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BIOECONOMY

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Overview and a proposed way forward

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Overview and a proposed way forward

Stefania Bracco, Almona Tani, Özgül Çalıcıoğlu, Marta Gomez San Juan and Anne Bogdanski

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ABBREVIATIONS AND ACRONYMS

BCI	Bioeconomy Contribution Index (Malaysia)
BERST	BioEconomy Regional Strategy Toolkit
CAP	common agricultural policy
DE	domestic extraction
DMC	domestic material consumption
EC	European Commission
EMF	Ellen MacArthur Foundation
EU	European Union
E-LCA	Environmental Life Cycle Assessment
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GEP	Green Economy Progress
GGKP	Green Growth Knowledge Platform
Gha	global hectares
IINAS	International Institute for Sustainability Analysis and Strategy
ILO	International Labour Organization
ISBWG	International Sustainable Bioeconomy Working Group
ISO	International Organization for Standardization
JRC	Joint Research Centre
KPIs	Key Performance Indicators
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MF	material footprint

MFA	material flow accounts
M&E	monitoring and evaluation
MPS	Maritime Spatial Planning
MS	Member States
PAGE	Partnership for Action on Green Economy
PEF	Product Environmental Footprint
P&Cs	Principles and Criteria
RMC	raw material consumption
RME	raw material equivalents
SCP	sustainable consumption and production
SCL	Standard, certificate and label
S-LCA	Social Life Cycle Assessment
SDG	Sustainable Development Goal
SETAC	Society of Environmental Toxicology and Chemistry
SOC	soil organic carbon
TAAS	Tracking Adaptation in Agricultural Sectors
TEEB	The Economics of Ecosystems and Biodiversity
TSC	The Sustainability Consortium
UNEP	United Nations Environment Programme (now UN Environment)
WEF	Water-Energy-Food

EXECUTIVE SUMMARY

FAO has been working for many years on non-food biomass products (including sustainable bioenergy) and biotechnology, and it received a mandate to coordinate international work on 'food first' sustainable bioeconomy by 62 Ministers present at the Global Forum for Food and Agriculture (GFFA) 2015. Moreover, FAO has received support from the Government of Germany to develop guidelines on sustainable bioeconomy development (Phase 1: 2016; Phase 2: 2017-mid 2020). This involves work on the bioeconomy monitoring, including the selection and use of indicators.

The ultimate aim of FAO's work on sustainability indicators is to provide technical assistance to countries and stakeholders in developing and monitoring sustainable bioeconomy, more particularly on identifying suitable indicators in line with the Sustainable Bioeconomy Aspirational Principles and related Criteria, agreed upon in 2016 by the International Sustainable Bioeconomy Working Group created in the context of FAO's project on Sustainable Bioeconomy Guidelines. These indicators shall help both policy makers and producers/manufacturers in monitoring and evaluating the sustainability of their bioeconomy strategies and interventions.

In order to cover all the relevant aspects and issues for a sustainable bioeconomy, our approach identifies impact categories from the sustainable bioeconomy principles and criteria. The monitoring approach suggested is balanced, since it considers the three sustainability dimensions (social, economic and environmental); at the same time, it proposes to use a limited set of core indicators, to keep the monitoring feasible and cost-effective.

The suggested methodology starts with a review of existing monitoring approaches to identify already available indicators, from which the authors compiled two comprehensive lists:

- indicators at the territorial level, which includes bioeconomy-relevant SDG indicators;
- indicators at the product/value chain level, including indicators used for standards, certificates, and labels (SCL).

One of the objectives of this review is to avoid replication and build on indicators and data that are already available and countries/stakeholders may already report on.

Important gaps and weaknesses emerge in the reviewed literature with regard to social, economic and environmental impact categories of the bioeconomy, and associated data availability. First, the indicators identified in the literature review, although quantitatively relevant, are unequally distributed among the various principles and criteria. For instance, environmental sustainability criteria are addressed the most, followed by social and economic sustainability criteria.

Secondly, this study introduces links between the territorial and the product/value chain levels. One key issue is how to clearly attribute the measurement of the indicators to the production and use of biomass. This methodological challenge is referred to as the "attribution issue" and it is connected to both the attribution of statistical data to the bioeconomy and the attribution of general effects to the bioeconomy.

Another key issue identified by this study is the availability and quality of data for the indicators. In fact, data for many indicators are often not collected on a regular basis and data quality is a key problem for the estimation of some indicators. The study suggests the use of proxy indicators as a complement to detailed measurement. Good practices are introduced as potential complementary indicators. Monitoring the adoption of good practices and the quality of their implementation can be useful to acknowledge and measure progress.

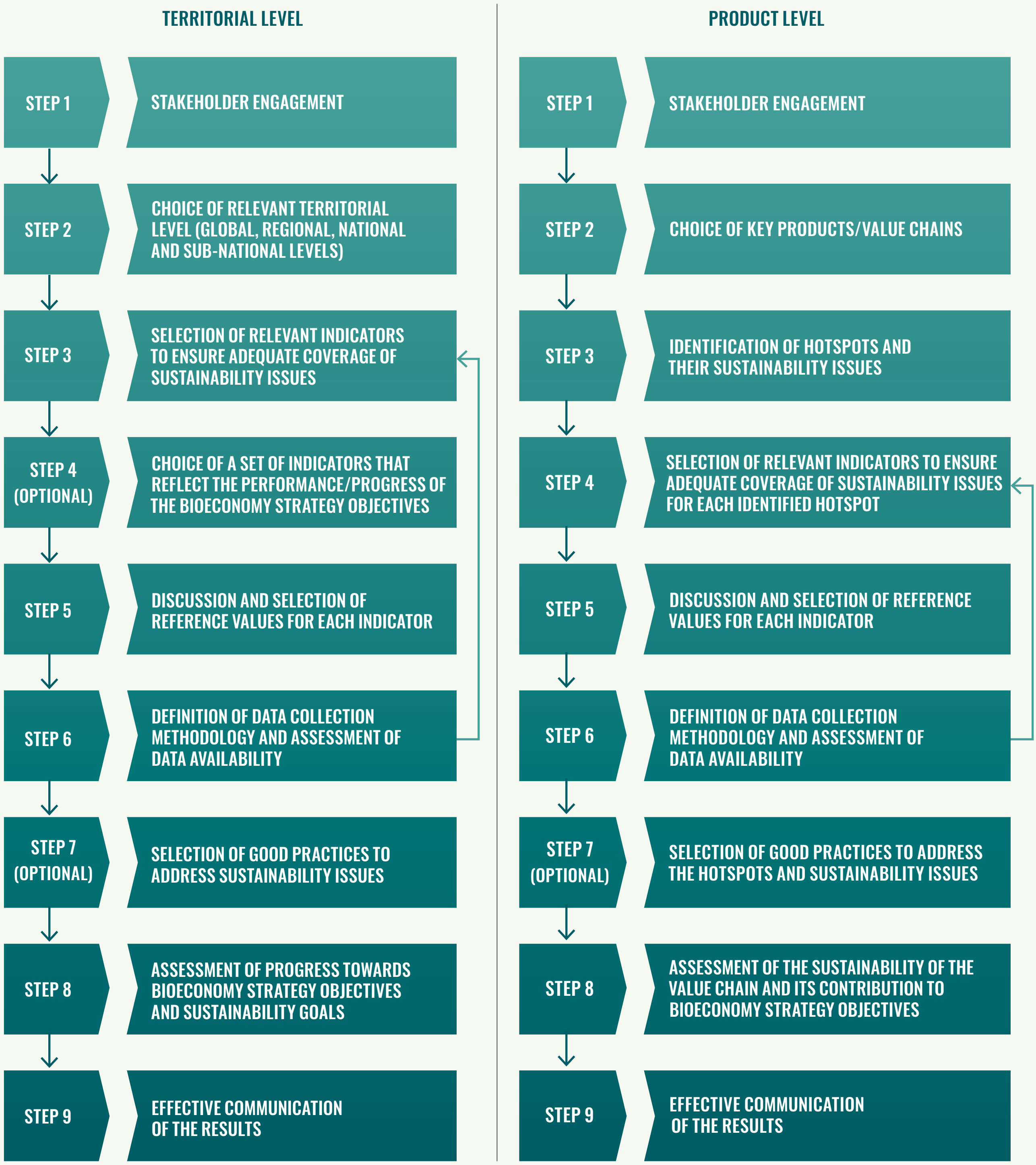
This report also discusses trade-offs and synergies between the different sustainability issues. For instance, economic development could happen at the expense of inclusiveness (including the type of jobs created and the fair treatment of employees and working conditions) and climate change mitigation.

Finally, the study identifies solutions and a possible way forward to help countries and practitioners in their monitoring and evaluation efforts: a stepwise approach to monitoring the bioeconomy sustainability, including the selection of relevant indicators, both at territorial and product levels (Figure ES1).

The recommended methodology is based on a participatory approach: the choice of relevant hotspots, priorities and indicators must occur through stakeholder and expert engagement. The methodology also allows for some flexibility to reflect circumstances and specific needs of the stakeholders. It also facilitates the inclusion of new indicators in order to improve the monitoring approach over time, and to adapt indicators as the sector and/or policy needs evolve over time.

FIGURE ES1.

STEPWISE APPROACHES TO INDICATOR SELECTIONS AT TERRITORIAL AND PRODUCT LEVELS



CHAPTER

1

INTRODUCTION

1.1 BACKGROUND AND RATIONALE

The concept of the bioeconomy aims to address several global challenges such as climate change, food security, health, and energy security in a coherent way. At the same time, the bioeconomy is seen as an engine for innovation, fuelled by new research and development in the biological and engineering sciences. However, despite these grand claims, there does not seem to be *one* common understanding of what the bioeconomy actually means. What does it entail, where are its boundaries? When discussing monitoring and evaluation (M&E) with regards to the impact of bioeconomy development, these are important questions to ask, because before one can start to measure, one needs to know where the measurement shall start and where it shall end.

Some sources depict the bioeconomy as a new development path, an alternate model to the current (petrol-based) economy. The bioeconomy is seen as a "master narrative" to tackle and overcome the limits of the current economic system. Biomass or biological resources are at the heart of the discourse. Shifting from the use of fossil fuel resources to the use of biological resources in the production and use of materials such as plastics, textiles and chemicals is seen as a way to make our daily lives "greener", "fairer" and "more inclusive". In a nutshell, this new development path is thought to lead to a more sustainable paradigm. Its boundaries are wide and open. In this narrative, the bioeconomy is sought to be a new economic model – at local, national, regional or global scale. The focus for M&E is the contribution of the bioeconomy to economic development, and its (positive and negative) impacts on nature and society.

Other sources look at the bioeconomy from a production angle. At the centre of the discourse is the bioproduct, not the economy as a whole. Rather than a new development path, this school of thought sees the potential of the biological and engineering sciences (among others) to replace selected fossil resource-driven processes and products with the variety of bio-technologies and innovations provided by research and development. The development of a bioeconomy at product level represents improvement opportunities along the various stages of existing resource flows, exchanging material and energy from fossil fuels with sources of biological origin. Be it agricultural residues or crops from the primary production stage, bio-waste from processing or food waste at the consumer stage – these are valuable resources for value addition.

Compared to the overarching vision that depicts the bioeconomy as a new development path, this production outlook is much more confined. The boundaries start and end with the biomass flows, from production and processing to use and re-use. The bioeconomy and its sustainability considerations, in this vision, are limited to selected processes and products of existing or new value chains. For this reason, it is important that the significant gap between these two bioeconomy "visions" is filled by additional work at research, private sector and governance levels.

While these two different outlooks on what the bioeconomy means and entails are an important distinction to make when discussing monitoring and evaluation of the bioeconomy, both perspectives require monitoring of the economy and beyond, including social and environmental aspects. To that end, the International Sustainable Bioeconomy Working Group (ISBWG) established in the context of FAO's project on sustainable bioeconomy guidelines, has proposed a set of Aspirational Principles and Criteria for Sustainable Bioeconomy (see **Table 1** below).

Starting from this logic, FAO has developed two approaches to M&E of a sustainable bioeconomy:

1. One approach uses territorial indicators to measure the impact of the bioeconomy at national, regional or sub-national scale, based on the assumption that the bioeconomy is a new development path. In this case, indicators seek to measure the contribution of the bioeconomy to the overall economy and wellbeing. This study considers four territorial levels: global level, regional level (macro-regions, such as the EU), national level, sub-national level. For simplicity, the results of these four levels are often shown together under the label "territorial".
2. A second approach on the use of product level/value chain indicators to measure the impact of bioeconomy at product level, based on the assumption that the overall impact of bioeconomy builds upon the effect of replacing fossil fuel resources with biological resources in the various value chain stages and the diversification of existing products from the same biomass.

The two approaches (territorial or product/value chain) can be complementary (Section 6.3). That being said, despite the aim of monitoring (sustainable) bioeconomy at both levels, commonly available methodologies for data collection and assessment are often not adequate to assess the contribution of the bioeconomy within the larger economy.

1.2 STUDY OBJECTIVE

Given the importance of monitoring the bioeconomy, one of the key outputs of the FAO "Towards sustainable bioeconomy guidelines" project concerns the **identification of indicators** to monitor and evaluate the performance of sustainable bioeconomy development. In that respect, a first step was the definition and agreement of aspirational Principles and Criteria (P&Cs) by the ISBWG established by the project in 2016. In addition, on 17-18 April 2018, FAO and the German Ministry for Food and Agriculture (BMEL) organized an international workshop on "Measuring the sustainability of the bioeconomy: Where do we stand/What gaps/What next?" in Berlin.

The ultimate aim of FAO's work on sustainability indicators is to provide technical assistance to countries and stakeholders in monitoring sustainable bioeconomy, more particularly on identifying suitable indicators in line with the ISBWG-agreed aspirational P&Cs. Appropriate indicators are deemed crucial to monitoring and evaluating the progress and impact of bioproducts and of different dimensions of bioeconomy development on sustainability. More particularly, to:

- strengthen the capacity of assessing and comparing the development of a sustainable bioeconomy,
- provide clear information for raising awareness,
- increase cooperation among different stakeholders, and
- support evidence-based policy making.

Following the recommendations of the international workshop, the work on indicators will:

i **Avoid 'reinventing the wheel' and reduce the risk of duplication.** This means that the bioeconomy monitoring and evaluation (M&E) should fit as much as possible into that of the Sustainable Development Goals **(SDGs),** because the latter already exist, countries have committed to them and are taking steps to measure their implementation. Moreover, the SDGs define sustainability in a comprehensive way, and every development strategy should fit into this context;

ii **Keep the monitoring and measurement of the bioeconomy simple** but still **internationally recognized** and **scientifically robust** (science-based), for instance by means of SMART (specific; measurable; achievable; relevant and time-bound) indicators;

iii While the national sovereignty principle is key, **international/global dimension** is also important: there is an existing gap on linking these two levels (e.g. no international convention - such as on climate change - and therefore no international accountability of countries). Indicators which ensure sustainable trade can help in bridging this gap;

iv **Be sufficiently inclusive in the development and implementation of bioeconomy M&E:** The inclusion of all relevant stakeholders is key to ensure public acceptance of the bioeconomy; which is in turn crucial to ensure sustainability in bioeconomy development (not least to ensure a market for bioproducts).

The above should take into account the two main typologies of approaches to measuring the bioeconomy, i.e. at **territorial** and at **product/ value chain levels**, and the need to link the two levels. The former are meant to inform policy making, while the latter will help to identify sustainable production processes, business/ investment opportunities, consumption behaviours and end-of-life options.

The remainder of the study is structured as follows. The next section introduces the methodology adopted to identify indicators for sustainable bioeconomy. Section 3 introduces some useful definitions and indicator typologies which help to interpret the results of the reviews done in Section 4 and 5. These two sections review the main M&E approaches at territorial and at product levels, provide a list of identified indicators and examine data availability. Section 6 discusses current approaches and points to gaps and shortfall of the reviewed indicators and monitoring approaches. The last section presents concrete suggestions for a guidance framework for countries and private sector actors that wish to monitor and evaluate the bioeconomy impacts at both national and product-levels.

CHAPTER

2

METHODOLOGY AND STRUCTURE OF THE REPORT

The transition to the bioeconomy is often associated with a range of economic, environmental and social benefits; however, the bioeconomy is not sustainable per se. Several environmental and socio-economic risks might undermine the sustainability of the bioeconomy, such as through an increase in land competition between food crops and fuel crops, direct and indirect land use change, the use of marginal lands with negative effects on biodiversity, GHG emissions, and biomass production posing pressure on the surrounding natural ecosystems, with a particular attention to water use and quality and soil degradation (Pfau *et al.*, 2014). For this reason, the bioeconomy should follow a holistic sustainability approach grounded on environmental, economic, and social aspects.

Since its birth in the Brundtland Report (Brundtland, 1987) and the Rio Earth Summit in 1992, the concept of sustainability has been gaining importance. In the new millennium, the need to measure sustainability performances became prominent. Purely economic measures, such as the GDP, are increasingly considered inadequate metrics to gauge well-being over time particularly in its economic, environmental, and social sustainability dimension (Stiglitz, Sen and Fitoussi, 2009). Research in recent years has produced a wide range of sustainability metrics and indicators, and many of these can be used in a monitoring framework for bioeconomy sustainability.

In Section 3, in order to cover all relevant sustainability aspects for the bioeconomy, this report adopts as a starting point the P&Cs agreed in 2016 by the ISBWG, and extracts impact categories from them. The authors of this study identified 69 impact categories through a desk review, based on the P&Cs. The impact categories link the criteria to the indicators in a comprehensive and accurate manner. For each impact category, a series of indicators is identified by means of a thoughtful review of existing approaches and initiatives to monitor sustainable bioeconomy both at territorial and product levels. The criteria that were taken into account in selecting the approaches are listed below:

- The geographical scope: this study covers different territorial levels – global, regional, national, sub-national - for monitoring and evaluation of the bioeconomy.
- Sector variety: in order to address the wide range of products and/or value chains involved in the bioeconomy, relevant approaches at sectoral and/or bioproduct levels have been reviewed. Following the UNStat-ISIC Sectors, the sectors have been divided into:

  i primary production sectors, involved mainly in the production of food and non-food biomass, i.e. agriculture, forestry and fishery,

  ii secondary production sectors, concerning mainly manufacturing, i.e. food and agroindustry, bio-based construction materials and furniture, pulp and paper, bio-based textiles, bio-based chemicals and polymers (incl. biomaterials), healthcare and bio-pharmaceuticals, and bioenergy, and

  iii tertiary sectors, regarding mainly consumption and end-of-life options, i.e. waste collection and treatment, R&D and education, advertising and marketing, public administration, and sports and recreation activities. In a product/value chain approach, the tertiary sectors are cross-cutting and concern activities related to both primary and secondary sectors. For instance, activities of the tertiary sectors are already part of the P&Cs, e.g. *5.1. Resource efficiency, waste prevention and waste re-use along the whole bioeconomy value chain is improved*, *6.1. Policies, regulations and institutional set up relevant to bioeconomy sectors are adequately harmonized*, *7.2. Knowledge generation and innovation are promoted*; thus, they have not been addressed separately by the selected approaches as in the case of the primary and secondary sectors (see Section 5).

  iv In addition to the ISIC Sectors, the indicators also cover ecosystem state and conditions, and consequently the capacity to provide ecosystem services. These include provisioning services such as food, feed and bio-based products as well as supporting, regulating and cultural services.

From these approaches, the authors compiled two comprehensive lists of indicators:

i one at the territorial level – priority was given to SDG indicators for addressing the impact categories, where possible, and

ii one at the product/value chain level – priority was given to standards, certificates, labels (SCL) indicators for addressing the impact categories, where possible.

The choice of prioritizing either SDG indicators or SCL indicators was adopted in order to reduce the risk of duplication, and to limit extra efforts and resources for M&E of sustainable bioeconomy. The review closes with a section on data availability to report on the selected indicators.

After the selection of indicators, gaps/shortfalls with regards to the M&E of the sustainable bioeconomy P&Cs are identified in Section 6. After discussing the most important gaps identified based on the literature review, the report proposes some solutions to help countries and practitioners in their M&E efforts.

FIGURE 1.

STEPS OF THE ANALYSIS

CHAPTER

3

DEFINITIONS AND INDICATOR TYPOLOGIES

3.1 SUSTAINABLE BIOECONOMY PRINCIPLES, CRITERIA AND IMPACT CATEGORIES

The starting point for the analysis is the list of sustainable bioeconomy P&Cs agreed in 2016 by the ISBWG. Based on the agreed P&Cs, one or more impact categories are derived from each criterion to facilitate the identification of indicators (**Table 1**). The indicators are clustered around the impact categories to ensure that all aspects of bioeconomy sustainability are covered.

The criteria are often cross-cutting across different dimensions, but for the purpose of this study, they were clustered as economic, social and environmental issues in order to express the balance among these three dimensions. In particular, eight criteria for each sustainability pillar were obtained. In reality, each criterion can have a mix of economic, social and environmental impact categories, as shown in **Table 1**, hence supporting the holistic view of sustainability. In particular, criteria 1.2 and 9.2 are a mix of economic and environmental aspects; criteria 3.2, 7.2 and 10.1 include both social and economic aspects; criteria 4.1 and 4.2 are holistic. Associating each criterion with a single sustainability pillar will guarantee a balanced set of indicators for the M&E framework for a sustainable bioeconomy, as summarized in **Figure 2**.

TABLE 1.

SUSTAINABLE BIOECONOMY P&Cs AND RELATED IMPACT CATEGORIES

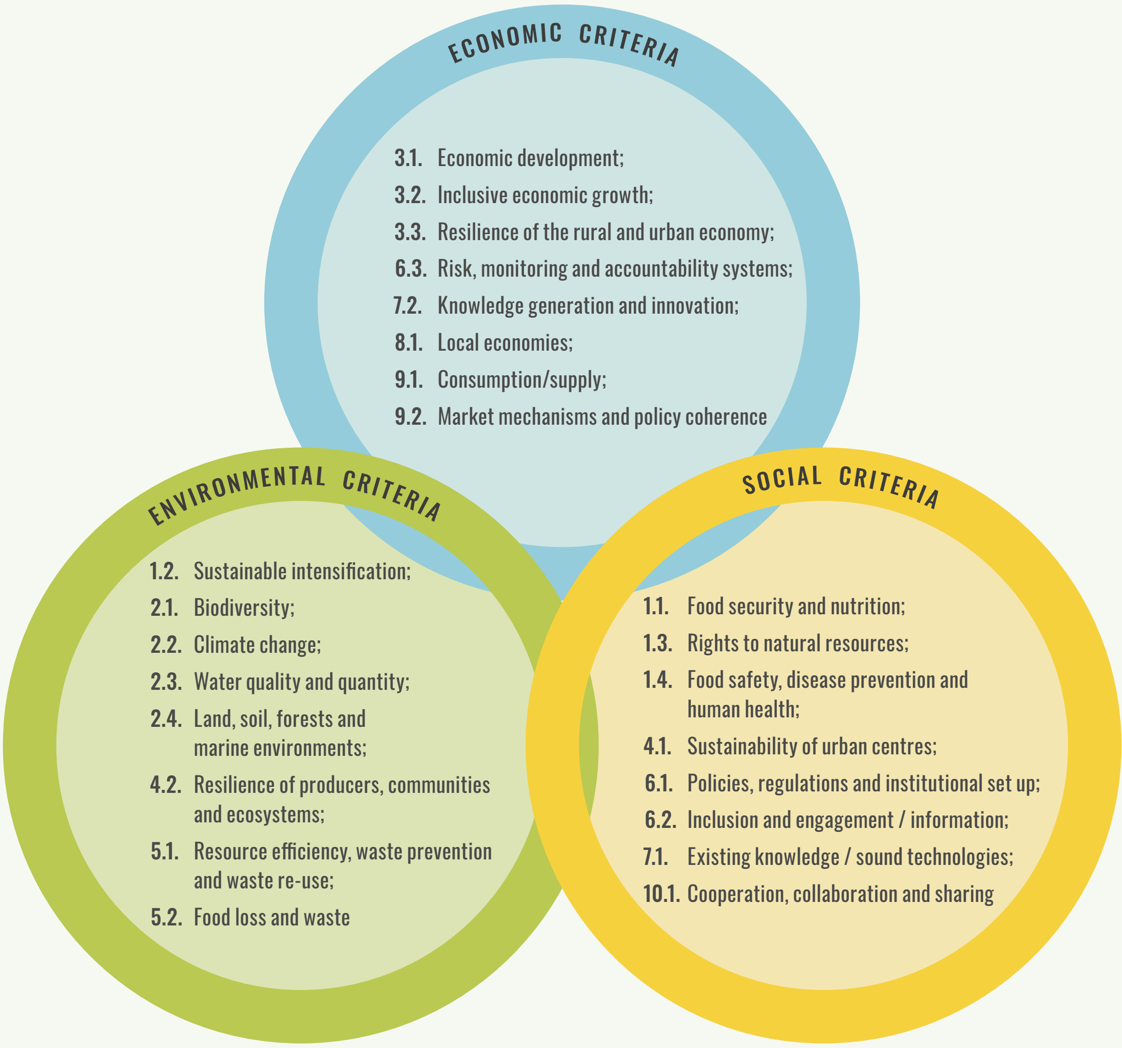
Colour code: Economic | Social | Environmental

PRINCIPLES	CRITERIA	NR	IMPACT CATEGORIES
Principle 1. Sustainable bioeconomy development should support food security and nutrition at all levels	**Criterion 1.1. Food security and nutrition are supported**	1.1.a	Food security (Social)
		1.1.b	Nutrition (Social)
	Criterion 1.2. Sustainable intensification of biomass production is promoted	1.2.a	Domestic biomass production (Economic)
		1.2.b	Yield / agricultural productivity (Economic)
		1.2.c	Land for biomass production (Environmental)
	Criterion 1.3. Adequate land rights and rights to other natural resources are guaranteed	1.3.a	Land rights (Social)
		1.3.b	Rights to other natural resources (Social)
	Criterion 1.4. Food safety, disease prevention and human health are ensured	1.4.a	Food safety (Social)
		1.4.b	Disease / hazards prevention (in biomass production and processing) (Social)
		1.4.c	Human health (Social)
Principle 2. Sustainable bioeconomy should ensure that natural resources are conserved, protected and enhanced	**Criterion 2.1. Biodiversity conservation is ensured**	2.1.a	Biodiversity conservation (Environmental)
	Criterion 2.2. Climate change mitigation and adaptation are pursued	2.2.a	Climate change mitigation (carbon and other GHG emissions) (Environmental)
		2.2.b	Climate change adaptation (Environmental)
	Criterion 2.3. Water quality and quantity are maintained, and, in as much as possible, enhanced	2.3.a	Water quality (Environmental)
		2.3.b	Water quantity/use/efficiency (Environmental)
	Criterion 2.4. The degradation of land, soil, forests and marine environments is prevented, stopped or reversed	2.4.a	Land use change (Environmental)
		2.4.b	Soil quality (Environmental)
		2.4.c	Soil quantity (Environmental)
		2.4.d	Forest quality (Environmental)
		2.4.e	Forest quantity (Environmental)
		2.4.f	Marine environments' quality (Environmental)
		2.4.g	Marine environments' quantity (Environmental)
		2.4.h	Air quality (Environmental)
		2.4.i	Hazardous substances in production and processing (Environmental)
Principle 3. Sustainable bioeconomy should support competitive and inclusive economic growth	**Criterion 3.1. Economic development is fostered**	3.1.a	Economic development (Economic)
	Criterion 3.2. Inclusive economic growth is strengthened	3.2.a	Employment (Economic)
		3.2.b	Working conditions (Social)
		3.2.c	Access to basic services (Social)
		3.2.d	Energy security (Social)
		3.2.e	Equality (Social)
		3.2.f	Gender equality (Social)
		3.2.g	Inclusiveness (Social)
	Criterion 3.3. Resilience of the rural and urban economy is enhanced	3.3.a	Rural income diversification (Economic)
		3.3.b	Linkages between rural and urban economy (Economic)
		3.3.c	Physical infrastructure (Economic)
		3.3.d	Financial stability (Economic)

PRINCIPLES	CRITERIA	NR	IMPACT CATEGORIES
Principle 4. Sustainable bioeconomy should make communities healthier, more sustainable, and harness social and ecosystem resilience	Criterion 4.1. The sustainability of urban centres is enhanced	4.1.a	Sustainability of urban centres
	Criterion 4.2. Resilience of biomass producers, rural communities and ecosystems is developed and/or strengthened	4.2.a	Resilience of biomass producers
		4.2.b	Resilience of rural communities - social protection
		4.2.c	Resilience of ecosystems
Principle 5. Sustainable bioeconomy should rely on improved efficiency in the use of resources and biomass	Criterion 5.1. Resource efficiency, waste prevention and waste re-use along the whole bioeconomy value chain is improved	5.1.a	Resource efficiency (Material footprint (secondary resources))
		5.1.b	Energy efficiency
		5.1.c	Waste prevention
		5.1.d	Waste re-use
		5.1.e	Waste treatment and hazardous waste
	Criterion 5.2. Food loss and waste is minimized and, when unavoidable, its biomass is reused or recycled	5.2.a	Food loss and waste minimization
		5.2.b	Food waste re-use or recycling
Principle 6. Responsible and effective governance mechanisms should underpin sustainable bioeconomy	Criterion 6.1. Policies, regulations and institutional set up relevant to bioeconomy sectors are adequately harmonized	6.1.a	Coherent policies, regulations in the bioeconomy sectors
		6.1.b	Coherent institutional set-up in the bioeconomy sectors
	Criterion 6.2. Inclusive consultation processes and engagement of all relevant sectors of society are adequate and based on transparent sharing of information	6.2.a	Consultation processes and engagement of all relevant sectors of society
		6.2.b	Transparent sharing of information
	Criterion 6.3. Appropriate risk assessment and management, monitoring and accountability systems are put in place and implemented	6.3.a	Risk assessment and management
		6.3.b	Monitoring and accountability systems
Principle 7. Sustainable bioeconomy should make good use of existing relevant knowledge and proven sound technologies and good practices, and, where appropriate, promote research and innovation	Criterion 7.1. Existing knowledge is adequately valued and proven sound technologies are fostered	7.1.a	Existing knowledge
		7.1.b	Proven sound technologies
		7.1.c	Capacity development (extension services)
	Criterion 7.2. Knowledge generation and innovation are promoted	7.2.a	Knowledge generation/ (high level) education
		7.2.b	Research and innovation
Principle 8. Sustainable bioeconomy should use and promote sustainable trade and market practices	Criterion 8.1. Local economies are not hampered but rather harnessed by the trade of raw and processed biomass, and related technologies	8.1.a	Net trade of raw biomass
		8.1.b	Value added of processed biomass
		8.1.c	Net trade of processed biomass
		8.1.d	Net trade of biomass-related technologies
		8.1.e	Sustainable market practices and trade policy
Principle 9. Sustainable bioeconomy should address societal needs and encourage sustainable consumption	Criterion 9.1. Consumption patterns of bioeconomy goods match sustainable supply levels of biomass	9.1.a	Sustainable consumption (which matches sustainable supply levels of biomass)
		9.1.b	Reducing dependence on non-renewable resources
	Criterion 9.2. Demand and supply- side market mechanisms and policy coherence between supply and demand of food and non-food goods are enhanced	9.2.a	Market mechanisms influencing supply and demand of food and non-food goods (e.g. prices, consumer awareness)
		9.2.b	Policy coherence between supply and demand of food and non-food goods (e.g. targets, mandates, incentives, tax, etc.)
Principle 10. Sustainable bioeconomy should promote cooperation, collaboration and sharing between interested and concerned stakeholders in all relevant domains and at all relevant levels	Criterion 10.1. Cooperation, collaboration and sharing of resources, skills and technologies are enhanced when and where appropriate	10.1.a	International Cooperation (transfer of resources, skills and technologies)
		10.1.b	Collaboration between private sector actors (e.g. licensing, contract)

FIGURE 2.

CRITERIA FOR SUSTAINABLE BIOECONOMY GROUPED BY SUSTAINABILITY PILLARS



3.2 TYPOLOGY OF INDICATORS

Indicators provide information that simplifies reality. They give information on trends and changes, but they do not necessarily provide an explanation for them, neither do they imply causal links.

Indicators can be ***qualitative*** or ***quantitative*** (numbers such as units, prices, proportions, rates of change and ratios). Quantitative indicators can be expressed in relative or absolute terms. Indicators can refer to levels/stocks (x), changes over time (Δx) and/or performance compared to a target. The reference levels or target values of indicators need to be determined based on relevant knowledge of the system of concern or shared understanding of the community that the system involves (Wu and Wu, 2012). When reference levels or targets are difficult to define, the preferred direction of change should still be specified. It would go beyond the purpose of this report to venture into the detail of reference/target setting, but it needs to be noted that indicators as such do not tell much, unless they are contrasted with an adequate reference value. For instance, if the reference value is a target value, the indicator provides information on the distance to the goal, while, if the reference value is a value at a previous point in time, the indicator can provide information about the direction of change.

A particular case is represented by dummy indicators, which can take only two values. An example of a dummy indicator can be an indicator that measures the presence of an implemented good practice, e.g. 1.2.*b Presence of an irrigation and water distribution system that optimizes crop productivity* (**Table 7**). This type of indicator can be transformed into quantitative indicators by assigning a maximum value (e.g. 1) to the dummy ***yes*** and a minimum value to the dummy ***no*** (e.g. 0).

Indicators can be ***descriptive*** indicators (or contextual or situational indicators, used to describe a situation or trend) or ***performance*** indicators (or normative or progress indicators, used to provide an assessment of progress towards established objectives and targets) (European Union, 2014). Performance indicators show progress, or the lack of it, towards objectives and targets or a desired end-state. They allow us to make statements that describe the situation as better or worse than before. Descriptive indicators describe a situation or trend as it is, without reference to how the situation should be. Depending on the context, the same data can be used as both a descriptive and a performance indicator, therefore it is vital to clarify the reference framework in which an indicator is being used. For instance, the data on greenhouse gas emissions can be a descriptive indicator providing a description of the quantity of CO_2 emissions in a certain area, or it can be an indicator of performance if it is linked to an agreed reduction target.

An important distinction has to be made between ***direct*** and ***indirect*** or ***proxy*** indicators, based on how precisely the indicators relate to the subject of analysis. Indirect or proxy indicators are useful when the subject of the analysis is abstract and cannot be measured directly (e.g. gender equality, good governance or living conditions) or when the subject can be measured only by means of a complex effort which could not be carried out systematically or frequently enough (European Union, 2014). On the contrary, direct indicators provide information directly relating to the subject of analysis. Also in this case, an indicator ***per se*** is neither direct nor indirect. It is the underlying question being answered that characterises it as one or the other (European Union, 2014). For instance, "household income (in $)" in country ***x*** over the last 10 years is a direct indicator if the question is related to changes in household income in the country over that period of time, but it is an indirect or proxy indicator if the question is related to household living conditions.

Proxy indicators to monitor and evaluate sustainable bioeconomy instead of/or complementary to using direct indicators can be the implementation of ***good practices*** and the monitoring of their performance. Whenever the adoption of other indicators is too demanding in terms of time and financial resources, or due to lack of data, indicators on good practice adoption and performance can be used at both territorial and product/value chain levels to acknowledge and measure progress in a robust and cost-effective way. Quantifiable good practice indicators can be complemented by a rapid assessment regarding the quality of implementation. For instance, the EU Common Agriculture Policy (CAP) in 2015 has linked a substantial part of income support to farmers to environmental requirements via the greening measures within Pillar 1 (Regulation (EU) 1 307/2013, see **Box 1**).

In 2017, a study from the European Commission evaluated the payment system for good practices beneficial for the climate and the environment two years after its introduction (European Commission, 2017a). The weaknesses of the EU mechanism are summarized in the table below, together with its positive aspects. The study suggests that there is scope to improve the efficiency of this type of mechanism in the future.

Good practices should be designed according to specific regional and local concerns. Similarly,

BOX 1. AN EXAMPLE OF COMBINATION BETWEEN DIRECT AND INDIRECT/PROXY INDICATORS: THE EUROPEAN UNION COMMON AGRICULTURAL POLICY APPROACH

A combination of both direct and indirect indicators is currently being applied for monitoring and reporting of the EU Common Agriculture Policy (CAP) across all EU member countries. CAP beneficiaries must comply with the established conditionality rules, which are requirements and standards (good practices) adapted by the Member States to specific characteristics. Failure to comply with these good agricultural and environmental practices implies a reduction in subsidies (direct payments). For instance, under the issue "Soil erosion", compulsory practices are "Minimum soil cover" and "Minimum land management reflecting site-specific conditions", and an optional practice is "Retain terraces" (Council Regulation (EC) No 73/2009. Annex III). Each country may adapt the practices to local conditions: for example, requirements for "Minimum soil cover" in Spain include, among others, "woody crops located in enclosures of slope equal to or greater than 15 percent cannot be grubbed up" (Council of the European Union, 2018).

Apart from being a useful system for deciding on sanctions and rewards, reporting on the implementation of good practices can help quantify milestones in relation to objectives and targets. Monitoring good practice implementation can be a way to acknowledge progress, which can result in incentives.

Payments to farmers who adopt agricultural practices beneficial for the climate and the environment ("greening measures") were introduced by the Direct Payments Regulation, part of Pillar 1 of the CAP 2015 (Chapter 3 of Title III of Regulation (EU) 1 307/2013).

The European Commission proposals that form part of the CAP reform package (CAP 2021-2027) include Strategic Plans and Annual Performance Reports to be drawn up by Member States, in which countries define interventions in line with nine objectives identified by the Commission. The CAP 2021-2027 approach will include a new system of possible rewards to ensure that progress towards the nine objectives is made (Council of the European Union, 2018). The implementation of good practices will increase its relevance. The "green architecture" for the future CAP will include the integration of environmental and climate interventions in the CAP Strategic Plans. For instance, under the specific objective "Improve the farmers' position in the value chain" countries will report using among others, the indicator "Share of farmers participating in supported Producer Groups, Producer Organizations, local markets, short supply chain circuits and quality schemes". The indicators used to report progress towards these objectives are usually expressed in the share of farmers or hectares under specific commitments, which often requires the implementation of good practices. Moreover, the proposals also outline new obligations and incentives for farmers, i.e. direct payments will be restricted to enhanced environmental and climate requirements and member states will be required to offer eco-schemes to support farmers in going beyond the mandatory requirements.

TABLE 2.

STRENGTHS AND WEAKNESSES OF REPORTING ON GOOD PRACTICES

STRENGTH	WEAKNESS
Can cover economic, social and environmental sustainability performance	Ensuring compliance requires frequent inspections
Monitoring the adoption and performance of good practices can temporarily substitute the measurement of more complex quantitative indicators	Difficulties in monitor the actual implementation of good practices (due to limited data availability)
Stakeholders or states can tailor the (compulsory) good practices to their own circumstances	Scarcity of data on the actual effects of good practices implementation

Source: Authors' elaboration based on (European Commission, 2017a) bioeconomy strategies must be adapted to individual situations and, accordingly, sets of indicators for measuring sustainable bioeconomy development need to allow a certain degree of flexibility (Stepping and Stoever, 2014). Multi-stakeholder processes can be carried out to identify good practices as improvement opportunities that address context-specific sustainability challenges. The implementation of good practices adapted to local conditions as a way to move towards a sustainable bioeconomy can be helpful in the M&E of sustainable bioeconomy development, as explained further in Section 6.4.

3.3 COMBINING SINGLE INDICATORS TO REPORT ON INDICATOR SETS AT TERRITORIAL AND PRODUCT LEVEL

The section above demonstrates that a single indicator is not sufficient to understand complex phenomena such as sustainable bioeconomy. Therefore to monitor a sustainable bioeconomy, we need entire systems of indicators representing its different facets.

This section reviews ways of combining, displaying and communicating individual indicators for the M&E of the bioeconomy. First, the section presents different approaches that can be used to group and display indicators both for at territorial and product levels; then it presents life cycle assessment (LCA) as a useful methodology to assess the impact of a product life cycle by means of indicators.

A group of indicators used together for a particular purpose or project is often referred to as an indicator set. A set of many indicators cannot be easily interpreted, especially when the indicators differ both in amplitude and in the direction of change. For this reason, the indicators are often aggregated through mathematical operations to produce indices. Aggregated indices have the advantage of reflecting the integrative characteristics of a system and provide an overall picture of the state or performance of a system in a simple and explicit manner (Wu and Wu, 2012). However, the three central steps of index formation (normalization, weighting, aggregation) do not always satisfy fundamental scientific requirements (Böhringer and Jochem, 2007). Often, the definition of "sustainability indicators" includes both indicators and indices.

Indicators at territorial and product level can be presented and analysed in different ways, four of which are described below (GGKP, 2016):

- **dashboard of indicators**: a set of metrics representing information from various areas, such as environmental, economic and social factors as well as combinations of these. A set of many indicators cannot be easily interpreted, especially when the indicators differ both in amplitude and in the direction of change. For this reason, the indicators are often aggregated through mathematical operations to produce indices.
- **composite (or aggregated) indices**: aggregate different metrics into one by scoring and weighting the underlying indicators; they have the advantage of providing an overall picture of the state or performance of a system in a simple and explicit manner (Wu and Wu, 2012). However, the three central steps of index formation (normalization, weighting, aggregation) are subject to significant value-judgement and do not always satisfy fundamental scientific requirements (Böhringer and Jochem, 2007).
- **footprint-type indicators**: aim to indicate, if current production/ consumption patterns are sustainable or in line with planetary boundaries; as **Table 3** shows, footprint-type indicators can be very useful to communicate results and can aggregate a multitude of economic and environmental issues into a single indicator. Examples of such type of indicators concern the "Four Footprints" (materials, carbon, water and land) introduced

by the Sustainable Europe Research Institute (SERI, 2013). Carbon footprints and material footprints are relatively advanced concepts, for which methodological guidelines and data are available and ensure a certain level of comparability. On the contrary, accounting standards as well as data coverage, disaggregation and quality still need to be improved for water and land footprints. Industrialized countries are increasingly outsourcing environmental burden to other regions via international trade, with footprints being significantly higher than the respective territorial indicators (SERI, 2013). This fact points to the importance of including footprint-type indicators in the analysis of territorial indicators and in the assessment of sustainable bioeconomy, in order to avoid misleading policy conclusions. Footprint-type indicators may help linking the national and global dimensions in bioeconomy M&E, for which not much literature is yet available (see Section 5.1.1).

- **"adjusted" economic measures** (e.g. green GDP, adjusted net savings and extended wealth): attempt to correct conventional economic variables by accounting for environmental or less frequently environmental and socially related dimensions.

TABLE 3.

STRENGTHS AND WEAKNESSES OF ANALYTICAL APPROACHES

STRENGTH	WEAKNESS
DASHBOARD OF INDICATORS	
Allows for a broad assessment, which is in line with the multidimensional nature of the bioeconomy	Indicators are measured with different units
Does not impose decisions on the importance of individual indicators	Does not provide a hierarchy among indicators
In line with the idea of "strong" sustainability, where each dimension of sustainability needs to be monitored and one is not assumed to be a substitute for another	Does not detect trade-offs and relationship among indicators
Allows explicit differences in the measurement horizons or areas (e.g. regions) regarding each single indicator	The large number of dimensions makes general international comparison difficult
COMPOSITE INDICES	
Can summarize complex or multidimensional issues	May send misleading policy messages if they are poorly constructed
Easy to interpret	May invite simplistic policy conclusions and fail to provide information on the distribution of effects
Facilitate the task of ranking alternatives over time on complex issues	May be misused, e.g., to support a desired policy, if the construction is not transparent and lacks sound statistical or conceptual principles
Allow straightforward comparisons across countries and time	Often in line with the "weak" sustainability concept, de facto assuming that improvements in one dimension can offset deterioration in another
Reduce the size of a set of indicators or include more information within the existing size limit	The selection of indicators and weights could be the target of political challenge
Place issues of performance and progress at the center of the policy arena	May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action
Facilitate communication with the general public and promote accountability	May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored
Reflect the integrative characteristics of a system	Aggregation, normalization and weighting of indicators may have a high degree of arbitrariness

STRENGTH	WEAKNESS
FOOTPRINTS	
Simple, flexible and visual tool that can be communicated easily to a non-expert	Aggregation requires simplification of a complex reality
Can aggregate a multitude of economic and environmental issues into a single indicator	Does not consider important social and environmental impacts other than those that can be translated into loss of resources
Typically relate to some kind of threshold or limit that is deemed sustainable	May fail to account for future technological progress
Tentative to standardize process and methodology (e.g. Global Footprint Network)	Thresholds and limits may be unknown or uncertain
Carbon footprints and material footprints are relatively advanced concepts, with methodological guidelines being available and ensuring a certain level of comparability	Water and land footprints need methodological improvements and harmonization
"ADJUSTED" ECONOMIC MEASURES	
Aim at adjusting conventional measures for accounting for the use of stocks of capital that serve to sustain production in the future, such as natural capital, and financial, physical and human assets	Does not consider important social and environmental impacts other than those that can be translated into stocks or assets
Introduce changes in environmental and human capital valued in monetary terms in traditional accounts measures	Philosophical and political objections to assign monetary values to environmental and human capital
Can be easily communicated	Most adjusted measures assume weak sustainability: depletion of natural capital can be offset with sufficient investment in other types of capital (e.g. physical or human)
Can provide a comprehensive metric if all changes in natural and other capital forms can be valued accurately	The valuation of non-marketed goods and services (e.g. ecosystem regulatory functions) is tricky, especially in the presence of non-linearities and threshold effects
Allow comparison between countries and time	Assume that trade-offs between resources are constant across countries and time

Source: Authors. Based on (Böhringer and Jochem, 2007; Bond and Morrison-Saunders, 2011; GGKP, 2016; SERI, 2013; Wu and Wu, 2012).

There is a debate over the degree to which a sustainability assessment should be reductionist (i.e. break down a very complicated natural and anthropogenic system into a few component parts), or the degree to which it should be holistic (considering systems as wholes) (Bond and Morrison-Saunders, 2011). Composite indices are an example of reductionist approaches, since they aggregate different components in a single value. The debate is out of scope for this study; still, **Table 3** summarizes the main strengths and weaknesses of the four approaches. It should be noted that the approaches are not mutually exclusive as, for instance, composite indicators can be included in dashboards.

At product level, the life cycle assessment (LCA) is a powerful methodology to measure the impact of a product life cycle by means of indicators. The indicators selected to perform an LCA can include environmental and socio-economic impacts – i.e. Environmental Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), Life Cycle Costing (LCC) (see **Annex 1** for a detailed description of each methodology).

Life cycle sustainability assessment frameworks are used to evaluate the potential environmental and socio-economic impacts from "cradle to grave", and depending on the boundary at hand, "cradle to cradle". They help identify and prevent the shift of burden between life cycle stages or processes in case efforts for lowering impacts in one process or life cycle stage unintentionally create (possibly larger) impacts in other processes or life cycle stages. For example, the substitution of fossil fuels with biofuels reduces GHG emissions from the use of fossil fuels in transport but increases emissions from the harvest and extraction stage when producing biofuel feedstock.

Although these frameworks are mostly used to study product systems, they can also be used to assess more complex impacts deriving from the production and consumption of energy, transport, waste management systems, and infrastructure. In all applications, the assessment takes a life cycle perspective having the function of the studied entity as a focal point.

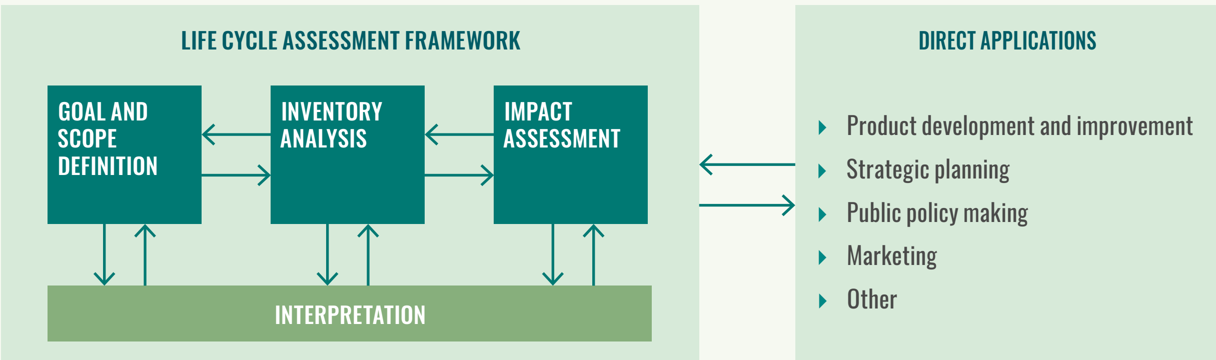
The methodology adopted by the life cycle assessment framework consists of four iterative phases (**Figure 3**).

1 The **goal and scope** definition phase describes the product, process, or activity of interest and identifies the reasons for carrying out the study and its intended use. Notably, it in this phase that the system boundaries, including sub-units, inputs, and outputs, are identified, the functional unit is defined, and the modelling approaches are specified.
2 The **Life Cycle Inventory (LCI)** phase defines the product system (or systems) and its constituent unit processes. For instance, the elementary flows between the product system and the environment, including inputs (e.g. extracted raw materials, land used, labor) and outputs (e.g. emissions to air, water and soil, food security, socio-economic benefits), are studied and compiled by means of data collection. The amount of elementary flows exchanged by the product system and the environment refer to one functional unit, as defined in the Goal and Scope phase.
3 The **Life Cycle Impact Analysis (LCIA)** phase includes the assessment of the potential (environmental, social, economic) impacts of the product system based on the data gathered during the LCI process. This is done by associating the LCI results with the stakeholders and impact categories and indicators. LCIA has a number of mandatory elements: selection of stakeholders and impact categories, indicators, and characterization models, along with the assignment of the LCI results to the various impact categories (classification) and the calculation of indicator results (characterization). This can then be followed by optional elements such as normalization, grouping and weighting.
4 The **Life Cycle Interpretation** phase combines the findings of the previous two phases with the defined goal and scope in order to reach conclusions or recommendations (Rios, Moore and Jones, 2007). It is important to note that LCA provides an assessment of potential impacts on the basis of a chosen functional unit.

The data required for the product life cycle impact assessment can be primary and/or

FIGURE 3.

THE FOUR PHASES OF THE LIFE CYCLE ASSESSMENT FRAMEWORK



Source: (ISO, 2006)

secondary data. Primary data are site-specific, company-specific (if multiple sites for the same product) or supply-chain-specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the company. Secondary data refer to data that is not directly collected, measured, or estimated by the company commissioning the LCA study, but sourced from a third-party life cycle inventory database or other sources. Secondary data includes industry-average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and can also be based on financial data, proxy data, and other generic data.

Life cycle assessment frameworks can serve as a powerful tool for the **monitoring and evaluation** of bioproducts, once the indicators are selected and they are appropriate for applying life cycle sustainability assessment tools (i.e. where inventorying is possible). For example, for the indicators (already selected, but not by means of life cycle assessment methodology) at product-level, life cycle assessment frameworks enable comparison of life cycle performances of sub-components of bioeconomy outputs at different stages of the value chain, (raw biomass production, bioproduct manufacturing, end of life etc.).

Afterwards, once the indicators are selected, life cycle sustainability assessment methodology and literature would provide a comparison baseline between bioproducts and conventional goods and services. This comparison contributes to the evaluation of potential environmental and socio-economic success achieved through the transition to the bioeconomy. **Table 4** summarizes the positive and negative aspects of life cycle sustainability assessment tools.

TABLE 4.

STRENGTHS AND WEAKNESSES OF LIFE CYCLE IMPACT ASSESSMENT FRAMEWORKS

STRENGTHS	WEAKNESSES
Life cycle assessment methodologies are suitable for quantifying emissions and estimating environmental and/or socio-economic burden of the whole life cycle of a bioproduct.	Data and labour requirements of LCA can turn its comprehensiveness from an advantage into a limitation. Depending on the goal and context, other frameworks such as Water Footprint (ISO 14 046), Greenhouse Gases Assessment (ISO 14 064), Economic Impact Analysis, Stakeholder Analysis and Gender Analysis could be simpler, less resource intensive alternatives which would provide sufficient information.
By evaluating all the stages of a product life cycle, the life cycle assessment methodologies can inform on the source and degree of environmental and/or socio-economic impact that must be improved.	Life cycle assessment tools provide a "snapshot" of the impacts associated with a product and a process, utilizing the input data, rather than a dynamic overview for the trends and future projections. For determining baseline values and comparison levels, Environmental Impact Assessment, Green Economy Progress Measurement Framework and Beneficiary Assessment would be more adequate frameworks.
Life cycle assessment methodologies provide standardized data and information to compare among and between fossil-based products and bioproducts.	To date, life cycle assessment tools cannot be used to paint a holistic (i.e. environmental, social, economic) picture since they measure one sustainability aspect at a time. For example, LCA cannot answer whether it is feasible to reduce pollution by increasing taxes. Cost benefit analysis combined with Health Assessment Studies and Multiple-Criteria Decision Analysis would be better tools for answering such a question (Bj, Molin and Laurent, 2018).
Life cycle assessment methodologies are useful for information flow among different stakeholders, e.g. producers, consumers, policy-makers, on environmental and socio-economic attributes of a bioproduct.	Life cycle assessment tools are not designed to assess a specific effect on a specific element of the system from a specific group of agents. It would be more meaningful to conduct Toxicity Assay and Assessment (Bj, Molin and Laurent, 2018). Similarly, one challenging issue concerning LCC is related to double counting the same costs in both internal and external categories. In such occasions, Demand Analysis and Access to Resources Methods could be more appropriate.
	Life cycle assessment methodologies are based on the average performance of the processes and do not support the consideration of risks associated with rare but very problematic events (e.g. marine oil spills, accidents at industrial sites). As a consequence, nuclear power, for example, appears quite environmentally friendly in LCA (Bj, Molin and Laurent, 2018).

Source: Authors.

CHAPTER

4

REVIEW OF INDICATORS AT TERRITORIAL LEVEL

4.1 REVIEW OF MONITORING APPROACHES AT TERRITORIAL LEVEL

This section reviews the main approaches to monitor sustainable bioeconomy at territorial level. Few approaches reviewed in this study are actually implemented at country level (e.g. in Argentina, Finland and Malaysia), albeit limited to economic sustainability. Others have been developed within regional or global projects by international organisations, NGOs or academia, but have not actually been implemented. Some use or suggest sets of individual indicators, while others develop composite indexes and footprint-type indicators.

4.1.1 Specific national monitoring approaches for sustainable bioeconomy

If a national bioeconomy strategy aims to contribute to sustainable development including environmental and social objectives, these aspects need to be included in the strategy and in the related monitoring and measuring approaches. However, frameworks to monitor sustainability progress in reaching the targets set in the bioeconomy strategies are currently lacking in most countries (FAO, 2016, 2018; German Bioeconomy Council, 2018). In 2016, the FAO report assessing "How sustainability is addressed in official bioeconomy strategies at international, national and regional levels" concluded that monitoring and evaluation approaches were weak in most bioeconomy strategies, and many countries suggested that sustainability standards and guidelines should be developed and agreed on an international level (FAO, 2016). In 2018, another FAO study analysed the national frameworks to assess the contribution of the bioeconomy to countries' economy, focusing in particular on Argentina, Australia, Germany, Malaysia, the Netherlands, South Africa and the United States of America (FAO, 2018). This study also showed that a framework to monitor progress in reaching bioeconomy targets is currently lacking in most countries. Most governments measure bioeconomy contributions in terms of economic factors (e.g. value added and employment), while in most cases social and environmental criteria are addressed only to a limited extent.

Several studies and projects, even at country level, aim at developing comprehensive bioeconomy monitoring systems, including indicators that encompass social and environmental aspects. Some of these studies look at the analysis developed for sustainable biofuels, forest, biomass and bioenergy over the past few decades. For instance, several countries are adopting criteria and indicators for sustainable forest management as a way to strengthen results-based management of national forest programmes (FAO, 2017a; Tegegne, Cramm and Brusselen, 2018). The Canadian bioeconomy strategy provides a first set of indicators for monitoring the progress made towards achieving a low-carbon forest based bioeconomy (German Bioeconomy Council, 2018).

According to the German Bioeconomy Council, several countries envisage monitoring and measuring activities in their bioeconomy strategy (German Bioeconomy Council, 2018). The Council reports that a growing number of countries (notably Argentina, Australia, Brazil, Canada, China, France, Italy, Latvia, New Zealand, Spain, the UK and the USA) are promoting measuring activities in order to monitor new (bio) technologies, biomass flows, bio-based products and services and their economic, ecological and social impacts (German Bioeconomy Council, 2018). Some of these will be discussed in more detail further in this report.

In addition, several countries are proposing to increase monitoring and measuring activities, including the implementation of integrated information and observatory systems, and others are in the process of developing comprehensive monitoring systems. One of these countries is **Argentina**, which is currently monitoring the country bioeconomy only by means of the contribution of bioeconomy sectors to GDP, without considering environmental and social aspects (Bracco *et al.*, 2018; Lechardoy, 2018). The Argentinian monitoring framework is included in this study as an example of the approaches focusing just on economic aspects. Other examples are provided by Malaysia and Finland.

The **Malaysian Bioeconomy Contribution Index** (BCI) is an interesting example of a composite index. This index is a combination of five economic parameters of the Malaysian bioeconomy: bioeconomy value added, bio-based exports, bioeconomy investments, bioeconomy employment and productivity performance (**Figure 4**). The BCI is constructed using the baseline year 2005 at 100 points and allows to monitor bioeconomy's economic performance in the country, compared to baseline. The BCI currently measures just economic flows, but it could be enhanced to take into account socio-economic or environmental performance. For instance, it could incorporate measures of poverty reduction or income inequality in the bioeconomy industry, or it could account for CO_2 emissions or level of local biodiversity (Al-Amin, 2015; Bracco *et al.*, 2018)

The **Finnish Bioeconomy Strategy** was drafted in a project set up by the Ministry of Employment and the Economy (MEE) in cooperation with several other ministries (MEE, 2014). The Finnish bioeconomy sectors (biomass producing sectors, food, wood products, pulp and paper, bioenergy, bio-construction sectors, treatment and supply of water and bioeconomy services of nature tourism and recreation, recreational fishing and hunting) have been monitored over the period 2010-2017 by means of five economic indicators: output, value added, investments, employment and exports of bioeconomy goods. These Finnish indicators are included in our study, even though they are currently under revision since the Finnish bioeconomy strategy is being updated (EC JRC, 2018a).

Germany is currently developing a comprehensive M&E approach to monitor the bioeconomy. The joint inter-ministerial effort is made of three main projects which include the

FIGURE 4.

COMPONENTS OF THE MALAYSIA BIOECONOMY CONTRIBUTION INDEX (BCI)

Source: (MOSTI and Bioeconomy Corporation, 2016)

monitoring of biomass flows, the identification of economic key performance indicators (KPIs) and the Systemic Monitoring and Modelling of the Bioeconomy (SYMOBIO)[1]. These three projects will be completed in the next biennium, therefore their results cannot be reported in this study. However, this report analyses indicators from the **Thünen Institute**, which are based on the German sustainable development strategy, linked to Germany's strategic framework to implement the SDG Agenda.

Italy has developed a set of sustainability indicators with measurable impacts on food security, natural resources sustainability, dependence on non-renewable resources, climate change, in addition to economic growth. The country aims to relate bioeconomy implementation and monitoring to a tentative set of EU KPIs developed by the BioEconomy Regional Strategy Toolkit (BERST), an EU-funded project to support regional stakeholders in Europe by developing smart strategies to explore their bioeconomy potential. These indicators refer to Eurostat and national data and allow for the implementation of benchmarking analysis. Italy further aims to relate their indicator framework to the "Systems Analysis Tools Framework for the EU Bio-Based Economy Strategy" (SAT-BBE) (Presidency of Council of Ministers, 2017), which addresses the sustainability dimensions of the bioeconomy.

4.1.2 Specific EU monitoring approaches for sustainable bioeconomy

The **European Commission (EC)** is financing several activities to monitor bioeconomy development in Europe, mostly under the "Bioeconomy Knowledge Centre" project led by its **Joint Research Centre (JRC).** First, the JRC assesses a **socioeconomic indicator set** for different bioeconomy sectors (number of persons employed, turnover, value added, labour productivity), and it estimates member state performance on a transition path to higher productivity (Ronzon, Camia and Barek, 2018). This approach is being reviewed in this study, as it provides an initial contribution to the monitoring of the bioeconomy in the European Union (EU). The second dimension is the biophysical dimension of the EU bioeconomy, which is analysed in different studies that capture biophysical indicators along the biomass supply chain, including the cascading and recycling flows of resources (this stream of work has not been reviewed since it goes beyond the boundaries of this study). Thirdly, the potential environmental impacts associated with a product, a process or a system along its life cycle are assessed by means of the life cycle assessment approach, as shown in the previous section. Lastly, the JRC is working on forward-looking analyses and simulation models to assess closed economic systems, address

[1] For more information, see (FAO, 2018).

multiple objectives in a consistent framework, capture behavioural aspects (consumers and producer choices), and test different conceptual models and policy options (EC JRC, 2018a). In particular, the economic modelling framework MAGNET (Modular Applied GeNeral Equilibrium Tool) has been applied to the bioeconomy for assessing policy coherence and SDGs (Philippidis *et al.*, 2018). This approach is not reviewed in this study, since it does not directly relate to the identification of sustainability indicators. Additionally, following the 2018 revision of the EU bioeconomy strategy, the European Commission is working on defining a comprehensive and holistic monitoring framework for the EU bioeconomy.

Another interesting European initiative is the BIOEAST initiative (Central and Eastern European initiative for knowledge-based agriculture, aquaculture and forestry in the bioeconomy), which was established by the Central and Eastern European countries to enforce cooperation, research and policy making. BIOEAST countries do not directly contribute to the development of the future EU bioeconomy monitoring system, but they aim to influence its scope, focus areas and priorities through the BIOEAST Strategic Research and Innovation Agenda (SRIA) (EC JRC, 2018a).

The Horizon 2020 research project BioMonitor aims to establish a sustainable and robust framework that different stakeholders can use to monitor the bioeconomy and its various impacts in relation to the EU and its Member States. The project started in June 2018, and its outcomes are still not available, so they were not included in this review.

Another EU funded initiative is the **MontBioEco** approach by the LUKE institute in Finland, which identifies indicators to monitor and assess existing bioeconomy strategies, policies or related initiatives at EU member states level, and the importance of existing bioeconomy sectors at national level. Their study identifies the most suitable key bioeconomy indicators that are important and feasible at the national context in order to contribute to the development of a common EU bioeconomy monitoring system (**Table 5**) (LUKE, 2018).

Another European research project, the **BERST** project, pilot tested in Italy as mentioned above, was completed in 2015 and resulted in a toolkit composed of a catalogue of criteria and indicators, a collection of instruments and measures, a catalogue of good practices and case studies and guidelines for elaborating regional profiles (BERST, 2019). The BERST project developed a set of quantitative and qualitative indicators to understand and to estimate the potentials and challenges of sub-national bioeconomies (clusters or regions). Some of these indicators are composite indexes. The **SAT-BBE** project was also completed in 2015 and has designed a systems analysis tools framework to monitor the evolution of the bioeconomy in the EU, and to analyse the socio-economic and environmental impacts of the bioeconomy and its relevant policies. The indicators retrieved by these projects are reported below in Section 4.2.

In addition, the International Institute for Sustainability Analysis and Strategy (IINAS) has developed "Sustainability Criteria and Indicators for the Bioeconomy" (**S2Biom**, 2015a) with the aim of delivering economic, social and environmental criteria and indicators for the sustainable supply of non-food biomass to support a resource-efficient bioeconomy in Europe. The project (which ended in 2017) identified 12 criteria and 27 indicators for the sustainability of bioenergy and bioproducts, which can be the basis for more specific indicators in certain bioeconomy applications.

4.1.3 Other approaches that are relevant for bioeconomy monitoring at territorial level

While the last two sections described monitoring approaches that have been ***specifically*** developed for the bioeconomy, there is a wealth of approaches available that cover bioeconomy relevant sectors and issues. While it would go beyond the purpose of the report to discuss all of them, this section highlights a few approaches that are relevant to the bioeconomy.

Firstly, in order to avoid 'reinventing the wheel' and reduce the risk of duplication, the M&E framework of the bioeconomy could fit in as much as possible into that of the SDGs, because the countries are already committed to the latter, SDG indicators already exist, and countries are taking steps to measure their implementation. For these reasons, we introduce relevant SDG indicators that could be used to measure the

TABLE 5.

IDENTIFIED MOST SUITABLE KEY INDICATORS UNDER THE BIOECONOMY OBJECTIVE IN THE LUKE APPROACH

EU BIOECONOMY STRATEGY OBJECTIVE	IDENTIFIED MOST SUITABLE KEY INDICATORS
CREATING JOBS AND MAINTAINING COMPETITIVINESS	Number of employed persons in rural and urban areas
	Value added
	Contribution to the GDP
	Investment in research and innovation
	Exports
	+ *Import (identified by the correspondents after the online-survey)*
REDUCING DEPENDENCE ON NON-RENEWABLE RESOURCES	Production of renewable energy *and* Production of biofuels and biogas *combined*
	Material and waste recycling and recovery rates
	Material replacing non-renewable resources
	Public financial support and private
	Investment in research and innovation
MITIGATING AND ADAPTING CLIMATE CHANGE	Carbon sequestration
	Forest carbon emissions/sinks
	Greenhouse gas emissions from agriculture
	Water area carbon emissions/sinks
	Public financial support and private investments
	Investment in research and innovation
ENSURING FOOD SECURITY	Domestic food supply of food commodities in terms of production, import/stock change
	Agricultural products
	Fish products
	Non-wood forest products
	New food products
	Public financial support and provate
	Investment in research and innovation
MANAGING NATURAL RESOURCES SUSTAINABILITY	Land cover
	Resource availability
	Sustainable resource use
	Environmental protection
	Public financial support and private investments for ecosystem services
	+ *Investments in research and innovation (identified by the correspondents after the online-survey)*

Source: LUKE, 2018.

sustainable bioeconomy P&Cs (Çalıcıoğlu and Bogdanski, forthcoming).

Furthermore, some countries' national accounts provide information on environmental, social and economic aspects. A good example is the compilation of information on EU member states, which are being compiled by EUSTAT. EUSTAT provides several statistical accounts that are very relevant for the bioeconomy: for instance, the EU's environmental accounts report on two broad groups of activities and/or products: environmental protection (e.g. all activities related to preventing, reducing and eliminating pollution and any other degradation of the environment) and resource management (preserving and maintaining the stock of natural resources). The environmental goods and services (EGSS) account provides information on the production of environmental products and the employment and gross value added linked to their production (Eurostat, 2019a). Since 2015, Eurostat is also implementing a monitoring framework to assess the progress towards a circular economy. Also, this framework reports ten indicators and 23 sub-indicators capturing the main elements of a circular economy (production and consumption of goods, waste management, secondary raw materials and competitiveness and innovation) by means of an online database and dedicated website (Eurostat, 2019b). Together with the comprehensive list of indicators, this framework has provided trend analysis and a big amount of data on each indicator to EU member states.

In addition to the national and regional efforts introduced above, this study also reviews some existing international initiatives/projects/studies which can provide useful approaches and/or indicators for sustainable bioeconomy M&E at territorial level. The initiatives are not exhaustive, since the study does not aim to cover *all* bioeconomy-related indicator initiatives. The selected sample covers important aspects to ensure bioeconomy sustainability (e.g. sustainable land use, biophysical boundaries and basic human needs) and illustrates which indicators are already monitored in areas relevant for the bioeconomy (such as bioenergy, green and blue economy, SDG reporting, etc.), for which more studies are available.

IINAS have adopted an interesting approach, which developed systemic indicators for Global Sustainable Land Use (IINAS/GLOBALANDS, 2015) to strengthen sustainable land use aspects within existing global governance systems (UN conventions and protocols). The approach identifies in particular socially-inclusive and actor-oriented systemic indicators for sustainable land use in the SDGs, and for safeguarding sustainable land use. The systemic indicator approach developed by IINAS/Globalands is based on a bottom-up approach developed on regional/national scale in a participatory process. The "real" application of the approach would take place when SDGs are implemented on regional and national scales.

Researchers from the Mercator Research Institute on Global Commons and Climate Change (**MCC**) and The Sustainability Research Institute have used indicators designed to measure a "**safe and just**" development space to quantify the resource use associated with meeting basic human needs (such as nutrition, sanitation, access to electricity, and the elimination of extreme poverty), and compare this use to downscaled planetary boundaries (measured by means of seven biophysical indicators) for over 150 nations (O'Neill *et al.*, 2018). To this end, they have estimated country performances with respect to social thresholds.

The **Global Bioenergy Partnership (GBEP)** has developed a set of 24 sustainability indicators for bioenergy, built on the consensus of a broad range of national governments and international organizations. The GBEP indicators have been tested in more than ten countries (GBEP, 2018). The Sustainability Task Force of GBEP is now working to develop an Implementation Guide on the use of the GBEP Sustainability Indicators, to improve their practicality and related guidance for users.

The UN Partnership for Action on Green Economy (PAGE) has developed a **Green Economy Progress (GEP)** Measurement Framework to help countries evaluate their progress towards an inclusive green economy and to enable across-country comparison of progress. The GEP Measurement Framework is composed of a *GEP Index* (made of 13 indicators) and a *Dashboard of Sustainability indicators* (which monitors key stocks of capital that are priorities to sustain life on the planet). The dashboard keeps track of the long-term sustainability of the factors that support human well-being by complementing the information assessment of green economy progress in the GEP Index (PAGE, 2017).

This study also includes ***blue economy* indicators**, by reviewing the OECD and EC studies on indicators for SDG 14; greening the ocean economy; marine protected areas and Maritime Spatial Planning (MSP) (European Commission, 2018; Mackie ***et al.***, 2017; OECD, 2017; Recuero Virto, 2017). The EC Handbook reviews indicators for: overarching Blue Growth objectives (creation of jobs and new sources of growth; protect the marine environment and reduce greenhouse gas emissions); global objectives (e.g. increase wind power generation at sea; Exploit stocks at maximum sustainable yield rate, etc.); immediate objectives (e.g. assigning maritime space for specific purposes); operational objectives (i.e. which deal with the actual designation of space for specific purposes, which is performed in the maritime spatial plans) and MSP process objectives (linked to ensuring appropriate MSP). The indicators proposed in the Handbook and reported here are not exhaustive since they are meant as examples for planning authorities to search for similar ones adjusted to the needs of their MSP process. All indicators can be interpreted only in the context of country-specific tasks, targets, goals and objectives.

Table 6 shows the approaches that have served as a basis for the territorial indicator review.

TABLE 6.

REVIEWED TERRITORIAL MONITORING APPROACHES AND THEIR GEOGRAPHICAL SCOPE

No	AUTHOR(S)/SOURCE	TITLE/TOOL	GEOGRAPHICAL SCOPE
1	Argentina (Lechardoy, 2018)	National Program for the Development of Bioeconomy in Argentina	Country
2	BioEconomy Regional Strategy Toolkit (BERST, 2014, 2018)	Criteria and Indicators describing the regional bioeconomy	Sub-national (regional)
3	EC Joint Research Centre (JRC) (Ronzon, Camia and Barek, 2018)	Quantifying indicators for the Bioeconomy: The JRC experience	EU member states and EU
4	European Commission (European Commission, 2018)	Maritime Spatial Planning (MSP) for Blue Growth	Country and member states authorities
5	FAO (FAO, *forthcoming*)	Linking the Bioeconomy to 2030 Sustainable Development Agenda: Can SDG indicators be used to monitor progress towards a sustainable bioeconomy and highlight synergies and trade-offs?	Global
6	Finland (MEE, 2014)	The Finnish bioeconomy strategy	Country
7	Global Bioenergy Partnership (GBEP)	GBEP Sustainability indicators for bioenergy (GSI)	Country
8	IINAS – GLOBALANDS (Fritsche, 2018; IINAS/GLOBALANDS, 2015)	Global Sustainable Land Use: Concept and Examples for Systemic Indicators	Systemic Indicator Approach combining sustainable practice, specific actors and certain regions
9	IINAS – S2Biom (Fritsche, 2018; S2Biom, 2015a)	Consistent Cross-Sectoral Sustainability Criteria & Indicators	Key criteria and indicators for biomass sustainability at local, regional, national and pan European level
10	Italy (Presidency of Council of Ministers, 2017)	Bioeconomy in Italy	Key performance indicators at national and regional level
11	Malaysia (Malaysian Bioeconomy Development Corporation Sdn Bhd, 2018)	Bioeconomy Contribution Index	Country
12	Mercator Research Institute on Global Commons and Climate Change (MCC) & Sustainability Research Institute (O'Neill *et al.*, 2018)	A good life for all within planetary boundaries	National performance with respect to social thresholds and per capita biophysical boundaries
13	MontBioEco/Luke (Lier *et al.*, 2018; LUKE, 2018)	Synthesis on bioeconomy monitoring systems in the EU Member States	EU member states and EU
14	OECD (Mackie *et al.*, 2017; OECD, 2017; Recuero Virto, 2017).	Greening the Ocean Economy; A preliminary assessment of indicators for SDG 14 on "Oceans"; Indicators on Terrestrial and Marine Protected Areas: Methodology and Results for OECD and G20 countries	National and regional performance
15	SAT-BBE Consortium (SAT-BBE, 2013)	Tools for evaluating and monitoring the EU bioeconomy: Indicators	Local / EU-wide / Global
16	Sustainable Europe Research Institute (SERI, 2013)	State-of-Play of National Consumption-Based Indicators	National performance
17	Thünen Institute (Thünen Institute, 2018)	Developing concepts for sustainability assessment of bio-economy as part of a bio-economy monitoring	Material flow analysis and cross-sectoral sustainability assessment
18	UN PAGE (PAGE, 2017, 2018)	The green economy progress (GEP) measurement framework	National and international level

Source: Authors

4.2 IDENTIFIED INDICATORS AT TERRITORIAL LEVEL

Table 7 reports the indicators identified through the review of the sources above. The indicators are grouped into impact categories derived from the sustainable bioeconomy P&Cs. For some impact categories, no indicator has been found in the literature (as further discussed in Section 6.1).

Some indicators can be slightly modified to better fit the purpose of this analysis. In particular, some indicators can be expanded to cover all bioeconomy sectors instead of a specific sector. For example, some socio-economic indicators developed by GBEP can be partially modified to adapt to all bioeconomy sectors and not only bioenergy (e.g. ***Value added of bioeconomy sectors*** instead of ***Value added of bioenergy sectors***).

The IINAS/GLOBALANDS system indicators approach identifies six environmental screening criteria (land degradation; biodiversity; soil (soil organic carbon (SOC), nutrients); water resources; water productivity; climate change) and eight socio-economic ones (food security; rural poverty; rural employment; land tenure and ownership; traditional knowledge; improving crop production; improving fodder production and supporting gender equity), but does not provide a list of indicators. For this reason, it is excluded from the Table below.

Similarly, some BERST criteria and indicators have been excluded since they do not provide a clear indication about how to measure them (unit), or because they are not specific to sustainable bioeconomy (e.g. demographic indicators).

For the MCC approach, we report both the social thresholds and the per capita biophysical boundaries since they are the "indicators" proposed by the approach. In fact, the indicators measure both impacts and performance towards goals. Not all indicators are quantitative, but many refer to the existence or implementation of a strategy/policy/practice (see also section 6).

Finally, the indicators reported below and their variation in time can be ***positive or negative***: an increase in an indicator can be linked to an improvement in sustainability (positive) or to a decrease (negative).

All the indicators reported in **Table 7** are derived from the sources mentioned in **Table 6** and do not reflect FAO's opinion.

TABLE 7.

INDICATORS FOR MONITORING SUSTAINABILITY AT TERRITORIAL LEVEL

Colour code: Economic Social Environmental

	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 1. SUSTAINABLE BIOECONOMY DEVELOPMENT SHOULD SUPPORT FOOD SECURITY AND NUTRITION AT ALL LEVELS	1.1. FOOD SECURITY AND NUTRITION ARE SUPPORTED	1.1.a Food security	Domestic food production ($) [13]
			Domestic food stock ($) [13]
			Price and supply of a national food basket (Tonnes; $; and percentage) [7]
			Change in food price volatility [10; 15]
			Change in food prices [10; 15]
			Change in demand for foodstuffs for food, feed, and fibre [7]
			Changes in the import and export of foodstuffs ($) [13]
			SDG 2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES) [5]
			SDG 2.c.1 Indicator of food price anomalies [5]
		1.1.b Nutrition	Nutrition (threshold of 2 700 kcal per capita) [12]
			Changes in macro-nutrient intake/availability [10; 15]
			Change in malnutrition or risk of hunger [10; 15]
			SDG 2.1.1 Prevalence of undernourishment [5]
	1.2. SUSTAINABLE INTENSIFICATION OF BIOMASS PRODUCTION IS PROMOTED	1.2.a Domestic biomass production	Domestic production of agricultural, blue, forestry and waste biomass (kg/capita) [2; 10]
		1.2.b Yield / agricultural productivity	Productivity of feedstock or by farm/plantation (tonnes ha per year) [7]
			Change in land use intensity (inputs / outputs / system based; e.g. felling ratio, crop yields and animal stocking density) [10; 15]
			SDG 2.4.1 Proportion of agricultural area under productive and sustainable agriculture [5]
			SDG 2.3.1 Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size [5]
		1.2.c Land for biomass production	Embodied human appropriation of net primary production (eHANPP) (t/capita/yr) [12]
			Total area of land for bioeconomy feedstock production, and as compared to total national surface [7]
			Land cover (share of total area, %): forest area and agricultural area (incl. cropland and grassland) [13]
			Land use (forestry; agricultural and horticultural land as % of total land area) [2; 18]
			Ecological Footprint (global hectares/capita/year) [12; 18]
	1.3. ADEQUATE LAND RIGHTS AND RIGHTS TO OTHER NATURAL RESOURCES ARE GUARANTEED	1.3.a Land rights	Land prices [15]
			Land tenure and property rights (Compliance with the Voluntary Guidelines on the Responsible Governance of Tenure of Land to secure land tenure and ownership) [15]
			Percentage of land – total and by land-use type – used for new bioeconomy production where: (1) a legal instrument or domestic authority establishes title and procedures for change of title (%); and (2) the current domestic legal system and/or socially accepted practices provide due process and the established procedures are followed for determining legal title (%). [7]
			Access to land [15]
			SDG 1.4.2 Proportion of total adult population with secure tenure rights to land, (a) with legally recognized documentation, and (b) who perceive their rights to land as secure, by sex and type of tenure [5]
		1.3.b Rights to other natural resources	Progress by countries in the degree of application of a legal/regulatory/policy/institutional framework which recognizes and protects access rights for small-scale fisheries (SDG 14.B.1) [14]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 1. SUSTAINABLE BIOECONOMY DEVELOPMENT SHOULD SUPPORT FOOD SECURITY AND NUTRITION AT ALL LEVELS	1.4. FOOD SAFETY, DISEASE PREVENTION AND HUMAN HEALTH ARE ENSURED	1.4.a Food safety	Organic farming [17]
			Contaminants in seafood [4]
		1.4.b Disease / hazards prevention (in biomass production and processing)	Occupational safety and health for workers (Compliance with health and safety regulations at the different supply chains) [9]
			Incidence of occupational injury, illness and fatalities in one sector (in relation to comparable sectors) [7]
			Average number of work days lost per worker per year [15]
			SDG 8.8.1 Frequency rates of fatal and non-fatal occupational injuries, by sex and migrant status [5]
		1.4.c Human health	Life expectancy at birth (number of years a new-born infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life) [9; 18]
			Healthy life expectancy (65 years) [12]
			Risks to public health (Measures taken to safeguard public health, i.e. regulation of noise level and prevention of accidents) [9]
			SDG 3.9.1 Mortality rate attributed to household and ambient air pollution [5]
			SDG 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services) [5]
			SDG 3.9.3 Mortality rate attributed to unintentional poisoning [5]
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED	2.1. BIODIVERSITY CONSERVATION IS ENSURED	2.1.a Biodiversity conservation	Rate of biodiversity loss [3; 7; 10; 15]
			Rate of habitat loss (forest and agriculture) [15]
			Rate of forest fragmentation [15]
			Protected areas and land with significant biodiversity values, and biodiversity conservation and management [9; 18]
			Proportion of fish stocks within biologically sustainable limits / Share of sustainably fished fish populations (SDG 14.4.1) [5; 13; 14; 17]
			SDG 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type [16]
			SDG 15.4.1 Coverage by protected areas of important sites for mountain biodiversity [5]
			SDG 15.5.1 Red List Index [5]
			SDG 15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species [5]
	2.2. CLIMATE CHANGE MITIGATION AND ADAPTATION ARE PURSUED	2.2.a Climate change mitigation (carbon and other GHG emissions)	SDG 9.4.1 CO_2 emission per unit of value added [5]
			Greenhouse gas (GHG) emissions, excluding land-use change and forestry (CO_2e/capita/year) [18]
			Greenhouse gas (GHG) emissions [16; 17]
			Change in GHG emissions (CO_2eq) [3; 4; 10; 15]
			Change in LULUCF carbon baseline [15]
			CO_2 emissions (2°C warming) [12]
			Life cycle-based CO_2eq including direct land use change, and other GHG emissions (gCO_2eq/MJ) [7; 9]
			Change in carbon stocks / Carbon sequestration (CO_2eq. Tonnes) [13]
		2.2.b Climate change adaptation	SDG 13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other) [5]
			Public financial support and private investments for mitigation and adaptation ($) [13]

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PRINCIPLE	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED	2.3. WATER QUALITY AND QUANTITY ARE MAINTAINED, AND, IN AS MUCH AS POSSIBLE, ENHANCED	2.3.a Water quality	Pollutant loadings to waterways and bodies of water attributable to fertilizer and pesticide application for biomass production (kg N and P/ha/year) [7]
			Total phosphate in flowing water [17]
			Nitrate in groundwater [17]
			Eutrophication (N, P concentration) [3; 15]
			Toxicity (herbicide concentration) [15]
			Presence of water pollutants (e.g. nitrate, phosphorous, pesticides, biochemical oxygen demand) [9; 10]
			SDG 6.3.1 Proportion of wastewater safely treated [5]
			SDG 6.3.2 Proportion of bodies of water with good ambient water quality [5]
		2.3.b Water quantity/ use/efficiency	Freshwater resources (billion m^3) ** [13]
			Freshwater availability (m^3/capita/year) [10; 13; 18]
			Blue water (4 000 km^3/year) [12]
			Water Exploitation Index (WEI) [15; 16]
			Water withdrawn from nationally determined watershed(s) for the production and processing of biomass (% and volume) [7]
			Water use for agriculture and forestry [15]
			Water use for manufacturing and recycling [15]
			Water use efficiency (Water use for biomass production (cropping), irrigation, and processing/kg biomass) [9]
			SDG 6.4.1 Change in water-use efficiency over time [5]
			SDG 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources [5]
	2.4. THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	2.4.a Land use change	Change in cropland area, grassland area, non-arable land use (e.g. "marginal" land use), short rotation plantations [7; 15]
			Artificial land or built-up area (km^2) [16]
		2.4.b Soil quality	Nitrogen balance (kg/ha) * [13; 15]
			Phosphorus balance (kg/ha) * [13; 15]
			Soil erosion (tonnes/ha) * [13; 15]
		2.4.c Soil quantity	SDG 15.3.1 Proportion of land that is degraded over total land area [5]
			Percentage of land for which soil quality (SOC) is maintained or improved out of total land on which bioeconomy feedstock is cultivated or harvested (%) [7]
		2.4.d Forest quality	Change in forest carbon content [15]
			SDG 15.2.1 Progress towards sustainable forest management [5]
		2.4.e Forest quantity	Forest area density (% of total land) [2]
			Change in forest area [15]
			SDG 15.1.1 Forest area as a proportion of total land area [5]
			Growing stock on forests available for wood supply (1 000m^3) ** [13]
			Ratio of annual increment and fellings in forest (%) [13]
			Ratio of fellings and estimated maximum sustainable level of cuttings in forests (%) [13]
			Annual harvest of wood resources by volume (m^3/ha/year) [7]
		2.4.f Marine environments' quality	Index of coastal eutrophication (ICEP) and floating plastic debris density (SDG 14.1.1) [14; 17]
			Average marine acidity (pH) measured at agreed suite of representative sampling stations (SDG 14.3.1) [14]

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Principle	Criterion	Impact category	Indicator (unit) [source]
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED	2.4. THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	2.4.g Marine environments' quantity	Fish resources (tonnes)** [13]
			Marine protected area (% of territorial waters) (SDG 14.5.1) [14; 18]
			Maritime space assigned for [Blue Economy sector X] [4]
		2.4.h Air quality	Level of emission of air pollutants (PM2.5, PM10, SO_2eq) [7; 9; 10; 15; 17; 18]
			Life cycle emissions of SO_2, NOx, NH_3 and HCl/HF from bioenergy provision, expressed in SO_2 equivalents and calculated in accordance to GHG emissions [9]
			Ammonia, NOx and SOx emissions (ktonnes) * [13]
			Emissions of non-GHG air pollutants, including air toxics, from: (1) feedstock production (mg/ha, mg/MJ, and as a percentage), (2) processing (mg/m³ or ppm), (3) transport of feedstocks, intermediate products and end products (mg/MJ) [7]
			Level of concentration of air pollutants [15]
			SDG 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted) [5]
		2.4.i Hazardous substances in production and processing	Pesticides sales (tonnes) * [13]
PRINCIPLE 3. SUSTAINABLE BIOECONOMY SHOULD SUPPORT COMPETITIVE AND INCLUSIVE ECONOMIC GROWTH	3.1. ECONOMIC DEVELOPMENT IS FOSTERED	3.1.a Economic development	Turnover/output of bioeconomy sectors ($) [3; 6; 17]
			Value added of bioeconomy sectors ($) [4; 6; 7; 11; 13]
			Change in turnover of bio-based sectors [15]
			Contribution of bioeconomy sectors to GDP (%) [1; 13]
			Sustainable fisheries as a percentage of GDP in small island developing States, least developed countries and all countries (SDG 14.7.1) [14]
			Change in GDP/GNI [15]
			Gross fixed capital formation in relation to GDP [17]
			SDG 8.1.1 Annual growth rate of real GDP per capita [5]
			SDG 8.2.1 Annual growth rate of real GDP per employed person [5]
			Household income ($) [2]
			Average income of employees in the bioeconomy sectors [2; 15; 17]
			Income (95% of people earning above $1.90 a day) [12]
			SDG 8.5.1 Average hourly earnings of female and male employees, by occupation, age and persons with disabilities [5]
			Domestic and foreign investments into bioeconomy sectors ($) [6; 11]
			Inclusive Wealth Index (millions of constant US$/capita) [18]
			Cluster size (number of businesses or employees in each cluster (% of total firms)) [2]
			SDG 1.2.1 Proportion of population living below the national poverty line, by sex and age [5]
			SDG 1.2.2 Proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions [5]
	3.2. INCLUSIVE ECONOMIC GROWTH IS STRENGTHENED	3.2.a Employment	Change in employment rate [4; 10; 15]
			Full Time Equivalent jobs [3; 6; 9; 15; 17]
			Income creation (value of jobs created within bioeconomy sectors) [11]
			Employment in each group of bioeconomy subsectors (% of total employment) [2]
			Number of employed persons in rural and urban areas (1 000 persons) [13]
			Job creation in skilled / unskilled labour [7; 10; 15]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 3. SUSTAINABLE BIOECONOMY SHOULD SUPPORT COMPETITIVE AND INCLUSIVE ECONOMIC GROWTH	**3.2.** INCLUSIVE ECONOMIC GROWTH IS STRENGTHENED	3.2.a Employment	Location quotient (proportion of persons employed in a particular sector and in a given Member State compared with the European proportion) [3]
			Labour productivity ($) [11]
			Full direct jobs equivalent in the biomass consuming region (or country) [9]
			Threshold of 94% employed (6% unemployment) [12]
			SDG 8.5.2 Unemployment rate, by sex, age and persons with disabilities [5]
			SDG 8.3.1 Proportion of informal employment in non-agriculture employment, by sex [5]
		3.2.b Working conditions	Human and Labour Rights (Adherence to ILO (1998) principles and voluntary standards) [9]
			SDG 8.8.2 Level of national compliance with labour rights (freedom of association and collective bargaining) based on International Labour Organization (ILO) textual sources and national legislation, by sex and migrant status [5]
		3.2.c Access to basic services	SDG 1.4.1 Proportion of population living in households with access to basic services [5]
			SDG 6.1.1 Proportion of population using safely managed drinking water services [5]
			SDG 6.2.1 Proportion of population using (a) safely managed sanitation services and (b) a hand-washing facility with soap and water [5]
			Sanitation (95% of people have access to improved sanitation facilities) [12]
			Education (95% enrolment in secondary school) [12]
			Education (mean years of schooling) [18]
			Composite measure created by the average access to three basic services: (a) access to improved water sources (% of total population), (b) access to electricity (% of total population), (c) access to sanitation facilities (% of total population) [18]
		3.2.d Energy security	Access to energy (95% people have electricity access) [12]
			SDG 7.1.1 Proportion of population with access to electricity [5]
			SDG 7.1.2 Proportion of population with primary reliance on clean fuels and technology [5]
		3.2.e Equality	SDG 5.4.1 Proportion of time spent on unpaid domestic and care work, by sex, age and location [5]
			Change in unpaid time spent by women and children collecting biomass [7]
			GINI index (measure of inequality of income or wealth) (70 on 0–100 scale (Gini index of 0.30)) [12]
			Palma ratio (Ratio of the richest 10% of the population's share of income divided by the share of the poorest 40%) [18]
			SDG 10.1.1 Growth rates of household expenditure or income per capita among the bottom 40 per cent of the population and the total population [18]
		3.2.f Gender equality	SDG 5.1.1 Whether or not legal frameworks are in place to promote, enforce and monitor equality and non-discrimination on the basis of sex [5]
			Employment benefits that are specific for women [9]
			Gender pay gap [17]
			SDG 8.5.1 Average hourly earnings of female and male employees, by occupation, age and persons with disabilities (see 3.1.a) [5]
			A composite measure reflecting inequality in achievements between women and men across three dimensions: (a) reproductive health; (b) empowerment; and (c) the labour market [18]
		3.2.g Inclusiveness	Share of population above statutory pensionable age receiving an old age pension, by contribution and sex [18]
			SDG 4.4.1 Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill [5]
			SDG 4.6.1 Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex [5]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 3. SUSTAINABLE BIOECONOMY SHOULD SUPPORT COMPETITIVE AND INCLUSIVE ECONOMIC GROWTH	3.3. RESILIENCE OF THE RURAL AND URBAN ECONOMY IS ENHANCED	3.3.a Rural income diversification	Annual amount paid to smallholders and suppliers of feedstock ($) [9]
		3.3.b Linkages between rural and urban economy	SDG 9.1.1 Proportion of the rural population who live within 2 km of an all-season road [5]
		3.3.c Physical infrastructure	Transport of freight (proxy) (tonnes per km²) [2]
			SDG 9.1.2 Passenger and freight volumes, by mode of transport [5]
		3.3.d Financial stability	Proximity to financial institutions (distance to closest major financial centre) [2]
PRINCIPLE 4. SUSTAINABLE BIOECONOMY SHOULD MAKE COMMUNITIES HEALTHIER, MORE SUSTAINABLE, AND HARNESS SOCIAL AND ECOSYSTEM RESILIENCE	4.1. THE SUSTAINABILITY OF URBAN CENTRES IS ENHANCED	4.1.a Sustainability of urban centres	SDG 11.6.1 Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities [5]
	4.2. RESILIENCE OF BIOMASS PRODUCERS, RURAL COMMUNITIES AND ECOSYSTEMS IS DEVELOPED AND/OR STRENGTHENED	4.2.a Resilience of biomass producers	SDG 10.4.1: Labour share of GDP, comprising wages and social protection transfers [5]
			Involvement of smallholders or small suppliers (% feedstock that originates from associated smallholders and outgrowers) [9]
		4.2.b Resilience of rural communities - social protection	SDG 1.3.1 Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable [5]
			Amount invested in community investment projects (e.g. CSR) (% of annual revenue) and qualitative description of investments including any projects specific for women [9]
			Social support (90% of people have friends or family they can depend on) [12]
		4.2.c Resilience of ecosystems	Environmental protection: 1. Protected forest areas (1 000 ha); 2. Standing and lying dead wood in forests (m³/ha); 3. Agricultural areas under Natura 2 000 (ha); 4. Area under agri-environmental commitments (ha); 5. Number of threatened species [13]
			Nitrogen emissions (kg/capita/year) [12; 18]
			Eutrophication of ecosystems [17]
			Phosphorus (6.2 Tg P/year or 0.89 kg P/year/capita) [12]
			Change in ecosystem service provision [15]
			Non indigenous species [4]
			Proportion of national exclusive economic zones managed using ecosystem-based approaches (SDG 14.2.1) [14]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 5. SUSTAINABLE BIOECONOMY SHOULD RELY ON IMPROVED EFFICIENCY IN THE USE OF RESOURCES AND BIOMASS	5.1. RESOURCE EFFICIENCY, WASTE PREVENTION AND WASTE RE-USE ALONG THE WHOLE BIOECONOMY VALUE CHAIN IS IMPROVED	5.1.a Resource efficiency (Material footprint (secondary resources))	Material Footprint (7.2 tonnes/year per capita) [12]
			SDG 8.4.1/12.2.1 Material footprint, material footprint per capita, and material footprint per GDP [5]
			Secondary resource efficiency (Raw material consumption of used biotic and abiotic materials (tons/person)) [9]
			Raw material consumption of used biotic and abiotic materials (tons/person) [18]
			Total raw material productivity [17]
		5.1.b Energy efficiency	Energy intensity of the economy [10]
			SDG 7.3.1 Energy intensity measured in terms of primary energy and GDP [5]
			Energy use (kg of oil equivalent) per USD 1 000 GDP (constant 2011 PPP) [18]
		5.1.c Waste prevention	Marine litter [4]
		5.1.d Waste re-use	Material and waste recycling and recovery rate (toe) [13]
			SDG 12.5.1 National recycling rate, tons of material recycled [5]
			Organic waste diverted from landfills [10; 15]
		5.1.e Waste treatment and hazardous waste	SDG 6.3.1 Proportion of wastewater safely treated [5]
			SDG 12.4.2 Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment [5]
	5.2. FOOD LOSS AND WASTE IS MINIMIZED AND, WHEN UNAVOIDABLE, ITS BIOMASS IS REUSED OR RECYCLED	5.2.a Food loss and waste minimization	SDG 12.3.1 Global food loss index [5]
		5.2.b Food waste re-use or recycling	-
PRINCIPLE 6. RESPONSIBLE AND EFFECTIVE GOVERNANCE MECHANISMS SHOULD UNDERPIN SUSTAINABLE BIOECONOMY	6.1. POLICIES, REGULATIONS AND INSTITUTIONAL SET UP RELEVANT TO BIOECONOMY SECTORS ARE ADEQUATELY HARMONIZED	6.1.a Coherent policies, regulations in the bioeconomy sectors	Regulation (commitment of policy makers and policy) [2]
			Cluster governance (the support provided by local/regional/national government in setting up and managing the cluster, as well as any cluster-friendly policies that are introduced) [2]
			Number of countries making progress in ratifying, accepting and implementing through legal, policy and institutional frameworks, ocean-related instruments that implement international law, as reflected in the United Nation Convention on the Law of the Sea, for the conservation and sustainable use of the oceans and their resources (SDG 14.C.1) [14]
		6.1.b Coherent institutional set-up in the bioeconomy sectors	Cluster management (Presence of a cluster organization which coordinates, manages and facilitates the biocluster; Presence of an incubator; Biocluster is integrated or closely tied to a science/technology park) [2]
			Institutionalised or non-institutionalised platforms/fora linking relevant national authorities, which have responsibilities with regards to MSP and Blue Growth (e.g. cross sectoral MSP expert working groups, advisory boards) [4]
	6.2. INCLUSIVE CONSULTATION PROCESSES AND ENGAGEMENT OF ALL RELEVANT SECTORS OF SOCIETY ARE ADEQUATE AND BASED ON TRANSPARENT SHARING OF INFORMATION	6.2.a Consultation processes and engagement of all relevant sectors of society	Democratic quality (index 0.80 (approximate US/UK value)) [12]
			SDG 17.16.1 Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the Sustainable Development Goals [5]
			Number of stakeholders from various stakeholder groups (i.e. public authorities, private business, NGOs, general public) involved in consultations during the development of the Marine Spatial Planning [4]
		6.2.b Transparent sharing of information	Freely availability of documentation necessary to inform stakeholder positions in a timely, open, transparent and accessible manner [9]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 6. RESPONSIBLE AND EFFECTIVE GOVERNANCE MECHANISMS SHOULD UNDERPIN SUSTAINABLE BIOECONOMY	6.3. APPROPRIATE RISK ASSESSMENT AND MANAGEMENT, MONITORING AND ACCOUNTABILITY SYSTEMS ARE PUT IN PLACE AND IMPLEMENTED	6.3.a Risk assessment and management	EMAS eco-management [17]
		6.3.b Monitoring and accountability systems	Number of spatial conflicts (between current / future human activities and nature) [4]
PRINCIPLE 7. SUSTAINABLE BIOECONOMY SHOULD MAKE GOOD USE OF EXISTING RELEVANT KNOWLEDGE AND PROVEN SOUND TECHNOLOGIES AND GOOD PRACTICES, AND, WHERE APPROPRIATE, PROMOTE RESEARCH AND INNOVATION	7.1. EXISTING KNOWLEDGE IS ADEQUATELY VALUED AND PROVEN SOUND TECHNOLOGIES ARE FOSTERED	7.1.a Existing knowledge	Industrial culture (rate of formation of SMEs and presence of multinationals) [2]
		7.1.b Proven sound technologies	SDG 12.a.1 Amount of support to developing countries on research and development for sustainable consumption and production and environmentally sound technologies [5]
			Diffusion of technology [2]
		7.1.c Capacity development (extension services)	Training and re-qualification of the workforce in the bioeconomy sector (share of workers, % per year) [7]
	7.2. KNOWLEDGE GENERATION AND INNOVATION ARE PROMOTED	7.2.a Knowledge generation / (high level) education	SDG 4.3.1 Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex [5]
			SDG 4.4.1 Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill [5]
			SDG 4.7.1/12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment [5]
			Prominent universities or research institute (quality of university) [2]
			Intellectual property rights (IPRs) (patent, trademark, design) applications in bioeconomy subsectors (number of application per 1 000 employees) [2; 10]
			Quality of workforce (secondary and tertiary education (% of total population)) [2; 10]
		7.2.b Research and innovation	Investment in R&D ($) [13]
			R&D expenditure [index (EU=1)] [2; 10]
			SDG 9.5.1 Research and development expenditure as a proportion of GDP [5]
			Proportion of total research budget allocated to research in the field of marine technology (SDG 14.A.1) [14]
			Private and public spending on research and development [17]
			SME birth rate (% of total firms) [2]
			As a measure of green technology innovation, patent publication in environmental technology by filing office (% of total patents) [18]
			R&D employment (% of total employment) [2; 10]
			Commercialization of innovative technologies (sales of innovation products) [2]
			Key enabling technology (KET) R&D focus [2]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 8. SUSTAINABLE BIOECONOMY SHOULD USE AND PROMOTE SUSTAINABLE TRADE AND MARKET PRACTICES	8.1. LOCAL ECONOMIES ARE NOT BE HAMPERED BUT RATHER HARNESSED BY THE TRADE OF RAW AND PROCESSED BIOMASS, AND RELATED TECHNOLOGIES	8.1.a Net trade of raw biomass	Change in cropland-based biomass net trade [15]
			Change in wood net trade [15]
		8.1.b Value added of processed biomass	Value added of bioeconomy sectors ($) (see 3.1.a) [7; 11; 13]
		8.1.c Net trade of processed biomass	Change in cropland-based biomass product net trade [15]
			Change in animal-based product net trade [15]
			Change in fish and fish product net trade [15]
			Change in forest products net trade [15]
		8.1.d Net trade of biomass-related technologies	Export and import of biomass related technologies (see 10.1)
		8.1.e Sustainable market practices and trade policy	SDG 17.11.1 Developing countries' and least developed countries' share of global exports [5]
			Export of environmental goods according to OECD and APEC (% of total export) [18]
PRINCIPLE 9. SUSTAINABLE BIOECONOMY SHOULD ADDRESS SOCIETAL NEEDS AND ENCOURAGE SUSTAINABLE CONSUMPTION	9.1. CONSUMPTION PATTERNS OF BIOECONOMY GOODS MATCH SUSTAINABLE SUPPLY LEVELS OF BIOMASS	9.1.a Sustainable consumption (which matches sustainable supply levels of biomass)	SDG 8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP [16]
			SDG 8.4.1/12.2.1 Material footprint, material footprint per capita, and material footprint per GDP [5]
			Change in cropland-based biomass demand for products [15]
			Change in wood/wood fibre demand for forest products [15]
			Change in consumption level of biomass [15]
			Change in wood resource balance [13; 15]
			Change in fish stocks [13; 15]
			Change in consumption of fish [13]
			SDG 14.7.1 Sustainable fisheries as a proportion of GDP in small island developing States, least developed countries and all countries [5]
		9.1.b Reducing dependence on non-renewable resources	Change in consumption of fossil resources [7; 15]
			Net energy balance (Energy ratio of the bioenergy value chain with comparison with other energy sources, including energy ratios of: (1) feedstock production; (2) processing of feedstock into bioenergy; (3) bioenergy use; and/or (4) lifecycle analysis.) [7]
			Share of renewable energy supply (of total energy supply) [13; 18]
			Production of biofuels and biogas (toe) [13]
			Primary energy consumption [17]
			Final energy consumption [9; 10; 17]
			SDG 7.2.1 Renewable energy share in the total final energy consumption [10; 17]
			MWh of wind power/tidal and wave energy generated at sea [4]
			Material replacing non-renewable resources (bio-materials) (m^3, tonnes, toe) [13]
			Public financial support and private investments for reducing dependence on non-renewable resources ($) [13]
	9.2. DEMAND AND SUPPLY- SIDE MARKET MECHANISMS AND POLICY COHERENCE BETWEEN SUPPLY AND DEMAND OF FOOD AND NON-FOOD GOODS ARE ENHANCED	9.2.a Market mechanisms influencing supply and demand of food and non-food goods (e.g. prices, consumer awareness)	Current levelised life-cycle cost, and future levelised life-cycle costs of biomass [9]
			Food, fuelwood and other products supply security (Measures to avoid risks for negative impacts on price and supply of national food basket, fuelwood and other products.) [9]
			Change in food prices (see 1.1.a); real wood prices; forest products prices [10; 15]
			Secondary material price change [10; 15]
			Consumer preferences (consumer demand) [2]
			Market share of goods certified by independently verified sustainability labelling schemes [17]

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	CRITERION	IMPACT CATEGORY	INDICATOR (UNIT) [SOURCE]
PRINCIPLE 9. SUSTAINABLE BIOECONOMY SHOULD ADDRESS SOCIETAL NEEDS AND ENCOURAGE SUSTAINABLE CONSUMPTION	**9.2.** DEMAND AND SUPPLY- SIDE MARKET MECHANISMS AND POLICY COHERENCE BETWEEN SUPPLY AND DEMAND OF FOOD AND NON-FOOD GOODS ARE ENHANCED	9.2.b Policy coherence between supply and demand of food and non-food goods (e.g. targets, mandates, incentives, tax, etc.)	SDG 12.1.1 Number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies [5]
			Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing (SDG 14.6.1) [14]
			Public financial support and private investments for ecosystem services ($) [13]
PRINCIPLE 10. SUSTAINABLE BIOECONOMY SHOULD PROMOTE COOPERATION, COLLABORATION AND SHARING BETWEEN INTERESTED AND CONCERNED STAKEHOLDERS IN ALL RELEVANT DOMAINS AND AT ALL RELEVANT LEVELS	**10.1.** COOPERATION, COLLABORATION AND SHARING OF RESOURCES, SKILLS AND TECHNOLOGIES ARE ENHANCED WHEN AND WHERE APPROPRIATE	10.1.a International Cooperation (transfer of resources, skills and technologies)	Export of bioproducts ($ or % of total exports) [2; 6; 10; 11; 13]
			Import of bioproducts (% of total exports) [10]
			SDG 2.a.2 Total official flows (official development assistance plus other official flows) to the agriculture sector [5]
			Consultations held with neighbouring countries, which are relevant to Blue Economy sectors (e.g. bi- and multilateral meetings, workshops, conferences) [4]
		10.1.b Collaboration between private sector actors (e.g. licensing, contract)	Density of firms in the (sub)sectors [2]

Note: $: national currency or USD or Euro

* these 5 indicators represent "sustainable agriculture" in the Luke approach

** these 3 indicators represent "resource availability" in the Luke approach

Sources are indicated in brackets [] and refer to the list in Table 6

4.3 DATA AVAILABILITY AT TERRITORIAL LEVEL

Some of the data required to report on the indicators listed in **Table 7** are already collected by national or international statistics. In particular, some data on economic aspects can be retrieved from national or international accounts (see Section 6.3) or by international databases such as the United Nations' statistics. Others are aspirational, hence data are currently not available or not being collected. Retrieving environmental and social statistics is often more complicated since they are not yet universally collected and available, despite some national, regional and international initiatives, such as those reported in Section 4.1.

By looking at the reported sources for each indicator (**Table 7**), it is possible to find out if data are already available and where they can be retrieved. For instance, the data which inform SDG indicators can be retrieved from the UN website database (United Nations, 2019). Data for the JRC approach are compiled within the JRC-Bioeconomics dataset and they can be gathered online (EC JRC, 2018b). Data for the indicators of the "Safe and Just approach" (MCC, O'Neill *et al.*, 2018) are available via an interactive website (University of Leeds, 2019), which allows users to request a dataset for each country. Other databases are mentioned by the SAT-BBE consortium in its effort to identify indicators and data for monitoring the evolution of the bioeconomy in the EU. IINAS-Globalands mentions WOCAT (World Overview of Conservation Approaches and Technologies) as a database on best practice and technologies for sustainable land management, with direct application to knowledge of soil and water conservation. Some approaches, such as the MontBioEco/Luke considered data availability in countries as one of the parameters for indicators selection. For OECD countries, the OECD statistics can be a useful source of data (OECD, 2018). SERI shows and evaluates different datasets for footprint-type indicators for materials, water, land and carbon. The FAO's World Programme for the Census of Agriculture 2020 (WCA 2020) provides guidance on agricultural censuses for the collection of structural data on the agriculture sector by countries in the period between 2016 and 2025 (FAO, 2017b). Finally, UN PAGE provides the data source for all the indicators in the Green Economy Progress (GEP) Index.

If data is not available, monitoring the indicators would be unfeasible in the short term. In such case, it could be possible to use proxy indicators such as practices that will promote the achievement of a target. For instance, in some cases, the SDG indicators or other available indicators could be adapted (see Section 6.4). For instance, SDG 13.2.1 ***Number of countries** that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production* can be adapted to become a national dummy (yes/no) indicator.

CHAPTER

5

REVIEW OF INDICATORS AT PRODUCT LEVEL

Two approaches, which are commonly used to assess the impact and progress of the bioeconomy at the product level are the ***sectoral*** approach and the ***value chain*** approach (European Commission, 2013). The first one, although considered more rational because it is embedded in well-established statistical systems and methodologies, is more difficult to apply since it requires a definition of sectors that are part of the bioeconomy. Moreover, this approach makes it difficult to establish a method to differentiate between traditional products and bio-based ones. This differentiation would require further detail at sectoral level and support from other methodological approaches.

The value chain approach can be helpful in this direction, since it is suitable for identifying bioproducts and monitoring the evolution of the bioeconomy at product level. This approach is relevant for the development and application of life cycle methods used for sustainability assessment of bioproducts, as explained in Section 3.3. However, the value chain approach is challenging when bioeconomy products and markets are at a very early stage since there are no well-defined and perfectly-distinguishable added values for bioproducts.

The following section presents a review of the main monitoring approaches at product/value chain level. Most of the approaches reviewed apply, or recommend applying, life cycle assessment frameworks for evaluating the sustainability of products by means of identified indicators. The approaches reviewed are developed and adopted by several organizations, ranging from Standards, Certificates and Labels (SCL) issuers and private consortia, to research projects and sectoral studies.

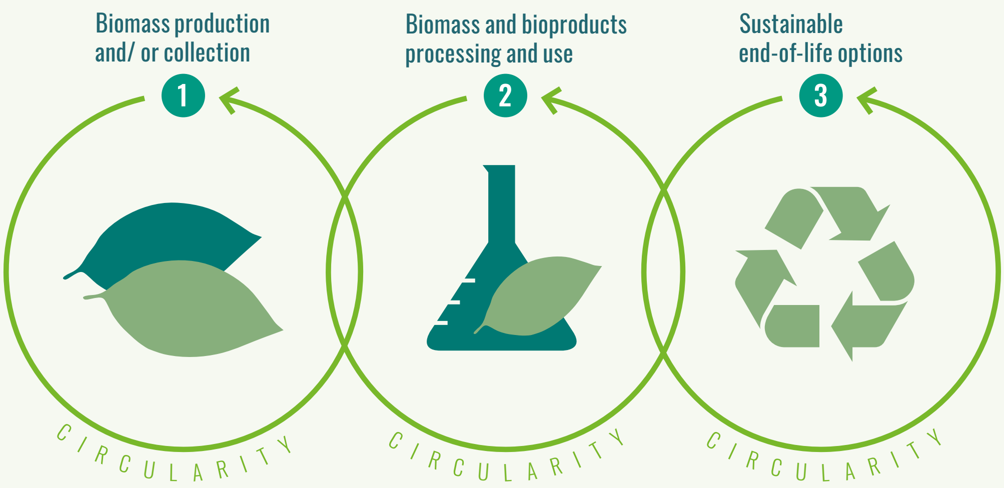
5.1 REVIEW OF MONITORING APPROACHES AT PRODUCT LEVEL

Monitoring the sustainability of bioeconomy, bioproducts and value chains (**Figure 5**) can be challenging due to their complex and multi-dimensional nature. Although many efforts have been put in place for M&E of sustainability at product level, to the best of the authors' knowledge, there are no holistic approaches currently implemented. Attempts to develop such holistic monitoring frameworks are on the way and will be discussed hereafter.

The M&E of the impact of bioproducts on sustainable development is crucial, *per se*, but also because their value chains are not limited to territorial boundaries and therefore also affect society and ecosystems globally. An important contribution to increasing information flows on the sustainability of bioproducts among value chain actors (biomass producers, processors, manufacturers, traders, consumers and waste collectors) is provided by Standard, Certification and Label (SCL) schemes. These schemes regulate production processes and end-of-life options and provide information on the management of bioproduct sustainability aspects. In this way, SCLs support companies to comply with national and international sustainability criteria, while facilitating risk management, traceability and market accessibility and uptake of bioproducts. A thorough analysis of SCLs and their capability to address the aspirational P&Cs is provided in a recent FAO paper on standards, certifications and labelling initiatives for bio-based products (Bracco *et al.*, forthcoming), emphasising the sustainability aspects mostly covered by SCLs[2]. Among the SCLs reviewed in the paper, only those covering a set of specific sustainability

FIGURE 5.

STAGES OF THE BIOMASS VALUE CHAIN



Source: (Gomez San Juan, Bogdanski and Dubois, 2019).

[2] Given the limited resources, this work excludes standards, labels and certification schemes targeting only food, feed products, heat/power, as well as certification schemes endorsed by laboratories (mostly in research companies) in the dermatological area, that evaluates the safety and effectiveness of cosmetic, pharmaceutical and home care products through clinical studies, because they are targeted only to a very limited set of products (Bracco *et al.*, forthcoming).

criteria were selected for identifying indicators at product level: Aquaculture Stewardship Council and Marine Stewardship Council, Blue Angel, Bonsucro, Cradle to Cradle Products Innovation Institute (C2C), DIN Certco, EU Eco Label, International Sustainability & Carbon Certification (ISCC), Rainforest Alliance, Roundtable on Sustainable Biomaterials (RSB), Roundtable on Sustainable Palm Oil in compliance with the EU Renewable Energy Directive requirements (RSPO-RED), and Round Table on Responsible Soy (RTRS). Hence, the aim is to provide a set of indicators for M&E sustainability at product level that are commonly demanded by SCLs and monitored by value chain actors.

Indicators identified in the SCLs address all the stages of a product value chain, from biomass production and processing to product manufacturing and end-of-life disposal. The indicators identified in SCLs relate mainly to environmental sustainability, covering particularly *2.4.i Hazardous substances in production and processing* and *5.1. Resource efficiency, waste prevention and waste re-use along the whole bioeconomy value chain is improved*. Socio-economic aspects of sustainability are covered to a smaller extent, focusing on *1.1.a Food security*, *1.4.b Disease/hazards prevention (in biomass production and processing)*, *1.4.c Human health*, *6.3. Appropriate risk assessment and management, monitoring and accountability systems are put in place and implemented*. Among the SCLs reviewed, RSB is the one mostly concerned with monitoring the social sustainability at product level.

Apart from Bonsucro, RSPO-RED and RTRS that aim at certifying the sustainable production and processing of biomass for renewable energy production, the SCLs reviewed do not address bioproducts particularly. However, by providing indicators for a cradle-to-cradle sustainability assessment of generic products, SCLs set the ground for building sustainability measurement approaches for bioproducts. The lack of specific SCLs for bioproducts along with the necessity for the M&E of sustainability of bioproducts, have paved the way for further commitment on this issue. For instance, the European Committee for Standardization (CEN), which is officially recognized by the European Union and by the European Free Trade Association (EFTA) as being responsible for developing and defining voluntary standards at a European level, has developed the standard EN 16 751:2016 Bio-based products - Sustainability criteria. However, this standard states that it "cannot be used to make claims that operations or products are sustainable since it does not establish thresholds or limits". However, it can be used for communication among value chain actors and/or for developing sustainability SCLs schemes at bioproduct level.

Bioproduct production contributes substantially to the sustainability impact of the bioeconomy as a whole. Indeed, bio-based value chain actors have key responsibilities in producing and processing biomass, manufacturing goods and consuming them in a socially and environmentally sustainable and economically viable way. For this reason, significant effort has been put in place by private, public and international organizations to align strategies and operations with sustainability objectives (see, among others, the World Business Council for Sustainable Development (WBCSD) and the UN Global Compact). For instance, Corporate Social Responsibility (CSR) provides an overview of the private sector impacts on and benefits from the social, economic and natural environment. The implementation of this policy goes beyond mere compliance with regulatory requirements by committing businesses to local sustainable development. Although CSR is deemed important for the company profile and its communication in the market and with policy-makers, it often builds on aspirational claims regulated by soft law (e.g. international standard ISO 26 000 framework) rather than on an accurate assessment of business activities' sustainability impact by means of monitoring approaches, indicators and data collection.

To support the private sector in assessing the sustainability of their operation, The Sustainability Consortium (TSC) has developed a product sustainability measurement approach. This measurement approach is comprehensive and standardized for a large number of product categories in order to identify, by means of a multi-stakeholder approach, activities in a product life cycle that have potentially the greatest impact – the hotspots. In addition, 'improvement opportunities' to address such hotspots are selected through a multi-stakeholder approach (TSC, 2016a). The TSC approach is aimed at capturing the complexity of sustainability assessment by addressing environmental, social and economic impacts according to five principles: (i) product category specific, (ii) holistic assessment (socio-economic and environmental impacts across the entire life cycle of a product), (iii) focused on areas of greatest impact, (iv) deep collaboration among different stakeholders, and (v) a "many-to-many" reporting platform (TSC, 2016b).

This approach provides a comprehensive framework for assessing the sustainability impact of products, including the identification of hotspots and indicators for monitoring their performance. However, indicators and data are not publicly available, and hotspots do not address specific products, but product categories, lacking context-specific aspects for bioproducts. Therefore, only the indicators retrieved by the Coffee Product Sustainability Toolkit that fit bioproduct purposes were included in this study.

Following this approach, TSC has developed a product sustainability toolkit based on nine steps that each company can adopt for monitoring the social, economic and environmental sustainability of products (**Figure 6**).

A step forward in the sustainability assessment framework is made by the UNEP-SETAC guidelines that aim to propose a standardized methodological approach for social sustainability assessment of products through Social LCA (S-LCA). The guidelines support the assessment of potential socio-economic impacts of a product life cycle in a cradle-to-cradle approach by means of stakeholder involvement. In addition, UNEP-SETAC developed the "Methodological Sheets for Subcategories in Social Life Cycle Assessment", which deliver detailed information on social indicators and impact categories in order to develop a comprehensive framework for social impact assessment (UNEP Setac Life Cycle Initiative, 2013). The indicators identified in the methodological sheets suitable for monitoring bioproducts were analysed for the purposes of this study. Further information on S-LCA is provided in **Annex 1**.

Having in mind the complexity of monitoring the sustainability of bioproducts and value chains, coupled with the need and lack of a fit-for-purpose sustainability monitoring approach, many research projects have engaged in building holistic frameworks and proposing standards for monitoring the sustainability impact of bioproducts. To address specific aspects of bioproducts a recently completed EU Horizon 2020 project, "Promoting stakeholder engagement and public awareness for a participative governance of the European bioeconomy" (BioSTEP) developed a comprehensive typology of bio-based product categories, production processes and types of biomass. The aim was to "make existing data on bio-based products and processes accessible to the general public and various stakeholder groups". Therefore, this project provides an overview of bioproducts' social, economic and environmental indicators for monitoring sustainability impacts. These indicators were taken into consideration when compiling **Table 9** on indicators for monitoring sustainability at product/value chain level.

Another EU Horizon 2020 project focuses on Sustainability Transition Assessment and Research of Bio-based Products (STAR-ProBio). The main objective of STAR-ProBio is to promote a harmonized policy framework through the development of fit-for-purpose sustainability monitoring schemes for bio-based products, including standards, certifications and labels. This project is completing the social, economic and environmental sustainability assessments of bio-based products built on the analysis of selected case studies. The publicly available social and environmental indicators selected and measured for the sustainability assessment in STAR-ProBio have been included in the indicator review.

Furthermore, a European Commission co-funded project concerned the "Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe" (S2Biom). The overall objective of S2Biom is to support the development and deployment of sustainable non-food biomass feedstock at local, regional, and pan-European level. One important result of the project, finalized in 2016, was the development of a toolset with associated databases and harmonized datasets in order to monitor the sustainability of biomass supply chains. Thus, the indicators assessed for S2Biom purposes were included in this study for covering the P&Cs associated with the primary sector - agriculture, forestry and fishery - mainly involved in biomass production and processing.

FIGURE 6.

PRODUCT SUSTAINABILITY TOOLKIT

Source: (TSC, 2016b)

To address biomass-specific sustainability criteria, two sustainability monitoring approaches have been investigated. The Global Bioenergy Partnership (GBEP), already described in section 4.2, has developed a set of indicators for monitoring the sustainability of bioenergy. While the focus of the GBEP Indicators is at national level, data for some indicators need to be developed at local level and aggregated to the national scale. In addition, the European Forest Institute provides a set of forest sector-specific indicators.

Only few indicators were retrieved from the JRC Bioeconomy Report 2016 – those applicable to the bioproduct level, because their report is aimed mainly at providing an overview of the European bioeconomy state-of-the-art at national and regional level.

All of these approaches, which are also listed in **Table 8**, have three aspects in common: they provide a set of indicators for monitoring sustainability aspects, they build upon LCA tools for assessing sustainability, yet they do not provide (publicly available) databases or datasets for data collection. As discussed in section 5.3, data availability remains the main challenge when monitoring sustainability at product level due to confidentiality issues and market strategies.

It is worth noting that, except for SCLs that focus on specific sectors, the majority of approaches provide indicators for bioproducts across different sectors. Moreover, the sectors mainly analysed are the primary sectors, e.g. Agriculture and Forestry, and parts of secondary sectors, like Bioenergy as part of the energy sector.

TABLE 8.

REVIEWED MONITORING APPROACHES AT PRODUCT LEVEL AND THEIR TARGET SECTORS

No	SOURCE	TITLE/TOOL	TARGET SECTOR
1	Aquaculture Stewardship Council and Marine Stewardship Council (Aquaculture Stewardship Council and Marine Stewardship Council, 2018)	ASC-MSC Seaweed (Algae) Standard	Marine Environment - Seaweed
2	BioStep (Hasenheit *et al.*, 2016)	Summary report on the social, economic and environmental impacts of the bioeconomy	Generic - Bioproducts independent of any sector
3	Blue Angel (Blue Angel, 2008, 2014a, 2014b, 2014c, 2014d, 2015, 2016, 2017a, 2017b)	Recycled Paper (RAL-UZ 14) / Biodegradable Lubricants and Hydraulic Fluids (RAL-UZ 178) / Low-Emission Panel-Shaped Materials (Construction and Furnishing Panels) for Interior Construction (RAL-UZ 76) / Compostable Plant Containers and other Mouled Parts (DE-UZ 17) / Low-Emission Floor Coverings, Panels and Doors for Interiors made of Wood and Wood-Based Materials (RAL-UZ 176) / Leather (RAL-UZ 148) / Unbleached Filter Papers for Use with Hot and Boiling Water (RAL-UZ 65) / Wallpapers and Woodchip Wallpapers made primarily from Recycled Paper (RAL-UZ 35) / Technically Dried Wood Chips/ Wood Pellets (RAL-UZ 153)	Recycled paper; biodegradable lubricants; wood materials for interiors; panel-shaped materials for construction; leather; unbleached filter papers; wallpapers; wood chips and pellets
4	Bonsucro (Bonsucro, 2016)	Bonsucro Production Standard Including Bonsucro EU Production Standard	Forestry and Agriculture
5	C2C (Cradle to Cradle Products Innovation Institute, 2016)	CRADLE TO CRADLE CERTIFIED: PRODUCT STANDARD VERSION 3.1	Generic - Products independent of any sector
6	DIN Certco (DIN Certco, 2015a, 2015b, 2017)	Biodegradable in soil [DIN SPEC 1 165 (CEN/TR 15 822)] / Biobased Products [in accordance with ASTM D 6 866 and/or ISO 16 620, Parts 1-3 and/ or DIN SPEC 91 236 (DIN CEN/TS 16137)] / Products made from compostable materials (according to DIN EN 13 432)	End-of-life

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No	SOURCE	TITLE/TOOL	TARGET SECTOR
7	EU Eco Label (European Commission, 2009, 2011a, 2011b, 2012a, 2012b, 2014, 2015, 2017b)	COMMISSION DECISION on establishing the ecological criteria for the award of the EU Ecolabel for converted paper products / for copying and graphic paper / or growing media, soil improvers and mulch / for printed paper / to lubricants / for newsprint paper / for tissue paper / for wood-, cork- and bamboo-based floor coverings	Converted paper products; graphic and copying paper; growing media, soil improvers and mulch; printed paper; lubricants; wood, cork, bamboo-based floor coverings
8	European Forest Institute (Wolfslehner *et al.*, 2016)	Forest bioeconomy – a new scope for sustainability indicators. From Science to Policy 4	Forestry
9	Global Bioenergy Partnership (GBEP, 2011)	GBEP Sustainability indicators for bioenergy (GSI)	Bioenergy
10	ISCC (ISCC, 2016)	Sustainability Requirements. V 3.0	Generic - Bioproducts independent of any sector
11	JRC Scientific and Policy Report (Ronzon *et al.*, 2016)	Bioeconomy Report 2016	Generic - Bioproducts independent of any sector
12	Marine Stewardship Council (Marine Stewardship Council, 2019)	MSC Fisheries Standard	Marine Environment - Fishery
13	Rainforest Alliance (Rainforest Alliance, 2017)	Sustainable Agriculture Standard: For farms and producer groups involved in crop and cattle production	Forestry and Agriculture
14	RSB (RSB, 2011, 2016)	RSB PRINCIPLES & CRITERIA/ Food Security Guidelines	Generic - Products independent of any sector
15	RSPO (RSPO, 2013)	Guidance document on: RSPO-RED Requirements for compliance with the EU Renewable Energy Directive requirements	Forestry and Agriculture
16	RTRS (RTRS, 2010)	RTRS Standard for Responsible Soy Production V3.1	Forestry and Agriculture
17	S2Biom (S2Biom, 2015b)	D5.2: Benchmark and gap analysis of criteria and indicators (C&I) for legislation, regulations and voluntary schemes at international level and in selected EU Member States: Main Report	Forestry, Agriculture, Bioenergy
18	STAR-ProBio (Star-ProBio, 2018)	D2.2: Selection of environmental indicators and impact categories for the life cycle assessment of bio-based products	Generic - Bioproducts independent of any sector (except food, feed, bioenergy)
19	The Sustainability Consortium (TCS, 2016)	GREENING GLOBAL SUPPLY CHAINS: From Blind Spots To Hotspots To Action. Impact Report	Generic - Products independent of any sector
20	UNEP-SETAC (UNEP Setac Life Cycle Initiative, 2009)	GUIDELINES FOR SOCIAL LIFE CYCLE ASSESSMENT OF PRODUCTS: The methodological sheets for sub-categories in Social Life Cycle Assessment (S-LCA)	Generic - Products independent of any sector
21	Vinçotte (Vinçotte, 2012a, 2012b, 2012c, 2013, 2015)	Program OK 01: Compostability of products / Program OK 2: Home compostability of product / Program OK 10: Bio products - degradation in soil / Program OK 11: Bio products - degradation in water / Program OK 12: Bio products - degradation in seawater	End-of-life

5.2 IDENTIFIED INDICATORS AT PRODUCT LEVEL

All the indicators suitable for bioproducts and bio-based value chains identified in the literature above are presented in **Table 9**.

As explained in Section 3, indicators can report quantitative, qualitative and dummy values, and they can be positive or negative. Indicators are positive if an increase of the indicator value shows an improvement in the sustainability of bioproducts, instead they are negative if an increase in the indicator value is associated with a deterioration in sustainability.

Each indicator is allocated to a specific sector in accordance with the target sector of the literature where the indicator has been derived from. If no target sector was specified, or the literature referred to bioproducts in general, indicators are applied to all sectors. The latter is applicable to the majority of indicators that address the social and economic impact categories of sustainability. There are also some impact categories and/or sectors for which no indicator has been found in the literature and thus are left empty in **Table 9**.

Indicators from SCL have been introduced in the list and should be prioritized by the private sector in order to limit measurement efforts. Companies are inclined to adopt SCL since they are very important for market uptake of bioproducts. Therefore, by selecting SCL indicators companies may have already collected the data needed for monitoring and evaluating the performance of bioproducts.

Part of the literature reviewed for compiling this comprehensive list of indicators has a territorial focus, e.g. European Forest Institute (Wolfslehner ***et al.***, 2016) or S2Biom (S2Biom, 2015b); it refers, either to particular sectors, or to certificates and standards in different sectors for building a territorial (national or regional) framework. Nonetheless, this literature has been taken into consideration for review since indicators at product/value chain level have a sectoral approach.

Some indicators are allocated to the impact category and/or criterion indicated in the literature, although they may be considered more suitable for addressing other impact categories and/or criteria, e.g. Amount of water used in the whole forestry wood chain is currently within the impact category ***1.1.a food security*** while it can better fit the impact category ***2.3.b water quantity/use/efficiency***. Allocation of indicators in each impact category depends on the rationale of choice. In the example above, the goal of the indicator may be to measure the amount of water left available for cultivating food (thus, not used in the forestry wood chain), rather than measuring the water use efficiency in the forestry wood chain.

Other indicators that were considered too broad, generic and without a particular focus on bioproducts have not been included in the list of indicators in **Table 9**.

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TABLE 9.

INDICATORS FOR MONITORING SUSTAINABILITY AT PRODUCT/VALUE CHAIN LEVEL

Colour code: Economic Social Environmental

			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
			PRIMARY SECTORS	SECONDARY SECTORS						
	CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
PRINCIPLE 1. SUSTAINABLE BIOECONOMY DEVELOPMENT SHOULD SUPPORT FOOD SECURITY AND NUTRITION AT ALL LEVELS	1.1. FOOD SECURITY AND NUTRITION ARE SUPPORTED	1.1.a Food security	Amount of water used in the whole forestry wood chain (m^3) [8]	-	Amount of water used in the whole forestry wood chain (m^3) [8]		-	-	-	Amount of water used in the whole forestry wood chain (m^3) [8]
			Amount of value-added food by-products available to the local market (kg) [14]							
			Ha of land set aside for food growing (or percentage of the total land used) [14]	-	-	-	-	-	-	-
			Opportunity for workers to carry out household-level food production (yes/no) [14]							
			Food availability (kg of household food production and number of varieties of crop diversity) [14]	-	-	-	-	-	-	Food availability (kg of household food production and number of varieties of crop diversity) [14]
			Food access (percentage food expenditure to total household expenditures) [14]	-	-	-	-	-	-	Food access (percentage food expenditure to total household expenditures) [14]
			Food utilisation (degree of access to services) [14]	-	-	-	-	-	-	Food utilisation (degree of access to services) [14]
			Food stability (stability of food prices and supply) [change in price ($) and amount (kg)] [14]	-	-	-	-	-	-	Food stability (stability of food prices and supply) [change in price (percentage or $) and amount (percentage or kg)] [14]
			Blue water footprint (m^3 of water consumed and/or polluted to produce a unit of non-agricultural good or service) [8; 19]	-	Blue water footprint (m^3 of water consumed and/or polluted to produce a unit of non-agricultural good or service) [8]		-	-	-	-
		1.1.b Nutrition	-	-	-	-	-	-	-	-
	1.2. SUSTAINABLE INTENSIFICATION OF BIOMASS PRODUCTION IS PROMOTED	1.2.a Domestic biomass production	-	-	-	-	-	-	-	-
		1.2.b Yield/ agricultural productivity	Estimated amount of organic or mineral fertilizers and pesticides used (kg) [2; 4; 13; 16]	-	-	-	-	-	-	-
			Presence of an irrigation and water distribution system that optimize crop productivity (yes/no) [13]	-	-	-	-	-	-	-
			Biotic production potential (BPP; Capacity of ecosystems to produce biomass) (kg) [18]	-	-	-	-	-	-	-
			Number of agricultural practices that optimize productivity and input use efficiency [13]	-	-	-	-	-	-	-
		1.2.c Land for biomass production	Ha of land for agriculture occupied for biomass production (ha/biomass production unit) [10; 18]	-	-	-	-	-	-	-

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PRINCIPLE 1. SUSTAINABLE BIOECONOMY DEVELOPMENT SHOULD SUPPORT FOOD SECURITY AND NUTRITION AT ALL LEVELS

		SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
		PRIMARY SECTORS	SECONDARY SECTORS						
CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
1.3. ADEQUATE LAND RIGHTS AND RIGHTS TO OTHER NATURAL RESOURCES ARE GUARANTEED	1.3.a Land rights	-	-	-	-	-	-	-	Allocation and tenure of land for new bioenergy production (yes/no) [9]
		Changes in land ownership (yes/no) [20]	-	-	-	-	-	-	-
		Number of coercions altering existing land rights or land use rights [13; 14]	-	-	-	-	-	-	-
		Presence of documented evidence of rights to use the land (yes/no) [4; 16]	-	-	-	-	-	-	-
		Compliance with the VGGT to secure land tenure and ownership (yes/no) [17]	-	-	-	-	-	-	-
	1.3.b Rights to other natural resources	-	-	-	-	-	-	-	-
1.4. FOOD SAFETY, DISEASE PREVENTION AND HUMAN HEALTH ARE ENSURED	1.4.a Food safety	-	Quality or number of information/signs on product health and safety [20]						
		Number of consumer complaints [20]							
		Presence of management measures to assess consumer health and safety (yes/no) [20]							
		Quality of labels of health and safety requirements [20]							
		Total number of incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services and type of outcomes [1; 20]							
	1.4.b Disease/hazards prevention (in biomass production and processing)	Rate of occupational injury, illness and fatalities / final product unit [9; 19]							
		Adequate general occupational health and safety measures are taken (yes/no) [1; 4; 10; 13; 20]							
		Hours of training on health and safety hazards as defined in national law and international standards [1; 4; 10; 13; 14]							
		Toxicity or chemical exposure in workplace (yes/no) [5]							
		-	% of crop supply came from health and safety low-risk countries with corrective actions taken for any known high-risk sites (level of risk of the country is calculated according to Amfori Country Risk Classification) [19]						
		-	% of crop supply came from health and safety high-risk countries that have high-risk sites for which we took corrective actions (level of risk of the country is calculated according to Amfori Country Risk Classification) [19]						
		Presence of sanitary facilities and potable water at workplace (yes/no) [4; 14]							
	1.4.c Human health	-	-	-	-	-	-	-	Change in mortality and burden of disease attributable to indoor smoke/ product unit [9]
		Human toxicity and cancer effects (Comparative Toxic Unit for humans, CTUh) [5; 11; 18]							
		Human toxicity - non-cancer effects (Comparative Toxic Unit for humans, CTUh) [11]							
		Ionising radiation / product unit (kg eq U235) [11]							
		Particulate matter as respiratory inorganics / product unit (kg eq PM2.5) [3; 7; 18]							
		Preventive measures and emergency protocols exist regarding pesticides and chemical exposure (yes/no) [10; 20]							
		Education, training, counselling, prevention and risk control programs in place to assist workforce members, their families, or community members regarding serious diseases (yes/no) [20]							

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
			PRIMARY SECTORS	SECONDARY SECTORS						
	CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
PRINCIPLE 1. SUSTAINABLE BIOECONOMY DEVELOPMENT SHOULD SUPPORT FOOD SECURITY AND NUTRITION AT ALL LEVELS	1.4. FOOD SAFETY, DISEASE PREVENTION AND HUMAN HEALTH ARE ENSURED	1.4.c Human health	-	% of hazardous (carcinogenic, reprotoxic, mutagenic) substances for human health/product unit [3; 5; 7]						
			Amount of genetically modified micro-organisms or any micro-organisms that pose a risk to human health is released outside the processing (µg/production facility) [10; 14]							
			-	-	Ozone Depletion Potential (ODP) / product unit (kg eq. Chlorofluorocarbons (CFC)-11) [3]	-	-	-	-	-
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED	2.1. BIODIVERSITY CONSERVATION IS ENSURED	2.1.a Biodiversity conservation	Ha of protected and/or High Conservation Value (HCV) areas and land with significant biodiversity values are used, degraded, destroyed/product unit [4; 10; 13; 17]	-	-	-	-	-	-	Ha of protected areas and land with significant biodiversity values used / product unit [17]
			% of biomass produced on land that is/was highly biodiverse grassland [4; 10; 13; 15; 16]							
			% of biomass produced on land that is/was a protected area [4; 10; 13; 15; 16]							
			Functional diversity (Number and variety of the elements of biodiversity that influence how ecosystems function) [10; 20]							
			Biodiversity damage potential (BDP; m²*year*PAS (potentially affected species) [18]							
			Presence of a plan or measures to ensure that the native vegetation and wildlife are being maintained and the rare, threatened or endangered species permanently or temporarily present at the property are protected (yes/no) [1; 10; 12; 16]	-	-	-	-	-	-	-
			% of functional seaweed and spawning habitat used for biomass (a functional habitat is a discrete area or habitat that is necessary for survival, function, spawning/reproduction, or recovery of fish stocks, for particular life-history stages) [1; 12]	-	-	-	-	-	-	-
			% of rare or unique seaweed habitat used for biomass (an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems) [1]	-	-	-	-	-	-	-
			Compliance with habitat alteration laws and constraints (yes/no) [10]	-	-	-	-	-	-	-

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PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED

		SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
		PRIMARY SECTORS	SECONDARY SECTORS						
CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
2.2. CLIMATE CHANGE MITIGATION AND ADAPTATION ARE PURSUED	2.2.a Climate change mitigation (carbon and other GHG emissions)	Life cycle GHG emissions (gr eq. CO_2/product unit) [5; 9; 14; 15; 16; 17; 19]							
		Rate of GHG emissions reduction or savings [4; 5; 10; 14; 15; 16]							
		Carbon stock (kg/unit of biomass) [14]	-	-	-	-	-	-	-
		Potential leakages (gr eq. CO_2/ product unit) [11]							
		-	-	Global Warming Potential (GWP100; gr eq CO_2) [3]	-	-	-	-	-
	2.2.b Climate change adaptation	-							
2.3. WATER QUALITY AND QUANTITY ARE MAINTAINED, AND, IN AS MUCH AS POSSIBLE, ENHANCED	2.3.a Water quality	Ecotoxicity for aquatic fresh water (Comparative Toxic Unit for ecosystems) [11; 18]							
		Acidification (mol H+ eq from NOx, SOx, NH_3) [3; 7; 11; 18]							
		Eutrophication (gr eq PO_4) [3; 7; 11; 18; 19]							
		-	-	-	Emission of Absorbable Organic Halogen (AOX) (kg / ADT) [7]	-	-	-	-
		-	Volume of water leaving the manufacturing facility meets drinking water quality standards (m^3 or as percentage of total amount of water leaving the manufacturing facility) [5]						
		Amount of dangerous substances deriving from burning or fermentation (kg) [14]							
	2.3.b Water quantity/ use/efficiency	Estimated amount of water used for irrigation (m^3) [13]	-	-	-	-	-	-	-
		Water exploitation index ((abstractions - returns)/renewable freshwater resources/product unit) [2]							
		% of irrigated crops and freshwater intensive operation systems established in long-term freshwater-stressed areas [14]							
		Water consumption (use) (m^3/product unit processed) [3; 5]							
		Number of facility-wide water audit (amount of water used and opportunities to reduce the amount) is completed [5]							
		Number and list of water-savings practices to increase the efficiency of the water use and reduce the amount of water used and/or wasted [10; 14]						-	-
		Presence of a statement of water stewardship intentions describing actions being taken for mitigating identified problems and concerns is provided (yes/no) [5]						-	-
		Water availability (m^3/product unit) [5; 17]							
2.4. THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	2.4.a Land use change	% of biomass obtained from land with high carbon stock (e.g. wetlands) [4; 10; 13; 15; 16]							
		% of biomass obtained from land that is/was peatland [4; 10; 13; 15; 16]							
		Agricultural land converted to energy crop (ha/ product unit or % of total agricultural land) [11]	-	-	-	-	-	-	Agricultural land converted to energy crop (ha/ product unit or % of total agricultural land) [11]
		Grassland converted to cropland (ha/product unit or % of total grassland) [11]	-	-	-	-	-	-	-
		Forest converted to cropland (ha/ product unit or % of total forests) [11]	-	-	-	-	-	-	-

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PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED

		SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
		PRIMARY SECTORS	SECONDARY SECTORS						
CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
2.4. THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	2.4.b Soil quality	Soil erosion / product unit (kg soil loss) [17; 18]	-	-	-	-	-	-	-
		Soil organic Carbon content (kg of C/kg of soil) [14; 17]	-	-	-	-	-	-	-
		Soil nutrient balance (g of nutrients/kg of soil) [17]	-	-	-	-	-	-	-
		Acidification (mol H^+ eq) [2; 11; 18]	-	Acidification (mol H^+ eq) [3]	-	-	-	-	-
		Amount of dangerous substances deriving from burning or fermentation (kg) [14]							
	2.4.c Soil quantity	-	-	-	-	-	-	-	-
	2.4.d Forest quality		% of crop supply, by mass, was grown on fields with zero conversion High Carbon Stock (HCS) forests [19]						
			% of crop supply, by mass, was grown on fields with zero conversion of High Conservation Value (HCV) forests [3; 19]						
		% of the total amount of wood used comes from sustainable forest management (economically viable, environmentally sound, socially responsible) or are waste wood according to waste wood categories [16]	-	% of the total amount of wood used comes from sustainable forest management (economically viable, environmentally sound, socially responsible) [3]	% of the total amount of wood used comes from sustainable forest management (economically viable, environmentally sound, socially responsible) recognized according to a globally accepted forest certification system [3; 7]	-	-	-	% of the total amount of wood used comes from sustainable forest management (economically viable, environmentally sound, socially responsible) recognized according to a globally accepted forest certification system [3]
		-	-	% of wood, wood-based, cork, cork-based, bamboo, bamboo-based materials originate from genetically modified organisms (GMO) [7]	-	-	-	-	-
		Share of forests certified for sustainable management (ha/product unit or % of total forests) [11]	-	-	-	-	-	-	-
	2.4.e Forest quantity	Wood consumption (kg/ product unit) [8; 11]	-	-	-	-	-	-	-
		-	% of crop supply, by mass, obtained from land that is/was primary forest or other wooded land [4; 19]						
		-	-	-	-	-	-	-	% of biofuels and bioliquids made from raw material obtained from land that is/was continuously forested [4]
		% of existing agroforestry shade tree cover maintained [13]	-	-	-	-	-	-	-
		% of deforestation or afforestation /product unit [11]	-	-	-	-	-	-	-
	2.4.f Marine environments' quality	Acidification (mol H^+ eq) [3; 11; 18]							
		Number of pests, pathogens, or non-native species introduced in the surrounding ecosystem because of seaweed and species translocation activity [1]	-	-	-	-	-	-	-
		% of wild seaweed and species populations which has been impacted in their genetic structure by the harvesting, farming or fishing activity [1]	-	-	-	-	-	-	-
		Eutrophication (gr eq PO_4) [3; 11; 19]							

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
			PRIMARY SECTORS	SECONDARY SECTORS						
	CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED	**2.4.** THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	2.4.g Marine environments' quantity	Seaweed and fish productivity (kg/m³) [1]	-	-	-	-	-	-	-
			% of seaweed and spawning stock level used for biomass without generating irreversible impact (a "serious or irreversible harm" shall be interpreted as the reduction of key features most crucial to maintaining the integrity of the habitat structure and function such that the habitat would be unable to recover at least 80% of its structure and function within five to 20 years if harvesting/farming on the habitat were to cease entirely) [1]	-	-	-	-	-	-	-
		2.4.h Air quality	-	Amount of volatile organic compounds (VOC) emitted (parts per billion (ppb), parts per million (ppm), or as micrograms per cubic meter (µg/m³)) [3; 5; 7]						
			-	-	Photochemical ozone formation (kg ethene (C_2H_4) eq.) [3]	-	-	-	-	-
			Climate regulation potential (CRP) (ton C/m³) [18]	-	-	-	-	-	-	-
			-	-	-	Emission of Absorbable Organic Halogen (AOX) (kg / ADT) [7]		-	-	-
			Emissions of non-GHG air pollutants (including air toxics) (µg / product unit) [9]							
			-	-	-	Emission of Chemical Oxygen demand (COD), S, NOx, P (µg/ADT) [7]	-	-	-	-
		2.4.i Hazardous substances in production and processing	Management effort to minimize use of hazardous substances (yes/no) [20]	-	-	-	-	-	-	-
			-	% of hazardous (carcinogenic, mutagenic, reprotoxic) substances [3; 4; 6; 21]						
			-	% of hazardous chemicals present in recycled contents [5]						
			-	-	-	-	-	% of plastic (synthetic plastic material, plasticizers, PVC) contained in the product [3]	-	-
			-	-	% of biocides [7]		-	% of biocides [3]	-	-
			-	-	-	% of bleach [3]	-	-	-	-
			-	% of halogenated compounds [3; 5; 7]						
			-	-	% of glyoxal or formaldehyde chemicals [3; 7]		-	-	-	-
			-	-	-	% of halogenated plastic used for packaging [3]	-	-	-	-
			-	-	-	% of hazardous colorants [3]	-	-	-	-
			-	-	-	% of chlorine, halogenated bleaching or directly biodegradable complexing agents [3; 7]	-	-	-	-
			-	-	-	-	-	-	-	% of pesticides and fertilizers [3]
			-	-	-	% of APEOs added to cleaning chemicals, de-inking chemicals, foam inhibitors, dispersant or coating [7]	-	-	-	-

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
			PRIMARY SECTORS	SECONDARY SECTORS						
	CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
PRINCIPLE 2. SUSTAINABLE BIOECONOMY SHOULD ENSURE THAT NATURAL RESOURCES ARE CONSERVED, PROTECTED AND ENHANCED	**2.4.** THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	2.4.i Hazardous substances in production and processing	-	-	-	% of biodegradable surfactants [7]	-	-	-	-
			-	-	-		-	% of peat [7]	-	-
			-	-	-	% of polycyclic aromatic hydrocarbon (PAH) in the washing agents' products [7]	-	% of polycyclic aromatic hydrocarbon (PAH) [7]	-	-
			-	-	% of flame retardants [7]	-	-	-	-	-
			-	-	% of plasticisers [7]	-	-	-	-	-
			-	-	% of VOC content in surface treatment [7]	-	-	-	-	-
			Presence of additives with toxic effect on microorganisms in soil (yes/no) [6]	-	-	-	-	-	-	-
			Hazardous chemicals use reduction [5]							
			-	% of product materials produced and managed to high environmental and social standards [5]						
			-	Concentration of heavy metals in paints, primers and varnishes (µg/l) [3; 5; 7]						
PRINCIPLE 3. SUSTAINABLE BIOECONOMY SHOULD SUPPORT COMPETITIVE AND INCLUSIVE ECONOMIC GROWTH	**3.1.** ECONOMIC DEVELOPMENT IS FOSTERED	3.1.a Economic development (income/GDP/ business)	Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R+D costs in relation to revenue, etc.) ($/product unit) [20]							
			Potential market share of the product [18]							
	3.2. INCLUSIVE ECONOMIC GROWTH IS STRENGTHENED	3.2.a Employment	Full time equivalent jobs along the full value chain of a product [17]							
			Provision of a living wage (potential of average wage being under the non-poverty guideline) (yes/no) [1; 4; 5; 10]							
			Wages are inflation-adjusted annually (yes/no) [13]	-	-	-	-	-	-	-
			Annual salary per category ($) [18]							-
		3.2.b Working conditions	Evidence of threats, intimidation, sexual abuse or harassment, or verbal, physical or psychological mistreatment to workers (yes/no) [13]	-	-	-	-	-	-	-
			Presence of explicit code of conduct and complaints or grievance mechanisms to protect human rights of workers, also among suppliers (yes/no) [13; 20]							
			Number of streamlined self-audit conducted to asses protection of fundamental human rights [5]							
			-	% of crop supply came from human rights low-risk countries with corrective actions taken for any known high-risk sites (level of risk of the country is calculated according to Amfori Country Risk Classification) [19]						
			-	% of crop supply came from human rights high-risk countries that have high-risk sites for which we took corrective actions (level of risk of the country is calculated according to Amfori Country Risk Classification) [19]						
			Risk of forced labour used for production of commodity (yes/no) [1; 4; 10; 13; 15; 16; 20]							
			Evidence of restriction to freedom of association and collective bargaining (yes/no) [1; 4; 10; 13; 15; 16; 20]							
			Adoption of Corporate Social Responsibility (CSR) certificate (yes/no) [20]							
			Presence of working children under the legal age (yes/no) [1; 4; 20]							

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
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PRINCIPLE 3. SUSTAINABLE BIOECONOMY SHOULD SUPPORT COMPETITIVE AND INCLUSIVE ECONOMIC GROWTH	3.2. INCLUSIVE ECONOMIC GROWTH IS STRENGTHENED	3.2.c Access to basic services	Number of workers provided access to health care and basic education [13]	-	-	-	-	-	-	-
		3.2.d Energy security	-	-	-	-	-	-	-	-
		3.2.e Equality	Presence of formal policies on equal opportunities (yes/no) [20]							
			Change in unpaid time spent by women and children collecting biomass /product unit produced [9]							
			Evidence of discrimination in labour, hiring, training, task assignment, labour benefits, promotion policies and procedures, and other opportunities for better conditions, pay, or advancement, including any distinction, exclusion or preference to invalidate or harm equality of opportunity or treatment in employment (yes/no) [10; 13; 16]							
			Benefit sharing mechanisms (yes/no) [17]							
		3.2.f Gender equality	Number of women having equal access to training and education and equal access to products and services as men [13; 16]	-	-	-	-	-	-	-
			Number of women having equal job opportunities as men [16]	-	-	-	-	-	-	-
			Ratio of basic salary of men to women by employee category [20]							
		3.2.g Inclusiveness	-	% of smallholder farmer sourced crop supply, by mass, was sourced from smallholder farmers that are supported by a program to increase opportunities for agricultural training, inputs, and services [19]						
			Hours of training to potentially less-advantaged group members, those in remote areas, and those with limited literacy [13]	-	-	-	-	-	-	-
			Support to vulnerable people (yes/no) [17]							
	3.3. RESILIENCE OF THE RURAL AND URBAN ECONOMY IS ENHANCED	3.3.a Rural income diversification	-	-	-	-	-	-	-	-
		3.3.b Linkages between rural and urban economy	-	-	-	-	-	-	-	-
		3.3.c Physical infrastructure	Presence of necessary infrastructure for safe burning of processing waste and by-products (yes/no) [14]							
			Strategy for creating the infrastructure and systems necessary for recovering and recycling materials (yes/no) [5]							
			Infrastructure and logistics for distribution of bioproducts (yes/no) [9]							
		3.3.d Financial stability	-	-	-	-	-	-	-	-

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PRINCIPLE 4. SUSTAINABLE BIOECONOMY SHOULD MAKE COMMUNITIES HEALTHIER, MORE SUSTAINABLE, AND HARNESS SOCIAL AND ECOSYSTEM RESILIENCE	**4.1.** THE SUSTAINABILITY OF URBAN CENTRES IS ENHANCED	4.1.a Sustainability of urban centres	-	-	-	-	-	-	-	-
	4.2. RESILIENCE OF BIOMASS PRODUCERS, RURAL COMMUNITIES AND ECOSYSTEMS IS DEVELOPED AND/OR STRENGTHENED	4.2.a Resilience of biomass producers	Number of innovative social project that positively impacts employees' lives and the social aspects of the whole supply chain [5]							
		4.2.b Resilience of rural communities - social protection	Number of innovative social project that positively impacts the local community [5]							
			Number of co-operatives and micro-credit schemes that support empowerment of small-scale farmers and rural communities [14]							
			Number of operations to optimise local employment [14]							
		4.2.c Resilience of ecosystems	Freshwater regulation potential (FWRP; Capacity of ecosystems to regulate peak flow and base flow of surface water; (b) Capacity of ecosystems to recharge ground) (millimetres of water recharged annually) [18]							
			Erosion regulation potential (ERP; Capacity of ecosystems to stabilize soil and to prevent sediment accumulation downstream) (mass of soil lost per unit area and time) [18]	-	-	-	-	-	-	-
			Water purification potential through physicochemical filtration (WPPPCF; Physicochemical capacity of ecosystems to clean a polluted suspension) (yes/no) [18]							
			Water purification potential through mechanical filtration (WPP-MF; Mechanical capacity of ecosystems to clean a polluted suspension) (yes/no) [18]							
			% of existing vegetated zones adjacent to aquatic ecosystems maintained [13]	-	-	-	-	-	-	-

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
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PRINCIPLE 5. SUSTAINABLE BIOECONOMY SHOULD RELY ON IMPROVED EFFICIENCY IN THE USE OF RESOURCES AND BIOMASS	**5.1.** RESOURCE EFFICIENCY, WASTE PREVENTION AND WASTE RE-USE ALONG THE WHOLE BIOECONOMY VALUE CHAIN IS IMPROVED	5.1.a Resource efficiency (Material footprint (secondary resources))	Carbon intensity (product value added/kg CO_2) [11]							
			% of the sales packaging for your final products, by mass, is formally assessed for material and process efficiency and weight or volume optimization [19]							
			-	Efficiency of systems of production and transformation (yes/no) [17]						
		5.1.b Energy efficiency	Energy saving practices (yes/no) [17]							
			Primary energy savings (kWh or % of total primary energy consumed) [11]							
			Energy Intensity (product value added / mJ primary energy) [11]							
			Number of energy-efficient infrastructure for drying and processing biomass [13]	-	-	--	-	-	-	-
			Fuel consumption for cultivation and drying of biomass (l/biomass unit) [10]	-	Fuel consumption (l/ manufacture process) [7]	Fuel consumption related to the pulp, laminating paper and board production (l/product unit) [7]	-	Fuel consumption (l/ manufacture process) [7]	-	-
			Energy consumption for cultivation and drying of biomass (kWh) [4; 7]	-	Energy consumption (kWh/ production process) [7]	-	-	Energy consumption (kWh/ production process) [7]	-	-
			-	Annual electricity consumption for manufactured products (kWh) [5; 7]						
		5.1.c Waste prevention	Waste generated (kg/ton of product) [7; 16]							
			% of the sales packaging for your final products, by mass, is recyclable [19]							
			-	-	-	Procedures for separating and using recyclable materials from the waste stream (yes/no) [7]	-	-	-	-
			Presence of measures that can help to reduce waste produced by the seaweed biomass production (yes/no) [1]	-	-	-	-	-	-	-
			Presence of an irrigation and water distribution system that minimize water waste (yes/no) [13]	-	-	-	-	-	-	-
			Declaration of end-of-life disposal (in the CSR report) (yes/no) [6; 14; 20]							
		5.1.d Waste re-use	% of recycled materials for packaging [13]	-	-	% of recycled materials for packaging [3]	-	-	-	-
			-	-	-	Procedures for recovering materials for other uses, such as incineration for raising process steam or heating, or agricultural use (yes/no) [7]	-	-	-	-
			% of recycled fibre raw material is used [7]							
			-	% of product is actively being recovered and recycled [5]						
				-		-	-	-	-	% of biofuels produced with co-products, residues and waste [14]
			-	-	-	-	-	% of materials totally or partially derived from sludges derived from municipal sewage water treatment and from sludges derived from the paper industry [7]	-	-

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
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PRINCIPLE 5. SUSTAINABLE BIOECONOMY SHOULD RELY ON IMPROVED EFFICIENCY IN THE USE OF RESOURCES AND BIOMASS	5.1. RESOURCE EFFICIENCY, WASTE PREVENTION AND WASTE RE-USE ALONG THE WHOLE BIOECONOMY VALUE CHAIN IS IMPROVED	5.1.d Waste re-use	-	-	-	-	-	% of materials totally or partially derived from the organic fraction of mixed municipal household waste separated through mechanical, physicochemical, biological and/or manual treatment [7]	-	-
			-	-	-	-	-	% of materials derived from recycling or recovery of any other biomass waste [7]	-	-
			-	-	-	-	-	% of materials derived from any other biomass by-products [7]	-	-
			-	-	-	-	-	% of materials derived from faecal matter, straw and other natural non-hazardous agricultural or forestry material [7]	-	-
			-	-	-	-	-	% of materials derived from animal by-products [7]	-	-
			-	-	-	-	-	% of materials derived from the recycling of bio-waste from separate collection [7]	-	-
			Practices to segregate different waste types to facilitate reuse, recycling or composting (yes/no) [13]	-	-	-	-	-	-	-
			-	-	% of the total amount of wood used is waste wood according to waste wood categories [3]	-	-	-	-	-
			% of the total amount of agricultural biomass used come from agricultural residues [11]							
			Number of innovative social projects that positively impacts reuse and recycle [5]							
			% of reused and/or recycled wastewater [14]							
			% of by-products or wastes reused by the processing/production facility or transferred to other sectors [14]							
			Recycling rate/cascading indexes [8]							
		5.1.e Waste treatment and hazardous waste	-	% of product-related process chemicals in effluent are directly discharged into a water body [3; 5; 14]						
			-	% of product-related chemicals are contained in effluent [5]						
			Amount of wastewater from processing operations is discharged into aquatic systems (m^3) [13]	-	-	-	-	-	-	-
			Amount of sewage is discharged into aquatic systems (m^3) [13]	-	-	-	-	-	-	-

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
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PRINCIPLE 5. SUSTAINABLE BIOECONOMY SHOULD RELY ON IMPROVED EFFICIENCY IN THE USE OF RESOURCES AND BIOMASS	**5.1.** RESOURCE EFFICIENCY, WASTE PREVENTION AND WASTE RE-USE ALONG THE WHOLE BIOECONOMY VALUE CHAIN IS IMPROVED	5.1.e Waste treatment and hazardous waste	% of biodegradability [3; 6]							
			% of wastewater containing potential organic and mineral contaminants are treated or recycled to prevent negative impacts [14]							
			-	-	-	-	Concentration of heavy metals on leather waste (μg/kg) [3]	-	-	-
			-	-	-	Procedures for handling, collecting, separating and disposal of hazardous waste as defined by the relevant local and national regulatory authorities (yes/no) [7]	-	-	-	-
			Practices for waste storage, treatment and disposal that do not pose health or safety risks to farmers, workers, other people, or natural ecosystems (yes/no) [10; 13]							
			% of chemical waste and empty containers is collected and disposed in compliance with good practices [10; 16]							
			Presence of measures that can help to reduce chemical and hydrocarbon wastes produced by the seaweed biomass production (yes/no) [1]	-	-	-	-	-	-	-
			-	-	% of halogenated organic compounds [3]	-	-	-	-	-
			-	-	% of biocides [3]	-	-	-	-	-
			-	-	-	% of plastic fibres [3]	-	-	-	-
			-	-	-	Filter papers manufacturing emissions in wastewater (yes/no) [3]	-	-	-	-
	5.2. FOOD LOSS AND WASTE IS MINIMIZED AND, WHEN UNAVOIDABLE, ITS BIOMASS IS REUSED OR RECYCLED	5.2.a Food loss and waste minimization	-	-	-	-	-	-	-	-
		5.2.b Food waste re-use or recycling	Post-consuming recycling rate/cascading indexes [8; 19]							
PRINCIPLE 6. RESPONSIBLE AND EFFECTIVE GOVERNANCE MECHANISMS SHOULD UNDERPIN SUSTAINABLE BIOECONOMY	**6.1.** POLICIES, REGULATIONS AND INSTITUTIONAL SET UP RELEVANT TO BIOECONOMY SECTORS ARE ADEQUATELY HARMONIZED	6.1.a Coherent policies, regulations in the bioeconomy sectors	Presence of a formal policy in place concerning health and safety of all workers, including contractors (yes/no) [14; 20]							
		6.1.b Coherent institutional set-up in the bioeconomy sectors	Existence of (legal) obligation on public sustainability report (yes/no) [20]							

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			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
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PRINCIPLE 6. RESPONSIBLE AND EFFECTIVE GOVERNANCE MECHANISMS SHOULD UNDERPIN SUSTAINABLE BIOECONOMY	**6.2.** INCLUSIVE CONSULTATION PROCESSES AND ENGAGEMENT OF ALL RELEVANT SECTORS OF SOCIETY ARE ADEQUATE AND BASED ON TRANSPARENT SHARING OF INFORMATION	6.2.a Consultation processes and engagement of all relevant sectors of society	Number of effective participatory processes and participatory methodologies used to ensure meaningful stakeholder engagement [14; 17]	-	-	-	-	-	-	-
			Number and variety of relevant stakeholders participating in the consultative process [14]							
			Number of informal workshops to build local understanding in the community of the processes that may impact them directly to aid meaningful engagement [14]							
			Promoting the involvement of small holders or small suppliers (yes/no) [14; 20]							
		6.2.b Transparent sharing of information	Presence of a law or norm regarding transparency (yes/no) [20]							
			Non-compliance with regulations regarding transparency (yes/no) [20]							
			Number of certifications/labels the organization obtained for the product/site [20]							
			Do internal management systems ensure that clear information is provided to consumers on end-of-life options (yes/no) [20]							
			Number of management documents publicly available, except where this is prevented by commercial confidentiality, of a proprietary nature or where disclosure of information would result in negative environmental or social outcomes [14]							
	6.3. APPROPRIATE RISK ASSESSMENT AND MANAGEMENT, MONITORING AND ACCOUNTABILITY SYSTEMS ARE PUT IN PLACE AND IMPLEMENTED	6.3.a Risk assessment and management	Risks for negative impacts on price and supply of fuelwood (yes/no) [17]	-	-	-	-	-	-	-
			-	Risks for negative impacts on price and supply of substitute products (yes/no) [17]						
			Strength of organizational risk assessment with regard to potential for material resource conflict (yes/no) [20]	-	-	-	-	-	-	-
			Presence of a system that ensures that all forms of bribery, conflicts of business interest and fraudulent practices are prohibited, including a written policy by the management and appropriate staff training (yes/no) [14]							
			Presence of a register containing all evidence of legal compliance (e.g. permits, licenses, evidence of lease, concessions, etc.) and a system ensuring that auxiliary conditions are met (yes/no) [4; 10; 14]							
			Presence of conflict management mechanisms (yes/no) [10; 17]							
			Presence of an integrated farm planning and management system that effectively addresses environmental and social compliance and risk (yes/no) [13]	-	-	-	-	-	-	-
				Management effort to minimize use of hazardous substances (yes/no) [20]						
		6.3.b Monitoring and accountability systems	Presence of a legal register or equivalent system with all relevant applicable international, national and regional laws and regulations (yes/no) [4; 10; 14]							
			Presence of a training system ensuring that personnel are aware of the laws and regulations and have access to the legal register (yes/no) [4; 10; 14]							
			Presence of a mechanism/system to receive, respond to, and document feedback, complaints and grievances from customers, workers and communities (yes/no) [4; 10; 13; 14; 16; 20]							

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PRINCIPLE 6. RESPONSIBLE AND EFFECTIVE GOVERNANCE MECHANISMS SHOULD UNDERPIN SUSTAINABLE BIOECONOMY	**6.3.** APPROPRIATE RISK ASSESSMENT AND MANAGEMENT, MONITORING AND ACCOUNTABILITY SYSTEMS ARE PUT IN PLACE AND IMPLEMENTED	6.3.b Monitoring and accountability systems	-	-	-	-	-	-	-	Presence of a tracking system of the amounts of sustainable material sourced and sold in order to prevent multiple claiming (yes/no) [4]
			-	-	-	-	-	-	-	Number of personnel and amount of budget allocated to implement and continuously monitor compliance with international standards [14]
			Number of fulfilled existing regulations on health and safety [4; 10; 15; 16]							
PRINCIPLE 7. SUSTAINABLE BIOECONOMY SHOULD MAKE GOOD USE OF EXISTING RELEVANT KNOWLEDGE AND PROVEN SOUND TECHNOLOGIES AND GOOD PRACTICES, AND, WHERE APPROPRIATE, PROMOTE RESEARCH AND INNOVATION	**7.1.** EXISTING KNOWLEDGE IS ADEQUATELY VALUED AND PROVEN SOUND TECHNOLOGIES ARE FOSTERED	7.1.a Existing knowledge	Capacity and flexibility of use of biomass (kg of biomass used for a variety of purposes) [9]	Capacity and flexibility of use of bioproducts (number and variety of bioproducts used and produced) [9]						Capacity and flexibility of use of bioenergy (kWh of energy used and produced for a variety of purposes) [9]
		7.1.b Proven sound technologies	Number of patents on resource efficiency technologies [8]							
			Presence of environmentally/friendly technologies (yes/no) [17]							
		7.1.c Capacity development (extension services)	Hours of training and requalification of the workforce on the competencies required to carry out their work [9; 13; 14]							
	7.2. KNOWLEDGE GENERATION AND INNOVATION ARE PROMOTED	7.2.a Knowledge generation/ (high level) education	Hours of education [8]							
		7.2.b Research and innovation	-	-	-	-	-	Development of advanced biorefinery technologies for producing materials (yes/no) [8]	-	Development of advanced biorefinery technologies for producing energy (yes/no) [8]
			Number of environment-related technologies (or % of all technologies) [8]							
			Sector efforts in technology development (yes/no) [20]							
			Sector R&D expenditure ($) [20]							
			Eco-innovation index (composite index of 16 indicators grouped into five dimensions: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes) [8]							
PRINCIPLE 8. SUSTAINABLE BIOECONOMY SHOULD USE AND PROMOTE SUSTAINABLE TRADE AND MARKET PRACTICES	**8.1.** LOCAL ECONOMIES ARE NOT HAMPERED BUT RATHER HARNESSED BY THE TRADE OF RAW AND PROCESSED BIOMASS, AND RELATED TECHNOLOGIES	8.1.a Net trade of raw biomass	-	-	-	-	-	-	-	-
		8.1.b Value added of processed biomass	-	-	-	-	-	-	-	-
		8.1.c Net trade of processed biomass	-	-	-	-	-	-	-	-

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			PRIMARY SECTORS	SECONDARY SECTORS						
	CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
PRINCIPLE 8. SUSTAINABLE BIOECONOMY SHOULD USE AND PROMOTE SUSTAINABLE TRADE AND MARKET PRACTICES	8.1. LOCAL ECONOMIES ARE NOT HAMPERED BUT RATHER HARNESSED BY THE TRADE OF RAW AND PROCESSED BIOMASS, AND RELATED TECHNOLOGIES	8.1.d Net trade of biomass-related technologies	-	-	-	-	-	-	-	-
		8.1.e Sustainable market practices (no negative externalities, no information asymmetries and unfair market power)	Number of incidents of non-compliance with regulatory labelling requirements annually [20]							
			Membership in alliances that behave in an anti-competitive way (yes/no) [20]							
PRINCIPLE 9. SUSTAINABLE BIOECONOMY SHOULD ADDRESS SOCIETAL NEEDS AND ENCOURAGE SUSTAINABLE CONSUMPTION	9.1. CONSUMPTION PATTERNS OF BIOECONOMY GOODS MATCH SUSTAINABLE SUPPLY LEVELS OF BIOMASS	9.1.a Sustainable consumption (which matches sustainable supply levels of biomass)		Change in cropland-based biomass demand for products or energy [2]						
			Change in wood/wood fibre demand for forest products [2]	-	Change in wood/wood fibre demand for forest products [2]		-	-	-	-
			Amount of sold crop exceeding harvesting volume	-	-	-	-	-	-	-
			-	-	-	-	-	-	-	Change of biomass demand for energy use [2]
		9.1.b Reducing dependence on non-renewable resources	Abiotic depletion (kg Sb eq.) [18]							
			Resource depletion (mineral, fossil) / product unit (MJ) [18]							
			Intensity of fossil fuel use (m^3/ton of product) [17]							
			Change in consumption level of fossil fuel resources / product unit [2]							
			-	% of biological content/ product [5]						
			-	-	-	-	-	% of carbon content derived from renewable raw materials [7]	-	-
			-	-	Renewable energies (RES) share in final energy consumption / product unit [7]	-	-	-	-	Renewable energies (RES) share in final energy consumption / product unit [3]
			-	Renewable electricity used for manufactured products (kWh or % of total electricity used) [5]						
	9.2. DEMAND AND SUPPLY- SIDE MARKET MECHANISMS AND POLICY COHERENCE BETWEEN SUPPLY AND DEMAND OF FOOD AND NON-FOOD GOODS ARE ENHANCED	9.2.a Market mechanisms influencing supply and demand of food and non-food goods (e.g. prices, consumer awareness)	Number of consumer unions for each sector [20]							
		9.2.b Policy coherence between supply and demand of food and non-food goods (e.g. targets, mandates, incentives, tax, etc.)	Government spending on product procurement programs ($ or % of total spending) [20]							

Continues on next page

			SECTOR-BASED PRODUCT/VALUE CHAIN INDICATORS (UNIT) [SOURCE]							
			PRIMARY SECTORS	SECONDARY SECTORS						
	CRITERION	IMPACT CATEGORY	AGRICULTURE, FORESTRY, FISHERY	FOOD AND AGROINDUSTRY	BIO-BASED CONSTRUCTION MATERIALS & FURNITURE	PULP AND PAPER	BIO-BASED TEXTILES	BIO-BASED CHEMICALS AND POLYMERS (INCL. BIOMATERIALS)	HEALTHCARE AND BIO-PHARMACEUTICALS	BIOENERGY
PRINCIPLE 10. SUSTAINABLE BIOECONOMY SHOULD PROMOTE COOPERATION, COLLABORATION AND SHARING BETWEEN INTERESTED AND CONCERNED STAKEHOLDERS IN ALL RELEVANT DOMAINS AND AT ALL RELEVANT LEVELS	10.1. COOPERATION, COLLABORATION AND SHARING OF RESOURCES, SKILLS AND TECHNOLOGIES ARE ENHANCED WHEN AND WHERE APPROPRIATE	10.1.a International Cooperation (transfer of resources, skills and technologies)	Involvement in technology transfer program or projects (yes/no) [20]							
		10.1.b Collaboration between private sector actors (e.g. licensing, contract)	Number of collaborations with service providers that comply with applicable sustainability environmental and social criteria [13]	-	-	-	-	-	-	-
			Number of partnerships in R&D [20]							

Note: $ – national currency or USD or Euro.

Sources are indicated in brackets [] and refer to the list in Table 8

5.3 DATA AVAILABILITY AT PRODUCT LEVEL

The major challenges at product/value chain level are data availability and accessibility. An accurate assessment of the sustainability of bioproducts highly depends on the context, which is different for each single product and producer. In contrast to databases at national level that contain at least some bioeconomy relevant data, product data is not readily available. The level of resolution that is needed to adequately describe the sustainability of a product along its value chain requires a lot of detail. Generic databases with average data could help the assessment, but could, by no means, replace a proper analysis of a specific product and its value chain.

For instance, the Social Hotspot Database (SHDB), developed by Benoit-Norris ***et al.*** (2012), represents a reference point for S-LCA methodology. However, this database provides neither bioproduct-specific data, nor data on production plants and/or products; it does provide data at the sectoral level. An additional database on "Product Social Impact Life-Cycle Assessment (PSILCA) has been developed by GreenDelta (sustainability consulting and software company). This database covers 88 indicators in total, addressing 25 subcategories. Notwithstanding, it does not provide specific data for bioproducts (Rafiaani ***et al.***, 2018).

The lack of readily available data is exacerbated by the fact that the private sector usually does not disclose details of their sustainability performance, due to market competition.

Data gaps at product/value chain level can be addressed by using proxy indicators, which monitor the performance of good practices. As shown in section 3.2, data for proxy indicators can be easier to collect and less resource consuming.

Acknowledging the need for comprehensive databases and robust methodologies for data collection in the bioeconomy context, BioMonitor (Monitoring the Bioeconomy), a Horizon 2020 funded project, aims to build a transparent framework for data and indicators that "***different stakeholders can use to monitor and measure the bioeconomy and its various impacts***" (Biomonitor.eu, 2019).

To gather data and information on bioproducts and bio-based value chains, additional collaboration and research is needed at the product/value chain and company levels. In the agricultural sector, the need for better statistical data is addressed by the FAO program Agricultural Integrated Survey (AGRIS). This farm-based modular 10-year survey programme is designed as a cost-effective tool for national statistical agencies to accelerate the production of quality disaggregated data on the technical, economic, environmental and social dimensions of farms, including smallholder farms (FAO, 2016b). Better data on farms allow to track progress towards the SDGs and improve policies in the agricultural and rural sector.

CHAPTER

6

DISCUSSION

This literature review resulted in two comprehensive, although not exhaustive lists of indicators for monitoring the sustainability of the bioeconomy and associated bioproducts and value chains. The authors identified several gaps and shortfalls, which are partially due to the complexity of the bioeconomy and the variety of aspects covered by the sustainable bioeconomy P&Cs.

Particular attention is dedicated to gaps focusing on trade indicators to link national and international bioeconomy impacts (see section 6.1), and circularity indicators to monitor the environmental burden and socio-economic impact of bio-based supply chains in a cradle-to-cradle approach (see section 6.2).

The main challenge for monitoring the bioeconomy sustainability is associated with the lack of methodologies for attributing a specific impact to the bioeconomy and related value chains, and consequently, for data collection. Therefore, an attempt to link different levels of the bioeconomy (i.e. the territorial level with the product level) in order to address the lack of clear boundaries, indicators and data is introduced in section 6.3. In this regard, the identification and reporting on the implementation of good practices complements the measurement of more complex indicators. Section 6.4 also discusses how the indicators identified through the literature review can support efforts to monitor the performance of good practices.

The blurred boundaries and well-established links among bioeconomy activities and sectors generate trade-offs and synergies between different impacts of sustainable bioeconomy development. This aspect is crucial for building a holistic view of bioeconomy sustainability impact and it will be dealt with in section 6.5.

6.1 GAPS/SHORTFALLS IN MONITORING BIOECONOMY SUSTAINABILITY AT TERRITORIAL LEVEL

Section 4 shows that some principles, criteria and impact categories can be measured by a large number of indicators, while for others there are few or no indicators available at territorial level. From the literature review we have identified at least one indicator for each impact category, with the only exception being *5.2.b Food waste re-use or recycling*, for which no indicators have been found. This is a significant gap since progress towards food circularity will be hampered by the lack of data on food waste, re-use and recycling.

A particular case is the impact category 2.2.b *Climate change adaptation* for which no standalone indicators have been retrieved. In fact, indicators for climate change adaptation are often coupled with indicators for mitigation. A recent FAO paper on this theme proposed a framework and methodology for "Tracking Adaptation in Agricultural Sectors" (TAAS) at the national level (FAO, 2017c). The TAAS framework and methodology examines processes and outcomes of adaptation at national and local levels, providing a flexible list of indicators built on existing indicators of sustainable development, climate change adaptation and disaster risk reduction. The study identifies four major categories of indicators (natural resources and ecosystems, agricultural production systems, socio-economics, and institutions and policies) and four subcategories for each of the four main categories[3]. Several subcategories and indicators proposed by FAO (2017b) are aligned with the impact categories and indicators identified by this study, while others can be included if a country wants to focus on adaptation measures (see Section 7.1).

With the only two exceptions mentioned above (*5.2.b Food waste re-use or recycling* and *2.2.b Climate change adaptation*), the literature review conducted for the territorial level has identified at least one indicator for each impact category. It must be noted that for several impact categories a SDG indicator is the only option available.

However, many of the indicators are still under development. For instance, the UN Inter-Agency and Expert Group on the SDG Indicators (IAEG-SDGs) classified the indicators into three "tiers" to show their status (IISD, 2018):

- **i** Tier I: the indicator is conceptually clear and available data exists for its measurement;
- **ii** Tier II: the indicator has a clear methodology but inadequate data;
- **iii** Tier III: the indicator requires methodological development.

Moreover, existing indicators are not always the most appropriate. For instance, trade and externality costs are not well covered in the impact categories related to sustainable production and consumption (under criteria 8.1, 9.1, 9.2). Most trade indicators retrieved from the literature review are limited to economic stocks, flows, outcomes and impacts that are observable in markets, whereas sustainability issues that relate to this field are often overlooked or not adequately addressed – despite their uttermost importance to sustainable bioeconomy. For these reasons, Section 6.1.1 analyses in more detail which type of indicators may cover environmental and social externalities related to trade.

Furthermore, many of the indicators collected from the literature do not measure the *specific* impacts of the bioeconomy, since they provide aggregated information that is adequate to measure sustainable development (see Section 6.3). For instance, an indicator on food security does not provide information on *how much* the bioeconomy has affected food security, but rather informs on the country's overall

[3] The TAAS methodology includes a scoring procedure, where indicators are given scores from 0 to 10, converted from raw quantitative and qualitative data. The scoring system matches the six levels of adaptation progress: very low, low, moderate, high and very high (FAO, 2017c).

performance. However, in a few cases, indicators specific to a bioeconomy sector performance (as opposed to a country's aggregate performance) are available. When available, these indicators will be more informative and should be preferred. For instance, criterion 3.1 (*Economic development is fostered*) can be measured by bioeconomy-specific indicators (turnover of bioeconomy sectors; value added of bioeconomy sectors; change in turnover of bio-based sectors; contribution of bioeconomy sectors to GDP (percent)) or by *SDG 8.1.1 Annual growth rate of real GDP per capita* and/or *SDG 8.2.1 Annual growth rate of real GDP per employed person*. If disaggregated data on bioeconomy sectors are available, they are preferable.

Some reported indicators can be disaggregated to bioeconomy sectors, even if they are originally proposed to inform on a country's overall performance. For instance, employment can be measured by employment in bioeconomy (sub) sectors instead of employment at national level. The use of disaggregated indicators will allow a more exact impact to be attributed to the bioeconomy (see Section 6.3).

Also, some of the indicators reported may be substituted by indicators at different territorial level or at a deeper level of detail, in order to provide more precise/relevant information, if those are available.

6.1.1 Sustainable consumption and production at territorial level: trade and related externality costs

While the principle of national sovereignty is key, fairness in the international or global dimension is also important. The lack of international conventions on "sustainable trade" leads to a gap on linking national and global sustainability performances. Some countries may "externalize" the social and environmental costs of their bioeconomy activities to other countries through trade flows (import/export). Trade-related indicators can help to bridge this gap by accounting for these externalities.

Among the indicators shown in **Table 7**, those dealing with sustainable trade and market practices (criteria 8.1 and 10.1), and partially the ones addressing sustainable consumption (criterion 9.1) and market mechanisms influencing supply and demand of food and non-food goods (criterion 9.2), provide information about trade flows. These indicators allow demand and supply quantities, imports and exports, and prices to be monitored; and provide information on the magnitude and composition of trade. Nevertheless, these indicators do not provide information on whether trade flows are sustainable from an environmental or social point of view. Several studies and approaches aim to improve the international accountability of countries to fill this gap.[4] For instance, 'The Economics of Ecosystems and Biodiversity' initiative (TEEBAgriFood) considers other hidden socio-economic and environmental stocks and flows, such as impacts on human health, social equity, livelihoods, poverty, climate change, freshwater scarcity and soil fertility, in the context of food systems (TEEB, 2018a).

Most studies focus on the so-called ecological and/or material footprints: the quantity of (natural) resources used to support people or an economy. Industrialized regions are increasingly outsourcing environmental burden to other world regions via international trade, with ecological footprints being significantly higher than the respective domestic indicators (SERI, 2013). For this reason, sustainable bioeconomy indicators have to complement territorial indicators with footprint-type indicators on social and environmental costs related to trade and material flow accounting indicators.[5]

The scheme below summarizes three different options for setting the boundaries to calculate resource use indicators (**Figure 7**):

- the **production**-based (territorial) perspective: includes resource use required to produce both domestic final consumption and exports;
- the **partial consumption** perspective takes into account also direct imports to

[4] The Thünen Institute is currently working on a study on sustainability impacts of selected import-commodities in the country of origin, not yet available.

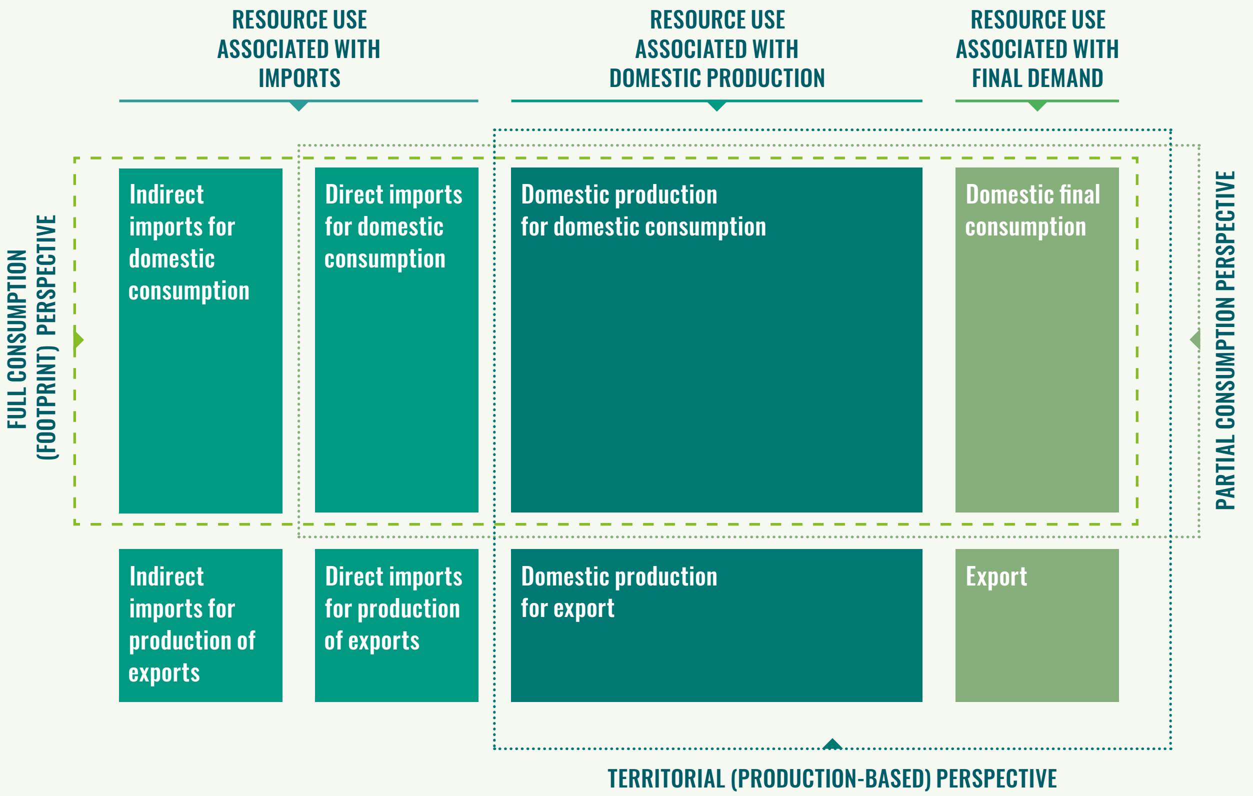
[5] Material flow accounting provides economy-wide data on material use.

the domestic economy and subtracts the direct exports;

- the **full consumption** (**footprint**) perspective includes the domestic production for final consumption as well as the total direct and indirect resource use associated with imports serving domestic final consumption.[6]

FIGURE 7.

PRODUCTION VS CONSUMPTION-ORIENTED ACCOUNTING OF RESOURCES



Source: (SERI, 2013)

The full consumption perspective uses footprint-type indicators to account for the externalities of resource use due to trade flows. **Table 10** shows a list of indicators that can be used to monitor the ecological and material footprints of domestic production, imports and exports of (food and non-food) biomass, and domestic consumption. Material footprints are derived from national accounts and material flow accounts (MFA) (Eurostat, 2013).

The first step to calculate the material footprint of a country is to estimate the ***domestic material consumption*** (DMC). This indicator corresponds to the SDG indicator 12.2.2: DMC, DMC per capita, and DMC per GDP, and it is already calculated for most countries. It is a standard MFA indicator and reports the apparent consumption of materials in an economy (UNStats, 2018a). It is calculated as the total amount of materials directly used in

[6] SERI (2013) identifies three main methodologies for calculating footprint-type indicators: input-output analysis (top-down approach), coefficient approaches based on process analyses (bottom-up approach) and hybrid approaches with elements from both basic methods.

TABLE 10.

INDICATORS FOR TRADE SUSTAINABILITY

INDICATOR	UNIT	SOURCES
Domestic material consumption (DMC), by type of raw material	Tonnes	SDG 12.2.2 (UNStats, 2018a)
DMC per capita, by type of raw material	Tonnes per capita	SDG 12.2.2 (UNStats, 2018a)
DMC per GDP, by type of raw material	Kilograms per constant 2010 United States dollars	SDG 12.2.2 (UNStats, 2018a)
Raw material consumption (RMC)	Tonnes	EUROSTAT (Eurostat, 2018a)
Raw material equivalent (RME)	RME	EUROSTAT (Eurostat, 2018a)
Domestic food biomass footprint	Tonnes per capita	SDG 12.2.1 (UN Environment International Resource Panel, 2018; UNEP, 2018)
Domestic non-food biomass footprint	Tonnes per capita	SDG 12.2.1 (UN Environment International Resource Panel, 2018; UNEP, 2018)
Imported food biomass footprint	Tonnes per capita	SDG 12.2.1 (UN Environment International Resource Panel, 2018; UNEP, 2018)
Imported non-food biomass footprint	Tonnes per capita	SDG 12.2.1 (UN Environment International Resource Panel, 2018; UNEP, 2018)
Ecological footprint	gha per capita	(Global Footprint Network, 2018b)
Ecological deficit or reserve	gha per capita	(Global Footprint Network, 2018b)

*Source: Authors' elaboration based on (Biber-Freudenberger **et al.**, 2018)*

the economy (used domestic extraction (DE) plus physical imports (IM)), minus the physical exports (EX), measured in metric tonnes. The DMC is a territorial (production side) indicator and does not include the materials embodied in imported and exported products (indirect flows of imports and exports), and unused domestic extraction (SERI, 2013; Wiedmann ***et al.***, 2015). Therefore, material consumption (MC) accounts do not provide an entirely consistent picture of global material footprints because they record imports and exports in the actual weight of the traded goods when they cross country borders instead of the weight of materials extracted to produce them. As the former are lower than the latter, economy-wide material flow accounts and the derived MC values underestimate the material footprint (Eurostat, 2018b; Wiedmann ***et al.***, 2015). For instance, in 2008 the total global MC amounted to 70 billion metric tons (Gt). Forty-one percent of this value (29 Gt) was indirectly associated with trade flows between 186 countries, far more than the 10 Gt of direct physical trade of materials and products (Wiedmann ***et al.***, 2015). In order to adjust for this difference, the weight of processed goods traded internationally can be converted into the corresponding raw material extractions they induce: their raw material equivalents (RME). DMC needs to be complemented with ***material footprint*** (MF), since together they cover the two aspects of the economy: production and consumption. The indicators for SDG 12.2.1: ***material footprint, material footprint per capita, and material footprint per GDP*** report the amount of primary materials (biomass, fossil fuels, metal ores and non-metal ores) required to serve final demand of a country. For instance, a country can have a very high DMC because it has a large primary production sector for export, or a very low DMC because it has outsourced most of the material intensive industrial process to other countries. The MF corrects for both phenomena (UNStats, 2018b). In absolute values, China is the largest exporter of primary resources embodied in trade, since sixty percent of its MF consists of construction materials, largely for export. The United States is the largest importer (in absolute terms) of primary resources embodied in trade, in particular construction minerals, fossil fuels, biomass and, to a smaller extent, metal ores (Wiedmann *et al.*, 2015).

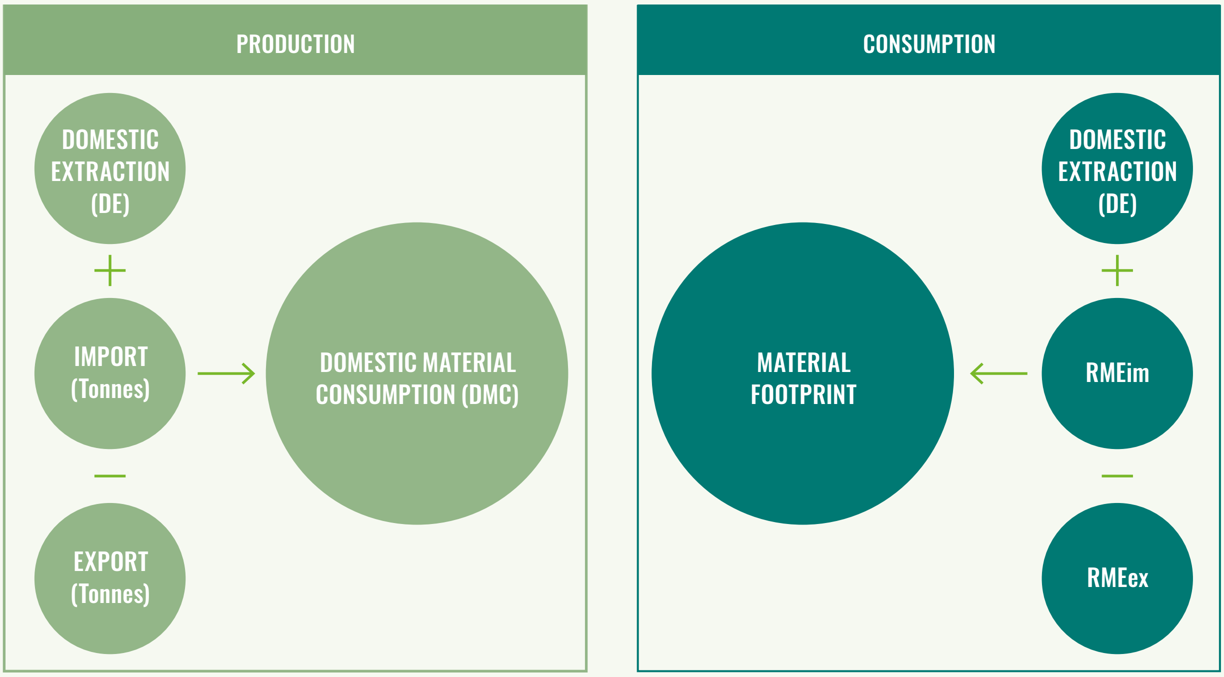
The MF is calculated as RME of imports (RME_{im}) plus domestic extraction (DE) of the raw material of a country minus RME of exports (RME_{exp}) (**Figure 8**). It is calculated by linking national MFA with a multi-regional input-output (MRIO) framework based on the EORA MRIO framework developed by the University of Sydney (Lenzen, Moran and Kanemoto, 2013), in order to estimate the attribution of the primary material needs of final demand[7]. UN Environment provides a Global Material Flows Database for most countries of the world and for different groups of materials (UN Environment International Resource Panel, 2018; UNEP, 2018). Still, the SDG indicator 12.2.1 (Material footprint, material footprint per capita, and material footprint per GDP) and other eight SDG 12 indicators on sustainable production and consumption are classified as Tier III, which means they cannot be used for reporting yet (IISD, 2018).

The Global Footprint Network also calculates the **ecological footprint**, which measures the ecological assets that a given population requires to produce the natural resources it consumes (including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions (Global Footprint Network, 2018a). It records the use of six categories of productive surface areas: cropland, grazing land, fishing grounds, built-up land, forest area, and carbon demand on land.

The Global Footprint Network compares this consumption of resources for a given entity (city, state, nation, region, and world) with its *biocapacity*, e.g. the productivity of its ecological

FIGURE 8.

SDG INDICATORS TO ACHIEVE THE SUSTAINABLE MANAGEMENT AND EFFICIENT USE OF NATURAL RESOURCES



[7] The global material flows database is based on country material flow accounts from the EU and Japan and estimated data for the rest of the world. Estimated data is produced on the bases of data available from different national or international datasets in the domain of agriculture, forestry, fisheries, mining and energy statistics. International statistical sources for DMC and MF include the IEA, USGS, FAO and COMTRADE databases. The data covers more than 170 countries (UNStats, 2018b).

assets (including cropland, grazing land, forest land, fishing grounds, and built-up land) in order to calculate its **ecological deficit or reserve**. Both the Ecological Footprint and biocapacity are expressed in global hectares (gha), which are globally comparable, standardized hectares with world average productivity. The network provides National Footprint Accounts for cropland, grazing land, forest land, fishing grounds, and built-up land in gha, gha per capita and number of Earths (Global Footprint Network, 2018b). These indicators help countries, regions, cities, etc. in monitoring their sustainability trends, and supporting better sustainability policy and actions.

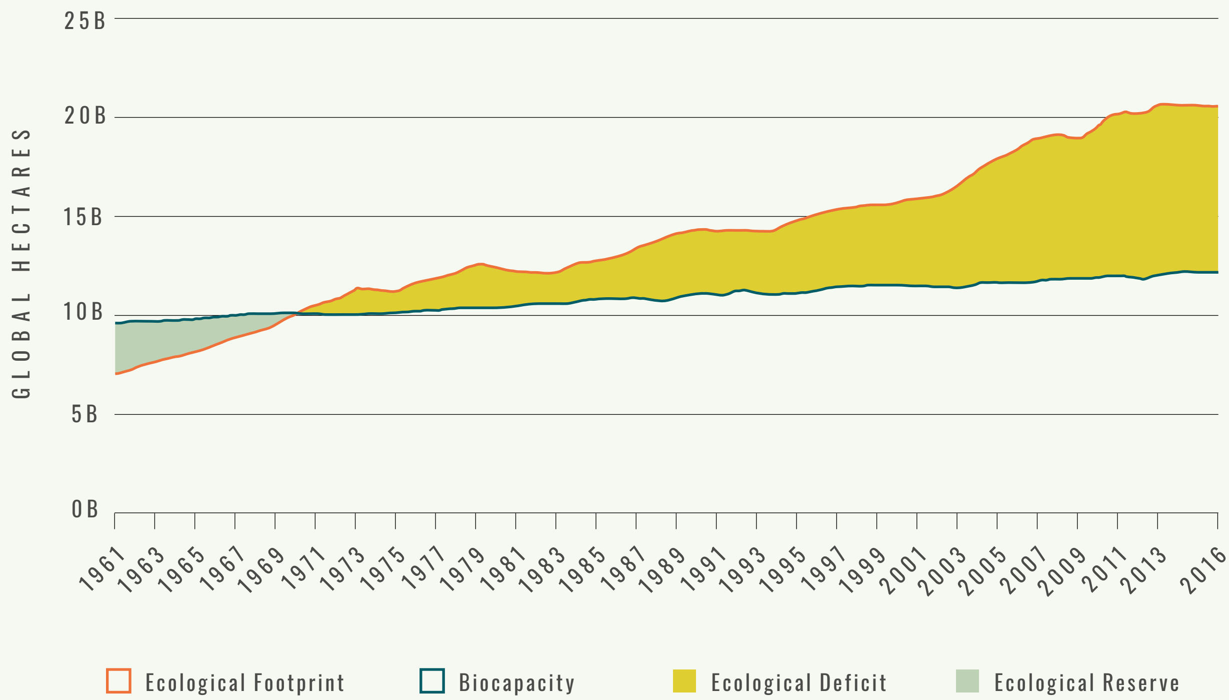
While keeping track of the environmental externalities linked to trade flows which translate into loss of resources, footprints do not account for other important social and environmental impacts. A completely different approach to trace whether imported goods are produced sustainably (also from a social perspective) is to refer to certification schemes.

Countries may also delegate to standard, certification and labelling (SCL) schemes the duty to guarantee the sustainability of the imported bioproducts that reach their market, as the EU required in the 2009 Renewable Energy Directive (RED) for bioenergy. The compliance of economic operators to the sustainability criteria is verified through private voluntary schemes approved by the European Commission, national systems of compliance that each Member State is required to develop, or by bilateral or multilateral agreement with third parties (2009/28/EC), Article 17).

This delegation system could be critical as it requires a high level of trust on the behavior of voluntary initiatives. The system expects that the approved voluntary SCL initiatives are able to strictly regulate, monitor and ensure the compliance of member companies to sustainability criteria. Unfortunately, in the case of bioenergy, these initiatives were rarely joined by the biofuels economic operators and sometimes unable to monitor and ensure

FIGURE 9.

WORLD ECOLOGICAL FOOTPRINT AND BIOCAPACITY (IN GLOBAL HECTARES), 1961-2016



Source: http://data.footprintnetwork.org/#/countryTrends?cn=5001&type=earth

compliance of their members (Antonelli *et al.*, 2018; Bracco, 2015, 2016; German and Schoneveld, 2012).

We have also reviewed some certification schemes for bioproducts to identify indicators that can be used at product/value-chain level to guarantee the sustainability of bioproducts. Sustainability criteria can be an opportunity for enhanced trade; however, in the bioenergy sector, an excessively high number of regulatory frameworks was perceived as a barrier (IEA Bioenergy, 2011). Harmonization of standards and indicators for a sustainable bioeconomy can become a major driver for the bioeconomy deployment. By reviewing the existing indicators, this study can inform a global standard for ensuring that bioproducts meet sustainability criteria.

6.2 GAPS/SHORTFALLS IN MONITORING BIOECONOMY SUSTAINABILITY AT PRODUCT LEVEL

This section provides an overview of gaps and shortfalls in relation to the main measurement approaches and indicators for a sustainable bioeconomy at product/value chain level. Due to the current production model and consumption behaviour, bioproduct production and consumption are at the core of the bioeconomy, and therefore contribute consistently to the achievement of regional, national and global sustainability goals.

The literature shows that stakeholder engagement is key to understanding and developing sustainable bioproducts and the bioeconomy in general. However, monitoring and evaluation of sustainable bioproducts remain challenging, mainly because of the complexity and dynamic nature of the bioeconomy, and its early stage of development and implementation. Some observations emerge from this review:

- Many studies and SCLs assess the sustainability of products, but few of them focus specifically on bioproducts. By missing the bioproduct-specific sustainability aspects, the impact assessment of bioproducts may result in biased conclusions.
- The three pillars of sustainability, i.e. environmental, social and economic, are monitored and evaluated in an unbalanced way among criteria and impact categories. While the criteria and impact categories *per se* are well-balanced (see section 3.1), those related to environmental sustainability are widely addressed with detailed indicators. For instance, ***Principle 2. Sustainable bioeconomy should ensure that natural resources are conserved, protected and enhanced*** alone includes four environmental criteria and 14 environmental impact categories and can be monitored with 82 indicators ranging from impact indicators to performance indicators and proxy indicators. The overall number of indicators retrieved from the literature review addressing all P&Cs and related impact categories is 268.

  Also, criterion ***5.1. Resource efficiency, waste prevention and waste re-use along the whole bioeconomy value chain is improved*** concerning the circular use of resources and products is monitored through a considerable number of indicators (51 indicators). This shows the necessity of a circular approach in production and consumption cycles for improving the sustainability of bioproducts. Indeed, additional studies on the sustainability impact of circular economy have been developed (see section 6.2.1). However, only one indicator addresses criterion ***5.2. Food loss and waste is minimized and, when unavoidable, its biomass is reused or recycled***, showing a gap in the food circularity analysis.
- End-of-life options for bioproducts can be monitored with indicators that focus either on the amounts of resources and products recycled, reused and recovered, or on monitoring the presence of practices that trigger the diffusion of the above-mentioned practices (i.e. recycling, reusing, recovering).

While these indicators are widely found in the literature (51 indicators for criterion 5.1), indicators that monitor the impact of these innovative waste management practices are lacking (e.g. efficiency, costs or social effects of recycling, reusing, recovering).

- The economic pillar of sustainability is hardly addressed. The aspects that have been taken more into account are *6.3.a Risk assessment and management*, *6.3.b Monitoring and accountability systems* and *7.2.c Research and innovation*.
- Two other important economic considerations emerge from this review. On the one hand, the acknowledgement that purely economic indicators, e.g. revenues, costs, market share, fail in capturing sustainability aspects. Thus they are not helpful for measuring the sustainability impact of bioproducts. On the other hand, there is a clear need to monitor and evaluate risk, accountability and research since these aspects are directly related to innovative products and systems such as bioproducts and the bioeconomy in general.
- The social pillar is well informed by indicators and addresses many impact categories ranging from *1.1.a Food security* to *1.4.c Human health*, *3.2.b Working conditions*, and *6.2.a Consultation processes and engagement of all relevant sectors of society*. Although recognizing the importance of social aspects in the bioeconomy, social impact categories and indicators are not bioproduct-specific but cover all types of production. Recent studies address relevant social aspects in the bioeconomy, which emphasise for the need to further develop S-LCA (Social Life Cycle Assessments) for bioproducts (Rafiaani *et al.*, 2018).
- It is important to highlight that transversal criteria that promote a level playing field for bioproducts, such as 8.*1.e sustainable market practices*, *9.2.a market mechanisms influencing supply and demand of food and non-food goods*, *9.2.b policy coherence between supply and demand of food and non-food goods*, *10.1.a international cooperation*, and *10.1.b collaboration between private sector actors*, are hardly addressed by the existing sustainability monitoring approaches.
- Many sustainability aspects are unequally monitored and evaluated among sectors. For instance, the primary sectors (i.e. agriculture, fishery and forestry) and bioenergy are more thoroughly monitored than secondary sectors, such as the food and agroindustry, manufacturing of bioproducts, or tertiary sectors focusing on consumption and end-of-life options. This is probably due to the fact that the main bioproduct sectors are relatively new, and that some sectors lack experience in undertaking an accurate and comprehensive (sustainability) impact assessment. Another reason can be the fact that the primary sectors in the bioeconomy operate at two levels: on the one hand, these sectors provide the resources that other sectors process and add value to, and on the other hand, they also demand and consume value-added products from the other sectors; which results in them being the most monitored sectors.
- The division of bioproducts into (bio)sectors allows for a life cycle view of bioproducts. However, adopting a (traditional) sectoral approach in monitoring and evaluating bioproducts may face challenges regarding data availability and accessibility. Gathering data for measuring the bioeconomy sustainability at product/value chain level is very difficult and very few databases are available for bioproducts. Since products are very heterogeneous, the data needed are different and they depend on the characteristics of the bioproducts and the local context in which they are produced. Therefore, there is the need to closely collaborate with companies for collecting sustainability relevant data that are very often sensitive and not disclosed to the public, i.e. confidentiality.

Although the rationale for producing sustainable bioproducts is not always associated with particular sustainability objectives, the product/value chain level lays the groundwork for achieving an overall sustainable bioeconomy.

6.2.1 Sustainable consumption and production of bioproducts: a circular approach

Among the main challenges for a sustainable bioeconomy remains the issue of direct and indirect Land Use Change (iLUC) and the issue of safeguarding food security in the potential competition of food crops vs crops used for bioproducts (i.e. dedicated crops). It is increasingly acknowledged that the utilization of dedicated crops, and raw materials in general, for producing and consuming new bioproducts in a linear fashion faces sustainability challenges in the long-run. For this reason, many experts argue that resources, materials and products should be managed following a circular approach, and that this approach is an integral part of a sustainable bioeconomy.

Against this framework, many countries have engaged in developing a strategy for boosting the circular economy. While the EU strategy focuses on recycling and recovery activities all along the life cycle of products, the US policy is more concentrated on waste reduction and increased efficiency (Circular CoLab, 2018; EEA, 2016). Other countries, such as China, have developed general guidelines at national level in support of the circular economy (Zhu ***et al.***, 2018).

The circular economy, seen as a closed-loop of resources flow, is based on an integration of various types of value chains in order to exploit resources according to the 4R framework, i.e. reduce, reuse, recycle, recover (**Figure 10**). The rationale behind this approach is the decoupling of economic growth and environmental burden by recovering and valorising waste and reintroducing it in the supply chain.

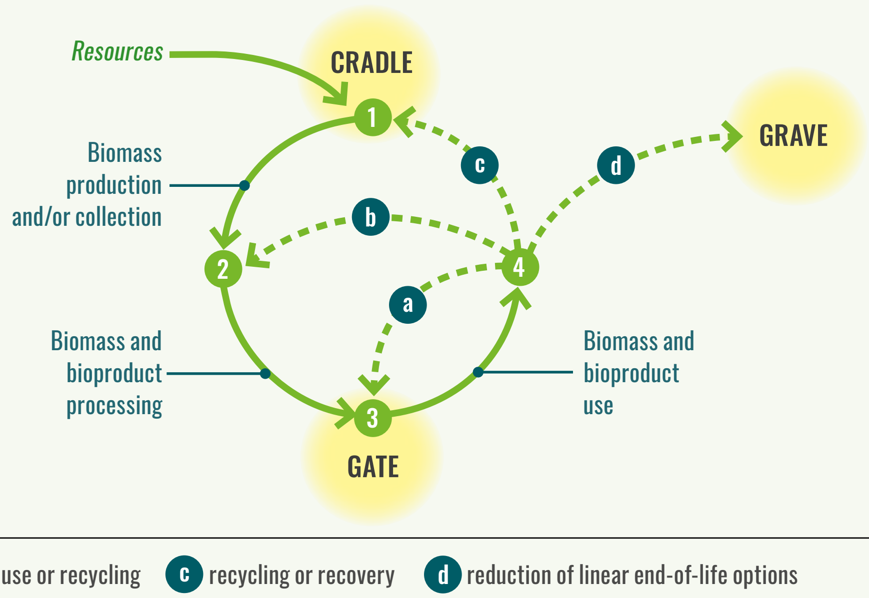
The transition towards a circular economy entails a progressive restructuring of the current socio-economic system according to the so-called basic "building blocks" defined by Ellen MacArthur Foundation (EMF, 2013):

A Product design and characteristics deal with the re-engineering efforts to design and produce products from recyclable materials with less hazardous substances and to facilitate product reuse and recycling;

B New business models that focus more on waste reduction, services for product reuse, product sharing systems, and the eradication of the ownership principle;

FIGURE 10.

CIRCULAR END-OF-LIFE OPTIONS IN THE BIOECONOMY



Source: (Gomez San Juan, Bogdanski and Dubois, 2019)

C Cascading principle contributes in closing the loop by using innovative technologies for recycling and cascading use of materials and thus reintroducing secondary raw materials into the system;

D Strong collaboration among actors and stakeholders for building new value chains and markets for waste valorization.

Accordingly, the development of a circular bioeconomy, grounded on the valorisation of waste for bioproducts production, can lead the bioeconomy toward more sustainable pathways. However, an important issue to deal with, among others, concerns the monitoring and evaluation of a circular approach for bioproduct production.

In this regard, Principle 5. ***Sustainable bioeconomy should rely on improved efficiency in the use of resources and biomass*** and related criteria deal with resources and energy efficiency, and waste management according to the 4R (i.e. waste reduction and prevention, waste reuse, waste recycling and waste recovery and treatment, including also hazardous waste). The indicators informing these criteria allow bioproduct performance in the context of circular economy to be evaluated: on the one hand, they monitor the presence of available practices for increasing efficiency and reducing the amount of resources for the production of products (e.g. 5.1.b Energy saving practices; 5.1.c Procedures for separating and using recyclable materials from the waste stream; 5.1.d Number of innovative social projects that positively impact reuse and recycle; 5.1.e Practices for waste storage, treatment and disposal that do not pose health or safety risks to farmers, workers, other people, or natural ecosystems); on the other hand, they evaluate the amount of resources and materials reintroduced in the system for closing the loop (5.1.b Primary energy savings (percent); 5.1.c percent of the sales packaging for your final products, by mass, is recyclable; 5.1.d percent of product is actively being recovered and recycled; 5.1.e percent of product-related process chemicals in effluent are directly discharged into a water body; 5.2.b Post-consuming recycling rate/cascading indexes) .

Three existing tools available online for free are aimed at evaluating products performance and improvements within the circular economy context, i.e. the Material Circularity Indicator, the Circular Economy Toolkit, the Circular Economy Indicator Prototype (Saidani ***et al.***, 2017).

The Material Circularity Indicator is used by European companies to assess the performance of their products and business models in a circular economy context (EMF, 2015). However, as it focuses on the materials or components level of a product, this tool fails in one key aspect of the circular economy – i.e. the system thinking. Indeed, characteristics like design, modularity and upgradability are not evaluated, and the stakeholders collaboration network associated with the 4R required for closing the loop, is not taken into consideration.

The Circular Economy Toolkit assesses the potential improvement of products' circularity (http://circulareconomytoolkit.org/). However, this tool is penalized by its trinary scale score that may provide only superficial information.

The Circular Economy Indicator Prototype evaluates products' circularity performance through an overall score and a spider diagram showing the performance of the different stages of the product life cycle (Griffiths and Cayzer, 2016). Two issues related to this tool have been identified; the first one concerns the inadequacy of a single score for capturing the complexity of the circular economy, and the second one deals with the stages of a product life cycle taken into consideration, hence focusing only on the manufacturing and end-of-life stages.

Table 11 summarises the features of these tools.

Moreover, Eurostat has developed a monitoring framework on the circular economy that consists of ten macro indicators divided into four thematic areas, i.e. production and consumption, waste management, secondary raw materials, competitiveness and innovation (Eurostat, 2019b). However, as described in section 4.1.3, the Eurostat monitoring framework contributes with data and indicators at the country and at EU level, thereby missing the product/value chain one.

It should be pointed out that neither Principle 5 nor the tools described above provide information on the sustainability impact generated by the increased efficiency and the closed loop in the circular economy context.

TABLE 11.

CHARACTERISTICS OF EXISTING TOOLS TO MEASURE PRODUCT CIRCULARITY

TOOL CHARACTERISTICS	CIRCULAR ECONOMY TOOLKIT (CET)	MATERIAL CIRCULAR INDICATOR (MCI)	CIRCULAR ECONOMY INDICATOR PROTOTYPE (CEIP)
DESCRIPTION	It is an assessment tool to identify potential improvement of products' circularity.	It aims at helping companies to measure their transition towards a circular economy.	The CEIP aims at evaluating product performance in the context of circular economy.
PLATFORM SUPPORT	Dynamic webpage	Excel spreadsheet	Excel spreadsheet
INPUTS	33 trinary-based questions divided into 7 sub-categories related to lifecycle stages.	Different percentages (reused, recycling) about material origin (feedstock) and destination (after use).	15 weighted questions divided into 5 lifecycle stages.
OUTPUTS	Qualitative: Improvement potential at 3 level (high, medium, low) for every of the 7 sub-categories.	Quantitative: The MCI, single score, gives a value between 0 and 1 where higher values indicate a higher circularity.	Quantitative: The CEIP score (%) and a radar diagram showing aggregated score for each lifecycle stage.

Source: (Saidani et al., 2017)

To address this gap, Elia ***et al.*** (Elia, Gnoni and Tornese, 2017) have developed a taxonomy of index-based methodologies for measuring the impact of products and services in a circular economy in terms of material and energy flows, land use and consumption, and life cycle analysis. The material flow methodology includes Water Footprint, Material Inputs Per unit of Service (MIPS) and Ecological Rucksack. The Water Footprint assesses the environmental impact on fresh water and is calculated as the total volume of water consumed or polluted all along the stages of a life cycle of a product. Water Footprint is context-based and takes into consideration the current state of the hydrological basin where the product is produced and/or from where the water is sourced. In this way it is possible to identify the stages of the supply chain that have the highest impact in order to improve water use efficiency and management. Instead, MIPS and Ecological Rucksack are helpful for measuring the material intensity per unit of product over its lifespan. While MIPS evaluates the impact of a specific material flow in a cradle-to-cradle cycle (thus, the material input used for the production, distribution, use, redistribution, and disposal of one unit of product), the Ecological Rucksack calculates the total sum of material inputs subtracting the mass of the product in order to assess the pressure of a product on the environment.

Since circular economy is expected to keep materials and products in the production cycle for as long as possible, one key aspect to monitor and evaluate is the quality of materials and their ability to preserve high quality after a perpetual use, reuse, recycling and recovering. In order to provide information on the circularity of bioproducts, an indicator can monitor the length of time that a material/product is retained in the system. A wider length of time means that the material/product has been reintroduced in many cycles and processes for a more sustainable use of resources. The material flow analysis has improved in this direction by studying the duration of material/product retention for "product systems at the firm level" (Franklin-Johnson, Figge and Canning, 2016: 592) based on three indicators: (i) initial lifetime, (ii) earned lifetime through refurbishment or reuse, and (iii) lifetime earned through recycling.

Energy flows, considered very important in the circular economy, can be measured through Cumulative Energy Demand, Embodied Energy, *Emergy* Analysis and *Exergy* Analysis. These methodologies are particularly useful for energy intensive processes or systems; however, they are single indicator methodologies and do not inform on other environmental impacts. The Cumulative Energy Demand is calculated as the total amount of energy required all along the life cycle of a product; hence, all forms of energy used for the extraction of raw materials, the production process, and the final disposal of a product. Embodied Energy is the sum of all direct and indirect energy flows required for one unit of product produced and is measured as quantity of energy per unit of weight, indicating the quantity of energy incorporated in the product. *Emergy* Analysis, similarly to Embodied Energy, estimates the total amount of direct and indirect energy used for one unit of product, but it is usually expressed in units of only one type of energy, e.g. solar energy. Instead, Exergy Analysis measures the potential of the flow to destabilize the system because of lack of a stable equilibrium in relation to the reference environment. In fact, Rosen and Dincer (2001: 4) define exergy as "the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment".

Land use and consumption are measured through the Ecological Footprint, the Sustainable Process Index and the Dissipation area index methodologies. These methodologies provide information on the human burden on the biosphere; thus, they measure different environmental impacts in an aggregated way. The Ecological Footprint measures the total amount of productive land needed to create a product or a service, including a calculation of the emissions generated by the production of food, the demand for energy and the construction of infrastructures (see also section 4). It estimates the biological capacity of the planet used by a production activity and is measured in global hectares (gha). Although the Ecological Footprint is context-specific, it can be used to compare different contexts. The Sustainable Process Index, similarly, measures the total amount of land that is necessary for the production of a product/service in a sustainable way, and is based on the assessment of mass and energy flows needed all along a product/service life cycle. Instead, the Dissipation area index measures the total amount of land necessary to absorb the output flows that cannot be reintroduced in the production cycle generated by the production of a product/service.

Life cycle analysis methodologies include the Carbon Footprint, the Ecosystem Damage Potential, the Environmental Performance Strategy Map, the Sustainable Environmental Performance Indicator, and the Life Cycle Assessment (for further detail on the latter, please see **Annex 1**). While the Carbon Footprint measures the human impact on global climate based on the GHG emissions generated all along the life cycle of a system, expressed as carbon dioxide equivalent (CO_2 eq.); the Ecosystem Damage Potential measures the human impact on ecosystems due to land use and land transformation. The damage is calculated based on the species diversity affected by the production of a product/service and depends on different land use types. In addition, the Environmental Performance Strategy Map provides a spider/radar/web diagram representation of a single composed indicator of five footprints (i.e. water, carbon, energy, emissions, working environment). The value of each footprint is expressed as a percentage of a target defined. The Sustainable Environmental Performance Indicator provides a measurement of the overall costs and impacts of the Environmental Performance Strategy Map and equals the volume of the pyramid that has the spider diagram as a base and the costs as the height.

These methodologies are very useful for monitoring and evaluation of the environmental impact of circular bioproducts. However, they do not provide any information on the socio-economic burden of circular life cycles. Moreover, given that these methodologies are specific to circular economy, they inform only on some aspects of circularity, i.e. mass, energy, time. The circular economy is highly complex and the tools and indicators for its monitoring and evaluation shall cover several criteria/aspects, i.e. levels (micro, meso, macro), loops (maintain, reuse/remain, recycle), performance (intrinsic, impacts), perspective (actual, potential), usages (e.g. improvement, benchmarking, communication), transversal (generic, sector-specific), dimension (single, multiple), units (quantitative, qualitative), format (e.g. web-based tool, Excel, formulas), sources (academics, companies, agencies) (Saidani *et al.*, 2018).

The complexity of a (circular) bioeconomy hampers the identification of an appropriate monitoring approach for M&E its sustainability. Therefore, potential approaches that can help the development of fit-for-purpose monitoring schemes and data collection are discussed in the next sections.

6.3 WAYS TO LINK THE TERRITORIAL AND THE PRODUCT/ VALUE CHAIN APPROACHES

This section aims at introducing links between the territorial and the product/value chain levels and underlines existing limitations of both approaches. In some cases, indicators related to entire value chains/sectors can be simply aggregated to inform the territorial level. In fact, economic indicators in particular can be calculated as a sum of sectoral indicators. For instance, the value added of the bioeconomy (at national level) can be calculated as the sum of the value added of bioeconomy-related sectors (Bracco *et al.*, 2018).

Practically, the attribution of impacts to the bioeconomy is often complicated. One main issue is how to attribute the data clearly to the production and use of biomass. This methodological challenge is referred to as the "attribution issue".

The identification of the bioeconomy within the whole economy is connected with the rules and conventions about how to draw the line between the bioeconomy and the rest of the economy. This is not the aim of this study, and we assume that each country is free to choose which economic sectors to include in its bioeconomy definition (e.g. agriculture; automotive and mechanical engineering; chemistry (incl. bioplastics); biofuels/bioenergy; biorefining; construction/building industry; feed; fisheries; food and beverage industry; forestry; health; knowledge/innovation; mining; pharmaceuticals industry; pulp and paper; textiles). The focus of the section is instead on the methodological challenges faced when attributing a specific contribution to the bioeconomy.

Despite the importance of this issue, there is hardly any literature that discusses how to go about it. One of the few exceptions is the recent technical paper by IINAS & IFEU (2018) on the attribution of impacts to bioenergy production and use for the implementation of the GBEP Sustainability Indicators for Bioenergy (GSI), developed for the GBEP Task Force on Sustainability. The paper addresses the attribution challenges for bioenergy's indicators, and part of its findings have been here extrapolated and amended to cover all bioeconomy sectors. These findings have been coupled with the methodology proposed by the *Borsa de Cereales* to measure the Argentinian bioeconomy (Wierny *et al.*, 2015).

A first challenge is the **attribution of statistical data** to the bioeconomy. A simple statistical approach can relate the share of the bioeconomy to the total economy or total land use by summing up the data from all the bioeconomy sectors. This top-down approach can be a first approximation for data attribution. The opposite bottom-up-approach would instead extrapolate the information for a single unit (e.g. farm, processing plant) for the entire bioeconomy activities of a territory. However, given the different activities included in the bioeconomy, this extrapolation would have to be done from a multitude of single units in order to cover the totality of the bioeconomy sectors/activities. This approach can be useful for sectors like textile and chemical, which cannot fully fall into the bioeconomy given that just part of them are bio-based. In fact, the most common classifiers of economic activity, trade and products at international-level (ISIC: International Standard Industrial Classification, NAICS: North American Industry Classification System, NACE: Classification of Economic Activities in the European Community; NET: Nomenclature for External Trade and CPC: Classifier per Category) are not compatible with the complexity of the bioeconomy. Even the System of National Accounts (SNA 08) from the United Nations does not incorporate measurement for the bioeconomy (Wierny *et al.*, 2015). Classifiers based on the traditional industrial activities are not conceived to classify the bio-based industry. ISIC, NACE and NAICS group production units according to the similarity of their productive processes, technology, inputs and equipment; therefore, they are not appropriate for the heterogeneous nature and variety of bio-based products. Their classifying criteria make no distinction between bio or non-bio inputs. In this case, useful data can only be extrapolated from single units and sectoral surveys.

Moreover, bio-based products are often manufactured jointly with products that are not derived from biomass, as sub-products or secondary activities. This creates difficulties in the recording of statistics because when organizations and industries are not homogeneous within a given level of statistical classification, they are assumed to have a main activity and one or more secondary activities. Inputs of secondary activities are not separated from those of principal activities, auxiliary activities are not analysed or classified according to their own nature, and related products are not presented as autonomous products (Wierny *et al.*, 2015). This challenge is common in the method of Life Cycle Assessment where environmental impacts have to be allocated to different products from a coupled production process (e.g. chlor-alkali electrolysis producing chlorine, sodium hydroxide and hydrogen at the same time) (IINAS & IFEU, 2018).

A second relevant issue for most of the social and environmental indicators identified in Section 4 is the **attribution of general effects to the bioeconomy**. Many indicators in fact refer to general effects that may only partially be correlated with bioeconomy development, such as prevalence of undernourishment, change of water quality, equality and many others. This attribution issue (to what extent this can be assigned to the bioeconomy), can only be solved with the help of cause-effect models or studies which are beyond the scope of this report. However, even when the aggregation issue cannot be solved, a link between bioeconomy development and a "general" indicator informs about the territorial performance in terms of sustainability. For instance, if bioeconomy development is correlated with an increase in the prevalence of undernourishment, the country should further enquire if there is any causal link between the trend and its bioeconomy strategy and revise the strategy if necessary.

From an environmental point of view, the footprint-type indicators introduced in detail in Section 4 can be a way to link territorial and product/value chain levels. For instance, the Joint Research Centre of the European Commission is promoting a Product Environmental Footprint (PEF) which employs a life cycle approach to quantify a product's environmental performance (EC JRC, 2012). The calculation of footprints at territorial and product level can be viewed as complementary activities, each undertaken in support of specific applications. The territorial footprint can be calculated using aggregated data representing the flows of resources and waste that cross a defined territorial boundary. Similarly, the territorial footprint can be disaggregated to the product level using appropriate allocation procedures.

Socio-economic aspects measured at product/ value-chain level can sometimes be scaled up to inform the territorial level and vice versa. When applying a Social Life Cycle Assessment (S-LCA) at product level the geographical location of the production plant is crucial. If case-specific data for a more precise assessment of the socio-economic impact of a product is not available, this impact can be assessed more generally using data at the territorial level (e.g. country level). According to UNEP-SETAC Guidelines (UNEP Setac Life Cycle Initiative, 2009), S-LCA is applied to all life cycle stages of a product and each of these stages is associated with a geographical location and impacts the main stakeholder categories identified (e.g. workers/employees, local community, public authorities, general society, consumers (incl. end-consumers), value chain actors). The impact stakeholder categories related to the territorial level (e.g. local community, public authorities) have a dual role: on the one hand, these stakeholders have a regulatory role and the ability to influence and characterize the production environment, and thus the socio-economic impact at product level; on the other hand, the territorial stakeholders are impacted by the production of bioproducts and their socio-economic impact is thus reflected at territorial level.

One way to ensure sustainability at territorial level is to delegate the assessment of bioproducts to SCLs, as the EU has done in the 2009 Renewable Energy Directive (2009/28/EC) (Bracco, 2016). The government at regional and/or national levels can require a sustainability certification for all the products produced, traded and commercialised within its territorial boundaries. The sustainability certification does not need to be released by an internationally recognized private body; the territorial authority can carry on the sustainability assessment in-house. Accordingly, the private sector can have access to low cost sustainability certification, and the public authority can access all the production sustainability data in order to build a database for transparent communication to the general public on the engagement towards sustainability.

An interesting programme by the International Trade Centre (Trade for Sustainable Development (T4SD)) provides information on standards, codes of conduct and audit protocols addressing sustainability hotspots in global supply chains to private sectors, public sectors or the international entities (International Trade Centre, 2019). A component of this programme, the Sustainability Map (accessible here: https://sustainabilitymap.org/home) enables stakeholders from the private sector to analyse standards-related data and self-assess their sustainability-related performance. This platform currently covers more than 220 standards initiatives applicable to more than 80 sectors and 180 countries.

In addition to these methodological issues, a significant challenge is the **lack of availability of data**, which affects both territorial and product/value-chain levels. At territorial level, disaggregated data that will allow for sector-specific attribution are often not available.

6.4 GOOD PRACTICES AS INDICATORS TO MONITOR AND EVALUATE BIOECONOMY SUSTAINABILITY

Indicators on adoption and quality of implementation of good practices can be used at both territorial and product/value chain levels to acknowledge and measure progress toward bioeconomy sustainability in a quite robust and cost-effective way. Section 3.2 on indicator typologies has introduced the reporting on good practices implementation as a viable alternative or complement to complex quantitative measurement systems. Good practices can be used as proxy indicators when the measurement of direct indicators is too demanding in terms of time and financial resources, or where data is lacking. Moreover, reporting on the implementation of good practices can help quantify milestones in relation to objectives and targets, thus it is a useful system to acknowledge progress, which can be used for public incentives and regulations as well as private project financing. Often, certification systems also require monitoring the implementation of good practices (Bracco ***et al.***, forthcoming).

It should be noted that some of the indicators collected from the literature reviews and mentioned in Section 4 and 5 are in fact good practices, for instance when they consist in qualitative or dummy information on whether a practice/policy/strategy exists. Examples of such indicators collected in Sections 4.2 and 5.2 include: "Presence of an irrigation and water distribution system that optimize crop productivity", "Presence of a cluster organization which coordinates, manages and facilitates the biocluster" and "SDG 13.2.1: Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production"".

At territorial level, this is relevant in particular for the indicators associated with Criterion 6.1. ***Policies, regulations and institutional set up relevant to bioeconomy sectors are adequately harmonized***; Criterion 6.2. ***Inclusive consultation processes and engagement of all relevant sectors of society are adequate and based on transparent sharing of information*** and 9.2.b ***Policy coherence between supply and demand of food and non-food goods***. In fact, indicators for these criteria report on, for instance:

- number of countries making or reporting progress in ratifying, accepting and implementing, through legal, policy and institutional frameworks, instruments and monitoring frameworks;
- presence of a cluster organization or of an incubator;
- institutionalised or non-institutionalised platforms;
- number of stakeholders from various stakeholder groups involved in consultations;
- free availability of documentation necessary to inform stakeholder positions in a timely, open, transparent and accessible manner;
- number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies;
- progress by countries in the degree of implementation of international instruments;
- public financial support and private investments ($).

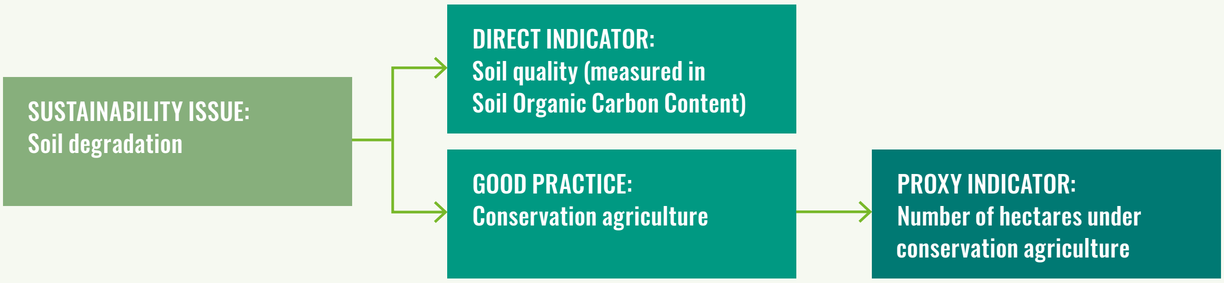
Therefore, good practices can be particularly useful to monitor and improve inclusiveness, as well as harmonization and coherence in the bioeconomy development, for which detailed quantitative measurement frameworks and indicators are not yet available.

Still, good practices can also be used to replace detailed technical measurements when these are difficult or impossible to implement at large scale. For instance, Criterion 2.1 "***Biodiversity conservation is ensured***" can be measured by a direct indicator such as "rate of biodiversity loss" or by a "proxy" indicator such as the implementation of the practice of protecting land. Examples of indicators for this practice retrieved from the reviewed literature are: "Protected areas and land with significant biodiversity values, and biodiversity conservation and management" or "SDG 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type" (**Table 7**).

Figure 11 gives an example of the direct and proxy indicators that could be identified to measure soil degradation. In the agriculture sector, conservation agriculture at the biomass production stage can be considered a good practice to address soil degradation. Proxy

FIGURE 11.

EXAMPLE OF THE ADOPTION OF A GOOD PRACTICE AS A PROXY MEASUREMENT



Source: (Gomez San Juan, Bogdanski and Dubois, 2019) indicators for soil degradation can thus be: "number of hectares under conservation agriculture" or "number of farmers having adopted conservation agriculture". At national level, good practices can also take the form of policies or strategies. For instance, "Policies for soil protection are developed, implemented and controlled". At territorial level, possible proxy indicators can be: "Euros invested/year on implementing the action plan detailed in the policy for soil protection", or "number of hectares/percentage of land under soil protection measures".

However, the adoption of good practices does not guarantee that the desired impacts are achieved. Section 6.5 below presents potential negative impacts and trade-offs that can occur when implementing agricultural practices in a causal loop in a specific context (TEEB, 2018b). For example, if 'agroforestry' is a selected good practice, an indicator to measure the extent of its implementation could be the 'number of hectares of mono-cropping replaced by agroforestry' or the 'number of farmers practising agroforestry', complemented by a rapid assessment regarding the quality of implementation. Monitoring both the quality of implementation and level of adoption of good practices is important for evaluating progress, and can be useful during the years in which precise data are not available. In fact, given the costs of retrieving data and measuring detailed indicators, these may be measured just every 5 or 10 years, with good practice monitoring occurring between these measurements.

Indicators can be used to monitor and evaluate the quality/performance of the implementation of good practices, or to assess whether the good practices actually cause change. Beyond using good practices for reporting purposes only, the adoption of good practices can directly contribute to addressing identified sustainability issues, both at product and territorial level. For a sustainable bioeconomy M&E, groups of stakeholders and experts should identify and prioritize good practices, as improvement opportunities related to sustainability challenges in bioeconomy such as hotspots in bio-based value chains and sectors. A good example at product level is the TSC approach (see section 5.2), an initiative for the private sector which demonstrates how good practices, so-called improvement opportunities, can address sustainability issues of primary concern (hotspots) within a specific value chain.

6.5 TRADE-OFFS AND SYNERGIES BETWEEN IMPACT CATEGORIES

In general terms, synergy is the interaction between two or more actions, which leads to an outcome greater than the sum of their individual impacts when carried out together. Conversely, a trade-off is an interaction which results in an impact less than the cumulative impact of individual actions. In the bioeconomy context, these interactions may be of particular importance to ensure sustainability. Identifying the synergies and trade-offs is particularly important not only to monitor the bioeconomy sustainability, but also to establish cross-sectoral integration and collaboration to explore the synergies, and opportunities to minimize the trade-offs as much as possible. On the complex network of causalities, trade-offs may arise in many instances. Therefore, the aim of this section is not to list all potential trade-offs, but rather to provide some examples, and insights on possible ways to consider them at a country-specific context.

One can consider the synergies provided by sustainable bioeconomy development (e.g. resource efficiency, circularity, etc.) as its inherent advantage and unique characteristic. Compared to those of the synergies, however, the consequences of the trade-offs are arguably more critical, as they may impose some boundaries on the extent to which bioeconomy practices can be implemented. Some potential trade-offs that might influence the sustainability and, in turn, limit the boundaries of the bioeconomy can be listed as:

- poverty vs. biodiversity (Hengsdijk *et al.*, 2007),

- water-energy-food (WEF) Nexus (FAO, 2014),
- agricultural productivity vs. climate change action (Ignaciuk and Boonstra, 2017),
- agricultural productivity vs employment (European Commission, 2008),
- nutrient recovery from wastewater vs. human health and soil quality (Kanyoka and Eshtawi, 2012),
- income-inequality nexus (Machingura and Lally, 2017),
- land use vs. ecosystem services (Machingura and Lally, 2017),
- sustainable forest management-related environmental vs. economic trade-offs (Si, Shahi and Chen, 2016), and
- soil quality vs. nutrient management (Bos ***et al.***, 2017).

Considering the (non-exhaustive) list above, for instance, if in a given country one of the bioeconomy objectives is to increase agricultural productivity, this objective can result in a decrease in employment potential. Therefore, the productivity objective should be coupled with a strategy to increase other sources of income for rural communities. Similarly, if both poverty and biodiversity loss are pressing issues in a given context, a bioeconomy strategy which can promote improvement in both of these aspects (e.g. through sustainable intensification of agricultural land) would be a win-win in this particular situation. Of course, one can argue that trade-offs are inevitable in any case. However, with their proper identification and monitoring, reducing their risk on hampering sustainability is possible.

It must be noted that some relationships listed above can also be synergies, depending on how bioeconomy is implemented. For example, in some cases, clear land rights can benefit biodiversity conservation. Similarly, depending on the intervention, it is possible to achieve synergies along the Water-Energy-Food (WEF) nexus. For instance, farm-scale anaerobic digestion and composting of manure can provide biomethane as an energy carrier, fertilizer for enhanced food production, and would avoid discharge of nutrients to water bodies.

Trade-offs and synergies can be identified and evaluated at any stage of bioeconomy development. It is ideal to analyse the country context in earlier stages of stakeholder engagement, or while conceptualizing the bioeconomy strategy, also looking from an angle to identify trade-offs. In addition to those that can be foreseen, potential trade-offs may arise from the implementation of the bioeconomy strategies, which could be identified along the way. It is also possible to extend the trade-off evaluation exercise to the network of selected indicators or impact categories. In this respect, selected indicators could be analysed from a perspective of the synergies and trade-offs they may have between each other.

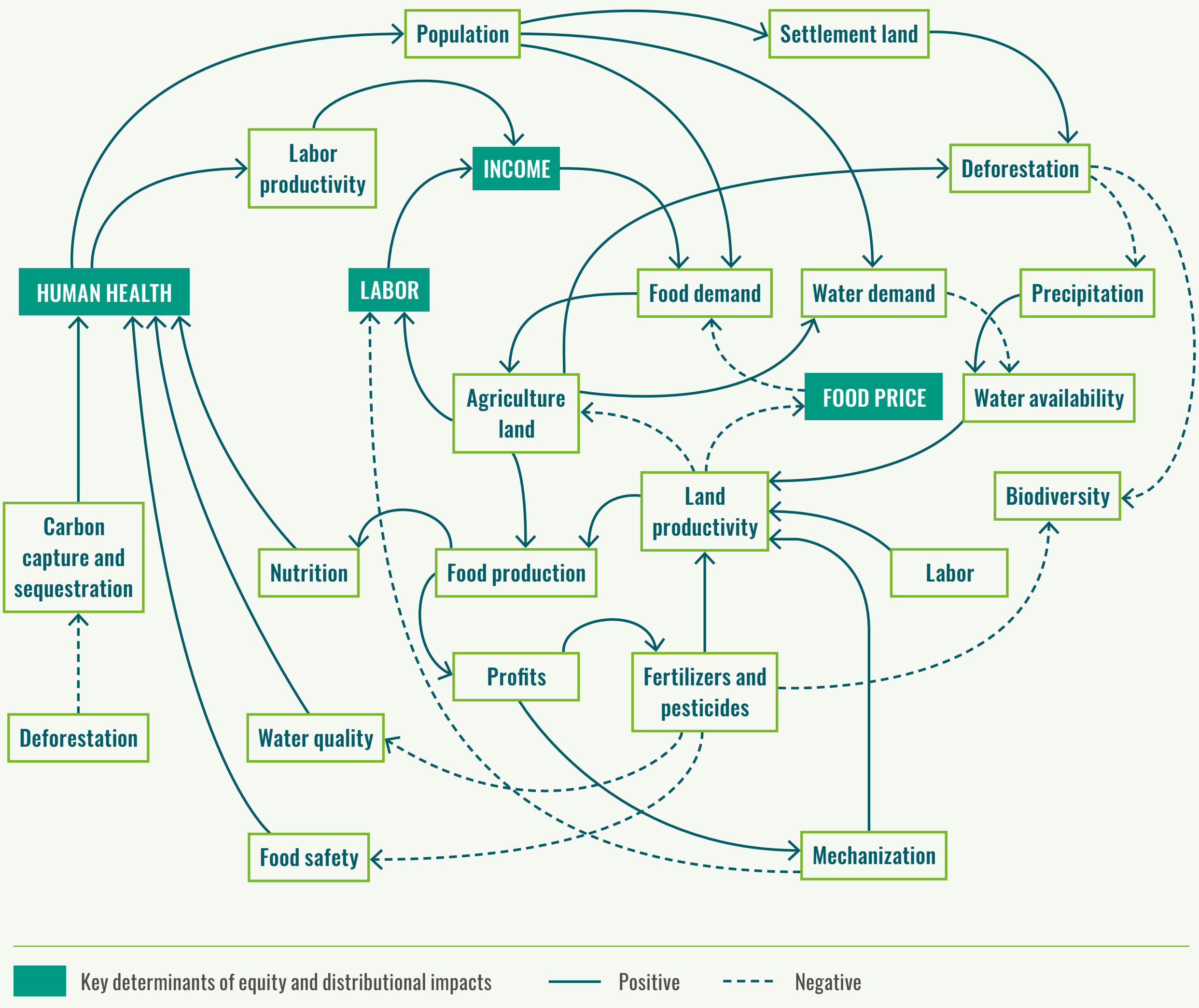
Regardless of the scope and the stage (i.e. while setting the bioeconomy objectives, selecting the indicators, or evaluating the results of the indicators in terms of trade-offs), there are several approaches one can take to analyse trade-offs. The most common ones are: participatory, empirical, optimization and simulation approaches, as summarized by Klapwijk *et al.*, (2014). These approaches will be further discussed and exemplified in a forthcoming FAO paper on SDG indicators and trade-offs in the bioeconomy (Çalıcıoğlu and Bogdanski, forthcoming). Since each approach comes with its strengths and weaknesses, it is advisable to produce a hybrid analysis framework, which will suit the level of precision and resolution required, while keeping in mind the available financial and human resources. In this respect, simulation and optimization methods require mathematical representation of the system, and could be too complex, costly, and too detailed at a policy-making context. Moreover, they are less sensitive in terms of processing qualitative data, which is essential for stakeholder engagement. In addition, once data is available, the relative differences in the changes of one indicator set against another can be (empirically) determined by statistical methods, which is less resource intensive compared to simulation and optimization approaches, yet still quantifiable. Therefore, a framework combining participatory and empirical approaches would probably be the first choice in the context of sustainable bioeconomy M&E.

The Economics of Ecosystems and Biodiversity initiative hosted by UN Environment developed an approach that uses causal loop diagrams as part of the evaluation framework for eco-agrifood systems (TEEB, 2018b). These causal loops can be constructed earlier during the bioeconomy strategy formulation by the engagement of the stakeholders, and therefore can be an example of a participatory approach. The TEEB eco-agrifood evaluation framework is designed to: (1) provide a comprehensive economic evaluation of the eco-agrifood systems' complex, and (2) demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and that a lack of awareness of dependency on natural, social, human and produced capitals exists. TEEB takes a systematic approach in quantifying the impacts of agricultural interventions and strategies. In turn, the approach reveals the impact of the decisions not only on one-dimensional agricultural productivity, but also their implications on other elements of the total eco-agrifood systems (e.g. human health and nutrition). The TEEB Evaluation Framework identifies sustainability issues, apart from economic viability and efficiency of agrifood chains, by revealing the feedback loops between agricultural productivity and other issues such as biodiversity, income, labour and food prices (**Figure 12**).

A methodology combining empirical and participatory approaches, comprising

FIGURE 12.

ILLUSTRATIVE CASUAL LOOP DIAGRAM OF ECO-AGRIFOOD SYSTEM AT THE TERRITORIAL LEVEL



Source: Simplified from TEEB (2018a)

correlations and benchmarks, has been developed by FAO for the evaluation of Water-Energy-Food Nexus trade-offs (FAO, 2014). In this approach, the overall sustainability of a country-specific intervention (e.g. solar pumps in Kenya) is evaluated in the junction of five nexus elements: water, energy, food/land, capital and labour. Food and land are grouped together because of their high interdependency. The indicators developed in the proposed methodology measure the impact of the change in one of the above-mentioned elements with respect to the change in another. In order to come up with sustainability benchmarks, this approach groups countries with similar typologies and calculates the selected indicators for individual groups as the arithmetic average of country performances. Then the actual measured indicator for the specific context under analysis is compared with the reference indicator (benchmark). In addition, weights are assigned to each indicator, depending on the importance of an indicator in the context of a specific intervention.

More information on highlighting the trade-offs and synergies resulting from the bioeconomy will be discussed in a forthcoming FAO paper (Çalıcıoğlu and Bogdanski, forthcoming). This report also provides insights for the construction of a framework to identify and communicate the trade-offs and synergies using the results of M&E activities, in order to inform and guide the decision and policy making processes.

CHAPTER 7

CONCLUSION AND PROPOSED WAY FORWARD

The bioeconomy can provide an opportunity to simultaneously address different sustainability challenges such as, for example, safeguarding food security, improving water quality and protecting health. However, important gaps and weaknesses emerge in the literature reviewed regarding monitoring approaches for social, economic and environmental sustainability impact of the bioeconomy and associated data availability. The indicators identified in the reviews presented in Sections 4 and 5 of this study, although relevant, are unequally distributed among the P&Cs agreed by the ISBWG. Environmental sustainability criteria are addressed the most, followed by those related to social and economic sustainability.

A key issue identified by this study is the availability and quality of data to measure the indicators. In fact, data for many indicators are often not collected on a regular basis and data quality is a key problem for the estimation of some indicators. Statistical systems and codes require some changes to be able to collect data and measure specific bioeconomy sectors and bioproducts. The monitoring framework on the progress of the SDGs can provide useful information also for the bioeconomy M&E, but many SDG indicators are actually still not measured. The EU is working on building comprehensive data sets and harmonized bioeconomy indicators (for example through the BioMonitor framework, the Montbioeco project and the JRC activities to develop a EU monitoring framework in the context of the EU Bioeconomy Strategy Action Plan).

Sustainable consumption and production (SCP) is a particularly important topic in the context of sustainable bioeconomy M&E, since, in this view, resource efficiency goes beyond territorial boundaries by linking the national to the international level. Therefore, our study has a special focus on approaches to ensure sustainable trade, which take into account the social and environmental costs that bioeconomy activities of one country may externalize to other countries through trade flows (import/export) (Section 6.1.1). Similarly, at the level of bioproducts we focus on a circular approach for promoting a cradle-to-cradle assessment of sustainability (Section 6.2.1).

While this study divides measurement approaches into territorial and product/value chain levels to targ*et all* types of bioeconomy stakeholders, it also provides some insights on the link between these two levels by assessing how to attribute the measurement of the indicators clearly to the production and use of biomass (attribution issue).

Given the possible trade-offs between the several dimensions of sustainability and among value chains, this study highlights the need for a holistic framework to monitor the sustainability impact of the bioeconomy.

In light of the findings of this study, a stepwise approach/methodology for monitoring the bioeconomy sustainability at both territorial and product level is proposed as a way forward. The development of this methodology is intended to help countries and operators that aim to promote a sustainable bioeconomy, in monitoring their performance and progress. This stepwise monitoring approach presented in the next section is both balanced, since it considers the three sustainability dimensions, and not too complex since it results in a limited set of indicators (cockpit screens).

The recommended methodology is grounded on a participatory approach: the choice of relevant hotspots, priorities and indicators must be done through stakeholder and expert participation. For instance, consumers are not fully aware of the bioeconomy framework and its sustainability aspects. Certification and labels can contribute to increasing consumer awareness of bioproducts, and some indicators can be useful to inform them. Harmonization of indicators and standards for sustainable bioproducts can become a major driver for their deployment.

Stakeholders from the public, private sectors and civil society must be involved from the definition of bioeconomy priorities to the establishment of any M&E framework. The stepwise approach includes the use of proxy indicators as a complement to detailed measurement, because data are not always available, and detailed monitoring may be time- and resource-consuming. Good practices are introduced as complementary indicators. Moreover, the added value of this approach derives from the flexibility to reflect context-specific circumstances and stakeholder needs. It also allows new indicators to be included as the sector demands in order to improve the monitoring of sustainable bioeconomy.

7.1 STEPWISE APPROACH TO MONITORING THE BIOECONOMY

This section presents a stepwise approach which aims to monitor the sustainability of bioproducts and the bioeconomy as a whole. The design of this approach builds on the results of the analysis presented in this report. As part of this approach, countries or bioproduct producers and manufacturers are provided with a long list of scientifically robust indicators (i.e. those listed in Tables 7/territorial and 9/product of this study), from which to choose a limited number of indicators that suits their needs and circumstances, following the "cockpit approach".[8] This approach reflects a balanced weighting exercise, and it is important for policy making, feasibility of measurement, and communication. Weighting the indicators calibrates the assessment according to their relevance and significance for given policies, strategies, programs or projects in a given country or region at a particular moment

[8] This metaphor relates to the situation in an airplane cockpit: a few indicators displayed in cockpit screens give sound and reliable indications which are fundamental to fly; others are also useful but complementary to the fundamental ones, and can be added later as appropriate.

(Villeneuve *et al.*, 2017). This step is crucial to calibrate the M&E framework to the realities and context in which it applies. For each indicator, the following question must be answered: is this indicator the "SMARTest" (most Specific; Measurable; Achievable; Relevant and Time-bound) metric for measuring and evaluating the criterion in a given country/region at a particular moment?

At the territorial level, the selected indicators can be adapted to the bioeconomy priorities of the countries. They may be already collected by the countries (for example, to report on SDG indicators) and should be displayed in a way that is easily communicable to all stakeholders.

At the product/value-chain level, the selected indicators can be adapted for each bioproduct based on the relevant value chain and its hotspots. The data for these indicators may already be available, for instance if the bioproduct is certified or labelled. Here again, it is important to ensure that results are displayed in an easy and communicable way to all consumers and users.

The stepwise approach may be also complemented by the use of indicators on good practice to complement the measurement of impacts.

There can be different motivations for developing a bioeconomy monitoring framework. At national level, this approach is particularly targeted at technical staff of Ministries or public institutions that are tasked with the development of a M&E system for sustainable bioeconomy. At product/value chain level, this document addresses the private sector stakeholders who want or have to report on the sustainability of their bioproducts/value chain.

The stepwise approach introduced above is further detailed hereafter. This section explains the steps to be followed in order to select a tailor-made "cockpit" of: (i) country-relevant criteria and indicators that concern both the country's bioeconomy objectives or country priorities and a range of related sustainability aspects that follow the SDGs, and (ii) bioproducts-relevant criteria and indicators that deal with sustainability issues along their value chains (i.e. hotspots) and that comply with sustainability objectives for market-uptake.

The prioritization of indicators at **territorial** (national/sub-national) **level** is based on the steps presented in **Figure 13**. It will result in about 15-25 indicators (the "cockpit screen"). In this approach, step one should ensure adequate coverage of the ISBWG P&Cs, as a guarantee of sufficient balance between the three sustainability pillars. In step 4, if needed, one can add indicators to reflect the country specific bioeconomy objectives. The sustainable bioeconomy P&Cs are in fact weighted as "essential" objectives, but countries' priorities can be added to the framework as "desirable" or "important" objectives (Villeneuve *et al.*, 2017). If appropriate, after Step 6 (which involve assessing data availability and data gaps regarding the selected indicators), Step 3 to 5 can be repeated.

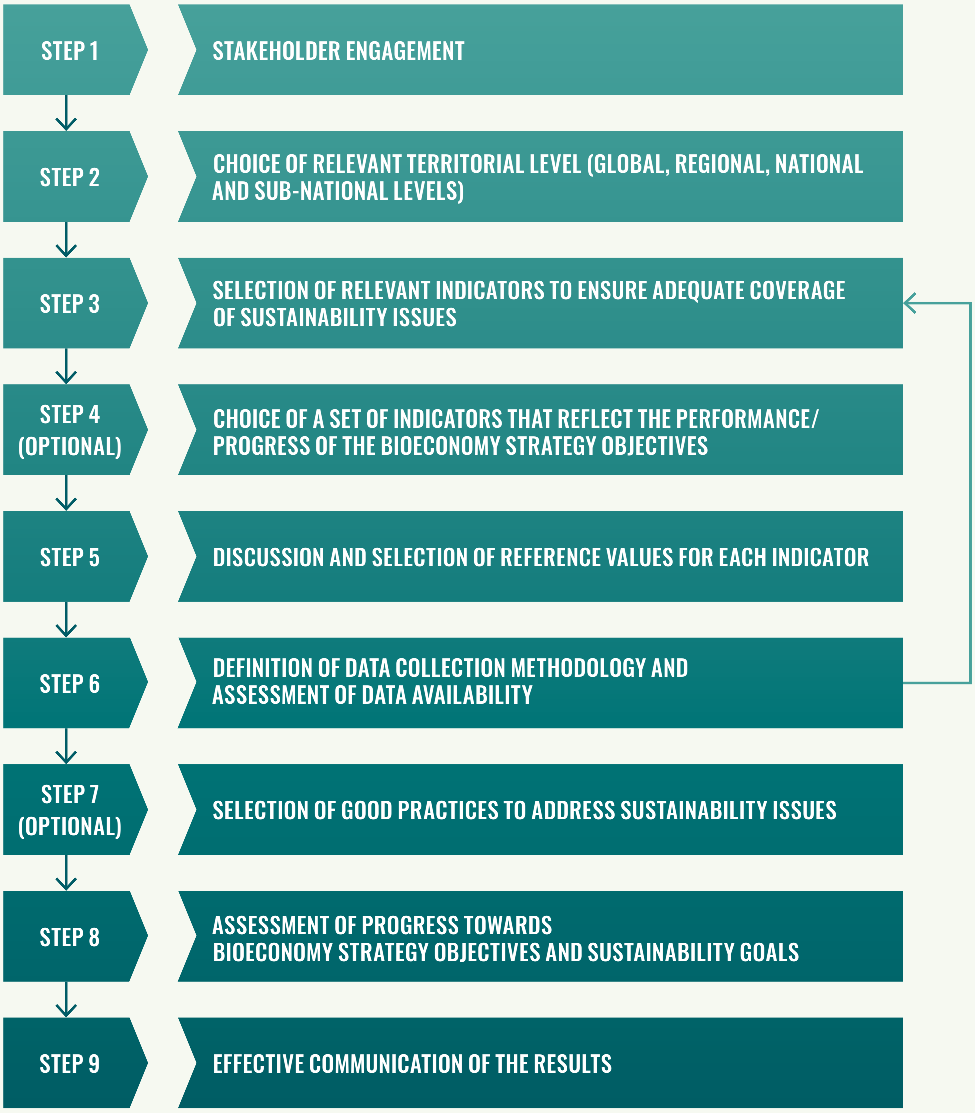
In as much as possible, the selection of indicators at territorial level should be linked to the SDG indicators, in order to avoid duplication, and favour the contribution of the bioeconomy measurement to the reporting on SDG implementation. For this reason, relevant SDG indicators have been included in the indicator list in **Table 7** (Section 4).

Similarly, a stepwise process to identify a tailored set of balanced indicators to monitor and evaluate bioproducts performance will result in a cockpit screen for the **product/ value chain level**. The set of indicators will address the performance of bioproducts in relation to hotspots along their value chains, and possible other relevant sustainability issues, both identified through a multi-stakeholder consultation process. Also in this case, indicators can reflect "essential", "desirable" or "important" objectives. The selection of SCL indicators should be prioritized since this allows companies to better target their measurement effort. Once step 6 is completed, steps 4 and 5 can be reiterated in case data is unavailable or difficult to collect. The above-mentioned process is illustrated in **Figure 14**.

The steps of the approaches are described below for both the territorial and the product/ value-chain levels.

FIGURE 13.

STEPWISE APPROACH TO INDICATOR SELECTION AT TERRITORIAL LEVEL



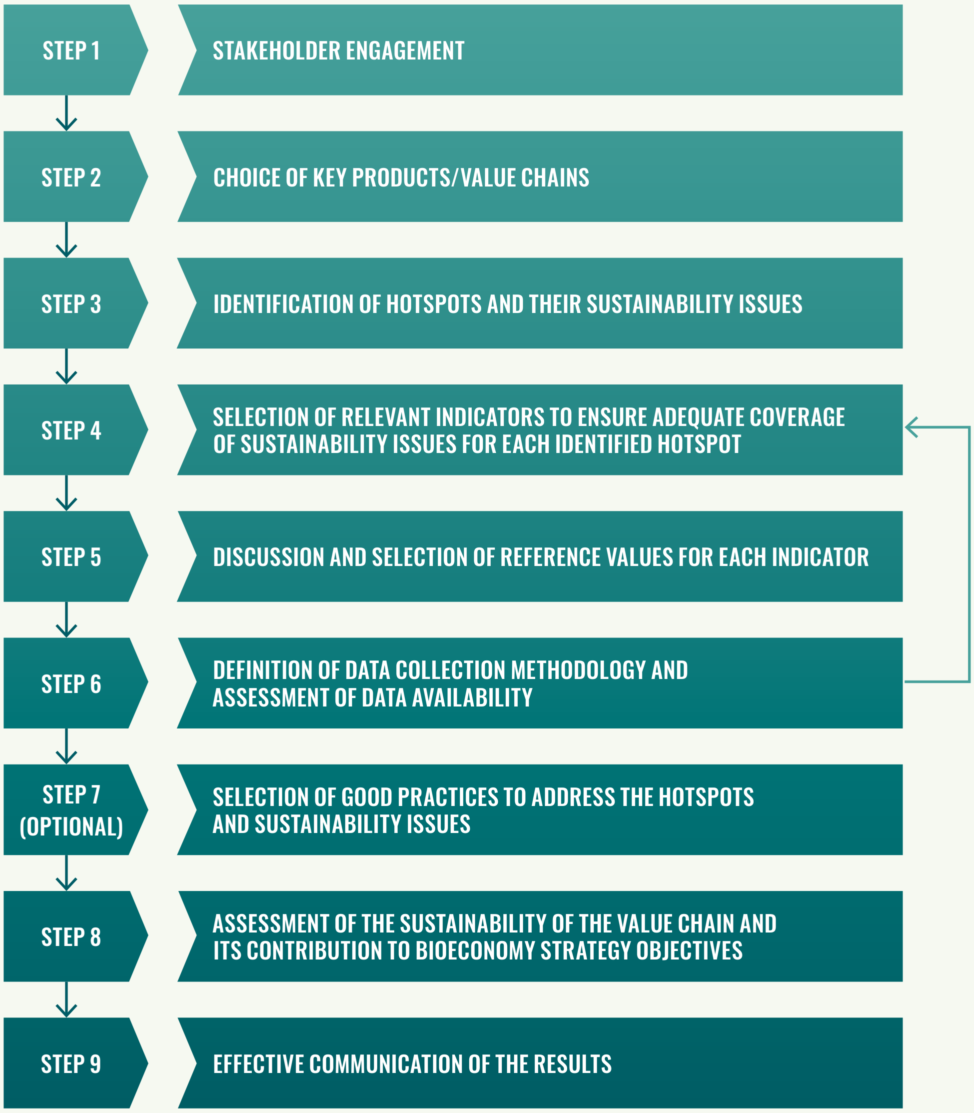
Step 1: Stakeholder engagement

The selection of indicators for the "cockpit screen" must be based on a participatory approach. Engagement and participation of all relevant bioeconomy stakeholders and experts is key for the choice of relevant priorities, hotspots and indicators. A multi-stakeholder platform including representatives from the public and private sectors as well as the civil society can be created to lead the process from the definition of bioeconomy priorities to the establishment of an M&E framework.

However, participatory approaches can be challenging, if there are many stakeholders with divergent views. Therefore, in some cases the stakeholders can be prioritized or included in distinct rounds. For instance, the European Commission iterates between formulations of ideas, proposal to high priority stakeholders, reformulation of ideas, return to high priority stakeholders with updated proposal and slowly enlarge to all stakeholders, once a formulation is agreed upon by core stakeholders.

FIGURE 14.

STEPWISE APPROACH TO INDICATOR SELECTION AT PRODUCT LEVEL



Step 2: Choice of system boundaries

Territorial level

As an initial step, a country should consider whether it wants to evaluate its performance at country or sub-national level. Most of the indicators retrieved from the literature describe national performance, but the BERST approach is an example of a regional (sub-national) level framework. Also IINAS (2015) provides criteria and indicators for biomass sustainability at local, sub-national and national levels. If a country wants to analyse sub-national performance, it can refer to indicators presented in these approaches.

Product/value-chain level

Relevant stakeholders need to define the components and boundaries of their value chain, according to their respective sector. The indicators from the literature review (*Table 9*) are divided by sector. The monitoring and evaluation of single products or entire sectors can be carried out by the private sector, but policy makers and/or actors from public institutions might also be interested in following this approach when implementing a market and/or sectoral sustainability policy.

Step 3: Identification of sustainability issues and relevant indicators

Territorial level

The study associates indicators to criteria from the ISBWG-agreed sustainable bioeconomy P&Cs. There are 24 criteria which cover economic, environmental and social aspects. Therefore, by selecting one or two indicator(s) for each criterion, the country can cover the three aspects of sustainability.

The country can select from **Table 7** the "best" indicator for each criterion of the sustainable bioeconomy P&Cs. The "best" indicator should be the "SMARTest": the most Specific; Measurable; Achievable; Relevant and Time-bound indicator for measuring and evaluating the criterion in the country. If the indicators listed (in **Table 7**) for a criterion are more than 10, the country can pick two or more options, otherwise it can select only one indicator per criterion. For the criteria for which no indicator is available, the country can propose one. In this exercise, a new indicator should be added only if an existing indicator is removed, in order to cap the maximum number of indicators in the framework. At this stage, the country can add and choose different indicators by means of a participatory approach and expert opinion, provided that they respect the impact categories of the sustainable bioeconomy P&Cs.

This step will lead to the selection of a set of about 24 balanced indicators that cover economic, environmental and social impacts and ensure compliance with the P&Cs. Often, the criterion can be measured by an SDG indicator. Since countries already have to report on their SDGs, they may choose to pick the SDG indicators (many SDG indicators are already collected by UNSTATS) (see **Box 2**), but should be aware of the attribution issue.

BOX 2. EXAMPLE OF STEP 3 AT COUNTRY LEVEL

Table 12 shows an example of the results of a first selection of one (or more) indicators for each sustainable bioeconomy criterion done by countries that wish to link their bioeconomy M&E to SDG reporting. The resulting set of indicators covers all three aspects of sustainability and can be further refined to better fit countries' objectives.

TABLE 12.

EXAMPLE OF INDICATOR SELECTION BASED ON THE SUSTAINABLE BIOECONOMY P&Cs

Colour code: Economic Social Environmental

CRITERION 1.1. FOOD SECURITY AND NUTRITION ARE SUPPORTED	
Indicator 1.1.8	SDG 2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)
Indicator 1.1.13	SDG 2.1.1 Prevalence of undernourishment
CRITERION 1.2. SUSTAINABLE INTENSIFICATION OF BIOMASS PRODUCTION IS PROMOTED	
Indicator 1.2.4	SDG 2.4.1 Proportion of agricultural area under productive and sustainable agriculture
CRITERION 1.3. ADEQUATE LAND RIGHTS AND RIGHTS TO OTHER NATURAL RESOURCES ARE GUARANTEED	
Indicator 1.3.5	SDG 1.4.2 Proportion of total adult population with secure tenure rights to land, (a) with legally recognized documentation, and (b) who perceive their rights to land as secure, by sex and type of tenure
CRITERION 1.4. FOOD SAFETY, DISEASE PREVENTION AND HUMAN HEALTH ARE ENSURED	
Indicator 1.4.6	SDG 8.8.1 Frequency rates of fatal and non-fatal occupational injuries, by sex and migrant status

CRITERION 2.1. BIODIVERSITY CONSERVATION IS ENSURED	
Indicator 2.1.7	SDG 15.5.1 Red List Index
CRITERION 2.2. CLIMATE CHANGE MITIGATION AND ADAPTATION ARE PURSUED	
Indicator 2.2.11	The country have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other) (based on SDG 13.2.1)
CRITERION 2.3. WATER QUALITY AND QUANTITY ARE MAINTAINED, AND, IN AS MUCH AS POSSIBLE, ENHANCED	
Indicator 2.3.8	SDG 6.3.2 Proportion of bodies of water with good ambient water quality
Indicator 2.3.18	SDG 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
CRITERION 2.4. THE DEGRADATION OF LAND, SOIL, FORESTS AND MARINE ENVIRONMENTS IS PREVENTED, STOPPED OR REVERSED	
Indicator 2.4.7	SDG 15.3.1 Proportion of land that is degraded over total land area
Indicator 2.4.13	SDG 15.1.1 Forest area as a proportion of total land area
Indicator 2.4.21	Marine protected area (% of territorial waters) (SDG 14.5.1)
CRITERION 3.1. ECONOMIC DEVELOPMENT IS FOSTERED	
Indicator 3.1.2	Value added of bioeconomy sectors ($)
Indicator 3.1.11	Average income of employees in the bioeconomy sectors
CRITERION 3.2. INCLUSIVE ECONOMIC GROWTH IS STRENGTHENED	
Indicator 3.2.4	Employment in each group of bioeconomy subsectors (% of total employment)
Indicator 3.2.14	SDG 8.8.2 Level of national compliance with labour rights (freedom of association and collective bargaining) based on International Labour Organization (ILO) textual sources and national legislation, by sex and migrant status
Indicator 3.2.15	SDG 1.4.1 Proportion of population living in households with access to basic services
Indicator 3.2.30	SDG 5.1.1 Whether or not legal frameworks are in place to promote, enforce and monitor equality and non-discrimination on the basis of sex
CRITERION 3.3. RESILIENCE OF THE RURAL AND URBAN ECONOMY IS ENHANCED	
Indicator 3.3.2	SDG 9.1.1 Proportion of the rural population who live within 2 km of an all-season road
CRITERION 4.1. THE SUSTAINABILITY OF URBAN CENTRES IS ENHANCED	
Indicator 4.1.1	SDG 11.6.1 Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities
CRITERION 4.2. RESILIENCE OF BIOMASS PRODUCERS, RURAL COMMUNITIES AND ECOSYSTEMS IS DEVELOPED AND/OR STRENGTHENED	
Indicator 4.2.2	SDG 1.3.1 Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable
Indicator 4.2.11	Proportion of national exclusive economic zones managed using ecosystem-based approaches (SDG 14.2.1)
CRITERION 5.1. RESOURCE EFFICIENCY, WASTE PREVENTION AND WASTE RE-USE ALONG THE WHOLE BIOECONOMY VALUE CHAIN IS IMPROVED	
Indicator 5.1.2	SDG 8.4.1/12.2.1 Material footprint, material footprint per capita, and material footprint per GDP
Indicator 5.1.11	SDG 12.5.1 National recycling rate, tons of material recycled
CRITERION 5.2. FOOD LOSS AND WASTE IS MINIMIZED AND, WHEN UNAVOIDABLE, ITS BIOMASS IS REUSED OR RECYCLED	
Indicator 5.2.1	SDG 12.3.1 Global food loss index
CRITERION 6.1. POLICIES, REGULATIONS AND INSTITUTIONAL SET UP RELEVANT TO BIOECONOMY SECTORS ARE ADEQUATELY HARMONIZED	
Indicator 6.1.1	Regulation (commitment of policy makers and policy)
CRITERION 6.2. INCLUSIVE CONSULTATION PROCESSES AND ENGAGEMENT OF ALL RELEVANT SECTORS OF SOCIETY ARE ADEQUATE AND BASED ON TRANSPARENT SHARING OF INFORMATION	
	n.a.

CRITERION 6.3. APPROPRIATE RISK ASSESSMENT AND MANAGEMENT, MONITORING AND ACCOUNTABILITY SYSTEMS ARE PUT IN PLACE AND IMPLEMENTED	
	n.a.
CRITERION 7.1. EXISTING KNOWLEDGE IS ADEQUATELY VALUED AND PROVEN SOUND TECHNOLOGIES ARE FOSTERED	
Indicator 7.1.4	Training and re-qualification of the workforce in the bioeconomy sector (share of workers, % per year)
CRITERION 7.2. KNOWLEDGE GENERATION AND INNOVATION ARE PROMOTED	
Indicator 7.2.5	Intellectual property rights (IPRs) (patent, trademark, design) applications in bioeconomy subsectors (number of application per 1 000 employees)
Indicator 7.2.9	SDG 9.5.1 Research and development expenditure as a proportion of GDP
CRITERION 8.1. LOCAL ECONOMIES ARE NOT HAMPERED BUT RATHER HARNESSED BY THE TRADE OF RAW AND PROCESSED BIOMASS, AND RELATED TECHNOLOGIES	
Indicator 8.1.4	Change in cropland-based biomass product net trade
CRITERION 9.1. CONSUMPTION PATTERNS OF BIOECONOMY GOODS MATCH SUSTAINABLE SUPPLY LEVELS OF BIOMASS	
Indicator 9.1.1	SDG 8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP
Indicator 9.1.16	SDG 7.2.1 Renewable energy share in the total final energy consumption
CRITERION 9.2. DEMAND AND SUPPLY- SIDE MARKET MECHANISMS AND POLICY COHERENCE BETWEEN SUPPLY AND DEMAND OF FOOD AND NON-FOOD GOODS ARE ENHANCED	
Indicator 9.2.10	The country has a sustainable consumption and production (SCP) national action plans or SCP is mainstreamed as a priority or a target into national policies (based on SDG 12.1.1)
CRITERION 10.1. COOPERATION, COLLABORATION AND SHARING OF RESOURCES, SKILLS AND TECHNOLOGIES ARE ENHANCED WHEN AND WHERE APPROPRIATE	
Indicator 10.1.3	SDG 2.a.2 Total official flows (official development assistance plus other official flows) to the agriculture sector

Product/value-chain level

The identification of hotspots and their sustainability issues at product/value chain level is based on the TSC approach. This approach identifies hotspots, which are "activities in the life cycle that cause one or more social or environmental impacts" (TSC, 2015), for each product category. This focus on hotspots is quite cost effective, as it ensures adequate assessment of the most important issues with a reduced amount of resources and time. The hotspots and related sustainability issues should be identified for each product/value chain through research complemented by expert consultation in a multi-stakeholder participatory approach.

Step 4: Choice of indicators that reflect bioeconomy strategy objectives or hotspots

Territorial level (optional)

This step requires a participatory process to agree and finalize a set of (additional, optional) performance indicators that reflect the progress in achieving the bioeconomy strategy objectives. In fact, in the context of bioeconomy strategies, each country aims to achieve context-specific objectives. Each country can choose additional indicators that could help in monitoring and evaluating their specific bioeconomy objective(s). These objective-related indicators may match the sustainability indicators selected in Step 3 or may add to them (see **Box 3**). In the latter case, their M&E would be optional.

Product/value-chain level

To carry out this step, stakeholders can select the SMARTest indicators from the comprehensive list provided in **Table 9** to monitor and evaluate the relevant sustainability issues associated with the hotspots identified. In order to make the measurement feasible, a limited number of indicators will be selected for each hotspot, e.g. 1 or 2, depending on the local context and specific needs. In case there is no indicator for a particular criterion, or the stakeholders identify

BOX 3. EXAMPLE OF STEP 4 AT TERRITORIAL LEVEL

In this step, each country can choose additional indicators that could help in monitoring and evaluating their specific bioeconomy objective(s). For example, if a country's bioeconomy priority is the promotion of sustainable intensification of biomass production, additional indicators listed in Table 7 under the criterion 1.2 can be chosen and monitored by the country. Similarly, a country with a strong focus on blue bioeconomy can select additional indicators related to this topic.

Table 13 shows some examples of additional indicators taken from the complete list that could inform the following bioeconomy objectives:

- Eco-Intensification
- Value-chain efficiency
- Promotion of Ecosystem Services
- Enhancing competition
- Job creation
- Climate action

The country can select these additional indicators also on the basis of availability of national data.

TABLE 13.

EXAMPLES OF OBJECTIVE-SPECIFIC INDICATORS

OBJECTIVE	INDICATOR NUMBER	INDICATOR
Eco-Intensification	Indicator 1.2.2	Productivity of feedstock or by farm/plantation (tonnes ha per year)
	Indicator 1.2.3	Change in land use intensity (inputs / outputs / system based; e.g. felling ratio, crop yields and animal stocking density)
Value-chain efficiency	Indicator 3.1.16	Cluster size (number of businesses or employees in each cluster (% of total firms)
	Indicator 6.1.2	Cluster governance (the support provided by local/regional/national government in setting up and managing the cluster, as well as any cluster-friendly policies that are introduced)
Promotion of Ecosystem Services	Indicator 2.4.3	SDG 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
	Indicator 9.2.9	Public financial support and private investments for ecosystem services ($)
Enhancing competition	Indicator 3.2.8	Labour productivity ($)
	Indicator 10.1.5	Density of firms in the (sub)sectors
Job creation	Indicator 3.2.6	Job creation in skilled / unskilled labour
Climate action	Indicator 2.2.1	SDG 9.4.1 CO_2 emission per unit of value added
	Indicator 2.2.9	Public financial support and private investments for mitigation and adaptation ($)
	Indicator 7.2.3	SDG 4.7.1/12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment

Source: Authors

better indicators, they can propose new ones. The indicators selected do not have to be balanced among the three pillars of sustainability (i.e. environmental, social, and economic), unless the sustainability issues associated with the identified hotspot address a generic aspect of sustainability. Many criteria are addressed by SCL indicators that stakeholders should prioritize in case they have already adopted a SCL (they already have the data for that indicator) or they aim to adopt one (in order to avoid duplication of measurement efforts).

Step 5: Discussion and selection of reference values for each indicator

After the indicators have been selected, they can be used to measure bioproduct and bioeconomy performance and impacts. This exercise requires that each indicator has a benchmark, target or reference value in order to measure its change/trend. Reference values can be historic data/time series, or they can be so-called normative policy- or science-based reference values, as commonly found in many sustainability studies.

Indicators that show significant or moderate progress against a target can be considered positive. Indicators that show insufficient progress against a target or a move away from it altogether can be considered negative. Directionality of indicators should be decided by local stakeholders, keeping in mind the planet's ecological boundaries (O'Neill ***et al.***, 2018). On the other hand, positive trends for social indicators are desirable. Economic indicators are often more critical, since their betterment can be linked to over exploitation of resources or could happen at the expense of social improvements. For example, an increase of GDP (at territorial level) or firm revenue (at product/value chain level) could be coupled with an increase in inequality, and/or be linked to overexploitation of natural resources. This topic is addressed also in the trade-off/synergies discussion (Section 6.5).

In some cases, indicators are qualitative or dummy (yes/not). One example is the existence of a policy which target climate change (e.g. *Indicator 2.2.11: The country has communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other*)). In the case of dummy indicators, it is possible to attach numerical value to the indicator. For instance, a positive reply to the existence of a policy on climate change ("yes") can be attributed a score 1 or 100 percent while a negative reply "no" can be attributed a zero score.

Step 6: Definition of data collection methodology and assessment of data availability

This step is very important for collecting the data needed for the indicators. Stakeholders can decide either to collect data through field analysis or to refer to already existing datasets and databases. However, the latter may be risky since it is challenging to identify data attributed exclusively to the bio-based value chains of a bioproduct and to the bio-based activities and sectors at a country level. In case of data gaps at territorial level, the country can aggregate the data at product/value chain level, or vice versa (data at territorial level can be disaggregated if there are gaps at product/value chain level). Once the assessment of data availability has been completed and data gaps regarding the selected indicators have been identified, stakeholders may consider reiterating steps 3 to 5 at the country level and steps 4 and 5 at the product/value chain level, if needed. By reiterating these steps, stakeholders have the possibility to change the set of indicators based on the data availability and accessibility.

Step 7 (optional): Selection of good practices to address sustainability issues

This step identifies good practices, i.e. improvement opportunities, to address sustainability concerns and hotspots at product/value chain level and at territorial level through a participatory stakeholder discussion and expert opinion. It also establishes regular monitoring of the improvement and progress made after the implementation of good practices. As presented in the discussion section, many indicators from the list of indicators in sections 4.2 and 5.2 are actually good practices. Good practices can also complement more complex indicators and serve as proxy indicators, saving time and financial resources in M&E activities.

Step 8: Assessment of progress towards bioeconomy strategy objectives and sustainability goals

Territorial level

At territorial level, this step provides data and information on bioeconomy progress towards the bioeconomy strategy objectives and sustainability goals. Once a benchmark situation is established and the "desirable" trend for each indicator is identified, the bioeconomy performance can be measured.

Product/value-chain level

The indicators selected in step 4 coupled with the data collected in step 6 will be used to calculate the sustainability performance of the bioproduct and/or sector selected in step 2 by means of life cycle sustainability assessment tools (see section 3.3 and **Annex 1**). The sustainability improvement of hotspots, and bioproducts and/or sectors in general, will be assessed based on the reference values identified in step 5 and through a participatory approach (Step 1). The sustainability progress at product/value chain level is expected to contribute to national goals.

Step 9: Effective communication of the results

The results should be presented in a sound but simple way. This is essential in order to communicate the results to policy-makers and to enable an informed decision-making process, and to the general public for increasing consumer awareness and bioproduct market uptake. For instance, spider diagrams and/or interactive graphics could be an effective way of showing progress in the analysed indicators (**Box 4** presents an example at the territorial level). Grouping indicators into the three sustainability pillars (economic, social and environmental indicators) may facilitate the communication of the results.

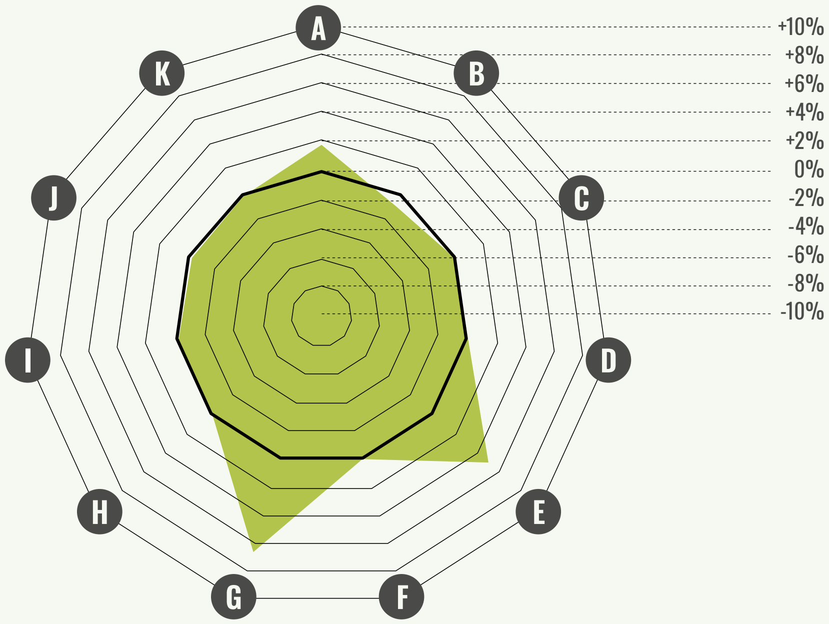
Since many aspects of sustainability are often interlinked, Section 6.5 described how to deal with the trade-offs and synergies of bioeconomy development. For example, economic development (Criterion 3.1) could happen at the expense of inclusiveness (Criterion 3.1), including the type of jobs created and the fair treatment of employees and working conditions, and climate change mitigation (Criterion 2.2).

BOX 4. EXAMPLE OF STEP 9 AT TERRITORIAL LEVEL

The graphs below show the performance of a country's bioeconomy in the three sustainability pillars (**Figure 15**). In these diagrams, performance has been calculated as percentage increase over the previous year's data. The progress can be considered sustainable when no negative change appears in the diagrams.[9]

FIGURE 15.

EXAMPLES OF SPIDER DIAGRAMS AT TERRITORIAL LEVEL - ENVIRONMENTAL INDICATORS



A

SDG 2.4.1 Proportion of agricultural area under productive and sustainable agriculture

B

SDG 15.5.1 Red List Index

C

The country have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other) (based on SDG 13.2.1)

D

SDG 6.3.2 Proportion of bodies of water with good ambient water quality

E

SDG 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources

F

SDG 15.3.1 Proportion of land that is degraded over total land area

G

SDG 15.1.1 Forest area as a proportion of total land area

H

Marine protected area (% of territorial waters) (SDG 14.5.1)

I

Proportion of national exclusive economic zones managed using ecosystem-based approaches (SDG 14.2.1)

J

SDG 12.5.1 National recycling rate, tons of material recycled

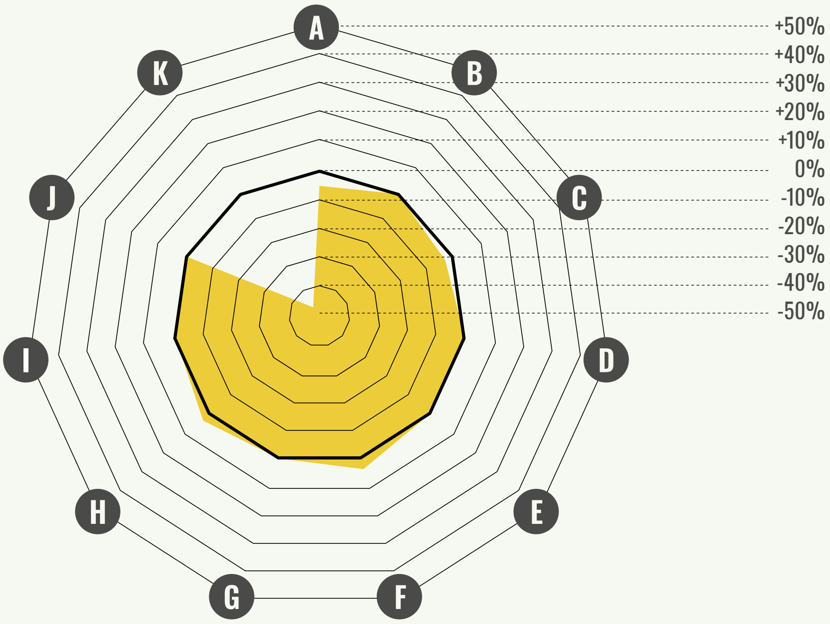
K

SDG 12.3.1 Global food loss index

[9] Data have been adjusted so that negative performance always mean a negative trend. For example, if the data for the indicator *SDG 15.3.1 Proportion of land that is degraded over total land area* increases (negative trend), the change is marked here is a negative change even if the change is numerically positive.

FIGURE 15.

EXAMPLES OF SPIDER DIAGRAMS AT TERRITORIAL LEVEL - SOCIAL INDICATORS



A

SDG 2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)

B

SDG 2.1.1 Prevalence of undernourishment

C

SDG 1.4.2 Proportion of total adult population with secure tenure rights to land, (a) with legally recognized documentation, and (b) who perceive their rights to land as secure, by sex and type of tenure

D

SDG 8.8.1 Frequency rates of fatal and non-fatal occupational injuries, by sex and migrant status

E

SDG 8.8.2 Level of national compliance with labour rights (freedom of association and collective bargaining) based on International Labour Organization (ILO) textual sources and national legislation, by sex and migrant status

F

SDG 1.4.1 Proportion of population living in households with access to basic services

G

SDG 5.1.1 Whether or not legal frameworks are in place to promote, enforce and monitor equality and non-discrimination on the basis of sex

H

SDG 1.3.1 Proportion of population covered by social protection floors/ systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable

I

Regulation (commitment of policy makers and policy)

J

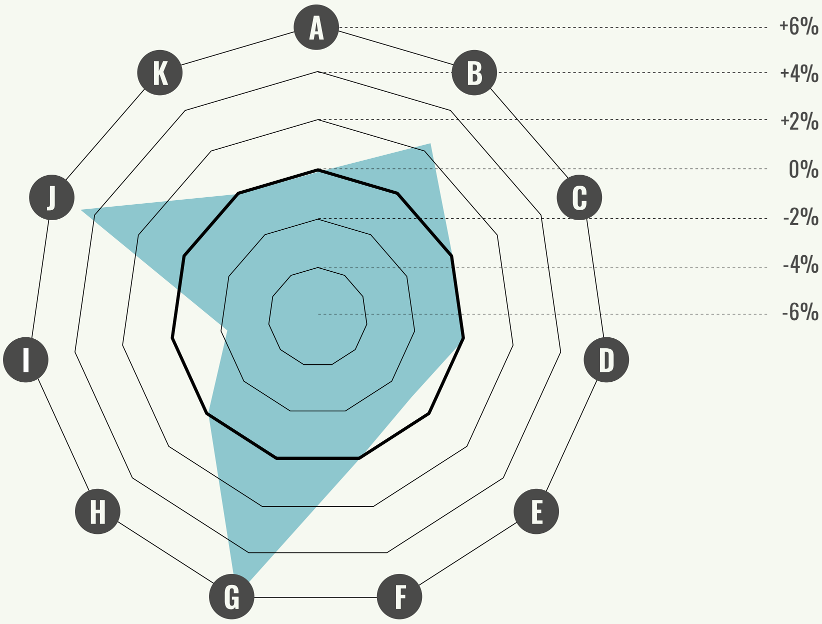
Training and re-qualification of the workforce in the bioeconomy sector (share of workers, % per year)

K

SDG 2.a.2 Total official flows (official development assistance plus other official flows) to the agriculture sector

FIGURE 15.

EXAMPLES OF SPIDER DIAGRAMS AT TERRITORIAL LEVEL - ECONOMIC INDICATORS



A

Value added of bioeconomy sectors ($)

B

Average income of employees in the bioeconomy sectors

C

Employment in each group of bioeconomy subsectors (% of total employment)

D

SDG 9.1.1 Proportion of the rural population who live within 2 km of an all-season road

E

SDG 8.4.1/12.2.1 Material footprint, material footprint per capita, and material footprint per GDP

F

Intellectual property rights (IPRs) (patent, trademark, design) applications in bioeconomy subsectors (number of application per 1000 employees)

G

SDG 9.5.1 Research and development expenditure as a proportion of GDP

H

Change in cropland-based biomass product net trade

I

SDG 8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP

J

SDG 7.2.1 Renewable energy share in the total final energy consumption

K

The country has a sustainable consumption and production (SCP) national action plans or SCP is mainstreamed as a priority or a target into national policies (based on SDG 12.1.1)

Source: Authors' elaboration based on fictitious data

7.2 LIMITATIONS AND WAY FORWARD

The stepwise approach described above proposes a methodology to engage in a discussion with stakeholders that are involved in the setting up of a bioeconomy monitoring framework. The operationalization and 'proof of concept' of the proposed methodology will require further refinement, as well as the clear definition of the aim and scope of the monitoring exercise in each concrete case. The operationalization of the approach will allow also for a review process to monitor the success of the proposed framework, to develop new indicators as needed and to adapt existing indicators in light of policy or sector developments.

The level of ambition of the monitoring framework will have to reflect available resources, timeframe and data, as well the ultimate objective for the M&E exercise. Moreover, the stakeholders will have to identify the scope of their monitoring framework. At national level, this will require, for instance, the identification of the sectors to include in the bioeconomy monitoring exercise. At product level, this may require to focus on specific impacts or segments of the value chains.

Furthermore, the selection of the indicators may go beyond the suggested choice of SMART indicators. Other factors that can inform decisions on indicators may be: policy relevance, robust/high quality data, high impact, existing data stream, comparability, frequency, timeliness and time series, accessibility, etc. The selection criteria will depend on the objectives and scope of the M&E, as well as on the availability of resources and data.

In June 2019, the International Bioeconomy Forum (IBF) provided a mandate to the FAO and the Joint Research Centre of the European Commission to lead a working group on bioeconomy indicators. In cooperation with other interested members, FAO and JRC will develop a guidance note, to support countries as they develop bioeconomy monitoring approaches. This would include help to define and select principles, criteria and indicators, based on best knowledge and good practices. To this end, the proposed stepwise approach will be further developed and refined to fit this task.

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ANNEX 1

MAIN CHARACTERISTICS AND STRENGTHS OF ENVIRONMENTAL, SOCIAL AND ECONOMIC LIFE CYCLE ASSESSMENT

1. LIFE CYCLE ASSESSMENT (LCA)

LCA provides both a holistic picture of a product's environmental impacts and comparisons between stages of the product's life (Dong and Adams, 2012). The most up-to-date International Standards set for the implementation of LCA are ISO 14 040:2006 and 14 044:2006, each providing guidelines and a framework for a high-quality assessment. The latter, ISO 14 044, also provides several requirements and recommendations to increase the comparability of different LCAs, although the comparison is only possible for studies with equivalent assumptions and contexts (ISO 14 044).

LCA covers a broad range of environmental issues. These issues include climate change, freshwater use, land occupation and transformation, aquatic eutrophication, toxic impacts on human health, depletion of non-renewable resources and eco-toxic effects from metals and synthetic organic chemicals. The core reason for considering multiple environmental issues is to avoid burden shifting, which is also why a life cycle perspective is taken. Here burden shifting happens if efforts for lowering one type of environmental impact unintentionally increase other types of environmental impacts.

The quantitative nature of LCA means that it can be used to compare environmental impacts of different processes and product systems. LCA results answer the question "how much does a product system potentially impact the environment?" Part of the answer may be "the impact on climate change is 87 kg of CO_2 equivalents".

2. SOCIAL LIFE CYCLE ASSESSMENT (S-LCA)

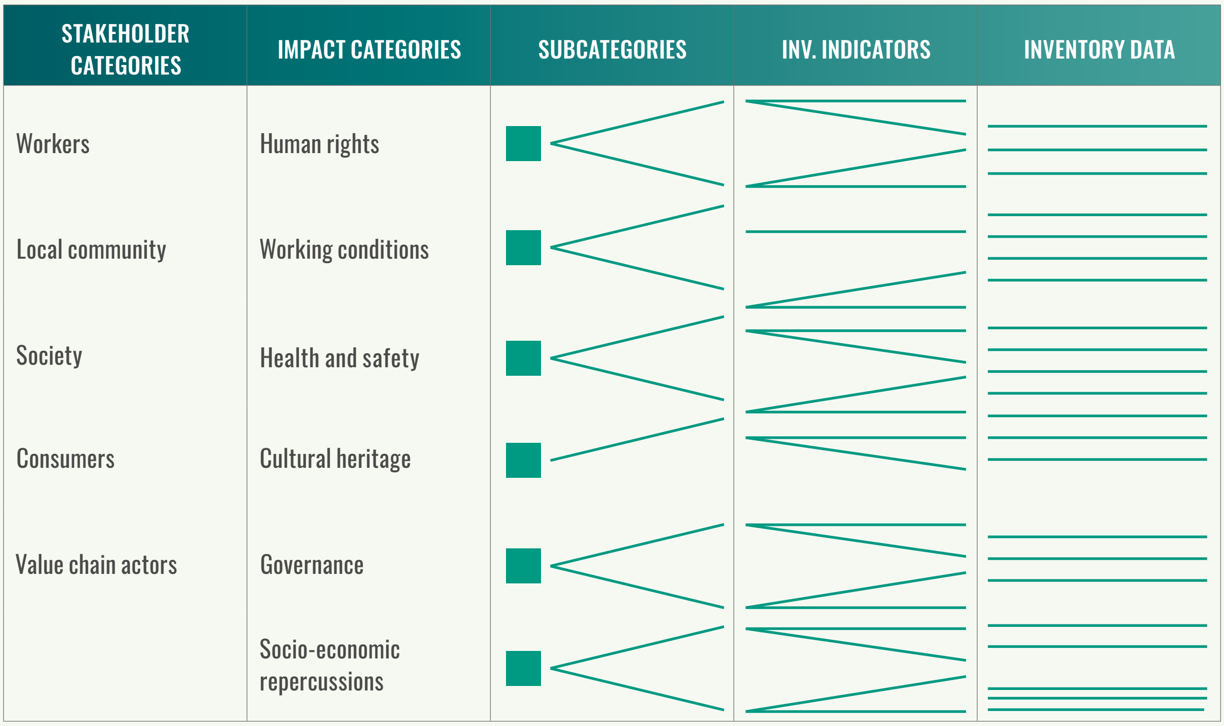
Similar to LCA, S-LCA address the entire life cycle of a product and follows the four phases described in the ISO framework (goal and scope definition, life cycle inventory, life cycle impact assessment and life cycle interpretation). The main difference between LCA and S-LCA is the focus of analysis, while the first one focuses on the environmental aspects of products and commodities, thus physical quantities related to production and disposal, the second one focuses on social impacts of the product, hence organizational aspects of the value chain. Consequently, in addition to the impact categories, S-LCA includes also the stakeholder categories that represent all social groups of actors affected throughout the life cycle of a product. It is worth noting that each stakeholder category is affected by several impact categories and vice versa.

The identification and selection of the stakeholder categories is considered to be the most important as well as the most critical issue in conducting a S-LCA since social criteria can be subjective and influenced by different perspectives and local contexts. The stakeholder categories are identified within the LCI analysis through the involvement of experts and stakeholders that are required to provide input on impacts.

The principal stakeholder categories identified by UNEP-SETAC (UNEP Setac Life Cycle Initiative, 2009: 46) as the "main group categories potentially impacted by the life cycle of a product" are presented in the figure below: (i) Workers/employees, (ii) Local community, (iii) Society (national and global), (iv) Consumers (covering end-consumers as well as the consumers who are part of each step of the supply chain), and (v) Value chain actors. As we can notice by the impact categories, the data needed to perform an S-LCA can be either quantitative or qualitative.

FIGURE A1.

S-LCA ASSESSMENT FRAMEWORK



Source: UNEP-SETAC, 2009 (Adapted from (Benoît et al., 2007))

3. LIFE CYCLE COSTING (LCC)

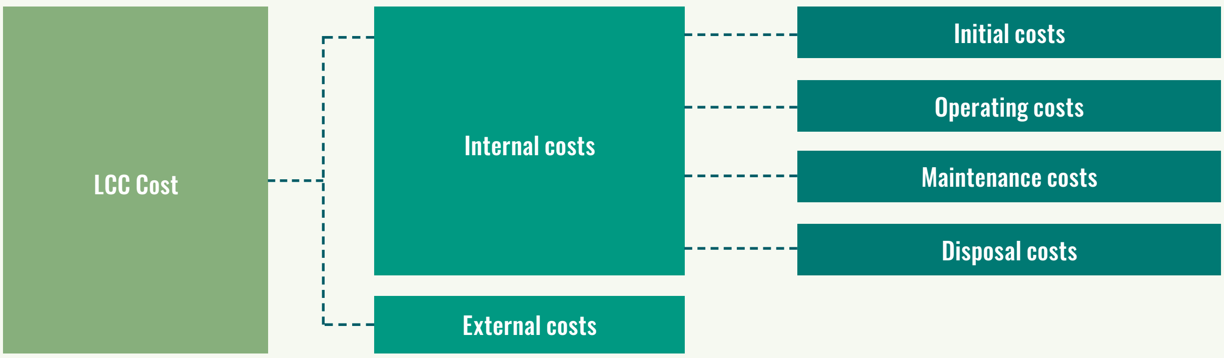
LCC assesses all the costs of a product during its entire life cycle. Costs can be internal, directly linked to the economic nature of a product, or external, concerning external environmental costs incurred during the product life cycle and/or by local communities and the general public (Figure A2). Internal costs include: (i) initial or investment costs, e.g. purchasing price, installation, initial training, (ii) operating costs include, among others, the resources needed for using the product, (iii) maintenance costs comprehend the cost of maintenance services and replacing parts of the product, and (iv) end-of-life or disposal costs.

LCC as well follows the four phases structured by the ISO standard in order to help defining consistent system boundaries for the same product system in order to apply in a complementary way LCC, S-LCA and LCA.

There are two main challenging issues concerning LCC. The first one regards the costs "borne by different actors with very different perspectives of the costs and potentially conflicting goals" (Swarr *et al.*, 2011: 390). Another critical aspect is related to double counting the same costs in both internal and external categories.

FIGURE A2.

LCC ASSESSMENT FRAMEWORK



Source: (OECD, 2016)

Almost fifty countries have placed the promotion of the bioeconomy on their political agendas. However, bioeconomy activities are not necessarily sustainable, and sustainability issues are not often considered in the implementation of the bioeconomy. Considering this, FAO developed a set of Aspirational Principles and Criteria for Sustainable Bioeconomy, which were agreed upon by the International Sustainable Bioeconomy Working Group in 2016 led by FAO. In line with these Principles and Criteria, FAO seeks to provide technical assistance to countries in developing and monitoring the sustainability of the bioeconomy.

The main objective of this report is to review existing approaches for monitoring and evaluation in order to identify already available indicators, from which the authors compiled two comprehensive lists:

- indicators at the territorial level, including bioeconomy-relevant SDG indicators;
- indicators at the product/value chain level, including indicators used for standards, certificates and labels.

To conclude, the authors propose a possible way forward to help countries and practitioners in their monitoring and evaluation efforts: a stepwise approach to select indicators for monitoring and evaluating the sustainability of the bioeconomy.

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