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Strengths and gaps of the EU frameworks for the sustainability assessment of bio-based products and bioenergy

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Abstract

Background: The high number of bioeconomy (BE) policies and strategies indicates the interest in the BE in many nations. The development of the BE holds opportunities but also risks for sustainability. Thus, the future development of a sustainable BE should be based on coherent policy frameworks. There are already links between private governance approaches and public policy frameworks that might support each other for this purpose. The aim of this study was to evaluate how the current EU BE policy frameworks consider sustainability aspects and if non-governmental governance approaches could support their enhancement.

Methods: An inventory of BE policy documents on EU and EU member state levels relevant to sustainability was conducted applying desktop research. Major sustainability risk perceptions in the BE sectors were identified. We provide a list of sustainability risks within different BE sectors, based on an expert survey. In a qualitative evaluation, most commonly identified sustainability requirements in policy documents were benchmarked against most important sustainability risk perceptions.

Results: Sustainability requirements have been identified in 56% of the policy documents. The influence of the policy frameworks on the industry was found to be rather low. Specific targets and goals are included in 72% of the analysed BE policy documents, but only 50% are quantifiable. Identification of major sustainability risks revealed that in the biomass production stage, mostly environmental risks are most relevant. A "hot spot sector" with accumulated sustainability risk perceptions or a tendency to higher risk levels was not identified. Most important sustainability risk perceptions matched with requirements in policy documents, but requirements were mostly stated in a noncommittal way.

Discussion and conclusions: Coherence amongst the sustainability criteria included in the various BE frameworks should be increased. Groundwork developed by non-governmental governance approaches should be picked up by policy makers for more harmonised terminologies of sustainability requirements, BE definitions, etc. BE monitoring approaches should take policy targets, sustainability requirements and sustainability risks into account and should adjust them in a dynamic way.

Keywords: Bioeconomy, Bio-based products, Policy frameworks, Sustainable biomass, Sustainability assessment, Sustainability certification, Standardisation

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Background

The bioeconomy (BE) concept has attracted enormous attention in the recent past. This is evident from the high number of existing regional, national and international BE strategies and policies [1, 2]. The elements included in these strategies and policies focus on both the traditional BE sectors such as food and feed production as well as novel biomaterial and biochemical sectors [3, 4].

Motivations for the development of the BE on European and national levels are manifold. Whilst objectives such as the development of rural areas and security of energy supplies are important motives for some regions, the contribution towards a more sustainable use of resources seems to be one of the most important elements across the existing strategies [5]. Given the experiences from the development of the EU biofuels sector in the past, it seems that an important precondition for the achievement of the latter is the development of a coherent sustainability framework for the BE [6]. One example for the importance of this topic is the debate on indirect land use change as a potential result of policy instruments addressing solely the biofuel sector without the necessary reference to the interlinkages of the different bioeconomy sectors [7]. Existing policy frameworks of the BE are partly fragmented and have been developed independently for the different BE sectors [8], such as agriculture, forestry, food and feed production, building materials, chemicals, consumer goods and pharmaceuticals as well as energy. Consequently, differences do exist regarding BE definition in the different sectors and the existing strategies and policy documents [3].

So far, the literature on the existing BE policy frameworks mostly focusses on strategic policies. For example, the Food and Agriculture Organization of the United Nations (FAO) reported in their "sustainable bioeconomy guideline program" on an analysis of how sustainability issues are addressed in 20 official BE strategies and 10 related BE roadmaps [9]. The focus of the policies was found to vary with the significance of biomass in the respective countries' economies. Moreover, specific indicators and methods to address sustainability issues were poorly included. Furthermore, there were differences in how comprehensively sustainability topics were addressed and the degree to which action plans were available to structure the implementation of activities to achieve the included targets. This indicates a lack of determinedness to push the BE development. The German Bioeconomy Council regularly reviews BE strategies of different nations across the world [3]. They could confirm FAO's result on missing action plans and operational roadmaps. Moreover, a lack of common BE definitions and the predominantly qualitative nature of included targets was reported [3]. Dietz et al. analysed 41 BE strategies using a qualitative approach to consider the link to the Sustainable Development Goals (SDGs) [10]. They stressed the need for a global governance framework for the development of national BEs as well as the risk of over- or underregulation as a result of inadequate monitoring of progress towards the goals. Hence, the development of a coherent policy framework addressing the relevant sustainability aspects needs to consider this status quo.

Over the past decades, private actors, such as NGOs and companies, have increasingly become involved in regulation activities [11]. There are some examples of existing links between the public governmental policy frameworks and activities organised by private stakeholders: An example for the use of a co-regulation instrument in the EU is the use of sustainability certification systems for the implementation of the Renewable Energy Directive (RED) [12] sustainability criteria. Another example for synergies between private governance and policies is the uptake of established voluntary sustainability schemes as basis for requirements in policy documents. This has been the case with the sustainable forestry certification schemes Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification Schemes (PEFC), which were accepted, for instance, by the German government as a mandatory public procurement requirement [13]. Certification systems, for instance, can be used to close gaps in the legal frameworks of jurisdictions. In this regard, the concept of co-regulation means that countries define legislative sustainability obligations for supply chains of a certain economic sector and allow private control mechanisms (e.g. certifications) for demonstration of compliance [14].

An important question for the future development of the BE is to which extent will it be possible to develop a more coherent policy framework, aiming to ensure sustainability based on the existing regulations for the various BE sectors. Against this background, the aim of this paper is to answer the following questions:

- Are there BE sectors with higher perceived sustainability risks? Could a priority be derived for the governance of sustainability?
- How do the BE policy frameworks in the EU currently consider sustainability aspects?
- Can non-governmental governance approaches support the enhancement of the BE policy frameworks?

In this paper, we analysed policy documents of the EU and national BE frameworks that are relevant for the assessment of sustainability. This assessment included strategies, roadmaps, action plans, etc. with voluntary requirements as well as mandatory requirements as those included in directives, ordinances and regulations. In the first step, we evaluated to which extent and in which

form the BE policy frameworks consider the concept of sustainability. In the second step, we identified the major risks to sustainability in different BE sectors in order to highlight where needs for improving sustainability governance of the BE are. In the final third step, we benchmarked the identified sustainability risks with the coverage of the corresponding sustainability issue in the existing BE policy frameworks. We discussed the role of sustainability certification and standardisation as well as co-regulation concepts in overcoming potential weaknesses and gaps in the public governmental policy frameworks. It is important to note that the motivation for this analysis stems from the work in a H2020 project called STAR-ProBio[1], in which the authors of this paper aim at the identification of links between sustainability assessment tools such as life cycle assessment (LCA) and certification with existing policies.

Methods

The general methodological approach for this study includes the workflow and a generic categorisation of the outcomes related to methods applied (Fig. 1). A comprehensive list of BE policy documents, the result of a comprehensive desktop research, served as a starting point for the subsequent steps. Each step will be further elaborated in the following sections. The methods are based on preliminary works within the STAR-ProBio project [15].

Identification of relevant policies and strategies

Initially, policy documents relevant for the BE and the sustainability assessment on EU and member state level were compiled by conducting desktop research. Thereby, national laws, EU directives, EU regulations, strategies, roadmaps and action plans were included for further study. This review resulted in a list of 101 documents. To allow for a feasible analysis of each document (see the "Analysis of selected policies and strategies" section), the selection was reduced to a processable number of documents using the selection criteria outlined below:

- European policies:
  As Europe was the geographical scope of the study, EU level policies and policies of EU member states were considered, aiming at a balanced sample
- Available languages:
  According to the language skills of the authors, only documents or translations in English, German, Dutch, French or Italian language were considered
- Accessibility:
  Documents had to be available online
- Reference to the BE:
  The scope of a policy had to be within one BE sector or in the BE as a whole
- Reference to sustainability:
  Sustainability or sustainability assessment had to be a relevant aspect of a policy
- Inclusion of reflection of future BE relevant challenges (e.g. circular economy, waste management):
  This criterion should reflect additional aspects relevant to BE

Application of the criteria in the above order resulted in a selection of 50 policy documents, which were compiled into two tables (Tables 1 and 2). With this step, we distinguished between more general documents and those with some mandatory elements. This differentiation was done using the classification "document type" and "mandatory character", derived from the analysis described in the "Analysis of selected policies and strategies" section (Table 3). We defined the document types strategy, road map, action plan, report, guidance and growth plan as less mandatory documents and directive, regulation and ordinance as a second group with more mandatory character. The tables were intended to serve as overview and at the same time as the basis for the next step.

Analysis of selected policies and strategies

In the subsequent step, policy documents were further analysed. To do so, a standard review template (see supplementary material 2) was created compiling desired data from the documents, such as general information, information on scope and significance as well as on links to sustainability and sustainability assessment (Table 3). The mandatory character arises from the type of policy (e.g. EU directives were per se considered mandatory) on one hand. On the other hand, the aspect was part of the review template and was thus under evaluation when documents were reviewed. To assess the role of sustainability assessment methods and tools in the documents, we analysed to which extent sustainability assessment was explicitly mentioned and whether direct links to sustainability certification, in terms of a specific scheme, exist. Moreover, for each document, it was evaluated whether certification could be useful to support the implementation of the particular policy[2] (Table 3). The template was, therefore, created to ensure data collection in a harmonised and uniform way. The processed review templates were a basis for a further evaluation which included a calculation of the frequency of different

[1]Please see www.star-probio.eu for more information

[2]Subjective, qualitative information

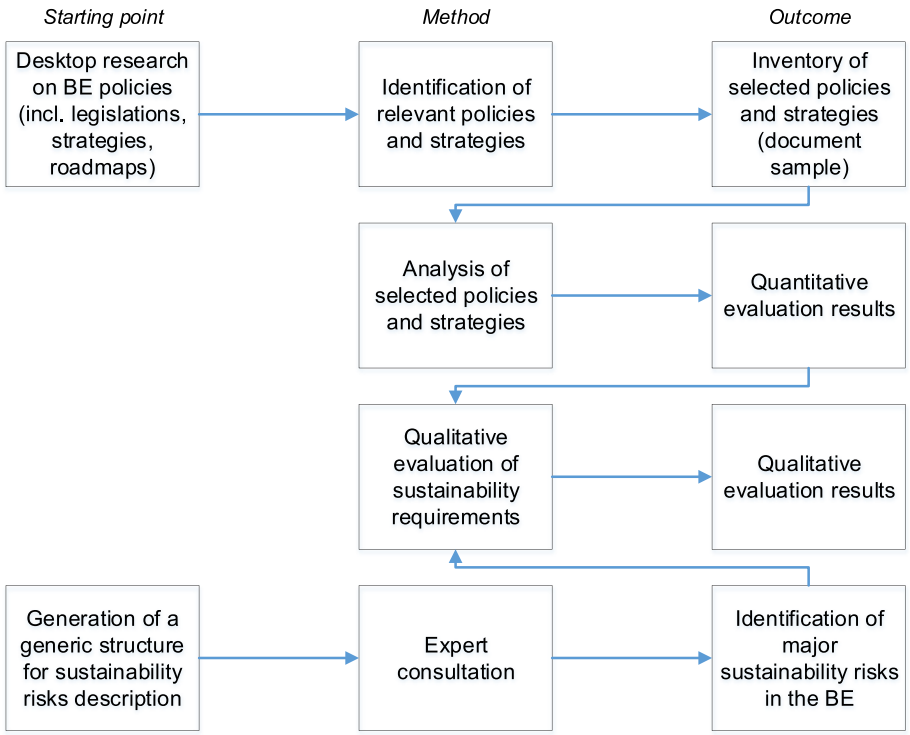

Fig. 1 Methodological approach for the bioeconomy (BE) policy analysis including applied methods and type of outcomes

parameters (e.g. the frequency of each of the included sustainability requirements). Result tables were generated (Table 1 and 2) as well as a table presenting the results in a condensed form (Table 4).

Results of this analysis were used to identify the level of which sustainability requirements were included as well as the potential reference to tools for the operationalisation of these criteria in the analysed policy documents.

Expert consultation

To outline the perception of risks for sustainability in the different sectors of the BE and to assess potential differences amongst them, a qualitative, stepwise approach was followed. This process was initiated as part of a workshop in the context of the STAR-ProBio project. The audience was composed of project members only. They represented seven European institutions from Belgium, Poland, Italy, Germany and the Netherlands. The majority of participants were scientists from different research organisations within the disciplines agricultural sciences, innovation economics, political economics, environmental and climate science, as well as bioenergy research. Additionally, participants from an environmental organisation (NGO) and a consultancy company took part.

In the beginning, a template for a table (see supplementary material 1) was presented. It comprised a generic structure for the illustration of risks to sustainability as a function of value chains in BE sectors. During a first discussion, this template was further conceptualised. This resulted in an improved version of the template, which was shared with the group. Moreover, additional instructions were given. Each institution was assigned to insert estimations (only) on potential major risks into the template with respect to the particular value chains in the BE sectors: final product (or main technology pathway), main feedstock (or feedstock group), main potential sustainability risk(s) and significance of the risk (low, medium, high). The task was not about filling the entire template, but only the lines listing the sectors for which the individual partners felt competent to give valid estimations, according to their specific background and expertise. Additionally, the receivers of the template were encouraged to have a discussion on their contribution within their institution.

After retrieving the contributions from the partners, a final table was created by means of aggregating the partial results. The filled tables of the participants were then compared. In case a risk was mentioned repeatedly, it was aggregated to one risk. The estimations for the significance of the risk were attributed to a group of risks, in order to express the risk level relevant to value chains in certain BE sectors. In case of conflicting views on risk level estimations in terms of considerable differences between the compared tables, discrepancies were discussed with the relevant partners. To complete this survey, a

Table 1 Analysed sample of overarching BE policy documents with relevance for sustainability assessment

Identifier	Policy title	Geographical relevance	Type of document	Mandatory	Effective date	Affected BE sectors	Influence on companies	Specific targets/ goals	Targets/ goals measureable	Addressed sustainability dimensions	Sustainability criteria incorporated	Certification explicitly mentioned	Direct links to certification	Certification appropriate instrument
1	2015 Circular Economy Strategy (Action Plan)	EU	Action plan	no	2015	all	no	-	-	En So	-	+	-	-
2	Bioeconomy Development in EU Regions Mapping of EU Member States' / Regions' Research and Innovation Plans & Strategies for Smart Specialisation (RIS3) on Bioeconomy for 2014 -2020	EU	Report	no	2017	all	no	-	-	En	-	-	-	-
3	Bioeconomy Regions in Europe	EU	Report	no	2017	all	no	-	-	En	-	-	-	-
4	Building the Single Market for Green Products Facilitating better Information on the Environmental Performance of Products and Organisations	EU	Strategy	no	2013	all	no	+	+	En	+	+	+	+
5	EU Forest Strategy	EU	Strategy	no	2013	all	no	+	-	En Ec So	+	+	+	+
6	EU Strategy for Plastics in the Circular Economy	EU	Strategy	no	2018	CP	no	+	+	En	+	+	+	+
7	Good Practice Guidance on the Sustainable Mobilisation of Wood in Europe	EU	Guidance	no	2010	F	no	+	-	En Ec	-	-	-	-

Table 1 Analysed sample of overarching BE policy documents with relevance for sustainability assessment *(Continued)*

Identifier	Policy title	Geographical relevance	Type of document	Mandatory	Effective date	Affected BE sectors	Influence on companies	Specific targets/ goals	Targets/ goals measureable	Addressed sustainability dimensions	Sustainability criteria incorporated	Certification explicitly mentioned	Direct links to certification	Certification appropriate instrument
8	Guidance on unfair Commercial Practices - Extract on Misleading Green Claims	EU	Guidance	no	2005	all	direct	-	-	-	-	+	+	+
9	Innovating for Sustainable Growth - A Bioeconomy for Europe (Bioeconomy Strategy)	EU	Strategy	no	2012	all	no	+	-	En Ec So	-	+	+	+
10	Promotion of Sustainable Mobilisation of Wood	EU	Strategy	no	2007	BEn, F	in-direct	+	-	En	+	+	-	+
11	Action Plan on Renewable Raw Materials	AT	Action plan	no	2015	F, C, T, CP, P, M/P	no	+	-	En Ec	+	+	-	+
12	Bioeconomy in Flanders	BE	Action plan	no	2014	all	no	+	-	En Ec So	+	+	-	+
13	Biorefineries Roadmap	DE	Roadmap	no	2012	BEn, F, Fo, Fe, CP, P, M/P	no	+	-	-	+	+	-	+
14	Forest Strategy 2020	DE	Strategy	no	2011	F	no	+	+	En Ec So	+	+	+	+
15	National Policy Strategy on Bioeconomy	DE	Strategy	no	2014	all	no	+	+	En Ec So	-	+	+	+
16	Plan for Growth for Water, Bio and Environmental Solutions	DK	Growth plan	no	2013	all	in-direct	+	+	En	+	+	-	+
17	The Spanish Bioeconomy Strategy 2030 Horizon	ES	Strategy	no	2016	F, Fo	no	+	+	En So	-	+	-	+
18	Finnish Bioeconomy Strategy	FI	Strategy	no	2014	all, emphasis on F	in-direct	+	+	En	-	-	-	-

Table 1 Analysed sample of overarching BE policy documents with relevance for sustainability assessment *(Continued)*

Identifier	Policy title	Geographical relevance	Type of document	Mandatory	Effective date	Affected BE sectors	Influence on companies	Specific targets/ goals	Targets/ goals measureable	Addressed sustainability dimensions	Sustainability criteria incorporated	Certification explicitly mentioned	Direct links to certification	Certification appropriate instrument
19	A Bioeconomy Strategy for France	FR	Strategy	no	2016	BEn, F, Fo, CP, M/P	no	-	-	En	+	+	-	+
20	Energy Transition for Green Growth Act	FR	Action plan	no	2016	BEn	no	+	+	En	-	+	-	-
21	National Action Plan for Green Public Procurement	FR	Action plan	no	2014	BEn, C, Fo, T, CP, M/P	direct	+	+	-	-	-	-	+
22	National Strategy of Ecological Transition towards Sustainable Development 2015-2020	FR	Strategy	no	2014	all	in-direct	+	+	En	-	+	-	+
23	National Environmental Technology Innovation Strategy 2011-2020	HU	Strategy	no	2012	BEn, C, Fo, Fe	in-direct	+	+	En Ec So	-	+	-	+
24	Renewable Energy Republic of Hungary - National Renewable Energy Action Plan 2010 2020	HU	Action plan	no	2010	BEn	direct	+	+	En	+	+	+	+
25	Action Plan for the Environmental Sustainability of Consumption in the Public Administration Sector	IT	Action plan	no	2006	all	no	+	+	En	+[a]	+	+	+
26	Bioeconomy in Italy	IT	Strategy	no	2016	all	no	+	+	Ec So	-	+	+	-

Table 1 Analysed sample of overarching BE policy documents with relevance for sustainability assessment *(Continued)*

Identifier	Policy title	Geographical relevance	Type of document	Mandatory	Effective date	Affected BE sectors	Influence on companies	Specific targets/ goals	Targets/ goals measureable	Addressed sustainability dimensions	Sustainability criteria incorporated	Certification explicitly mentioned	Direct links to certification	Certification appropriate instrument
27	Towards a Model of Circular Economy for Italy	IT	Report	no	2017	F, C, Fo, CP	no	-	-	En So	+	-	-	+
28	A Circular Economy in the Netherlands by 2050	NL	Strategy	no	2016	all	in-direct	+	+	En Ec So	-	+	+	+
29	Strategy for a Green Society	NL	Strategy	no	2013	all	no	+	-	En Ec So	-	-	-	+
30	Green Growth Commitment	PT	Strategy	no	2015	all	in-direct	+	+	En	+	+	+	+
31	Swedish Research and Innovation Strategy for a Bio-based Economy	SE	Report	no	2012	Fo, T, CP, P, M/P	no	+	-	En	-	+	+	+
32	UK Bionergy Strategy	UK	Strategy	no	2012	BEn	in-direct	+	-	En Ec So	+	+	+	+

[a]Incorporation of FSC/PEFC certification scheme as a whole

The BE sectors are coded as follows: *BEn* bioenergy, *F* forestry, *Fo* food, CP chemicals and plastics, *M/P* materials/products, *C* construction, *T* textiles, *P* pharmacy, *Fe* feed. Sustainability dimensions are coded as followed: *En* environmental, *Ec* economic, *So* social; + stands for "included"; – stands for "not included"

Table 2 Analysed sample of regulatory BE policy documents with relevance for sustainability assessment

Identifier	Policy title	Geographical relevance	Type of document	Mandatory	Effective date	Affected BE sectors	Influence on companies	Specific targets/ goals	Targets/ goals measureable	Addressed sustainability dimensions	Sustainability criteria incorporated	Certification explicitly mentioned	Direct links to certification	Certification appropriate instrument
33	Commission Decision of the EU Ecolabel for textile products (2014/350/EU)	EU	EC Decision	no	2014	T, M/P	in-direct	-	-	En So	+	+	+	+
34	Commission Decision of the EU Ecolabel for wood-, cork- and bamboo-based floor coverings (2017/176)	EU	EC Decision	no	2017	M/P	in-direct	-	-	En So	+	+	+	+
35	Directive 2008/56/EC on Marine Strategy Framework	EU	Directive	yes	2008	Fo, M/P	no	-	-	En	+	+	+	+
36	Directive 2008/98/EC on waste	EU	Directive	yes	2008	All	direct	+	+	En	+	-	-	+
37	Directive 2009/28/EC on Renewable Energy (RED)	EU	Directive	yes	2009	BEn	in-direct	+	+	En	+	+	+	+
38	Directive 2015/1513/EU on indirect land use change	EU	Directive	yes	2015	BEn	direct	+	+	En Ec So	+	+	+	+
39	Directive 94/62/EC on packaging and packaging waste	EU	Directive	yes	2015	CP, M/P	direct	+	+	En	-	-	-	+
40	Regulation (EC) No 1069/ 2009 on Animal by-products	EU	Regulation	yes	2009	BEn, Fo, Fe	direct	-	-	En	-	-	-	-
41	Regulation (EC) No 1830/ 2003 on genetically modified organisms (GMO)	EU	Regulation	yes	2003	All	direct	-	-	En	-	-	-	+
42	Regulation (EC) No 1935/ 2004 on Food Contact Materials	EU	Regulation	yes	2004	Fo, CP, M/P	direct	-	-	-	-	-	-	-
43	Regulation (EC) No 761/ 2001 on Eco-management and Audit Scheme (EMAS)	EU	Regulation	no	2001	All	in-direct	-	-	En Ec So	+	+	+	+
44	Regulation (EU) No 995/ 2010 on European Timber (EUTR)	EU	Regulation	yes	2010	BEn, F, C, M/P	direct	+	-	En	+	-	-	+
45	Decree on Public Procurement of Wood Products	DE	Ordinance	yes	2011	F, C, M/P	direct	+	+	En Ec So	+	+	+	+
46	Renewable Energy Sources Act (EEG)	DE	Ordinance	yes	2017	BEn	in-direct	+	+	-	+	+	-	+
47	A Resource Opportunity - Waste Management Policy in Ireland	IR	Policy	no	2012	BEn, F, C, T, CP, M/ P	no	+	+	En	+	+	+	+

Table 2 Analysed sample of regulatory BE policy documents with relevance for sustainability assessment *(Continued)*

Identifier	Policy title	Geographical relevance	Type of document	Mandatory	Effective date	Affected BE sectors	Influence on companies	Specific targets/ goals	Targets/ goals measureable	Addressed sustainability dimensions	Sustainability criteria incorporated	Certification explicitly mentioned	Direct links to certification	Certification appropriate instrument
48	Delivering our Green Potential	IR	Policy statement	no	2012	BEn, F, Fo, Fe, CP, P, M/P	in-direct	+	+	En	+	-	-	+
49	National Programme for Waste Reduction	IT	Policy	yes	2017	C, Fo, Fe	no	+	+	En	+	+	-	-
50	Hoofdlijnennotitie Biobased Economy (BBE)	NL	Policy	yes	2012	All	no	-	-	En	+	+	+	+

BEn bioenergy, *F* forestry, *Fo* food, CP chemicals and plastics, *M/P* materials/products, *C* construction, *T* textiles, *P* pharmacy, *Fe* feed. Sustainability dimensions are coded as followed: *En* environmental, *Ec* economic, *So* social; + stands for "included"; − stands for "not included"

Table 3 Type of information derived from each policy document analysed using the standard review template (supplementary material 2)

General information	**Scope and significance**
- Document name/identification	- Affected/promoted products or resources
- Origin	- Affected BE sectors
- Geographic relevance	- Precise objective
- Mandatory character	- Influence on companies in the industry
- Document type	- Specific targets/goals
- Effective date	- Measurability of included targets/goals
Link to sustainability and sustainability assessment	
- Addressing of sustainability dimensions	
- Incorporation of sustainability requirements/criteria[a]	
- Explicit reference to sustainability certification or sustainability assessment	
- Direct links to sustainability certification	
- Suitability of certification for implementation of the policy/regulation/strategy	

[a]The terms "criteria" and "requirements" are used synonymously in this context and the following, as they were found to be poorly defined in the investigated documents

second workshop was arranged, in which the result was presented and discussed. An agreement on the finalised table could be reached amongst the attendants in the end.

Qualitative evaluation of sustainability requirements most commonly identified in policy documents

For sustainability requirements most frequently identified in the analysed policy sample, a qualitative evaluation was done. This was conducted by reconsidering the sustainability requirements in the 50 policy review sheets (derived from the previous step of our methodology) and the respective policy document. This step enabled us to provide context around the requirements, allowing an evaluation of the way in which sustainability requirements are incorporated thereby increasing the understanding of their effect.

Table 4 Results of the evaluation of the policy documents ($n = 50$)

Topic included in the policy documents analysed	Coverage (in %)
Policy documents with mandatory character, %	24
Policy documents having direct influence on companies, %	24
Policy documents having indirect influence on companies, %	26
Policy documents having no influence on companies, %	50
Specific targets/goals included, %	72
Targets/goals measurable, %	50
Sustainability requirements included, % (see Fig. 2 for more details)	56
Sustainability assessment/ certification explicitly mentioned, %	72
Direct links to certification, %	44
Suitability of certification as instrument for implementation of the policy, %	76

Results

This chapter is structured as follows: Below, perceived major sustainability risks in BE value chains are presented. This is followed by the second part, in which the current BE policy frameworks relevant for sustainability assessment are analysed. In this way, the second part of this article starts with an inventory of BE policy documents which have been analysed ("Inventory of BE relevant policies and strategies" section). The results of the analysis of sustainability and sustainability assessment relevant elements in policy documents are presented in the "Inclusion of sustainability and certification in the policy documents analysed (quantitative evaluation)" section. The qualitative evaluation of most frequently identified sustainability requirements in the final section of this chapter will bring the two parts together ("Qualitative evaluation of sustainability requirements in the policy frameworks" section) in order to answer the question: How do the policy frameworks consider the main perceived risks to sustainability?

Identification of major sustainability risk perceptions linked to the BE

Major risks for sustainability within different BE value chains as perceived by different experts are reported in Table 5. It must be pointed out that this table is not meant to present a complete and comprehensive list of results. The idea was to highlight value chains with need for regulation, indicated by a concentration of sustainability risk perceptions (hot spots). Therefore, in accordance with the survey instructions (cf. the "Expert consultation" section in "Methods"), the most relevant risks identified as risk perceptions are highlighted in the following:

- Potential risk perceptions for sustainability were identified in all BE sectors
- We found that the majority of identified risks are related to environmental sustainability, whereas only a limited number of potential risks for social

Table 5 Major identified risk perceptions for sustainability in different BE value chains based on the expert survey

Bioeconomy sector	Final product(s)/main technology pathway(s)	Main feedstock or feedstock group	Main sustainability risk(s)	Risk level / significance
Bioenergy	Biofuels (focus on biodiesel, bioethanol and biomethane)	Oilseed crops	LUC and ILUC	high[a]
		Starch and sugar crops	Deforestation	
			Food price increase	
			Biodiversity loss (by expanding cultivation area and by intensification)	
			Water quality (leaching of nutrients)	
		Lignocellulosic energy crops	Deforestation	high[a]
			Biodiversity loss (by expanding crop cultivation areas)	
		Wastes and residues	Creation of competing uses due to the introduction of strong policy incentives.	low
	Heat & power	Lignocellulosic energy crops	Deforestation	medium to high
	Heat (small scale units)	Lignocellulosic energy crops	Biodiversity loss (by expanding cultivation areas)	
			Air quality	
Forestry	Buildings and industrial applications	Timber	Illegal logging causing deforestation	high
			Biodiversity loss	
			Negative impacts on local communities (imported wood)	
	Paper and board		Labour conditions in producing countries	
Construction	Construction materials, fibreboards, thermal insulation	Timber	Illegal logging causing deforestation	low to medium[b]
			Biodiversity loss	
			Non-certified import from other countries or poor certification processes	
			Negative impacts on local communities (at least on imported wood)	
		Fibre crops (hemp, flax)	Competition with food/feed production	low
Food & Feed	Plant-based food & feed	Grains Rice	Biodiversity loss	high
			Soil erosion	
			Decrease in soil and water quality (nutrients leaching)	
			Impact of fertilisers and pesticides	
		Oilseed crops	LUC and ILUC causing deforestation	low to high
		Sugar crops	Land use rights	
			Higher food prices	
Textiles	Garments, fabric, carpets, geotextiles, etc.	Cotton	High input of energy, water and agrochemicals	high
			LUC and ILUC (cultivation)	
			Labour conditions in producing countries	

Table 5 Major identified risk perceptions for sustainability in different BE value chains based on the expert survey *(Continued)*

Bioeconomy sector	Final product(s)/main technology pathway(s)	Main feedstock or feedstock group	Main sustainability risk(s)	Risk level / significance
			Chemicals use and leakage (production)	
		Fibre crops (flax, hemp)	Competition with food/feed production	low
		Wool	Competition with food/feed production	low
			Labour conditions in producing countries	
Chemicals and Plastics	Bioplastics, packaging materials, bottles, bags, mulch film, biolubricants, biopolymers	Starch and sugar crops	End of life & reuse	high
		Oilseed crops	Same as bioenergy	same as bioenergy
Pharmacy	Medicine applications & pharmaceuticals	Plants	Chemical use and leakage (production)	medium
		Algae		
Materials/ Products	Cardboard, filters, cords	Fibre crops (hemp, flax)	Competition with food/feed production	low
	Biocomposites	Lignocellulosic crops	Same as bioenergy	same as bioenergy

EoL end of life, *LUC* land use change, *ILUC* indirect land use change
[a]Depending on the cultivation region
[b]It is low to medium, because of the amount of feedstock used at the moment, but pressure on raw material will grow when demand for bio-construction products grow

sustainability were identified and none relating to economic risks (Table 5).
- Environmental, social and economic impacts may occur along the entire life cycle of a BE product. In our analysis, the experts perceived major environmental sustainability risks which are, to an increasing degree, linked to the feedstock production (Table 5).
- Overall, most frequently mentioned risks were biodiversity loss, deforestation, land use change, indirect land use change, food price increase and illegal logging (in the order mentioned). As these risks are mostly associated with the biomass cultivation and do not depend on end-uses, the differences between the different BE sectors are moderate, meaning there is no hot spot sector or a sector without any risk. The lowest risk levels were assigned to value chains, which are assumed to mostly source feedstock regionally (or at least) within Europe. A comparatively small and local risk (use and leakage of chemicals during the production) was perceived for the pharmacy sector.
- Food and feed crops (oil, starch and sugar crops) were predominantly assessed to be associated with a high risk level. Wastes and residues, as well as algae and fibre crops were the type of biomass assessed with the lowest risk level.
- The relevance of the main risk areas identified is also dependent on the geographical focus of the respective value chain of a bio-based product. This aspect was also part of the discussion with the experts. For the transportation biofuel sector, some of the most critically discussed sustainability risks associated with feedstock supply were related to biomass produced in Southeast Asia and some Latin-American countries. It was generally assessed that there is a perception of risk that feedstock contribute to the loss of native forests in the tropics.
- For the major sustainability risks highlighted in relation to the use of forest biomass, there seems to be an unequal distribution of the assessed risks around the globe, with risks assessed to be higher in developing regions.

Inventory of BE relevant policies and strategies

The selected policy and strategy documents, which were found relevant for further analysis based on the defined criteria for selection, are given in Table 1 and Table 2. The analysed policies took effect between 2001 and 2018. For a better overview, the selection was separated according to the strength of their commitment. Thus, 32 (64% of the sample) strategies, roadmaps, action plans, guidances and documents referred to as “report” were compiled in Table 1. As a second group, 18 documents (36% of the sample) considered to have mandatory character were categorised as policies, ordinances, regulations, directives and decisions (Table 2). Twenty-two of the documents were EU documents valid in all member states. As well, this selection included national documents from 14 different EU member states.

To initially characterise this sample, the table shows general information in the left columns and more specific and topic related information in the right columns. Moreover, the influence of the policy documents on companies was characterised by a differentiation between "direct influence", "indirect influence" and "no influence". In this context, directly influencing policies are characterised by a certain level of obligation to fulfil sustainability requirements and punishment for not fulfilling those, respectively. Indirect influence means that a voluntary implementation of sustainability principles or criteria will be rewarded, which includes incentivising policies as well. Non-influencing policies are expected to have no effect on companies in any way.

The relevant documents cover a broad spectrum of topics, as can be seen from Table 1 and Table 2. This reflects the broad scope of the BE. There are documents dedicated to the BE in general, on the one hand. On the other hand, there are more specific ones. These policies mostly focus on biomass resources (e.g. forest, agriculture, waste) and biomass utilisation (e.g. energy, bio-based products). Additionally, a third category can be assigned to cross-cutting issues, e.g. circular economy and waste management. Moreover, a multitude of strategies, roadmaps, action plans, etc., on BE is available on EU level and on national level in several EU member states (Table 1).

The inventory exemplifies the focus on sustainability whilst distinguishing between the three sustainability dimensions (Table 1, Table 2). A comprehensive consideration of environmental, economic and social aspects has only been found for 12 of the 50 documents.

The inventory for our analysis of less compulsory BE policy documents included 32 documents on EU and member state level (Table 1). Interestingly, a first screening of the documents showed that the majority include references to sustainability requirements as well as references to tools, such as sustainability certification.

Obviously, most of the documents listed in Table 2 were characterised as mandatory. Many of them cover very specific topics (e.g. regulation on animal by-products). Compared to the documents given in Table 1, more policy documents have an EU wide geographical scope. Additionally, more policy documents were characterised as having direct or indirect influence on companies. Characteristics with regard to sustainability and sustainability assessment will be further elaborated in the following section.

Inclusion of sustainability and certification in the policy documents analysed (quantitative evaluation)

From all documents analysed, less than one quarter had a mandatory character. Policy documents were screened according to the presence of specific targets or goals with respect to the topic of the policy, which appears to differ substantially. The identified targets and goals ranged from quantitative and very precisely formulated ones, e.g. "meeting 40% of energy needs through biofuels by 2020" (no. 47 in Table 2) to rather general, qualitative ones, e.g. "engaging in circular low-carbon economy" (no. 22 in Table 1). The bigger part (72%) of all analysed documents included targets. Only half of the mentioned targets were found to be measurable (Table 4).

With respect to the influence of the policy frameworks on companies, the results showed that the overall influence seems to be limited, as 50% of the documents were classified to have no influence. A share of 24% of the documents was considered to have direct influence and 26% to have indirect influence.

Sustainability requirements were included in some policy documents. These requirements are mostly not mandatory to follow but have rather a guiding character. The presence of the requirements was assessed in order to describe the significance of certain sustainability aspects in certain areas. In 56% of the policy documents, requirements were included. They are shown below, depending on the frequency they occurred in the documents, in which "climate change" and "waste/end-of-life aspects" were found to be the most frequently occurring (Fig. 2). Two more observations were made. When relating the criteria to one of the three sustainability pillars (economic, social and environmental), requirements from the environmental pillar were predominant, whilst social and economic requirements were less well represented. Furthermore, in some cases no specific, individual requirements were included, but reference was made to established sets of requirements or established certification schemes, respectively. RED criteria and criteria of the PEFC/FSC were frequently found as an element of policy documents. In 72% of the analysed documents, explicit reference was made to sustainability assessment or certification (Table 4).

Qualitative evaluation of sustainability requirements in the policy frameworks

Generally, perceived major sustainability risks in BE value chains (Table 5) showed a high overlap with the requirements identified in the analysed policy sample (Table 1 and Table 2). At a first glance, there is no direct match between perceived risk and policy requirement identifiable for some cases. However, "land use change causing deforestation", for instance, will result in elevated greenhouse gas (GHG) emissions and, therefore, indirectly concerns the policy requirement "climate protection". The analysis of the frequency with which sustainability requirements occur in policy documents does not allow for any conclusions regarding the adequacy of the considerations of major sustainability risks within the policy frameworks. To further tackle this problem, a

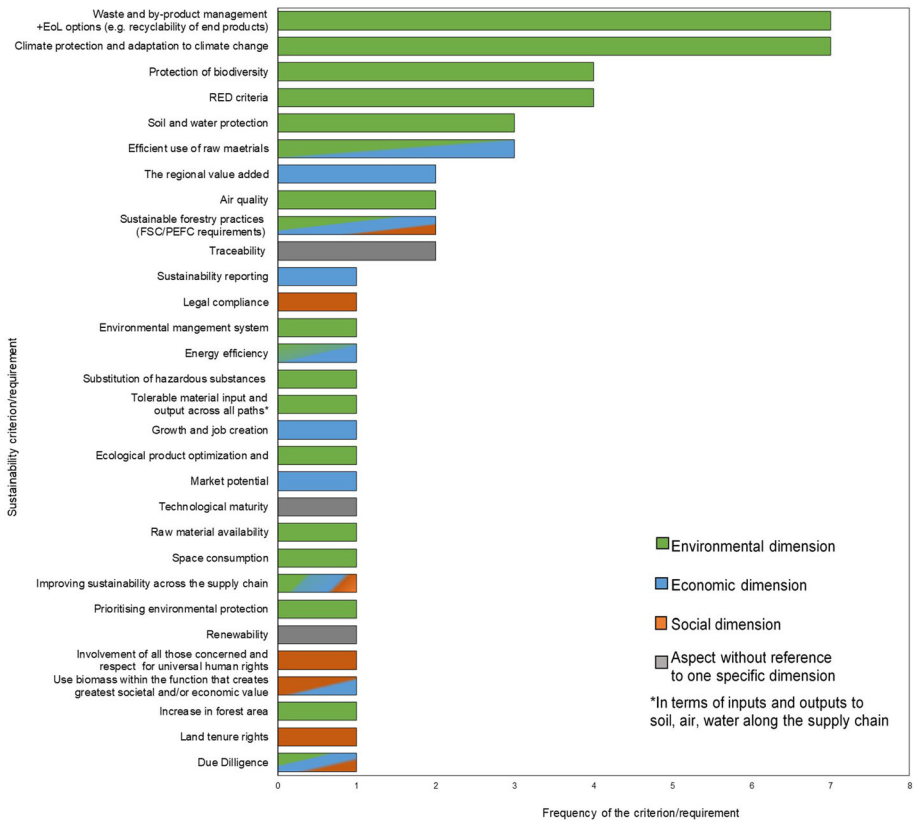

Fig. 2 Sustainability requirements included in the analysed policy document sample (n = 50) against the frequency of the requirement. In 56% of the analysed documents, requirements were included (EoL, end of life; RED, Renewable Energy Directive)

qualitative evaluation (Table 6) was undertaken for the four requirements that were most commonly found (Fig. 2) in the initial screening of the policy documents via the templates.

Some of the four requirements overlap with each other. The "RED criteria" are treated as a criteria set. This set also includes the criterion prohibiting support for biofuels obtained from land with high biodiversity value in the EU market (RED Article17 (3.) [12]). In addition, the GHG emissions saving criterion in the RED supports "climate protection and adaption to climate change".

Although the four requirements in Table 6 are frequently included in the analysed policy documents (Fig. 2), we found no requirements which are mandatory, when evaluating the context. The most strict sustainability requirement was found in the RED. Even these criteria are in fact not mandatory, as non-compliant biofuels and bioliquids are still allowed on the EU market. For financial support mechanisms and the fulfilment of quotas obligations, conformity with RED is a precondition.

Most requirements are worded very airy. In the majority of cases however, the intention to be supportive of a more sustainable development with respect to the requirements is expressed. Also, statements to promote more sustainable practices are given. But it is not clear how that should precisely be achieved. Details, e.g. thresholds or indicators, which could verify any progress towards fulfilment were not found (Table 6).

There are many soft wordings, e.g. "systematic use of LCA is promoted" or "CO_2 emission reduction should be quantified". These can be laid-out with lower or higher ambition. On the other hand, RED serves as an example for a systematic use of GHG emissions saving requirement. These criteria have a life cycle approach, are well operationalised, clear and can be adopted for target-oriented purposes.

Discussion and conclusions

In this paper, we studied existing BE policy frameworks and which are the sustainability aspects included. Furthermore, the analysed frameworks have been discussed in context of a set of perceived sustainability risks for the BE identified by experts.

There is a high number of policy documents forming the frameworks for sustainability adopted for the BE. An in-depth analysis of a sample of these documents revealed that many different sustainability requirements are currently already included. These primarily address

Table 6 Qualitative evaluation of most frequently included sustainability requirements in the analysed document sample

Sustainability requirement	Fitting perceived sustainability risk (Table 5)	Context around sustainability requirements (identifier of policy documents according to Table 1 and Table 2 in brackets)	Evaluation
"RED criteria"	LUC and ILUC, Biodiversity loss, Deforestation	Intention to extend RED criteria to other sectors (32,10,50), implementation of European legislation on national level (24), fulfillment of criteria are precondition for financial support and quota obligations in EU member states (37), amendment to 37 (38), statement, that does not express sustainability ambition on top of existing legislation (13)	Besides documents referring to the origin of the criteria (RED), only intentions for further implementation or extension to other sectors are declared.
"Climate protection and adaption to climate change"	Deforestation, LUC and ILUC	Systematic use of LCA, including total GHG emissions, is promoted (19), materials should be assessed for impacts, incl. GHG emissions, CO_2 emission reduction should be quantified (30, 11), minimum requirements (e.g. positive climate balance) are recommended (13), reducing total GHG emissions (48), climate protection as area of action (14)	The requirements are associated with GHG emission reduction. Particular emission saving targets or obligations for emission reductions are missing.
"Protection of biodiversity"	Biodiversity loss, Deforestation, Illegal logging	"Protection of biodiversity (48) and nature conservation" as area of action (14), review of an assessment of indirect effects and impacts on biodiversity (38)	Very broad requirements, in which precise provisions to protect biodiversity are not included
"Waste and by-product management and EoL options"	End of life and reuse	Maximization of (organic) residual and waste stream utilization and recycling for the closure of circuits (12), systematic use of LCA (considering waste and by product management and EoL options) is promoted to assess environmental benefits of biobased products (19), Public bodies should consider recyclability and disposal when procuring construction materials and maximize the use of recycled, recyclable material when procuring textiles (reference to guidelines) (47), waste prevention (no specification) (49), "inner circle approaches" such as reuse, repair, redistribution, remanufacturing ahead of recycling and energy recovery (27), recommendation of closed material cycle for raw materials as min. requirement (13), new rules shall be proposed which encourage reuse activities(1), curb microplastic pollution, support recycling (6)	Statements, that describe mainly the intention to achieve a more circular economy, but details, thresholds, timelines or similar are not included

The frequency of sustainability requirements is given in Fig. 2
EoL end of life, *LUC* land use change, *ILUC* indirect land use change

the environmental sustainability dimension. The results of the survey on sustainability risk perceptions showed no specific hot spot in individual BE sectors which should be prioritised in order to prevent severe risks associated with the further development of the BE. Instead, the results highlight the biomass production stage as most associative for the perception of sustainability risks. Sustainability requirements in policy documents and the perceived sustainability risks were found to be largely overlapping, which indicates that perceived risks are addressed by the frameworks in the first instance. However, a qualitative analysis of the context, in which the requirements are embedded, showed overall low concreteness and vague wording of the requirements.

Our study on BE relevant policy documents showed the difficulty of precisely evaluating the consideration of sustainability concerns in the policy frameworks. We argue that the current presentation of sustainability aspects in the documents is one important reason. In many cases, there seems to be no clear demarcation between the concepts of "bioeconomy", "bio-based economy", or "circular economy". For that reason, we did not limit our analysis to policy documents referring to "bioeconomy" only. Even for "bioeconomy", there is no clear, commonly accepted definition [16], which must be considered to be a disadvantage, because it can be unclear which sectors are subsumed under one of the mentioned terms. Amongst others, this impacts the coherence of system boundaries for the proposed policy targets. The reason for the lack of common terminologies, as well as the potential lack of a coherent BE policy framework, might partly stem from the historic development of the different BE sectors. Moreover, the sheer scope of the relevant policy fields might be another reason.

Private governance tools evolved and have been widely applied, for example in co-regulation as a means for documenting compliance with RED in the recent past. As a result, groundwork for combining public and private regulation is available [17] and various forms of co-regulation have been expanding during the last decade [18]. Several sustainability certification schemes have been recognised by the European Commission and have been applied for the purpose of RED over the last decade [19].

The groundwork also includes particular standards aiming at compiling sustainability criteria and indicators for bioenergy (DIN ISO 13065) and bio-based products (EN 16751) [20, 21]. These standards can be used to ease the comparability of different processes or entire value chains with respect to their sustainability performance. However, their relevance in practice seems very low. In our analysis of policy documents, we did not find that sustainability requirements aligned with these standards, by direct reference to them.

Even though there is potential for harmonisation amongst different certification and assessment systems, the general availability of sustainability criteria and indicators applicable to BE value chains is high [17]. In the context of certification, criteria are usually presented in a very clear manner, as they need to be verifiable.

In our analysis, we found very imprecisely formulated requirements in many policy documents. Therefore, we see the preliminary work from the non-governmental governance activities as very relevant for the enhancement of sustainability governance in policies. Harmonisation of terminologies, definitions, criteria, indicators, etc. could provide a common language [22], beneficial for the development of more sustainable markets within the BE. Policy making could, therefore, make use of the previous developments of certification schemes and standards targeting a harmonised presentation of sustainability aspects in policy documents.

There is literature available focusing on, at least in parts, risks to sustainability in the context of a developing BE or of bio-based value chains. Studies cover different qualitative and quantitative methods, but mostly focus on specific BE sectors [23–25] instead of the BE as a whole. Diez at al. illustrated risks by aligning them to the SDGs covering food security, poverty/inequality, natural resources, health and climate change [10]. Most frequently, perceived risks in our study cover climate change and biodiversity loss, which can be considered two of the most important environmental problems requiring immediate and determined action on all levels [26, 27]. The quantitative analysis of the policy frameworks indeed showed that these challenges are, in a way, addressed. The qualitative analysis, however, revealed that the analysed frameworks clearly lack ambitious sustainability requirements to approach these challenges in an effective way.

In our limited discussion of risks, food and feed crops were generally associated with a higher risk level (Table 5). This seems to be well considered within the policy frameworks, as within the scope of the revised Renewable Energy Directive (RED II), where the support of biofuels derived from food and feed crops will be limited to the 2020 consumption (plus 1%) with a maximum at 7% of the final energy consumption in the transport sector (within each EU member state) [28].

Our survey on perceived sustainability risks in BE sectors suggests that, across all value chains, sustainability provisions at the biomass production stage should be strengthened. The importance of biomass cultivation in this regard is well in line with several LCA studies investigating potential environmental impacts of bio-based products and bioenergy, which unfold the biomass production stage as the most influential stage along the life cycle (e.g. [27]). The existing sustainability criteria for liquid biofuels in the EU, as included in the RED, address the cultivation of biomass in particular. These RED criteria were found to be the only concrete and purpose-oriented criteria in the qualitative analysis of sustainability requirements in the analysed policy documents. A way to ensure a sustainable development of the BE suggests, therefore, the application of similar basic criteria (e.g. based on the RED criteria) for all uses of biomass [29–31].

From these considerations, the question of how basic biomass cultivation criteria should be implemented still remains. Since 2009, sustainability criteria for liquid biofuels in the EU have been implemented with a co-regulative approach, meaning that compliance with the criteria is verified by private organisations with voluntary schemes recognised by the European Commission [19]. This governance method has proven to work and will be continued during the RED II validity period 2021–2030 [28]. With that, do the RED sustainability criteria have a real impact towards higher levels of sustainability?

There are only few studies on the impact of the RED. Frank et al. concluded that RED has a small or even no effect, due to leakage effects caused by indirect land use change, as only one single sector is addressed [32]. Furthermore, there are doubts on the accuracy of the GHG calculation methodology [33]. It is also questioned whether the consideration of GHG emission savings as a sole life cycle impact category is sufficient or if additional impact categories, such as eutrophication or acidification, should be taken into account as well [34]. More studies on the effect of the RED should be conducted.

The RED II expands the scope of the sustainability criteria as it includes the bioheat and bioelectricity sectors [28]. This will not prevent leakage effects from continuing to happen. But an expansion of the scope to all bio-based value chains seems to be unrealistic in the near future. It seems, therefore, the only option is to extend

common criteria sector by sector. When doing this, the RED II criteria need to be further developed in parallel, considering the current state of knowledge relevant to the added sectors.

In the end, a mix of private and public governance instruments, with their strengths on different levels, might be critical to achieve more sustainable value chains [35]. Other than that, accompanying instruments, such as public procurement, labelling or cross-national agreements on specific sustainability criteria should be supported.

In terms of overall sustainability governance in the BE, a learning monitoring system considering major sustainability risks, policy targets and consistent sustainability criteria should be implemented on the highest international level possible. This system should be reviewed and adapted regularly, taking the latest scientific developments and political priorities into account and adjusting policy targets and sustainability criteria accordingly.

Abbreviations

BBP: Bio-based product; BE: Bioeconomy; EoL: End of life; FSC: Forest Stewardship Council; GBEP: Global Bioenergy Partnership; GHG: Greenhouse gas; GSI: GBEP sustainability indicators; ILUC: Indirect land use change; LCA: Life cycle assessment; LUC: Land use change; PEFC: Programme for the Endorsement of Forest Certification Schemes; RED: Renewable Energy Directive; RED II: Revised Renewable Energy Directive; SDG: Sustainable Development Goal; UN: United Nations

Authors' contributions

DM planned and conducted the analysis and prepared the manuscript. SM was involved in the development of the conceptual approach for the manuscript and its preparation. SU critically reviewed the manuscript and provided valuable input with regard to co-regulation. SW and LL critically reviewed the manuscript and provided valuable input with regard to the standardisation. DT contributed to the critical reading of the draft manuscript and provided valuable input for the final manuscript. The authors read and approved the final manuscript.

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Competing interests

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