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Linking bioenergy and the bioeconomy: The GBEP Sustainable Bioenergy Indicators and Sustainable Bioeconomy Indicators - Similarities, Differences and Perspectives for Convergence

Susanne Köppen, Horst Fehrenbach, Silvana Bürck

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ifeu Wilckensstraße 3 69120 Heidelberg Telefon +49 (0)6 221. 47 67 - 0 E-Mail ifeu@ifeu.de www.ifeu.de

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Authors: Susanne Köppen, Horst Fehrenbach, Silvana Bürck

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Wilckensstraße 3 - D-69120 Heidelberg - Germany

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Content

1 Background and objective

The updated European Bioeconomy Strategy adopted in October 2018 aims to develop a sustainable bioeconomy for Europe and strengthen the link between economy, society and environment (EU Commission 2018). It addresses global challenges such as meeting the Sustainable Development Goals (SDGs) set by the United Nations (2015) and the climate targets of the Paris Agreement.

Since the intensive start of the scientific discussion on sustainability criteria for bioenergy in the mid-2000s, numerous standards and schemes have been developed. Some are policy-based and have legal status, such as the Renewable Energy Directive (RED) in the EU. Many, however, have been developed on the basis of supranational and industrial initiatives. There is also a growing awareness that a limitation to bioenergy is not expedient, but that it should be possible to apply them holistically to the bioeconomic complex.

In November 2011, the Global Bioenergy Partnership (GBEP) adopted a set of 24 indicators to assess and monitor the sustainability of modern bioenergy. These set of GBEP sustainability indicators (GSI) still provide a baseline for policy-makers and other stakeholders that informs on the development of the bioenergy sector and that allows monitoring the impact of related policies and programs.

It is the objective of this brief paper to show similarities, differences and perspectives for convergence of the GSI for the discussion of a sustainable bioeconomy. For this purpose, the authors present a synopsis (annotated table) on the application of the GBEP indicators in the previous and ongoing country implementations.

The following work is intended to show a selection of the standards and schemes that currently exist and which sustainability criteria are particularly important for the bioeconomy. Moreover, it is the objective of this brief paper is to compile the various topics mentioned in these reference works, to work out congruencies and to point out the specifics of the criteria or indicators included with regard to sustainability assessment for the bioeconomy.

Chapter 2 gives an analysis regarding the application of GSI by country. Chapter 4 gives a selection of standards, schemes and research projects presenting sustainability indicators for bioenergy and/or bioeconomy. Chapter 7 gives overall conclusions and prospection.

2 Application of GSI by country

2.1 Analysis

Table 1 gives a synopsis of the countries having applied the GSI. It contains information on

- scale,
- year of measurement,
- which bioenergy pathways have been considered
- which GBEP indicators have been evaluated
- which attribution approach have been an
- about the Lessons learned

Table 2 displays country has applied GSI by indicator.

Table 1: Application of GSI by country

Country	Scale, year of measurement	Existing bioenergy pathways; pathways considered	GBEP indicators evaluated	Attribution approach	Lessons learned
Argentina	Value chain approach 2013 – 2015	• Transport fuels: biodiesel (soy), bioethanol (corn, sugarcane) • Electricity & heat: bagasse and forest-industry residues • Biogas (very little) Assessment: sugarcane, soybean as transport fuels	Complete measurement: N° 1, 17, 18, 19, 20, 22 Partial / qualitative measurement: 2, 4, 6, 7, 8, 9, 10, 11 Reamining indicators: no data and / or not relevant	Focus was on two pathways / value chains ➔ no allocation necessary	• Data gaps regarding statistical data on biofuels and data on different phases of value chains • Difficulty to measure indirect effects of pathways since pathways assessed only are very small part of overall resource production ➔ sustainability policies and decisions should be targeted to the whole sector
Colombia	Value chain approach 2011 – 2014	• Transport fuels: ethanol (sugarcane), biodiesel (palm oil) • Electricity / heat: bagasse, traditional biomass, biogas (manure) Assessment: sugarcane ethanol, palm oil biodiesel	Indicators excluded (due to lack of relevance): N° 3, 13, 14, 15	mass balance; for selected economic indicators economic value allocation	• Data gaps since data are either not collected or are not accessible due to commercial sensitiveness • Further guidance needed on attribution
Egypt	Local / project based 2012 - 2013	Assessment: rice straw, corn stalks for thermal gas for cooking stoves at homes	N° 1, 2, 4, 11, 12, 15, 20, 21	Value chain / project perspective ➔ no attribution necessary	

Country	Scale, year of measurement	Existing bioenergy pathways; pathways considered	GBEP indicators evaluated	Attribution approach	Lessons learned
Ethiopia	LCA approach 2019	Assessment: biogas, solid biomass (charcoal) at household level	all	Value chain approach ➔ not necessary	• importance of access to good-quality and detailed primary data, requiring wide geographic coverage and large survey sizes • Strengthening the coordination among regional and national government's institutions is key
Germany	National 2012 – 2014 (1st round) 2018 - 2019 (2nd round)	• Transport biofuels (FAME, bioethanol, upgraded biogas), • Electricity and heat (biofuels, biogas, woody biomass) Assessment: all	Indicators excluded (due to lack of relevance): N° 13, 14, 15, 21 and 23	simple allocation based proportionality between bioenergy and other uses of the same feedstock	• Mostly good database to answer the indicators; many indicators already covered by monitoring systems ➔ respective data are collected on an annual basis • More guidance needed to attribute effects of bioenergy against effects from biomass used for other purposes • More guidance needed on how to deal with potential negative effects of imported biomass / bioenergy
Ghana	National 2011 - 2013	n/a Assessment: wood resources, jatropha, sunflowers and agricultural residues	N°1, 2, 3, 4, 10, 12, 14, 17, 18, 20, 23	n/a	• Lack of data, no data collection infrastructure / data collection not focused on bioenergy • Amount and detail of information needed for the individual indicators is high ➔ can impede practical implementation ⇨ More selective and less detailed approach would make more sense
Indonesia	National 2011 - 2014	Biodiesel (palm oil), traditional biomass, manure biogas Assessment: Biodiesel, Crude Palm Oil (CPO)	all	mass balance; economic value allocation for economic indicators	• Lack of data for various indicators (especially within the social basket) since data is either not available or cannot be accessed due to commercial sensitiveness

Country	Scale, year of measurement	Existing bioenergy pathways; pathways considered	GBEP indicators evaluated	Attribution approach	Lessons learned
Jamaica	Local (application of LCA methodology (modelling with Simapro) 2012 – 2014	Ethanol (sugarcane), cogeneration (bagasse) -	N° 1, 4, 5, 6, 9, 11, 12, 13, 15, 16, 17, 19, 20, 22	Mass balance approach, economic allocation	• Lack of data, especially for sLCA
Japan	Project based (specific municipal biodiesel plant) 2018	Biodiesel (waste cooking oil from food service sectors, food processing sectors and households) for municipal garbage trucks and local buses	N° 1, 4, 5, 11, 12, 16	LCA / bottom up approach ➔ not necessary	• imported bioenergy dominates certain share in domestic supply ➔ sustainability of imported bioenergy has to be assessed • too much emphasis on reflecting country-specific condition might result in a lack of comparability to other countries or regions ➔ one has to balance the comparability and the reflection of country specific condition
Kenya	LCA approach 2019	Sugarcane bagasse briquettes, charcoal	All	Value chain approach ➔ not necessary	• Biggest challenge: lack of data and the broad distribution of data among different organizations • No standardized data related to the bioenergy sector at other organizations – both national and international
Netherlands	National 2011 - 2012	traditional biomass for stoves; forestry resources (fresh wood, waste wood and processing residues) for stoves, co-firing and incineration agricultural residues (including manure) for	Indicators excluded (due to lack of relevance): N° 9, 10, 13, 14, 15, 21	na	• Partly lack of data, partly difficulties to adjust / modify the exact scope of GBEP • In general, data specificity and skill level necessary to complete the GBEP methodology very high (providing a complete and detailed overview of the bioenergy sectors) • GBEP indicators should be linked to other existing monitoring initiatives; requires coordination between relevant government organizations and institutes

Country	Scale, year of measurement	Existing bioenergy pathways; pathways considered	GBEP indicators evaluated	Attribution approach	Lessons learned
		co-firing, incineration and biofuel production; wastes for incineration/biogas; rapeseed and used cooking oil (UCO) based biodiesel; maize based ethanol; short rotation coppice (SRC); and miscanthus Assessment: maize, rapeseed, SRC, miscanthus as well as traditional biomass			• Alternative approaches for the GBEP methodologies should be included in case of lack of data or methodology is too time intensive • bioenergy sector does not exist as a separate economic sector, especially ➔ outcomes of the GBEP indicators may present a distorted picture when non-sustainable activities take place outside the country
Paraguay	LCA based approach 2016 – 2018	Wood energy at household and industrial scale; ethanol from sugarcane and maize for transport; biodiesel from soybean; and biogas from livestock manure Assessment: Woody biomass (including eucalyptus chips from dedicated forest plantations); bioethanol (sugarcane, maize)	N° 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 16, 17, 18, 19, 20, 21, 22, 23, 24	LCA-based approach; economic allocation	• at the beginning of the GSI implementation it is important to agree on the use of the same data source • difficult access to data from private sector

Country	Scale, year of measurement	Existing bioenergy pathways; pathways considered	GBEP indicators evaluated	Attribution approach	Lessons learned
Urugay	LCA approach 2015	Assessment: Wood residues, biodiesel, bioethanol	Indicators excluded (due to lack of relevance): N° 13, 15	Value chain approach ➔ not necessary	• Not always data readily available for answering the indicators
Vietnam	LCA approach 2016 – 2018	Agricultural residues (heat and power), Traditional biomass, Biogas, Biodiesel, Gasification of solid biomass, Bioethanol Assessment: Pig manure for biogas production; cassava wastewater for biogas production; cassava chips for ethanol production	N° 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 17, 18, 19, 20, 22, 23, 24	Proportional with national ethanol consumption Biogas: the situation as of 2016 (with biogas) was compared with a scenario without biogas	• at the beginning of the GSI implementation it is important to agree on the use of the same data source • difficult access to data from private sector

Table 2: Application of GSI by indicator in the respective countries (approach: VS = value chain approach; National = application at national level)

		Argentina	Colombia	Egypt	Ethiopia	Germany	Ghana	Indonesia	Jamaica	Japan	Kenya	Nether-lands	Paraguay	Uruguay	Vietnam
Approach		**VS**	**VS**	**VS**	**VS**	**National**	**VS**	**VS**	**VS**	**VS**	**VS**	**National**	**VS**	**VS**	**VS**
Environmental pillar															
1	Lifecycle GHG emissi-ons	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2	Soil quality	x	x	x	x	x	x	x	-	-	x	x	x	x	x
3	Harvest lev-els of wood resources	-	-	-	x	x	x	x	-	-	x	x	x	x	x
4	Emissions of non-GHG air pollutants, including air toxics	x	x	x	x	x	x	x	x	x	x	x	x	x	x
5	Water use and effi-ciency	-	x	-	x	x	-	x	x	x	x	x	x	x	x
6	Water qua-lity	x	x	-	x	x	-	x	x	-	x	x	x	x	x
7	Biological di-versity in the landscape	x	x	-	x	x	-	x	-	-	x	x	x	x	x

		Argentina	Colombia	Egypt	Ethiopia	Germany	Ghana	Indonesia	Jamaica	Japan	Kenya	Nether-lands	Paraguay	Uruguay	Vietnam
8	Land use and land-use change	x	x	-	x	x	-	x	-	-	x	x	x	x	x
Social Pillar															
9	Allocation and tenure of land for new bioen-ergy produc-tion	x	x	-	x	x	-	x	x	-	x	-	x	x	x
10	Price and supply of a national food basket	x	x	-	x	x	x	x	-	-	x	-	x	x	x
11	Change in in-come	x	x	x	x	x	-	x	x	x	x	x	x	x	x
12	Jobs in the bioenergy sector	-	x	x	x	x	x	x	x	x	x	x	x	x	x
13	Change in unpaid time spent by women and children col-lecting bio-mass	-	-	-	x	-	-	x	x	-	x	-	-	-	-

		Argentina	Colombia	Egypt	Ethiopia	Germany	Ghana	Indonesia	Jamaica	Japan	Kenya	Nether-lands	Paraguay	Uruguay	Vietnam
14	Bioenergy used to expand access to modern energy services	-	-	-	x	-	x	x	-	-	x	-	-	x	x
15	Change in mortality and burden of disease attributable to indoor smoke	-	-	x	x	-	-	x	x	-	x	-	-	-	-
16	Incidence of occupational injury, illness and fatalities	-	x	-	x	x	-	x	x	x	x	x	x	x	x
Economic pillar															
17	Productivity		x	-	x	x	x	x	x	-	x	x	x	x	x
18	Net energy balance	x	x	-	x	x	x	x	-	-	x	x	x	x	x
19	Gross value added	x	x	-	x	x	-	x	x	-	x	x	x	x	x
20	Change in consumption of fossil fuels	x	x	x	x	x	x	x	x	-	x	x	x	x	x

		Argentina	Colombia	Egypt	Ethiopia	Germany	Ghana	Indonesia	Jamaica	Japan	Kenya	Nether-lands	Paraguay	Uruguay	Vietnam
	and tradi-tional use of biomass														
21	Training and requalifica-tion of the workforce	-	x	x	x	-		x	-	-	x	-	x	x	-
22	Energy diversity	x	x	-	x	x	-	x	x	-	x	x	x	x	x
23	Infrastruc-ture and lo-gistics for distribution of bioenergy	-	x	-	x	-	x	x	-	-	x	x	x	x	x
24	Capacity and flexibility of use of bioen-ergy	-	x	-	x	x	-	x	-	-	x	x	x	x	x

2.2 Findings

The analysis of the national GSI applications reveals the following observations:

- Only a few countries applied the indicators in accordance with their actual objectives at national level.
  - Requirements for data basis and methodological knowledge for processing the indicators are high
  - Main reason: no / only few data on the bioenergy sector available
    - Are not systematically recorded
    - New sector
    - Often private sector (not accessible)
    - Distributed among various institutions not centrally recorded
- Countries with comprehensive data base have other difficulties
- Biomass for bioenergy must be distinguished from other uses Allocation is necessary, or it was suggested to apply the indicators to the entire biomass sector in principle
  - Data often available in existing monitoring programmes, but must be adapted to the GBEP indicators.
- If bioenergy only accounts for a small part of biomass production, indirect effects in particular (e.g. soil quality, food prices) are difficult to measure.
- In countries with high biomass imports, negative effects in countries of origin must be dealt with.
  - Often not consistent within the indicators (e.g. GHG recording of foreign emissions, not for other indicators)
- Dealing with missing data basis
  - Collection of primary data
  - Implementation of indicators rather on project / value chain level
- In principle, all countries tried to cover as wide a range of indicators as possible, gaps tended to be in the social and economic indicators.

3 Indicators for bioeconomy – a selection of standards, schemes and research projects

3.1 Analysed documents

The following is a brief overview of the status of sustainability indicators for the bioeconomy from the perspective of relevant EU projects as well as from ongoing international processes. Table 3 samples the analysed documents

Table 3: Listing the standards, schemes and research projects analysed

	Project, reference	Type	Link
1	*GBEP (2011):* The Global Bioenergy Partnership Sustainability Indicators for Bioenergy	International Organisation	Http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/Report_HYPERLINK_updated_CM_25-05-2017.pdf
2	FAO (2019): Indicators to monitor and evaluate the sustainability of bioeconomy	International Organisation	https://www.fao.org/publications/card/en/c/CA6048EN/
3	*ICAO (2021): CORSIA Sustainability Criteria for CORSIA Eligible Fuels*	International Organisation	https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202021.pdf
4	*ISO 13065* :2015*:* Sustainability criteria for bioenergy	International Organisation	https://www.iso.org/standard/52528.html
5	*BIOMONITOR* – Monitoring of Bioeconomy	EU project	https://biomonitor.eu/
6	*Star-Probio* - Sustainability Transition Assessment and Research of Bio-based Products	EU project	http://www.star-probio.eu/
7	S2Biom - Consistent Cross-Sectoral Sustainability Criteria & Indicators	EU project	https://www.s2biom.eu/images/Publications/D5.4_S2Biom_Cross-Sectoral_Sustainability_Indicators_Final.pdf
8	Kilsedar et al. (2021): Implementation of the EU Bioeconomy Monitoring System dashboards	JRC Research study	https://publications.jrc.ec.europa.eu/repository/handle/JRC127762
9	Wackerbauer et al. (2019): Ermittlung wirtschaftlicher Kennzahlen und Indikatoren für ein Monitoring des Voranschreitens der Bioökonomie	Bioeconomy Monitoring system for Germany	https://www.ifo.de/DocDL/ifo_Forschungsberichte_104_2019_Monitoring-Biooekonomie.pdf
9a	Jander et al. (2020) Monitoring Bioeconomy Transitions with Economic–Environmental and Innovation Indicators:	Bioeconomy Monitoring system for Germany	https://www.mdpi.com/2071-1050/12/11/4683

	Project, reference	Type	Link
	Addressing Data Gaps in the Short Term		
10	Bringezu et al. (2020): Pilotbericht zum Monitoring der deutschen Bioökonomie	Bioeconomy Monitoring system SYMOBIO for Germany	https://kobra.uni-kassel.de/handle/123456789/11591
10a	Egenolf und Bringezu (2019): Conceptualization of an Indicator System for Assessing the Sustainability of the Bioeconomy	Addition to the SYMOBIO publication	https://www.mdpi.com/2071-1050/11/2/443
11	Linser & Lier (2020): The Contribution of Sustainable Development Goals and Forest-Related Indicators to National Bioeconomy Progress Monitoring	Research study	https://www.mdpi.com/2071-1050/12/7/2898
12	Kardung et al. (2021): Development of the Circular Bioeconomy: Drivers and Indicators	Research study	https://www.mdpi.com/2071-1050/13/1/413
13	Karvonen et al. (2017): Indicators and tools for assessing sustainability impacts of the forest bioeconomy	Research study	https://forestecosyst.springeropen.com/articles/10.1186/s40663-017-0089-8
14	Lier et al. (2018): Synthesis on bioeconomy monitoring systems in the EU Member States -indicators for monitoring the progress of bioeconomy Synthesis on bioeconomy monitoring systems in the EU Member States	Research study	https://www.researchgate.net/publication/339325322_Synthesis_on_bioeconomy_monitoring_systems_in_the_EU_Member_States_-indicators_for_monitoring_the_progress_of_bioeconomy_Synthesis_on_bioeconomy_monitoring_systems_in_the_EU_Member_States_-indicators_
15	Goh (2017) Monitoring the bio-economy: Assessing local and global biomass flows, land-use change, carbon impacts and future land resources	Research study	https://dspace.library.uu.nl/handle/1874/350036
16	Böttcher et al. (2020): Ressourceneffizienz und Landnutzung – Ansätze zur mehrdimensionalen umweltpolitischen Bewertung der Ressourceneffizienz bei der Biomassebereitstellung	Research study (German)	https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-03-04_texte_45-2020_nexus-ressourceneffizienz-landnutzung.pdf
17	Iost et al (2020): Setting up a bioeconomy monitoring: Resource base and sustainability	Research study	https://www.thuenen.de/media/publikationen/thuenen-workingpaper/ThuenenWorkingPaper_149.pdf
18	Roundtable on sustainable biomaterials RSB (2016); RSB (2018)	Certification scheme for sustainable biomaterials	https://rsb.org/the-rsb-standard/ https://rsb.org/wp-content/uploads/2020/06/RSB-STD-01-001_Principles_and_Criteria-DIGITAL.pdf https://rsb.org/wp-content/uploads/2020/06/RSB-GUI-01-007-01-RSB-Conservation-IA-Guidelines_3.0.pdf
19	Forst stewardship council FSC (2015); FSC (2018); FSC (2021)	Forest certification scheme	https://fsc.org/en/document-centre/documents/resource/392 https://fsc.org/en/document-centre/documents/resource/262

3.2 Indicators for bioeconomy – prevailing indicators

Table 4 gives a synopsis of the indicators covered by the examined references. The indicators are sorted along with the GBEP sustainability indicators (GSI), while additional indicators are supplemented.

Regarding the wording: the item “indicator” is defined and used rather different from study to study. In its use, it is often not clearly distinguished from related terms such as principle, criterion, impact or more generally: theme.

Depending on the document, indicators as well as criteria etc. are formulated very detailed and with high specificity, which is very essential for the application. However, this makes it difficult to provide an overall view of various documents, as not all of the original wording can be reproduced in a paper such as this one. In the synopsis, therefore, simplifications were necessarily made with regard to the indicator definitions. In many cases, largely similar requirements are therefore combined under one term, such as “biodiversity” or “climate protection”. The exact design of indicators, especially with regard to their application to the bioeconomy, is discussed below for a selection of references.

In Table 4 is marked with an “X” for each indicator (which is also referred to as a criterion in the case of individual references) if there is a broad correspondence. An “(X)” is indicated if the indicator is included in the reference in some sense.

Reference number 2 (FAO 2019)[1] includes a number of more than hundred indicators, sorted under 25 criteria. This is of course quite exhaustive. It covers all GBEP indicators and includes many more (in Table 4 just mentioned at the criteria level). Moreover, the FAO study distinguishes between indicators applied at territorial level and at product level. This is a fundamentally important distinction, particularly in the context of the bioeconomy. However, the analysis in the context of this paper cannot be carried out at this level of granularity, but requires more generalisations.

[1] Based on a FAO’s project on sustainable bioeconomy guidelines at the ISBWG (International Sustainable Bioeconomy Working Group)

Table 4: Sustainability indicators or criteria implemented by the analysed schemes and research projects

	GBEP Indicator (*in addition to GSI*)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Σ**
	Environmental indicators																			
1	Lifecycle GHG emissions	X	X	X	X		X	X	X	X	(x)	X	X	X	(x)	X	X	X		16
	Land with high carbon stock	X	X	(X)										X	X	(x)		(X)		7
2	Soil quality	X	X	X				X	X					X		X	X	X	X	9
3	Harvest levels of wood resources	X			X		X	X	X	X	X			X		(x)			X	9
4	Emissions of non-GHG air pollutants	X	X	X			X	X	X				X	X	(x)	(x)		X		11
5	Water use and efficiency	X	X	X	(x)		X	X	X	X	(x)							X	X	10
6	Water quality	X	X	X			X	X	X				X	X			X	X	X	10
	Pesticide use	X	X	X					X					X				X		6
7	Biological diversity in the landscape	X	X	X	X		X	X	(x)	(X)	X	X	X	X		X		X	X	14
	Resilience of ecosystems	X						X											X	2
	Ecosystem services	X						(x)			X			(x)				X	X	5
	Buffer zones and corridors																	X	X	1
	No invasive species	X	X	X				X										X		5
8	Land use and land-use change	X		X	X		X	X	X	X	X	X	X	X	X	X				13
	Resource efficiency, waste prevention and waste re-use	X	X	X	X		X	X	X	X	X			X	X			X	X	12
	Energy efficiency	X		X			X	(x)												4
	Waste management	X	(X)	X	X						X			X				X	X	7
	Food loss and waste	X					(x)	X	X	X										5

	GBEP Indicator (*in addition to GSI*)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Σ
	Social indicators																			0
9	Allocation and tenure of land for new bioenergy production	X	X	X			X													4
10	Price and supply of a national food basket	X	X															X		3
11	Change in income	(X)			(x)			X			X						(x)	X		6
12	Jobs in the bioenergy sector	X			X		X	X	X		X			X			X	(X)		9
	Local and social development	(X)	X					X		(x)			X	X				X		7
13	Change in unpaid time spent by women and children collecting biomass	X																(X)		2
14	Bioenergy used to expand access to modern energy services	X																		1
15	Change in mortality and burden of disease attributable to indoor smoke	X																		1
16	Incidence of occupational injury, illness and fatalities	X					X	X			X		X							5
	Human and labour rights	X	X	X			X	(x)					X					X	X	7
	Legality																	X	X	1
	Working conditions	X		X	(x)		X	X					(x)					X	X	7
	stakeholder consultation with Free, Prior & Informed Consent																	X	X	1
	No discrimination												X					X	X	2
	Indigenous Peoples' Rights																	X	X	1
	Water use rights	X	X	X														X		4

	GBEP Indicator (*in addition to GSI*)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**Σ**
	Economic indicators																			**0**
17	Productivity	**X**						**X**	**X**		**X**						**X**			**5**
18	Net energy balance	**X**			**X**			**X**	**(x)**		**X**			**X**						**6**
19	Gross value added	**(X)**			**(x)**			**X**	**X**		**X**	**X**	**X**	**X**			**X**			**9**
20	Change in consumption of fossil fuels and traditional use of bio-mass	**(X)**			**X**			**X**	**X**			**X**	**X**	**X**			**X**			**8**
21	Training and requalification of the workforce	**X**																**X**	**X**	**2**
22	Energy diversity				**X**			**X**	**X**		**X**			**X**						**5**
23	Infrastructure and logistics for distribution of bioenergy	**X**																		1
24	Capacity and flexibility of use of bioenergy	**X**			**X**			**X**	**X**		**X**	**X**		**X**						7
	Fair business practices			X																1
	Financial risk management			X				**(x)**												2
	Novel products, new value chains (e.g. food)	**(X)**						**X**												

The matrix in Table 4 allows following findings:

1. The number of indicators for measuring the sustainable of bioeconomy (be at territorial level or at level of product value chain) have developed largely during the last years.
2. Though being focused on bioenergy and worked out a decade ago, the GSI prove to be still useful baseline to frame all the indicators under study, since
   - they capture most of the indicator proposed by the analysed studies being much more recent and focused on bioeconomy
   - only few new themes need to be added to complete the picture and
   - most of these added themes represent further specifications or variations of existing GSI.
3. The environmental indicators show the highest level of concordance between the standards, schemes, and studies; are they are also the most extensively represented (see also Figure 1).
4. Indicators for sustainable bioeconomy show no relevant deviation from indicators for sustainable bioenergy, or interpreted differently: so far, no or hardly any indicators have been developed for the bioeconomy that are distinct from indicators for sustainable bioenergy.
5. Thus, Indicators for sustainable bioeconomy still concentrate on the issue of biomass resources.

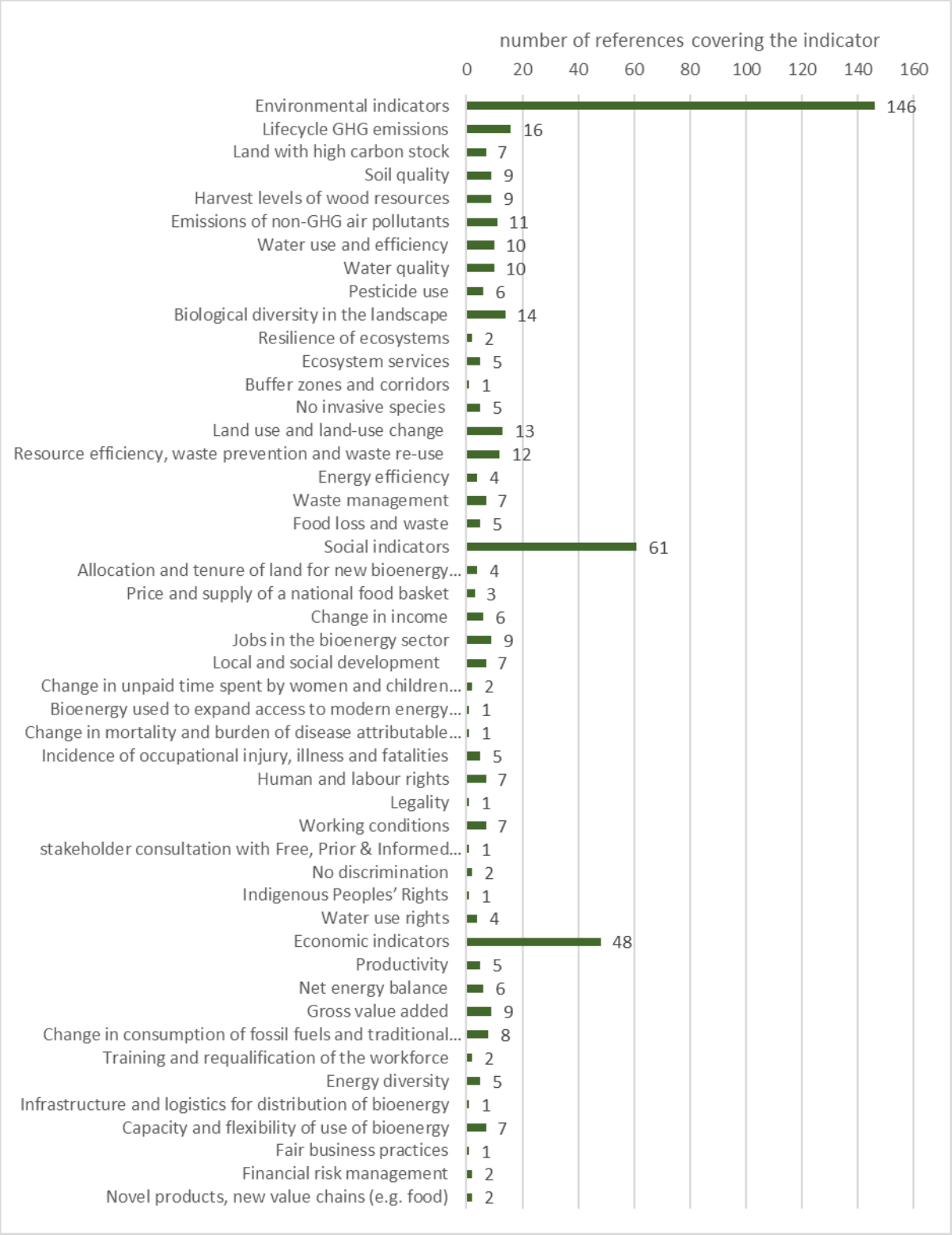

Figure 1: Coverage of sustainability indicators or criteria implemented by the analysed schemes and research projects

3.3 Some findings regarding selected works

The collection of the works examined is highly diverse. Above all, the depth of differentiation of the indicators varies greatly. Especially in the case of standards for certification systems (of which only two have been selected here for reasons of limited resources), direct practical application to the concrete case is indispensable. So-called "meta-standards", which merely provide a framework and need sharper guidance for concrete application, more often formulate the indicators in more general terms.

Standards for concrete products and supply chains differ fundamentally from indicator systems for the policy sector. While the topics of the indicators mostly overlap or are even identical, the design for application varies. This fact is often not emphasised clearly enough and can lead to misapplication if, for example, a policy indicator system such as that of GBEP is to be applied to supply chains.

This is excellently addressed by the work of FAO (2018), which, as already mentioned above, includes indicator sets for use at territorial and at product levels.

The monitoring system for the bioeconomy developed in Germany, SYMOBIO, is explicitly for the territorial area (Bringezu et al. 2020; Wackerbauer et al. 2019). Interestingly, it is based on "classic" environmental footprints (carbon, water, land, material, etc.) which in principle originate from LCA. In order to apply them at the national level, as is the case here, corresponding macroeconomic data is required, such as is available in Germany from the *Environmental Economic Accounting*[1] in the form of input/output tables.

The price of being able to draw on statistical data and thus calculate results for the bioeconomy at the level of the national economy relatively quickly is the low specific resolution.

This is particularly difficult to map given the often very filigree diversity of bioeconomic developments. On the other hand, these broad economic data provide a very robust answer to the question of biomass resources. This would again make it clear that the assessment of the sustainability of the bioeconomy (or bioeconomic processes and products) is strongly focused on biomass. Particularly innovative developments (biotechnology, enzymes, pharmaceuticals, etc.) are only noticeable in the measurement by the indicators, or only in the absence of certain negative effects of biomass production.

This is particularly true for the environmental indicators, which are mostly focussed on risk reduction. Actually, only the GHG criterion is oriented in a “positive” direction due to substitution of fossil resources by biomass. This is different with regard on the economic indicators which consider also opportunities. However, also there the mainstream indicators are to coarse regarding the granularity of bioeconomic innovations.

Kilsedar et al. (2021), with the implementation of the EU Bioeconomy Monitoring System dashboards, include some indicators with more focus also on novel products, in particular addressing the food sector.

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[1] https://www.destatis.de/EN/Themes/Society-Environment/Environment/Environmental-Economic-Accounting/_node.html

4 Conclusions and prospects

The first conclusion is: There is a **large volume of work** on how to assess the sustainability of the bioeconomy or activities in the bioeconomy or products of the bioeconomy. This brief paper does not at all claim to have listed and evaluated all available standards, schemes or studies dealing in this area. The selection made with 19 papers is already very broad and represents a challenge in terms of complexity and the amount of content.

A second observation is, that many works have only been produced **in recent years** and have benefitted from the opportunity to refer to the continuously growing number of previous studies. The **topic of the bioeconomy** has only been in focus for about five years. Previously, the question of sustainability assessment focused either generally on biomass production and use or (as in most cases) on bioenergy. The need for an overall view of what is generally understood by the bioeconomy has only become clear in recent years.

The GBP sustainability indicators (GSI) from 2011 also refer to Bioenergy. However, it is significant that they can apparently still be classified as a **quasi leading standard** in the variety of new work and in particular standard setting aimed at the bioeconomy. Although some of the works considered bring new or more specific factors into play, they are mostly variations of the indicators contained in the GSI.

The overall view of the papers also reflects the dynamics involved in the development of the bioeconomy. This is of interest in multiple respects, since the exact framing of the bioeconomy is still unclear an there is still not one common understanding of what the bioeconomy actually means. Nonetheless, the concept of the **bioeconomy addresses grand claims**, such as climate change, food security, health, and energy security. Bioeconomy shall tackle these targets shall be tackled in a congruent way, and at the same time, it is seen as the engine for innovation, driven by novel research and development.

The indicators that transfer precisely these innovative elements into a sustainability assessment are therefore also only at the beginning of development. It is difficult to evaluate potential impacts from technologies that are only just emerging. Some work is already doing good pioneering work here. This will be a major focus of further work in the coming years. The diversity and **complexity of biotechnological processes** and their applications can hardly be overlooked.

On the other hand, the core question for the bioeconomy will remain: how do we deal with **the biomass of the planet as a whole** in an actual sustainable way? This question can already be made tangible to a large extent by the many of the works presented. However, the challenges continue to accelerate, as the current alarm signals from observing global climate change and the rapid loss of biodiversity - to name just two major crises - make clear.

Thus, research will have **to continue to progress indicators and monitoring systems** and to get them **congruent** in order to **keep pace** with the rapid developments in bioeconomy.

5 Literature

In addition to the analysed standards, schemes, studies (see Table 3)

EU Commission (2018): A sustainable Bioeconomy for Europe: Strengthening the connection between economy, society and the environment. *COM(2018) 673 final*. Brussels

United Nations (2015): Transforming our world: the 2030 Agenda for Sustainable Development. New York