. However, it is beyond doubt demonstrated that the bioeconomy can have a strong potential to be sustainable if implemented wisely. A sustainable bioeconomy that includes such sustainability measures mentioned above has a strong potential to be a very useful concept to achieve the targets of the SDGs.

Complementarily, the SDGs can and should be used as an appropriate sustainability benchmark for bioeconomy concepts as well as individual bioeconomy activities. This analysis demonstrates that the establishment of the bioeconomy can have widespread effects, which are very well captured by the wide scope of the SDGs. The German government already recognized this circumstance. In their Bioeconomy Evaluation Report 2017, the federal ministry for education and research recommended to emphasize the relevance of bioeconomy research for the achievement of the SDGs, when distributing future research assistant measures within the bioeconomy research portfolio. On this way the bioeconomy should be brought into line with the national sustainability goals, national climate and environmental protection targets, and the SDGs (Hüsing et al., 2017). This paper provides an overview on the strength and weaknesses of the bioeconomy in terms of the SDGs and highlights aspects that require increased efforts and further research. As a next step, bioeconomy activities need to be analyzed quantitatively to evaluate their individual effects on the respective targets. This work indicates areas to concentrate on by further research.

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Data

The data set for this evaluation is provided as supporting information.

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