Delivery of sustainable supply of non-food biomass to support a “resource-efficient” Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

Deliverable 5.5:

Guidelines on assessing bioeconomy value chain sustainability performance

Final Version

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About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a "computerised and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

Project coordinator

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Project partners

About this document

This paper is the deliverable D 5.5 which presents brief guidelines on how to apply the sustainability criteria and indicators within the S2BIOM tools and their application.

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List of Acronyms

C	carbon
C&I	criteria and indicators
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact (model)
CED	cumulated energy demand (or primary energy factor)
CFS	Committee on World Food Security
CH_4	methane
CO_2	carbon dioxide
CO_{2eq}	carbon dioxide equivalents
EC	European Commission
EFI	European Forest Institute
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAWS	forest area available for wood supply
FPIC	Free Prior & Informed Consent
FTE	full time equivalent
GBEP	Global Bioenergy Partnership
GEF	Global Environment Facility
GEMIS	Global Emissions Model for integrated Systems
GHG	greenhouse gas(es)
ha	hectare(s)
HNV	high nature value
IC	Imperial College London
IINAS	International Institute for Sustainability Analysis and Strategy
ILO	International Labour Organisation
ILUC	indirect land use change(s)
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre (of the EU)
LCA	life-cycle analysis (or assessment)
LUC	land use change(s)
m^2	square meter
MJ	MegaJoule (10^6 Joule)

N	nitrogen
NA	not applicable
NO_x	nitrogen oxides
NH_3	ammonia
N_2O	nitrous oxide
P	phosphorous
PM_{10}	particulate matter, diameter below 10 micrometer
RED	Renewable Energies Directive 2009/28/EC
SDGs	Sustainable Development Goals
SO_2	sulfur dioxide
SOC	soil organic carbon
TARWR	total actual renewable water resources
UN	United Nations
UNEP	United Nations Environment Programme
VGTT	Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security
WP	Work Package

1. Introduction to the "Sustainability" Work Package

The general objective of S2Biom Work Package 5 (WP5) was to provide an improved understanding among decision-makers in policy and industry regarding **sustainability requirements** in biomass value chains addressed in Theme 1.

This goes beyond previous discussions on sustainability of liquid biofuels and the ongoing discussions on solid/gaseous bioenergy and biomaterials in aiming to develop comprehensive sustainability requirements for **all non-food biomass** in the broader **bioeconomy**[1]. To achieve this, specific objectives of WP5 are:

- Adaptation of the life-cycle-based EC Environmental Footprint methods in order to develop a complementary methodology specific to non-food biomass value chains[2]
- Identification of sustainability criteria and indicators (C&I) for non-food biomass value chains, gap analysis of respective legislation, regulation and voluntary schemes at international, European and Member State level[3]
- Compilation of consistent sustainability C&I for the short- and medium-term bioeconomy, and an outlook for long-term developments[4].
- Development of guidelines for evaluating the environmental performance with the toolset developed in WP4 of all lignocellulosic feedstocks for the various industrial routes, building on existing tools, and extending to bio-based products (chemicals; materials, etc.), and their interrelations – i.e. this report.

To this end, WP5 consisted of five tasks, as shown in Figure 1.

The outcomes of the first three tasks served - in addition to their own value – as an input to Task 5.5.

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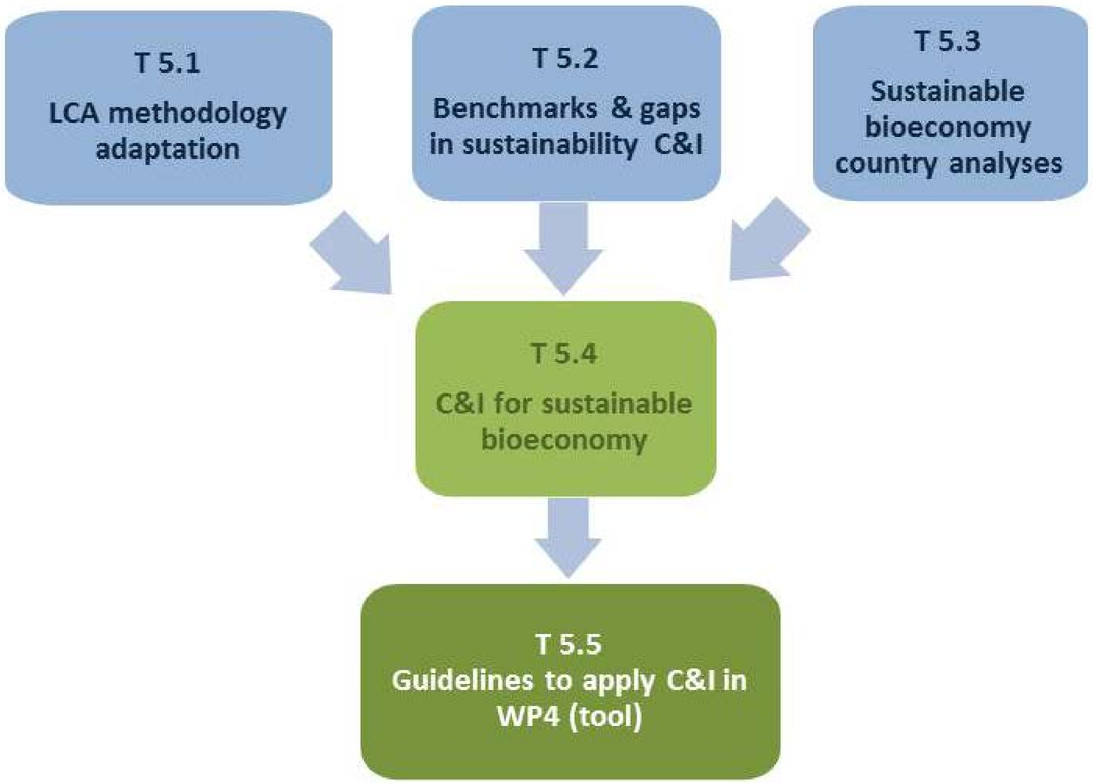
[1] Bioeconomy encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy (EC 2012a+b). For a discussion of activities on bioeconomy sustainability requirements, see Fritsche & Iriarte (2014).

[2] See WP5 Task 5.1 (carried out by the JRC) with its deliverable D5.1 http://www.s2biom.eu/images/Publications/ReqNo_JRC90897_s2biom_del5_1_-_env_sust_ass_meth_-_july_2014.pdf.pdf

[3] See WP 5 Task 5.2 (carried out by IINAS) and the respective deliverable D5.2 http://www.s2biom.eu/images/Publications/IINAS_2015_S2Biom_D5_2_Benchmark_and_gap_analysis_Main_report_30_Mar.pdf as well as Task 5.3 (carried out by IC) with its deliverable 5.3 http://www.s2biom.eu/images/Publications/S2Biom_D5.3.pdf

[4] See WP 5 Task 5.4 (carried out by IINAS) and the respective deliverable D5.4 http://www.s2biom.eu/images/Publications/IINAS_2015_S2Biom_D5_4_Sustainability_C_I_proposal_Main_report_30_Mar.pdf

Figure 1 Structure of Sustainability Activities in S2Biom



Source: own elaboration

Task 5.5 focused on elaborating the guidelines for integration of a harmonised bioeconomy sustainability assessment in all S2Biom tools developed in WP4. Task 5.5 build on Task 5.4 results, and considered two levels of assessments:

- An easy-to-use "traffic light" system aiming at governmental and private decision-makers will identify the sustainability performance for each route, based on default inputs.
- A refined quantitative analysis using the criteria and indicators, and user-specified inputs (within validity ranges) to derive comparative results.

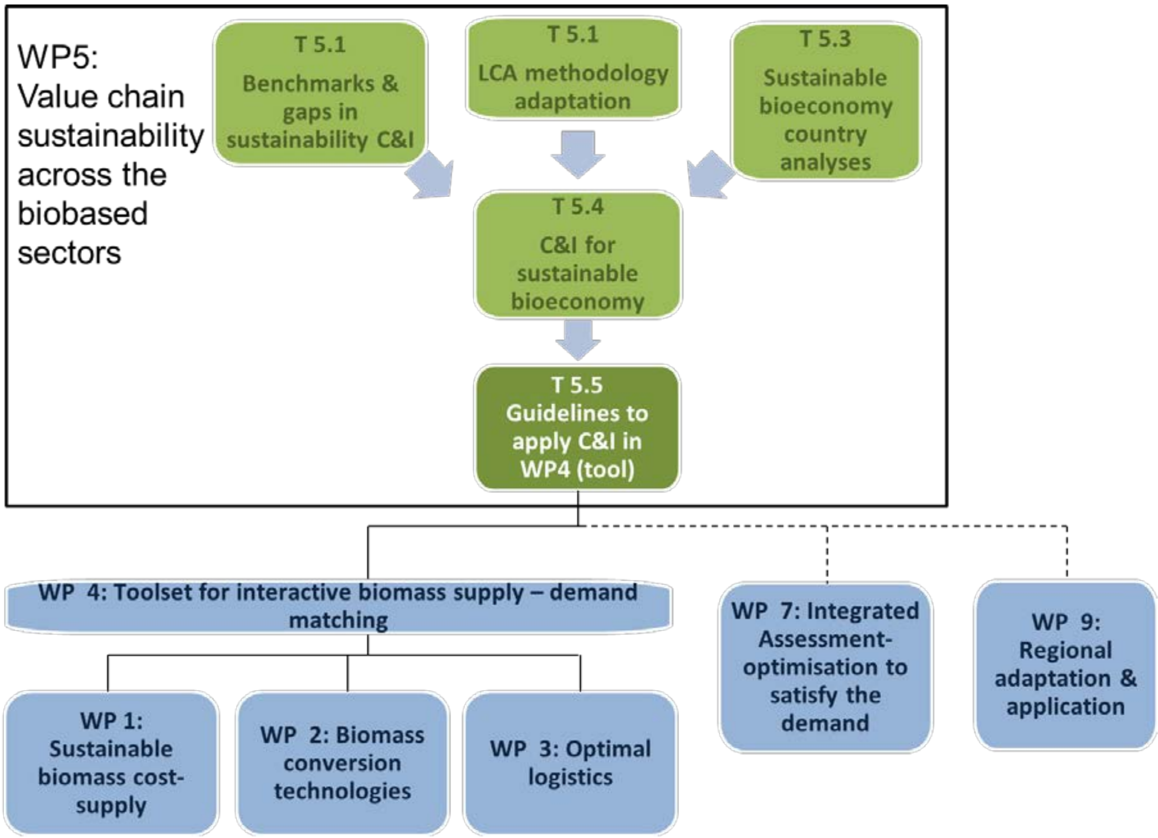
Special consideration was given to previous work[5], and specific tools[6].

[5] The following EU-funded projects were taken into account: Biomass Futures (www.biomassfutures.eu), Biomass Policies (www.biomasspolicies.eu), Biotrade 2020 plus (www.biotrade2020plus.eu), the EU process to establish Product Environmental Footprints (PEF), the European Life Cycle Database (ELCD, see http://eplca.jrc.ec.europa.eu/ELCD3/), as well as the international projects "Bioenergy Environmental Impact Analysis (BIAS) Analytical Framework" of FAO (Fritsche et al. 2010) and the GEF Global Assessments and Guidelines for Sustainable Liquid Biofuels Production in Developing Countries (Franke et al 2013).

[6] The tools considered were Biograce II (http://www.biograce.net/biograce2/), EcoInvent (www.ecoinvent.org), GEMIS (www.gemis.de), and ToSIA (http://tosia.efi.int/).

Furthermore, Task 5.5 helped integrating the sustainability criteria and indicators developed in Task 5.4 into WP1 (biomass availability), WP2 (conversion technologies) and WP3 (optimal logistics), and gave inputs to WP7 (scenarios) and WP9 (case studies), as shown in the following figure.

Figure 2 Interaction of Task 5.5 with other WPs in S2Biom



Source: own elaboration

2. Methodological approach for and implementation of sustainability indicators in the S2Biom Work Packages

The S2Biom project concerns the delivery of sustainable non-food biomass for the bioeconomy. This implies that the sustainability definition must apply to a **broad variety** of products with alternative end-uses (energy, or materials). Given this, Task 5.4 developed an **umbrella approach** for sustainability criteria and respective indicators from which more specific indicators can be derived[7].

The working hypothesis of the S2Biom project was that **all** non-food biomass in the bioeconomy should be subject to **the same** sustainability requirements, regardless of feedstocks and end-uses (bioenergy or bio-based products). The respective C&I are shown in the following table.

Table 1 The S2Biom criteria and indicators for the bioeconomy

Theme	Criterion	Indicator Description		
		#	Indicator	Definition
Environment	1. Resource use	1.1	Land use efficiency	Biomass (including by- and co-products along life cycles) per hectare of cultivated area
		1.2	Secondary resource efficiency	Heating value of biomass output divided by heating value of secondary resource; applies to conversion of residues and wastes
		1.3	Energy efficiency	Cumulative energy requirements (all inputs based on LHV primary energy) compared to outputs
		1.4	Functionality (Output service quality)	Economic value of outputs (€/GJ and €/ton), compared to economic value of heat which could be produced from burning (dried) primary inputs (reference = heat from natural gas ~ 10€/GJ); economic values excluding taxes, for industrial customers
	2. Climate Change	2.1	Life cycle-based CO_2eq including direct land use change	GHG emissions during the whole value chain (i.e. crop growth & harvesting, logistics, pre-treatment and conversion, distribution and end-use phase) in relation to the final output (combination of electricity, useful heat, biofuels & biomaterials)
		2.2	Other GHG emissions	GHG from indirect land use changes (ILUC) and carbon stock changes in forests
	3. Biodiversity	3.1	Protected areas and land with significant biodiversity values	Categories established by the RED: - Protection of land with high biodiversity value (Art. 17.3). Primary forests, areas designated by laws, and other highly biodiverse areas (recognized by international agreements or

[7] Some specific criteria (e.g. recyclability, degradability) relevant for e.g. biomaterials are not explicitly included in S2Biom, as this would be too specific for the "umbrella approach". Yet, recyclability is implicitly covered under the Criterion 1, Indicators 1.1-1.3.

Theme	Criterion	#	Indicator	Definition
				IUCN) and natural and non-natural highly biodiverse grasslands should be excluded. - Protection of land with high carbon stocks (Art. 17.4). Wetlands, continuously forested areas and lightly forested areas with this status in January 2008 but no longer have it should be avoided (not applicable if the status in January 2008 is maintained). - Protection of peatlands (Art. 17.5).
		3.2	Biodiversity conservation and management	"Agrobiodiverse cultivation" (crop rotation; diversity in the landscape; avoidance of alien species), amount of chemicals (pesticides/herbicides), and release/ monitoring of Genetically Modified Organisms
	4. Soil	4.1	Erosion	Probability of erosion where mitigation measures are not feasible
		4.2	Soil Organic Carbon	Probability of soil organic carbon loss where mitigation measures are not feasible (it depends on the type of crops - perennials and annual crops- and respective land management)
		4.3	Soil nutrient balance	Probability of nutrient balance loss where mitigation measures are not feasible
	5. Water	5.1	Water availability and regional water stress	Water use in relation to TARWR (total actual renewable water resources), or average replenishment from natural flow in a watershed
		5.2	Water use efficiency	Water use for biomass production (cropping), irrigation, and processing/kg biomass
		5.3	Water quality	Presence of water pollutants (e.g. nitrate, phosphorous, pesticides, biochemical oxygen demand)
	6. Air	6.1	SO_2 equivalents	Life cycle emissions of acidifying gases (SO_2, NO_x, NH_3 etc.) from bioenergy provision, expressed in SO_2 equivalents and calculated in accordance to GHG emissions
		6.2	PM_{10}	Life cycle emissions of PM_{10}, calculated in accordance to GHG emissions
Social	**7. Participation and transparency**	7.1	Effective participatory processes	Enable effective participation of all directly affected stakeholders by means of a due diligence consultation process, incl. Free Prior & Informed Consent (FPIC) when relevant
		7.2	Information transparency	Freely availability of documentation necessary to inform stakeholder positions in a timely, open, transparent and accessible manner
	8. Land Tenure	8.1	Land Tenure assurance	Compliance with the Voluntary Guidelines on the Responsible Governance of Tenure of Land to secure land tenure and ownership (CFS 2012)
	9. Employment and labor	9.1	Direct job equivalents along full value chain	Number of jobs (gross figure) from biomass along the full value chain, given in FTE
		9.2	Direct job equivalents in the	Number of jobs (gross figure) from biomass in the biomass consuming region (or country), given in FTE

Theme	Criterion	#	Indicator	Definition
			biomass consu-ming region (or country)	
		9.3	Human and Labour Rights	Adherence to ILO (1998) principles and voluntary standards
		9.4	Occupational safety and health for workers	Measures taken to guarantee occupational and health safety for workers
	10. Health risks	10.1	Risks to public health	Measures taken to safeguard public health, i.e. regulation of noise level and prevention of accidents
	11.Food, fuelwood	11.1	Food and fuelwood supply security	Measures to avoid risks for negative impacts on price and supply of national food basket, fuelwood and other products.
Economic	12. Production costs	12.1	Current levelised life-cycle cost	Current levelised life-cycle cost, excluding subsidies (excl. subsidies, incl. capital and operating cost)
		12.2	Future levelised life-cycle costs	Future levelised life-cycle cost, excluding subsidies (excl. subsidies, incl. capital and operating cost)

Source: S2Biom D5.4 (see Leire & Fritsche 2015)

The next table shows how each indicator is to be **measured**, depending on the biomass categories.

This table guides the application of sustainability indicators throughout the S2Biom project.

Table 2 Application of S2Biom sustainability indicators for biomass categories

#	Indicator	Biomass crops on agricultural land	Forest biomass, incl. primary residues	Secondary wood residues	Secondary residues from industry	Wastes
1.1	Land use efficiency	Full LCA		NA		
1.2	Secondary resource Efficiency	NA		Full LCA MJ_{out}/MJ_{prim} or MJ_{out}/MJ_{ton}		
1.3	Energy efficiency	Full LCA MJ_{out}/MJ_{prim} or MJ_{out}/MJ_{ton}		NA		
1.4	Functionality (Output service quality)	Full LCA				
2.1	Life cycle-based CO_2eq including direct land use change	Avoidance of direct land cover changes. Full LCA to determine GHG emissions.		LCA for GHG emissions, no upstream for residue/waste (RED approach)		
2.2	Other GHG emissions	Avoidance of ILUC (only land "set free" conside-red)	No stemwood	No displacement of previous uses		
3.1	Protected areas and land with significant biodiversity values	Exclusion of use of protected areas, high nature value farmland	Increase of protected areas	NA		
3.2	Biodiversity conservation and management	No use of Natura 2000/ HNV farmland, no grassland conversion, no use of fallow land if share < 20%, no mono-cultures	Increase in retained trees	NA		
4.1	Erosion	Maximum slope limits for perennials, use to protect from erosion	Restriction of harvesting on slopes	NA		
4.2	Soil Organic Carbon	No use of land with high C stock, protection of SOC	Restricted residue extraction	NA		
4.3	Soil nutrient balance	Restricted extraction to maintain soil fertility	Restricted residue extraction	NA		
5.1	Water availability and regional water stress	Crops only where minimal water require-ment is met by preci-pitation, no irrigation for perennials	NA	NA		
5.2	Water use efficiency	Preference for water use efficient crops in drought- prone regions	NA			
5.3	Water quality		Restricted residue extraction	NA		
6.1	SO_2 equivalents	Full LCA to determine acidifying emissions				
6.2	PM_{10}	Full LCA to determine acidifying emissions				
7.1	Effective participatory processes	Check if VGTT are applied/met		NA		
7.2	Information transparency	Make project information publicly available, apply FPIC principle				
8.1	Land tenure assurance	Check if VGTT are applied/met		NA		
9.1	Direct jobs along value chain	Full LCA to determine employment				
9.2	Direct jobs in biomass consuming region (or country)	Calculate only direct employment, no LCA				

#	Indicator	Biomass crops on agricultural land	Forest biomass, incl. primary residues	Secondary wood residues	Secondary residues from industry	Wastes
9.3	Human and Labour Rights	Check if ILO standards are implemented				
9.4	Occupational safety and health for workers	Check if ILO standards are implemented				
10.1	Risks to public health	Consider “hot spots” in value chains				
11.1	Food, fuelwood and other products supply security	Avoidance of food/feed competition: only land “set free” considered	No displace-ment of previous uses	No displacement of previous uses		
12.1	Current levelised lifecycle cost	Full calculation for value chain				
12.2	Future levelised life-cycle costs	Full calculation for value chain				

Source: own compilation; NA = not applicable

As can be seen, not all indicators apply to all biomass categories – the main differences are between “land-based” biomass feedstocks (i.e. from agriculture and forests), and residues/wastes for which no land use is assumed.

Furthermore, there are many **qualitative** indicators (i.e. they describe a certain activity), while 11 out of the 27 indicators are **quantitative** (i.e. their measure is a number expressed in certain units).

2.1. Sustainability approach and indicators in WP1

The biomass resource potentials assessment in WP1 differentiates several potentials, which include varying constraints to biomass supply – and one type of constraints are sustainability considerations. The potential levels were labelled as technical, “base” and “user defined”. They differ in the type and application of constraints. The technical and the base potentials are determined applying assumptions that are defined consistently across all biomass source categories (e.g., agriculture, forestry), whereas the third type can be “composed” by the user in applying selected constraints (user-defined potentials).
The basic generic definitions are as follows:
The technical potential represents the absolute maximum amount of ligno-cellulosic biomass potentially available for energy use assuming the absolute minimum of technical constraints and the absolute minimum constraints by competing uses. This potential illustrates the maximum that would be available without consideration of sustainability constraints.

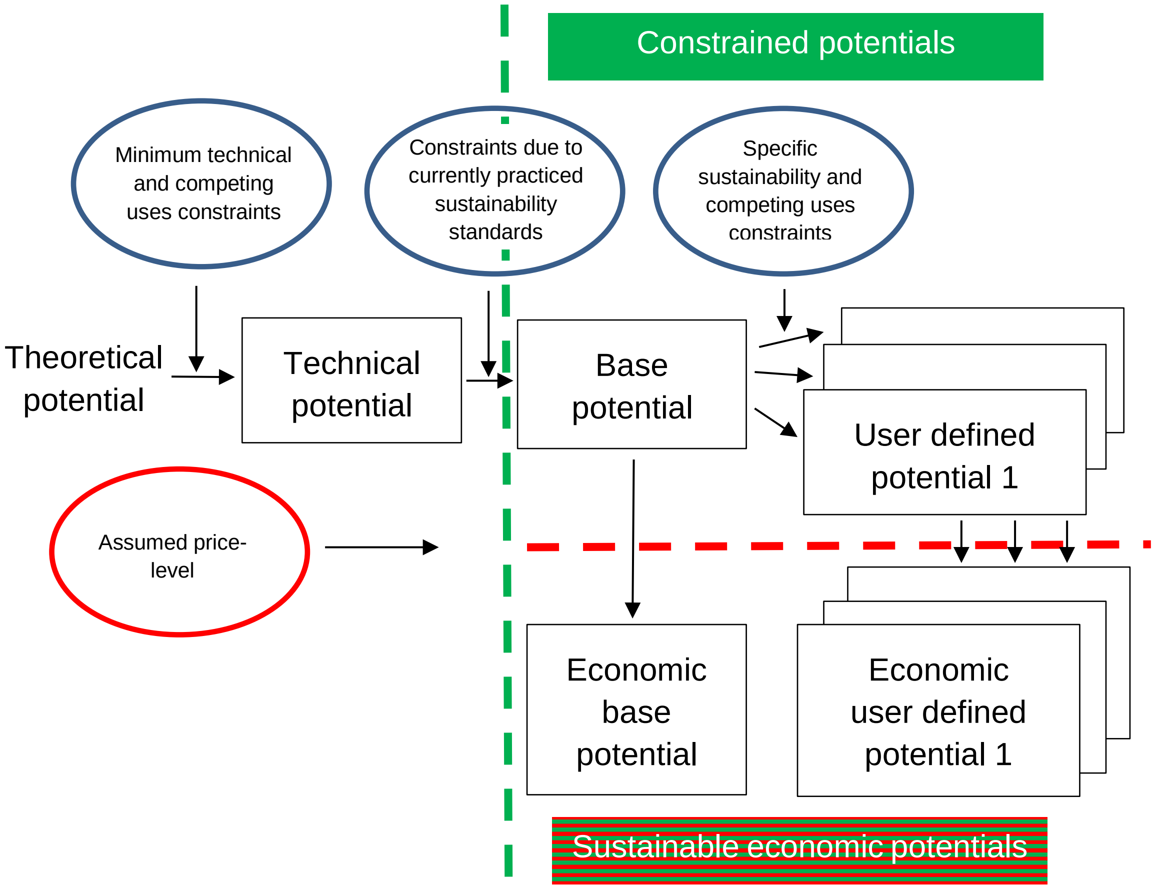
S2Biom WP1 defined the base potential as the technical potential plus additional considerations of agreed sustainability standards for agriculture, forestry and land management. These include sustainability standards in CAP (Common Agricultural Policy) for agricultural farming practices and land management and in (national and regional) forestry management plans for forests.

This also includes the consideration of legal restrictions such as restrictions from management plans in protected areas and sustainability restrictions from current legislation. This corresponds to the application of the basic set of indicators applied (see D5.4).

The <u>user-defined potentials</u> vary in terms of type and number of considerations per biomass type. The user defined potentials differ in the constraints considered vs the base potential and among each other. The user can choose the type of biomass and the sustainability considerations he/she would like to add and calculate the respective potential. This flexibility is meant to help the user to understand the effect on the total biomass potential of one type of consideration against the other. These can include both increased potentials (e.g. because of enhanced biomass production) or more strongly constrained potentials (e.g. because of selection of stricter sustainability constraints).

The following figure illustrates the types of potentials determined in S2Biom.

Figure 3 Different levels of potentials presented in S2Biom



Source: own compilation

2.1.1. Forestry

For forestry, the different potential levels and the constraints applied to calculate these potentials are presented in the following table[8].

[8] User potentials 1-4 represent additional sustainability constraints compared to the base potential. Further detail on the application of particular constraints is given in Deliverable 1.6 (Dees et al. 2017).

Table 3 Overview of woody biomass potential types used in S2Biom

Potential	Area/ basis	Yield, growth	Technical & environmental constraints	Use competition	Mobili-sation
Technical	Forest area available for wood supply, excl. protected and protective areas, where no harvesting is allowed (Indicator 3.1)	Growth based on regional to national conditions, incl. changes in incre-ment due to climate change. Yield according to regional manage-ment guidelines (age limits for thinnings + final fellings)	Max. volume of annually harvested stemwood during 50-year periods (Indicator 1.1) Technical constraints on residue and stump extraction (recovery rate) (Indicator 1.1)	None	None
Base	As for technical potential	As for technical potential	As for technical potential, but considering additional constraints for residue and stump extraction: -Site productivity (1.1) -Soil and water protection: rugged-ness, soil depth, soil surface texture, soil compaction risk (4.2, 4.3,5.3) -Soil bearing capacity. (3.1)	None	None
High	As for technical potential	As for technical potential	As technical potential, but considering additional constraints for residue and stump extraction: • Site productivity • Soil and water protection: ruggedness, soil depth, soil surface texture, soil compaction risk • Soil bearing capacity	None	None
UP1	Reduction of FAWS by 5%	As for technical potential	Equivalent to increase of protected forest area by 5%.	None	None
UP2	Reduction of FAWS by 5%	As for technical potential	Increase of protected forest area by 5% and increase in retained trees by 5%.	None	Reduction in harvest by 5%
UP3	As for technical potential	As for technical potential	No stump extraction.	None	None
UP4	Reduction of FAWS by 5%	As for technical potential	Increase in protected forest by 5% plus increase in retained trees by 5% plus no stump extraction	None	Reduction in potentials by 5%
UP5	As for base potential	As for base potential	As for base potential	Roundwood for material use subtracted from base potential	None
UP6	As for base potential	As for base potential	As for base potential	Roundwood for material use excl. for pulp and paper and board industry	None

Potential	Area/ basis	Yield, growth	Technical & environmental constraints	Use competition	Mobili-sation
				subtracted from UP4.	
UP7	As for UP4	As for UP4	As for UP 4	Roundwood for material use subtracted from BP.	As UP4
UP8	As for UP4	As for UP4	As for UP4	Roundwood for material use excl. pulp and paper and board industry subtracted from UP4.	As for UP4

Source: own compilation based on S2Biom Deliverable 1.6 (Dees et al. 2017)

2.1.2. Primary residues from agriculture

Biomass residues includes primary residues from arable crops (straw and stubbles), pruning, cutting and harvesting residues from permanent crops (see Dees et al. 2017). The potential supply of agricultural residues was estimated for 2012, 2020 and 2030 using as a main input the land and yield predictions made for these years by the CAPRI model for most of the European countries covered in S2Biom. For the non-EU countries not covered in CAPRI, national agricultural statistics at regional level were used. First, technical potential of the agricultural residues was estimated (see Table 2). Second, environmental constraints were defined and quantified that reduce the harvestable amount of biomass. Step 3 combined the technical potentials from Step 1 with the constraints for the biomass potential types (Step 2).

The assessment of residues from arable crops builds on methodologies and assessments developed in the EU projects BiomassPolicies (www.biomasspolicies.eu) and Bioboost (www.bioboost.eu). The overall advantage of using agricultural residues is that it is a biomass with low ILUC risk.

From a sustainability perspective, there is concern about what sustainable removal rates for straw and prunings, particularly in relation to maintaining soil organic carbon content. Currently, these residues are not always harvested and/or removed from the field, and their mobilisation often requires changes in farming practices. Following this reasoning, there are three types of potentials:

- The **Technical potential** represents the absolute maximum amount of lignocellulosic residues potentially available assuming the absolute minimum of technical constraints.
- The **Base potential** which takes account of what amount of residues are needed to keep the soil organic carbon (SOC) content stable. The rest of the biomass is not needed for SOC stabilization and thus can be seen as potential, as this amount could be removed from the field. The assessment of this potential uses the Miterra model that calculates carbon balances, taking account the specific regional climatic and soil circumstances and yield levels at the average of region (NUTS2 level).

- The **User-defined potentials** which for both straw and stubbles and prunings build on current practices and competing use levels.

Table 4 Agricultural residue potentials and sustainability indicators

Potential	Area/ basis	Yield, growth	Technical & environmental constraints	Use competition	Mobilisation
Technical (straw & stubbles)	Area in 2012, 2020, 2030 with cereals, rice, sunflower, rape, corn maize	Growth based on regional growing conditions & management. Yield according to regional averages including expected development of yields for 2020 and 2030	Maximum volume of straw and stubbles that could be harvested in 2012, 2020 and 2030	None	None
Technical (prunings permanent crops)	Area in 2012, 2020, 2030 with fruit trees, vineyards, olive & citrus	Growth based on regional growing conditions & management. Yield according to regional averages including expected development of yields for 2020 and 2030	Maximum volume of prunings and cuttings that could be harvested in 2012, 2020 and 2030	None	None
Technical (sugarbeet leaves & tops)	Area in 2012, 2020, 2030 with sugar beet	Growth based on regional growing conditions & management. Yield according to regional averages including expected development of yields for 2020 and 2030	Maximum volume of sugarbeet leaves and tops that could be harvested in 2012, 2020 and 2030	None	None
Base (straw & stubbles)	As for technical potential	As for technical potential	Only biomass not needed to keep SOC stable, assessed by C removed with residues, and SOC level to be maintained (Indicator 4.2)	None	None
Base (prunings permanent crops)	As for technical potential	As for technical potential		None	None
Base (sugar beet leaves & tops)	As for technical potential	As for technical potential	Removal of leaves and tops from field is allowed only in nitrate vulnerable zones where N surplus needs to be reduced through removal of N-rich biomass. (Indicator 4.3)	None	None
User potential (straw & stubbles)	As for technical potential	As for technical potential	As in base	For cereal straw. demands for animal bedding & feed are subtracted. For rice straw, corn stover and sunflower and rape stubbles, no competing uses are assumed.	None
User potential (prunings & cuttings)	As for technical potential	As for technical potential	All pruned material that is currently not used to maintain SOC and soil fertility is available. Thus, the part that is currently	None	Potential not used for maintain SOC level and fertility according to

Potential	Area/ basis	Yield, growth	Technical & environmental constraints	Use competition	Mobilisation
			removed for energy uses or is burned with/ without energy recovery is seen as potential. This follows the common treatment practices of prunings as inventorised in the EUROpruning project.		current practices. Mobilized gradually as it requires changed management. Availability: 50% in 2012, 60% in 2020, 70% in 2030.

Source: own compilation based on S2Biom Deliverable 1.6 (Dees et al. 2017)

2.1.3. Dedicated crops for lignocellulosic biomass on agricultural area

The theoretical potential (yield potential) was defined as the maximum amount of crop biomass that could be annually harvested, not considering biophysical limits. For the technical potential assessment of perennials it is, therefore, logical to consider all types of lands but it is recommended especially to put effort in identifying lands that are no longer productively used for food and feed production (released land, fallow), but also other unproductive (marginal) lands.

The S2Biom indicators (see Table 2) were used to identify land suitable for the production of biomass crops and to select suitable woody and herbaceous crops per location. The S2Biom indicators represent a wider interpretation of the RED criteria, as it is assumed that they are **applied to all** biomass, and not only to feedstocks used for liquid biofuels. The S2Biom assessment of the base potential used the following indicators to guide the land suitability and allocation:

1) Avoid competition with food and feed production for the economic and sustainability considerations already discussed in the former. Overall it is clear that mobilisation of perennial biomass cropping is not expected to take off on good agricultural lands.
2) Make the RED sustainability criteria for biofuels applicable as indicators for solid and gaseous biomass sources to be used for producing heat, electricity and chemicals/materials.
3) Integration of CAPRI unused land as available for perennial cropping, taking into account yields, water requirements and cost levels.

THE S2Biom indicators were implemented to identify land available for dedicated biomass crops and make a selection of best suitable perennial biomass crops per region in Europe. The indicators were also used to assess different dedicated cropping potentials, and include restriction of biomass production in protected areas (national and international), restriction on areas with high biodiversity value (Natura 2000 and HNV farmland) and land with high carbon stock (primary forest and wooded land, wetlands and peatlands), as well as promoting the use of surplus land.

The S2Biom indicators – following the RED - also set a maximum slope limit for cultivation and require that perennial crops are grown only on sites susceptible to soil erosion; that management practices (crop choice and yields) are adapted to local biophysical conditions, particularly no depletion of natural water resources. In addition, they should also enhance agrobiodiversity and lower soil erosion risks.

2.2. Sustainability approach and indicators in WP2

The S2Biom sustainability indicators were developed to support the analysis and assessment of biomass value chains (Iriarte & Fritsche 2015). In WP2, the **database** for conversion technologies in biomass value chains was developed and integrated into the S2Biom online toolset[9]. The technology data do not contain any sustainability information, i.e. data is given only for the technological characteristics, investment costs, and direct employment.

To give users information about the sustainability performance of biomass value chains, the following approach was developed in WP5:

A relevant part of the S2Biom sustainability indicators is quantitative, and most of these indicators are measured through so-called **life-cycle analysis** (LCA)[10] which gives a comprehensive representation of the full value chains of biomass systems. Life cycles encompass resource extraction (e.g. plantation, forest, waste collection), processing (e.g. pelletisation) and conversion (e.g. biorefinery, boiler for process heat, CHP plant for electricity and heat), and include transport of biomass feedstocks, and intermediate products.

Furthermore, the materials for the construction of the processes are included, as well as waste disposal ("end-of-life"). This "cradle-to-grade" approach was developed over several decades, and is guided by an ISO standard (ISO 2006a+b).

There are many tools for LCA, but most use proprietary software and require respective licensing. An exception is the publicly available GEMIS model and database[11], which is in the public domain since 1990, and has been applied for LCA in the biomass domain in several EU and EEA projects and studies.

The following table maps the S2Biom sustainability indicators with the respective quantitative results of GEMIS.

9 http://s2biom.alterra.wur.nl/web/guest/conversion

10 LCA is originally the acronym for "life cycle assessment", as codified in the ISO Standards 14000ff. In S2Biom, LCA stands for life cycle **analysis**, indicating that not a "full" LCA according to ISO is carried out, but only the **analytical** parts, i.e. scoping, and life cycle inventory

11 See www.gemis.de for details, and the brief overview given in Fritsche (2017).

Table 5 S2Biom sustainability indicators for the bioeconomy and their quantification with GEMIS

No.	Indicator name	Quantifiable with GEMIS?
1.1	Land use efficiency	Y
1.2	Secondary resource efficiency	Y
1.3	Energy efficiency	Y
1.4	Functionality (output service quality)	-
2.1	Life cycle GHG emissions (CO_2eq), including direct LUC	Y
2.2	Other GHG emissions	(possible)
3.1	Protected areas and land with significant biodiversity values	N
3.2	Biodiversity conservation and management	N
4.1	Erosion	N
4.2	Soil Organic C	N
4.3	Soil nutrient balance	N
5.1	Water availability and regional water stress	N
5.2	Water use efficiency	(possible)
5.3	Water quality	(possible)
6.1	SO_2 equivalents	Y
6.2	PM_{10}	Y
7.1	Effective participatory processes	-
7.2	Information transparency	-
8.1	Compliance with VGGT to secure land tenure and ownership	-.
9.1	Full direct jobs equivalents along the full value chain	Y
9.2	Full direct jobs equivalent in biomass consuming region (or country)	(possible)
9.3	Human and Labour Rights	-
9.4	Occupational safety and health for workers	-
10.1	Risks to public health	-
11.1	Risks for negative impacts on price/supply of food basket/fuelwood	-
12.1	Levelised life-cycle cost (excl. subsidies)	(possible)

Source: own elaboration; "-" means not applicable, as the indicator is not quantitative

As can be seen, 18 of the 27 S2Biom indicators are quantitative, i.e. GEMIS **could**, in principle, calculate those.

Yet, GEMIS currently does **not** cover some indicators (e.g. 1.4 Functionality, 4.1 Erosion, 4.2 Soil organic carbon), and some others (e.g. 5.1 and 9.2) are regionalized so that additional data would be needed.

Thus, GEMIS can determine a – relevant – **subset** of the S2Biom indicators.

This quantitative subset of S2Biom sustainability indicators was then calculated with GEMIS for selected biomass value chains related to the conversion processes in the S2Biom database, and results were made **directly available to users** in an Excel spreadsheet[12]. The results were differentiated for the 2020 and 2030 time horizon, and the conversion of S2Biom conversion technology data for the modelling in GEMIS is given in an extra worksheet in the Excel file.

Furthermore, users can download a brief explanation of the GEMIS model (Fritsche 2017) to inform about scope, system boundaries, and data background.

2.3. Sustainability approach and indicators in WP3

The S2Biom WP3 developed tools for identifying optimal logistics for the regional implementation of biomass plants, and the respective spatial analyses, and carried out several case studies.
The approach to sustainability and respective indicators is discussed in Section 2.4.3 with regard to the specific tools.

2.4. Sustainability approach and indicators in WP4

2.4.1. Sustainability in the S2Biom toolset

In the S2Biom online toolset[13] which was developed in WP4, the sustainability aspects were integrated into the "biomass chain data" part in an **own submenu** and respective webpage[14].
This page offers direct links to the WP5 deliverables for downloading, and an "extract" of the S2Biom **sustainability indicators** as an Excel file for downloading[15] so that users can directly use the indicator tables, which were differentiated for the two main biomass feedstock categories (land-based biomass, and residues and wastes).

2.4.2. Sustainability indicators for the S2Biom conversion technologies and selected biomass value chains

In addition, the value chain **LCA results** (see Section 2.2) are available to users for download in an Excel spreadsheet[16].

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12 See http://s2biom.alterra.wur.nl/data/Conversions%20technologies_sustainability.xlsx

13 http://s2biom.alterra.wur.nl/web/guest/home

14 http://s2biom.alterra.wur.nl/web/guest/value-chain-sustainability1

15 http://s2biom.alterra.wur.nl/data/Sustainability%20Indicators_S2BIOM%20-%20final.xlsx

16 http://s2biom.alterra.wur.nl/data/Conversions%20technologies_sustainability.xlsx

2.4.3. Sustainability in the S2Biom modelling tools

The specific modelling tools in the S2Biom toolset offer a more restricted coverage of the S2Biom sustainability indicators:

- Bio2Match[17] is considering only the physical properties of biomass feedstocks and intermediate products, i.e. it does not give sustainability information.
- BeWhere[18] considers costs and GHG emissions in the optimization of biomass plant localization.
- LocaGIStics[19] builds on BeWhere in localizing optimal plant sites in more detail, and considers costs, net energy yield, and GHG emissions.

These restrictions result from the limited data availability during the S2Biom project work phases, and limitations of the optimization concepts used in BeWhere and LocaGIStics.

Thus, the larger number of sustainability indicators calculated with GEMIS for the selected biomass value chains (see Section 2.2) should be used as a **screening tool** either before BeWhere and/or LocaGIStics are applied to specific feedstock-technology-region settings, or after BeWhere and/or LocaGIStics runs, to check how the selected biomass value chains compare with regard to the broader set of quantified sustainability indicators calculated with GEMIS.

During this screening, users can address both the **non-quantifiable** sustainability indicators and the ones requiring specific **regional** data, as the respective information on sites and value chains can be collected.

2.5. Sustainability approach and indicators in WP7

The S2Biom WP7 developed and analysed **scenarios** for the bioeconomy in the EU28 until 2030, taking into account the cost-supply curves developed in WP1, the technology data from WP2, and demand considerations.
Due to the optimization logic of the RESOLVE model used in WP7, the scenario results address **cost and GHG emissions** as the key sustainability indicators[20]. It must be noted, though, that the cost-supply curve development in WP1 already

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17 http://s2biom.alterra.wur.nl/matchingtoolviewer.pdf

18 http://s2biom.alterra.wur.nl/doc/BeWhere_Description.pdf

19 http://www.s2biom.eu/images/Publications/D3.5_Formalised_stepwise_approach_for_implementing_logistical_concepts_161118.pdf

20 http://www.s2biom.eu/images/Publications/D7.3_S2Biom_Integrated_Assessment_Final.pdf

reflected many of the S2Biom sustainability indicators (see Section 2.1) so that the "screening logic" discussed above for the WP4 tools has implicitly been applied already.

2.6. Sustainability approach and indicators in WP9

S2Biom WP9 carried out several **case studies** to develop and test the tools and their database, and to inform decision-makers about the application of the S2Biom toolset[21].

Furthermore, "strategic" case studies helped engaging and informing stake-holders in several regions about sustainable bioeconomic options.

The logistical case studies used the sustainability indicators of the respective S2Biom tools (see Section 2.4.3), while the strategic case studies did not address sustainability issues beyond the biomass potential stage (see Section 2.1), except the Germany-Poland case study[22], which used the sustainability approach of the EU FP7 BIOBOOST project[23].

This approach is based on the GBEP indicators (GBEP 2011), and combines the LCA approach as specified by ISO (2006a+b) with monetizing environmental aspects into "external cost". The key focus of the Germany-Poland case study was to determine the sustainable straw potential, and the approach taken is very similar to the WP1 approach for residues and wastes (see Section 2.1).

The S2Biom "umbrella" approach took up the additional LCA-based indicators from GBEP[24] so that there is good compatibility as well.

21 http://www.s2biom.eu/images/Publications/D3.4_D3.6_S2Biom_Logistical_case_studies_cover_report.pdf

22 http://www.s2biom.eu/images/Publications/S2biom---T932---SCS-Germany-Poland---report.pdf

23 http://www.bioboost.eu/uploads/files/bioboost_d6.4_sustainability_assessment_v1.2-final.pdf

24 For a discussion of the GBEP indicators with regard to the S2Biom umbrella approach see S2Biom Deliverable 5.2 (Iriarte et al. 2015).

3. Summary of the S2Biom sustainability approach and the developed guidelines, and respective limitations

3.1. Brief summary of the role of sustainability indicators in the S2Biom workflow and its outcome

The S2Biom sustainability indicators developed in WP5 have been taken up in the overall project[25], especially in the analysis of sustainable potentials (WP1, see Section 2.1), and the S2Biom toolset (WP4, see Section 2.4).
Thus, the ambition to make the sustainability approach applicable and useable for the S2Biom project work and its prospective future application was realised.
Yet, the overall uptake of the approach was lacking as regards two aspects:

- The integration of the full S2Biom sustainability indicators into the development of the specific tools (Bio2Match, BeWhere, and LocaGIStics, see Section 2.4.3) was not possible, as the focus of these tools was to **optimize** – especially the trade-off between the key indicators cost, and GHG emissions, not to provide a comprehensive sustainability analysis. The successful integration of the sustainability indicators into the work on the potentials (WP1), though, implies that the specific tools using these potentials also "carry over" the sustainability considerations. Furthermore, the S2Biom social criteria and respective indicators are – with the exception of employment – **qualitative** aspects, for which translation into quantitative optimization is problematic, disregarding whether optimization is carried out by linear programming models, or heuristically.
- Similarly, and due to the - planned - parallel development of the S2Biom sustainability indicators in WP5 and WP9 work on the case studies, full integration was not possible. As the case studies did not have the objective to "test" or apply the WP5 results, this is not a weakness, but a consequence of the overall workflow.

3.2. The guidelines for the sustainability indicator application

The developed **guidelines to measure** the S2Biom indicators (see Table 2) and the **procedural guidelines** to apply quantitative LCA results as a **screening tool** (see Section 2.4.3) are workable solutions for the S2Biom toolset as a whole.

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25 Note that the S2Biom approach has also been taken up in the parallel EU IEE projects BiomassPolicies (www.BiomassPolicies.eu), and BioTrade2020plus (www.BioTrade2020plus.eu).

3.3. Limitations of the S2Biom sustainability approach

The S2Biom sustainability criteria and indicators were developed (mainly) from discussions around bioenergy (and biofuels), and extended from that to – principally - all of the bioeconomy in a cross-sectoral approach, as discussed in Deliverable 5.4 (Iriarte & Fritsche 2015). In that regard, the S2Biom work benefitted from developments in the realm of (voluntary) sustainability certification schemes for biomass, especially ISCC and RSB, which tend to become more “integrative” and move beyond bioenergy to “all” biomass (Iriarte et al. 2015). There is clear evidence that the (scientific and political) discussions on the sustainability of bioenergy/biofuel is a sound bases from which the sustainability of the broader bioeconomy can be explored (Lamers et al. 2016).
Yet, work on sustainability approaches for biomaterials, and bio-based products in general, is – in comparison to the broad base of articles, projects, studies and policies addressing the sustainability of bioenergy and biofuels – still rather limited, both in the literature, and in political and public discussions. Furthermore, some of the specific issues relevant for biomaterials (see footnote 7) are of small relevance for e.g. biomass use for energy, food or feed, and the core issue of GHG mitigation is highly relevant for bioenergy and biomaterials, but so far less for food and feed products. Thus, a “full integration” of all aspects relevant in all sectors of the bioeconomy is yet an unfulfilled ambition.
The S2Biom umbrella approach has “stepped over” this limitation by synthesizing criteria and indicators into a **common aggregate,** which is applicable across the sectors of the bioeconomy. This meta concept is scientifically sound and was accepted in the broad stakeholder discussions held within S2Biom WP5, but it does not deliver on the above mentioned “full integration”.

4. Perspectives for further work

It remains to be seen if future work can further bridge the conceptual differences in defining sustainability indicators between the bioenergy/biofuel, biomaterials and food/feed sectors of the bioeconomy. This is **not only** a scientific endeavor, though: as sustainability is a **normative** concept, there is a clear role for policy and civil society as well as economic stakeholders to engage in this discussion.
As has been pointed out in the S2Biom Deliverable D5.4 (Fritsche & Iriarte 205), the overall framework for sustainability can be based on the **Sustainable Development Goals** (SDGs) which were unanimously adopted in September 2015 by the UN General Assembly (UN 2015).

Thus, the SDGs are an adequate **normative reference**, and the majority of the SDGs are directly or indirectly related to the bioeconomy – either as "drivers" to achieve goals or the goals are "safeguards" against bioeconomy risks, as depicted in the following figure.

Figure 4 The SDGs and the Bioeconomy

SDG	Key wording	Driver	Safeguard
1	End poverty in all its forms everywhere	(✓)	(✓)
2	**End hunger, achieve food security and improved nutrition and promote sustainable agriculture**	✓	✓
3	Ensure healthy lives and promote well-being for all at all ages		
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all		
5	Achieve gender equality and empower all women and girls		
6	Ensure availability and sustainable management of water and sanitation for all	(✓)	
7	**Ensure access to affordable, reliable, sustainable and modern energy for all**	✓	(✓)
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all		
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation		
10	Reduce inequality within and among countries		
11	Make cities and human settlements inclusive, safe, resilient and sustainable	(✓)	(✓)
12	**Ensure sustainable consumption and production patterns**	✓	(✓)
13	**Take urgent action to combat climate change and its impacts**	✓	✓
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	(✓)	(✓)
15	**Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss**	(✓)	✓
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels		
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development	(✓)	(✓)

Bold text: *SDG related to biomass; ✓ = relevant, (✓) = partially relevant*

Source: Fritsche & Iriarte (2016)

The SDGs are implemented nationally and on the EU level[26], and this process offers the opportunity to discuss the sustainability of the bioeconomy – and respective criteria and indicators (UN-ESC 2017) – with a broader set of stakeholders and the general public.

Furthermore, recent research activities in EU Member States – especially France[27], Germany[28], Italy[29] and The Netherlands[30] - and by the EC[31] concern **increased public dialogue** and other forms of stakeholder involvement in discussions on the sustainability of the bioeconomy.
The process towards a "European Bioeconomy Stakeholders Manifesto" may offer another opportunity to discuss sustainability issues of the bioeconomy more broadly[32].

Given these developments, the stage is prepared to forward the S2Biom sustainability approach for the bioeconomy into the public discussion, and to deepen dialogue on respective criteria and indicators with many stakeholders.

The authors hope that the guidelines developed in this paper, and the S2Biom deliverables giving the scientific background for the sustainability criteria and indicators (Iriarte & Fritsche 2015; Iriarte et al. 2015) will be a constructive input into these discussions.

[26] See e.g. EC (2016), and UBA (2016)

[27] See GF (2017) Une stratégie bioéconomie pour la France. Gouvernement français. Paris http://www.iar-pole.com/wp-content/uploads/2017/01/170119_planstrategique_bioeconomie.pdf

[28] The German Federal Ministry for Research and Education (BMBF) has initiated research concerning the societal dialogue on the bioeconomy and its sustainability, and the German Federal Ministry for Agriculture (BMEL) has announced to finance respective projects to foster and substantiate this dialogue

[29] BIT (2016) Bioeconomy in Italy. A unique opportunity to reconnect ECONOMY, SOCIETY and the ENVIRONMENT. Consultation Draft http://www.agenziacoesione.gov.it/opencms/export/sites/dps/it/documentazione/NEWS_2016/BIT/BIT_EN.pdf

[30] See results of BioEconomyUtrecht2016 (4th BioEconomy Stakeholders' Conference) held 12-13 April 2016 in Utrecht under the auspices of the Dutch EU Presidency: http://www.bioeconomyutrecht2016.eu/

[31] H2020 call "Strategies for improving the bioeconomy knowledge of the general public", see http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/bb-08-2017.html

[32] See https://lumencms.blob.core.windows.net/site/30/Manifest_revisie_13_juni.pdf

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