Handbook on regional and local bio-based economies

www.be-rural.eu

ABOUT BE-RURAL

BE-Rural (www.be-rural.eu) explores the potential of regional and local bio-based economies and supports the development of bioeconomy strategies, roadmaps and business models. To this end, the project focuses on establishing Open Innovation Platforms (OIPs) within selected regions in five countries: Bulgaria, Latvia, North Macedonia, Poland and Romania.

BE-Rural collaborates with the Horizon 2020 project Power4Bio (https://power4bio.eu/), which also assesses technology options and business models for regional and local bio-based economies. A joint guidance document will summarise the relevant outputs of the two projects and provide concrete recommendations for policymakers regarding the application of bio-based technology options and business models in specific regional contexts. The present handbook will contribute to this joint output. For further complementary information from the Power4Bio project, we encourage the reader to visit: https://power4bio.eu/project-material.

ABOUT THIS DOCUMENT

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Abbreviations

%	Percentage
€	Euro
°C	Degree Celsius
AD	Anaerobic digestion
BM	Business model
bn	Billion
c	Heat capacity
C/N	Carbon Nitrogen ratio
Ca	Calcium
CH_4	Methane
CHP	Combined heat and power
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Coefficient of performance
CS_2	Carbon disulphide
DIN	Deutsches Institute für Normung
e.g.	Exempli gratia - for example
EN	Europe norm
etc.	Et cetera – and so forth
EU	European commission
EWC	European waste catalogue
FAO	Food and agricultural organisation of the united nations
FBC	Flourishing business canvas
Fe	Iron
FFA	Free fatty acid
FSC	Forest stewardship council
FT	Fischer-Tropsch
GDP	Gross domestic product

GHG	Greenhouse gas
GMO	Genetically modified organism
GNI	Gross national income
GO	Governmental organisation
GWP	Global warming potential
H_2	Hydrogen
H_2S	Hydrogen sulphide
HP	Horsepower
i.e.	Id est - that is
IEA	International energy agency
ILUC	Indirect land use change
IRR	Internal rate of return
ISCC	International system for carbon certification
ISO	International standards organisation
J/kg × K	Joule per kilogram and kelvin
JRC	Joint research centre
kg	Kilogramme
kg/h	Kilogramme per hour
kW	Kilowatt
kWe	Kilowatt electrical
kWh/t	Kilowatt hour per tonne
LCA	Life cycle assessment
LULUCF	Land use, land-use change, and forestry
m	Metre
m^3	Cubic meter
MBT	Mechanical-biological treatment
Mg	Magnesium
mm	Millimetre
MPa	Megapascal
Mt	Million tonnes
MW	Megawatt
MWe	Megawatts electric
n.d.	No date
NGO	Non-governmental organisation
OIP	Open innovation platform

PA	Polyamide
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PBT	Polybutylene terephthalate
PE	Polyethylene
PEFC	Programme for the endorsement of forest certification
PET	Polyethylene terephthalate
pH	A scale used to specify how acidic or basic a water-based solution is
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid
PP	Polypropylene
PPP	Public-private partnership
PS	Polystyrene
PTT	Trimethylene terephthalate
PUR	Polyurethane
PUR	Polyurethane
PVC	Polyvinyl chloride
R&D	Research and development
R&I	Research and Innovation
RED II	New renewable energy directive
RSB	Roundtable on sustainable Biomaterials
RSPO	Roundtable on sustainable palm oil
RTRS	Roundtable responsible soy
SAM	Social accounting matrix
SDGs	Sustainable development goals
S-LCA	Social life cycle assessment
SME	Small to mid-size enterprise
TPC-ET	Thermoplastic copolyester elastomer
TPS	Thermoplastic starch
TRL	Technology Readiness Level
vs	Versus – in contrast to
W/(m × K)	Watts per meter-Kelvin
WWF	Worldwide fund
λ	Thermal conductivity

1 Introduction

The bioeconomy could tackle tackles some of the most urgent challenges nowadays, such as limitations of natural resources, climate change, world population growth, and loss of biodiversity. Its holistic view could help identifying socially acceptable solutions that combine economic growth and competitiveness with global responsibility for world nutrition and for the protection of our environment and climate as well as for animal welfare. This accompanies with a sustainable resource management and a reduction of dependencies on non-renewable resources (Figure 1). It is not enough to simply shift the raw materials basis from fossil to renewable resources in industrial applications. What is needed is a macrosocial structural change that interlinks economic growth with ecological and social compatibility (Bourguignon 2017, Hoff et al. 2018, Jalasjoki 2019, MECE 2019).

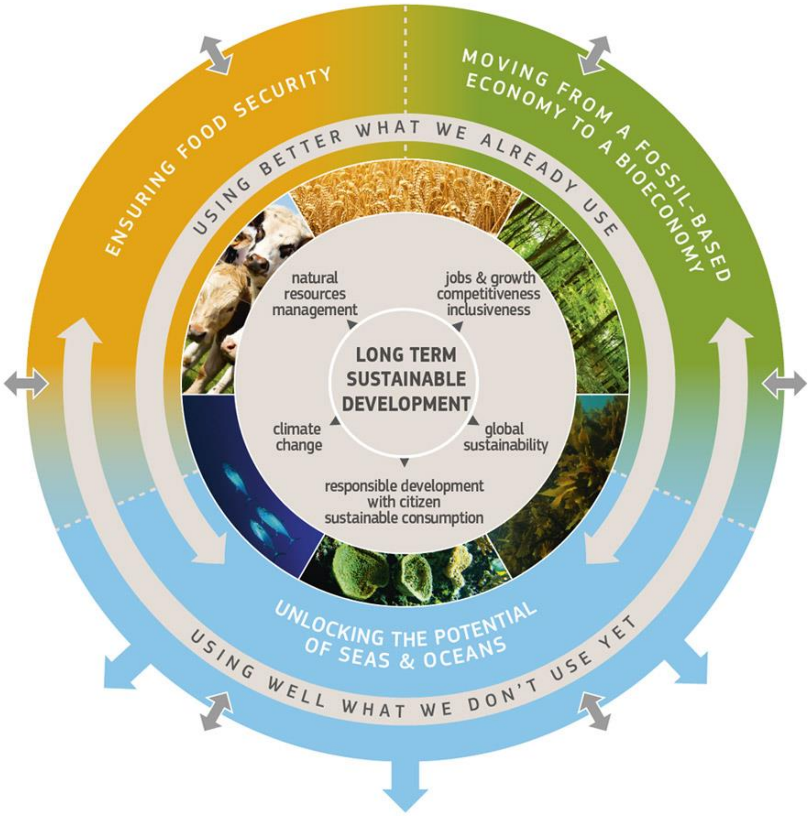


Figure 1: Aims of the bioeconomy strategy (European Commission 2018)

The bioeconomy is a concept that encompasses policies involving research, industry and energy, agriculture, forestry and fishery as well as climate and environment and development policies (BMBF 2017). Due to the widespread availability of biological resources, implementation of a modern bioeconomy is not restricted to industrialised nations only. In principle, it offers participation to all countries - beyond today's prosperity and system boundaries. Especially rural and coastal areas could profit from the bioeconomy’s potential of creating economic growth and jobs. New business and innovation opportunities may emerge in the agricultural (expanding the scope of the sector beyond food production to biomass production and processing), marine and maritime (valorising bycatches and fish processing residues in a blue bioeconomy) and forestry sectors (e.g. through integrated biorefinery concepts). Such sector-specific multifunctional concepts can be embedded in new business models and rural and coastal development pathways. This leads to an increased quality of life and allows farmers, fishermen and foresters to preserve an equitable share of added value. Moreover, the regional economies become more and more diversified which leads to an increased economic stability.

The bioeconomy can speed up the adoption of sustainable and climate friendly practices in rural areas (Bourguignon 2017, Hoff et al. 2018, Jalasjoki 2019, MECE 2019).

Even though biomass is considered renewable (over a time period of years and decades), it remains a finite resource with regard to different influencing factors such as water and land availability. Furthermore, additional demand and competition on resources, changes in prices of food and commodities must be considered when it comes to the implementation of bioeconomy strategies. The bioeconomy concept aims to counter those challenges by establishing appropriate supply-and demand-side measures. Approaches like the cascading use of biomass, whereby biomass is used more than once (e.g. cascading down from material use in the beginning to energetic use at the end), if technically and economically realisable and feasible, are big chances within a resource efficient bioeconomy.

The bioeconomy encourages the society to transform the way of linear thinking to a more sustainable, cautious and circular thinking. This means e.g. that added value must be allocated equally along the supply and value chains, natural boundaries respected, and consumption patterns changed. Therefore, a robust tool of measures is needed which allow a fair distribution of costs and benefits. Improved international cooperation play an important role at this stage of bioeconomy development (Bourguignon 2017, Hoff et al. 2018, Jalasjoki 2019, MECE 2019).

2 Basics about the regional bioeconomy

2.1 The bioeconomy

According to the European Commission, the bioeconomy is defined as "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. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling and industrial technologies, along with local and tacit knowledge" (European Commission 2012). This definition has been set in the European Bioeconomy Strategy.

The bioeconomy generated a turnover of € 2.3 trillion in 2019. Thus, it can already be considered as an important pillar in the EU economy (Biobased Industries Consortium 2019). As bio-based products and processes may require considerable quantities of biomass as feedstock, the updated EU Bioeconomy Strategy calls for the consideration of safe ecological limits within the development of Member State bioeconomies (European Commission 2018). Specifically, the strategy states: “It is crucial to ensure that biological resources are used within their sustainability thresholds so that they can recover and replenish, and that ecosystems are not pushed beyond safe boundaries e.g. through exceeding the capacity of specific provisioning ecosystem services” (European Commission 2018). Action 3 of the EU Bioeconomy Strategy embodies this consideration of safe ecological limits and calls to ‘Understand the ecological boundaries of the bioeconomy’. Within this action point, Member States are encouraged to (1) enhance the knowledge on the bioeconomy to deploy it within safe ecological limits; (2) increase observation, measurement, monitoring and reporting capabilities; and (3) better integrate the benefits of biodiversity-rich ecosystems in primary production (European Commission 2018).

A major strength of the bioeconomy concept is the development and support of rural, costal and remote areas by adding values to commodities which are produced by the agricultural, forestry, fishery or waste sectors. This could reduce the rural exodus through job creation and improve the territorial cohesion through social innovation. Within the scope of a bioeconomy, underused or even unused potentials and resources can be identified, analysed and valorised. The overall goal is a more proportionate and fair sharing of the benefits of a competitive and sustainable bioeconomy across (rural) regions, countries and whole Europe.

One of the 14 actions that was defined by the Bioeconomy Strategy of Europe is to deploy local bioeconomies across Europe through the following sub-actions:

- Development of a “Strategic Deployment Agenda for sustainable food and farming systems, forestry and bio-based production in a circular bioeconomy”. This is defined as a systemic and cross-cutting approach that links actors, territories and value chains with a long-term vision and a focus on a sustainable domestic (EU level) production. This action addresses food waste and by-products, sustainable use of seas and oceans, bio-based innovations in farming, and aquaculture among others.
- Implementation of five “pilot actions to support local bioeconomy development (rural, coastal, urban) via Commission instruments and programmes”. This is aimed at enhancing synergies between existing EU instruments to support local activities while introducing an explicit focus on the bioeconomy. Some of these pilot projects involve the so-called “Blue Bioeconomy” or “inclusive bioeconomies in rural areas”.
- Setting up an “EU Bioeconomy policy support facility and a European Bioeconomy Forum for Member States” under the Horizon 2020 Framework Programme for Research and Innovation

in order to support the development of national/regional bioeconomy strategies, including remote areas and candidate and accession countries.

- Promoting “education, training and skills across the bioeconomy”. This is considered an important pre-condition for dealing with the systemic and cross-cutting nature of emerging bioeconomy approaches and value chains, which require adaptation and flexibility according to different needs across the bioeconomy sectors. (European Commission 2018)

The guiding principle of the bioeconomy is the establishment of a circular economy that enables optimal utilisation and multiple use of raw materials and material flows in the sense of resource efficiency and sustainability – also on a cross-sectoral basis. In order to build such a bioeconomy, respectively bioeconomy strategies, a set of principles according to Mathijs et al. (2015) should be followed:

- **Food first** - How can availability, access and utilisation of nutritious and healthy food be improved for all in a global view. Relevant policies, such as those related to agriculture, food, environment, health, energy, trade, foreign investments should be checked through a food security test, and direct and indirect impact assessment should become common currency.
- **Sustainable yields** - Users should consider the renewable nature of biomass production and apply economic rules that govern their exploitation, such as the sustainable yield approach that prescribes that the amount harvested should not be larger than regrowth. This should be regarded from a holistic view, which takes all biomass into account, including that in the soil. An important indicator here is the amount of organic matter in the soil.
- **Cascading approach** - To avoid unsustainable use of biomass, the concept of cascading use prescribes that biomass is used sequentially as often as possible as material, and finally for energy. Cascading use of biomass increases resource efficiency, the sustainable use and the generation of value added from biomass and is part of the circular economy. Creating higher resource efficiency also increases the general availability of raw material supply, because biomass can be used several times. While appealing in theory, the practical application of cascading rules meets with two problems: (1) how can a sequential use of biomass be implemented and (2) how can rules be implemented if they run against today’s existing market environment.
- **Circularity** - The cascading approach does not address the issue of waste reduction per se. Waste is generated where the costs of reuse and recycling are higher than the value created. The concept of a circular economy is based on three principles: (1) waste does not exist, as products are designed for a cycle of disassembly and reuse; (2) consumables should be returned to the biosphere without harm after a cascading sequence of uses, contributing to its restoration, while durables are designed to maximise their reuse or upgrade; and (3) renewable energy should be used to fuel the process.
- **Diversity** - Production systems should be diverse, using context-specific practices at different scales and producing a diversity of outputs. As diversity is key for resilience, innovations in the bioeconomy should be developed to foster diversity rather than limit it.

Implementing these principles is in fact very challenging. Availability of natural resources is bound to become a major challenge for our societies in the years to come. In particular, sufficient food supply for the growing population is globally challenging the existing systems to renew themselves and the industries to produce significantly more with higher sustainability. Sensible management of natural resources and global cooperation may provide an opportunity to identify sustainable solutions, although one needs to be aware that partial optimisation does not lead to sustainable solutions, especially not in the long run (European Commission n.d.). Furthermore, a bioeconomy could cause competition for agricultural land and water resources, in case the raw materials do not originate from waste of residues pools. This competitive state is often called food versus fuel, which could lead to negative effects on food production, security and prices (see section 5). Competition between bio-based products such as bioenergy and bio-based materials could emerge as well, e.g. due to finite resources and uneven support schemes. Thus, bioeconomy transitions can increase the demand for land, water and further natural resources but also for political, economic and social changes (e.g. inclusiveness) (Bourguignon 2017, Hoff et al. 2018).

The bioeconomy can also cause negative environmental impacts such as resource degradation or the damage of forests and other ecosystems (indirect and direct land use changes) and their biodiversity, functions and services (e.g. carbon storage in forests) (Bourguignon 2017, Hoff et al. 2018, MECE 2019) (see section 5).

In order to encounter those challenges different approaches and measures are needed. These include technical as well as social innovation. For the latter, informative dialogues are needed for building a knowledge base that can cope with the arising challenges. The European Commission facilitates the development of innovative technologies, roadmaps and strategies and the sharing of knowledge for establishing bioeconomies in Europe.

At the regional level, bioeconomy deployment occurs mainly through individual projects and initiatives promoted by stakeholders including regional and local public authorities, private companies, universities, research centres and/or technology and innovation service providers. These stakeholders often rely on European and/or national co-funding, but sometimes draw on local and regional resources. The most important funding source for bioeconomy-related R&I at the EU-level are the European Framework Programmes for Research and Technological Development.

The BE-Rural project, funded under the Horizon 2020 programme, has been developed with the aim of supporting the development of regional bioeconomy strategies and roadmaps that promote a sustainable use of agricultural, forest and marine ecosystems. The conceptual foundation of BE-Rural builds on a Quintuple Helix Approach, which combines knowledge and innovation generated by key stakeholders from policy, business, academia and civil society within the frame of the environment (Figure 2) (Abhold et al. 2019).

Figure 2: Quintuple Helix Approach (Abhold et al. 2019)

This approach embeds previous approaches of the Triple Helix and Quadruple Helix. The prior focuses on knowledge creation, production, application, diffusion and use generated from the interaction between academia, industry and the government. The Quadruple Helix takes this one step further and frames the Triple Helix within the context of the public (i.e. “media-based and culture-based public”) so that knowledge production, application, diffusion and use take into consideration social acceptance and uptake. Building on these developments, the Quintuple Helix Approach then embeds the consideration of the natural environment into these knowledge-generation and innovation processes. In other words, the environment acts as a “driver for the creation of new knowledge and innovation in response the environmental challenges” (Abhold et al. 2019).

2.2 Biomass – the core of bioeconomy

Biomass is defined as "the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste" (European Commission 2009).

The development of the bioeconomy depends primarily on the availability of biomass as a solely feedstock. It can be divided in two premises. Firstly, large amounts of biomass are currently underexploited, and many waste streams remain used in an inefficient way or not used at all. Thus, more materials as well as energy can be extracted from current biomass streams. Secondly, the biomass potential can be boosted by closing yield gaps, extending productive and using marginal, less fertile land, and by introducing new and improved extraction and processing technologies. The development of new innovative technologies for using and transforming living matter has opened the way to a plethora of application areas (Mathijs et al. 2015).

Especially in the agricultural and forestry sectors, renewable raw materials are collected specifically to produce materials and energy in form of heat, electricity or fuel. The basic prerequisite is that these products do not compete with the food and feed production. Renewable raw materials have several advantages over fossil resources. When used for energy production, they release less greenhouse gases than fossil fuels. When used to produce bio-based materials, the carbon dioxide stored in them is effectively locked into the product. This makes renewable raw materials an option for climate change mitigation. Their use is often associated with environmental benefits, for instance in environmentally sensitive areas. Products made from renewable feedstocks are often less (eco) toxic and their production is often less energy intensive (FNR n.d.). Moreover, contrary to public perception, the cultivation of renewable raw materials does not only offer risks, but also opportunities to broaden the range of species in agriculture. The range of energy and raw material plants is wide and much larger than the spectrum of food and fodder plants that are mainly grown today. If renewable raw materials are produced in domestic agriculture and forestry and further processed and consumed in the region, the associated value creation remains in the region and generates new jobs. This offers great opportunities and new perspectives for the local population, especially in structurally weak rural areas that must fight rural exodus (FNR n.d.).

Renewable raw materials are used in a wide variety of industry branches and in the private sector. Beside the storable bioenergy, which can be converted into electricity, heat and fuels by using various technologies and processes, a wide range of products can be manufactured using renewable raw materials. It ranges from building materials to paper and cardboard, construction materials, lubricants, intermediate and end products for the chemical industry to pharmaceuticals, cosmetics, dyes, textiles and much more (FNR n.d.).

Pursuant to estimates of JRC (2019), 1.2 billion tonnes of biomass were used in the EU in 2015. The biomass comes mainly from primary sources (1 billion tonnes) such as agricultural crops (51.5%) and their collected residues (9.9%), grazed biomass (11.7%), forestry (26.6%) as well as fisheries and aquaculture (0.3%) (Figure 3).

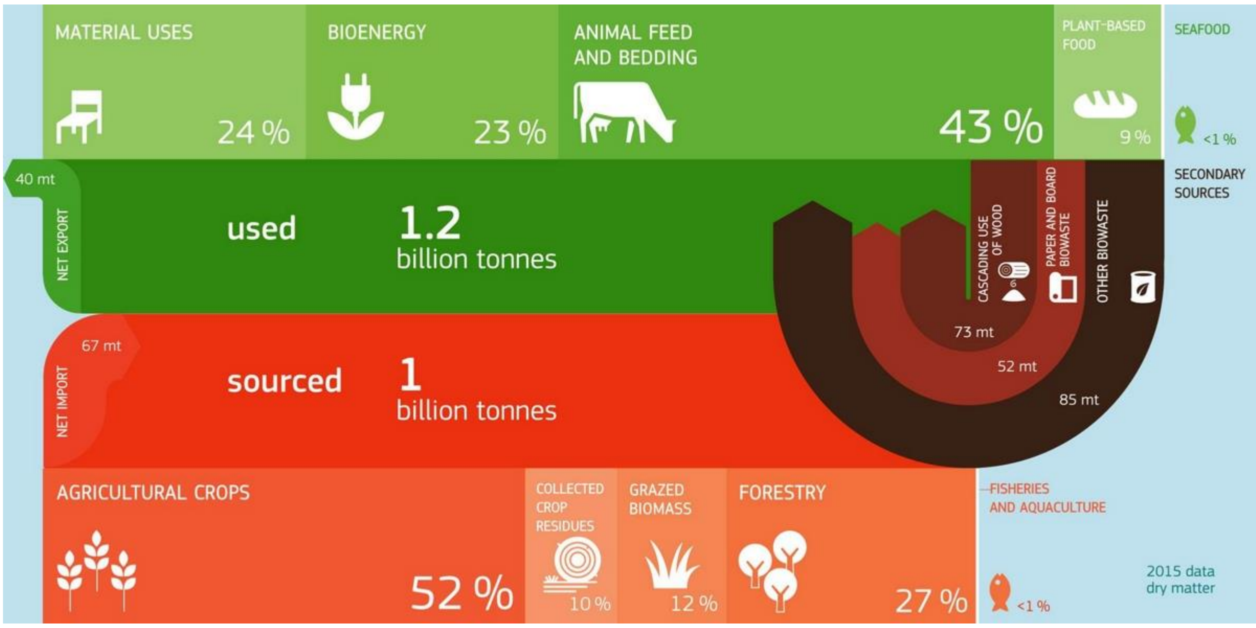


Figure 3: Sources and uses of biomass in the EU (EU Science Hub 2019)

The remaining 0.2 billion tonnes come from secondary sources such as recycled paper, by-products from wood processing and recovery of wood and other bio-waste from the primary and secondary sectors and municipalities (EU Science Hub 2019). It is noticeable that more and more biomass is being recovered from waste. The amount of biological waste that was not recovered (via recycling or energy recovery) was reduced by 45% between 2010-2015. The biomass is used to cover different needs in different fields, ranging from animal feed and bedding (43.3%), plant-based food (9.3%) and seafood (0.3%) to energy (23.3%, including heat, power and biofuels), various material uses (23.8%) such as wood products and furniture, textiles, and different types of innovative bio-based chemicals (EU Science Hub 2019, Sillanpää and Ncibi 2017).

Over the period 2010-2015, the overall biomass use in the EU has grown by around 8.5% (Figure 4).

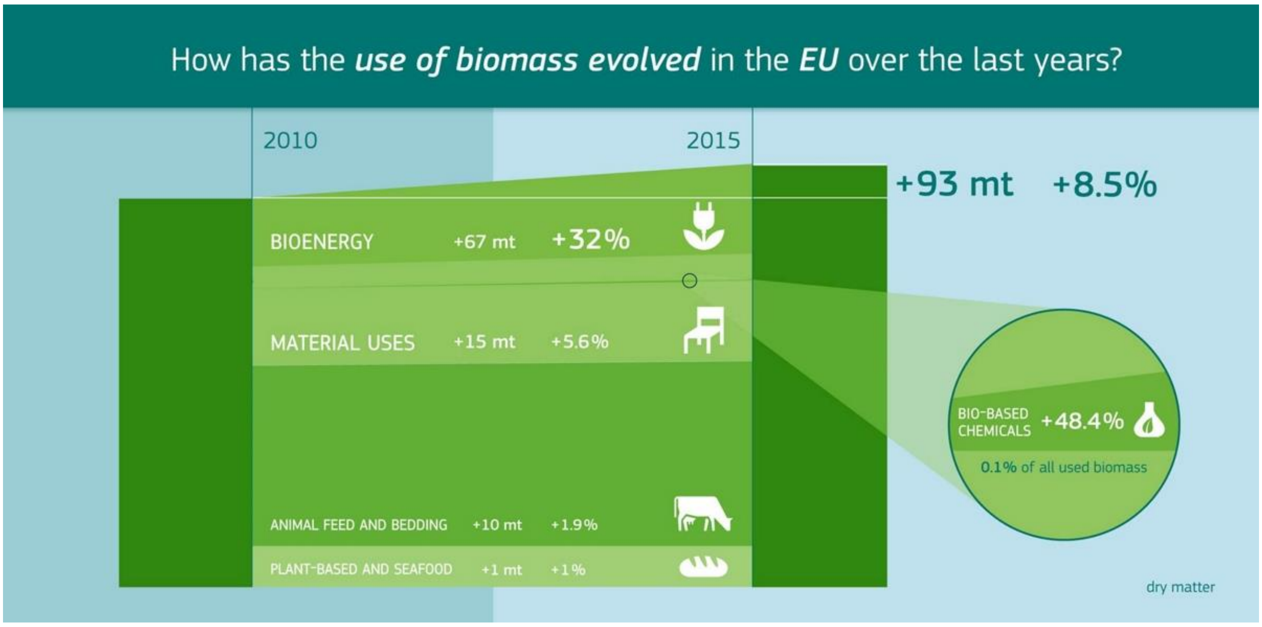


Figure 4: Evolution of biomass use in the EU (EU Science Hub 2019)

In absolute terms, the lion's share of this increase comes from the rising demand for bioenergy (+67 Mt), followed by increased demand for bio-based materials (+15 Mt) and for animal feed and bedding (+10 Mt). Relatively spoken, the use of biomass for energy increased by about 32% during this period. In the same period, the use of biomass for producing materials has increased by 5.6%. Here, the bio-based chemical sector shows the highest relative increase (+48.4%) (EU Science Hub 2019).

Biomass feedstock types can be categorised in several ways with different level of detail. From the bioenergy perspective, the most important biomass feedstocks can be separated in dedicated crops, such as sugar, starch crops, oil and lignocellulosic crops, algae and aquatic biomass and in wastes and residues such as oil-based, lignocellulosic and organic residues and waste gases (ETIP n.d.). Bio-based products are often made of similar feedstocks. The most common types of biomass used for bio-based products are sugar, starch, proteins, natural oils, wood and natural fibres. Nonetheless, bio-based materials can be produced from specific niche raw materials that are sufficient and suitable for the production of small quantities at low TRLs (InnProBio 2020). Furthermore, it is possible to produce several bio-based intermediates and products from one specific raw material as it is demonstrated in Figure 5.

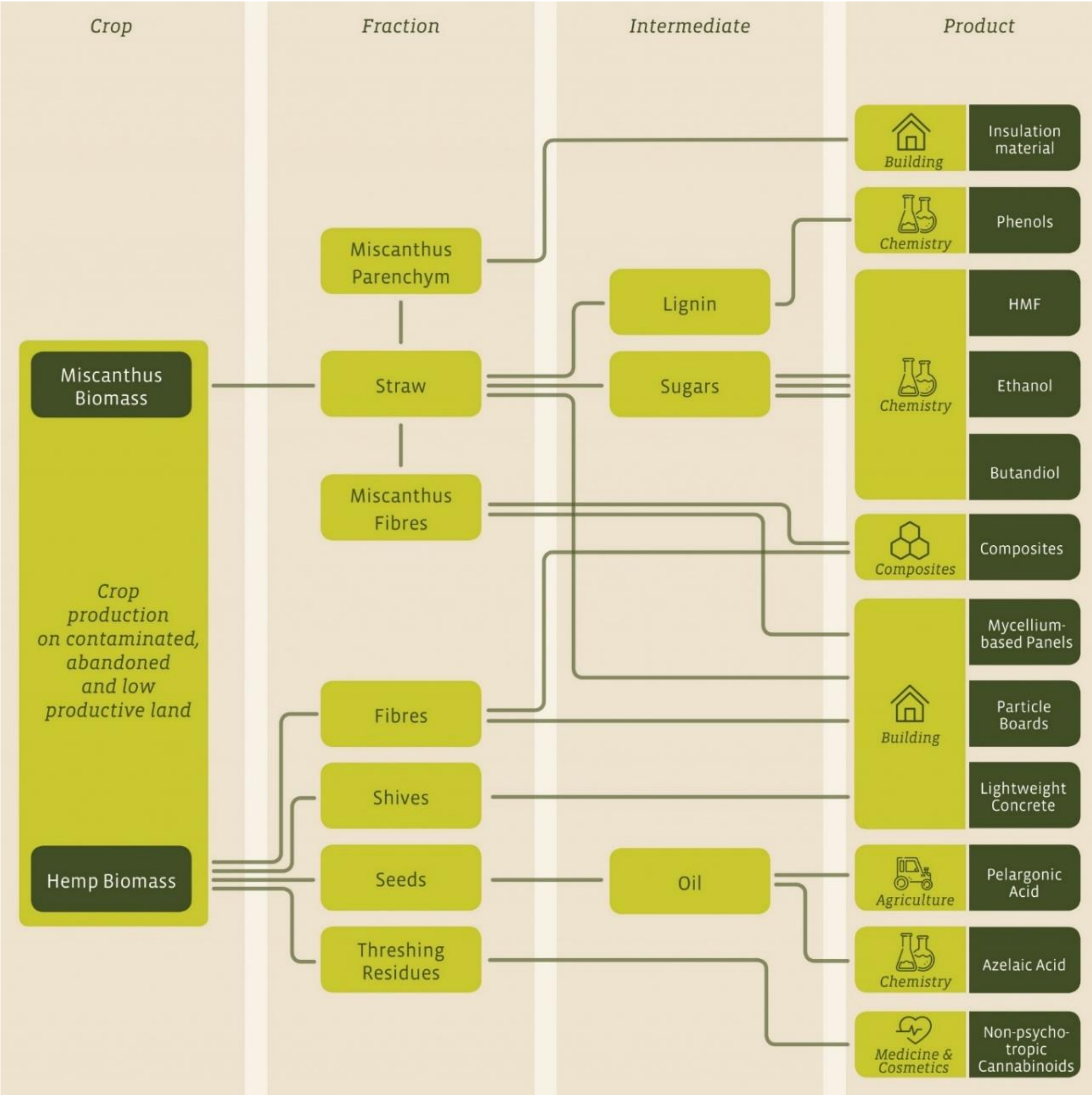


Figure 5: Usability of hemp and miscanthus shown for various products and applications (Bioökonomie BW 2019)

2.3 Biomass conversion

A variety of conversion concepts can be applied in a biorefinery. There are different approaches to systematise biorefinery concepts. Within IEA Task 42[1], the foundations for a classification system for biorefineries were developed for the first time. This classification system focuses on the intermediate as the biorefinery platform and is thus oriented towards the value chain of the chemical industry (Figure 6). The systematization takes place according to four structural elements: raw material, platform, products and processes. The core element of the system are intermediate(s) which arise in primary refining and function as a platform for the biorefinery for secondary refining. The raw materials and products are then assigned to this platform and processes are the connecting element. The conversion processes will be explained and described in more detail below. The following descriptions for the structural elements of raw materials, products and processes are no special features of biorefineries but rather valid for other biomass conversion paths (BMELV 2012).

Raw material	**Agricultural biomass** → Oil crops → Starch crops → Sugar crops → Grasses → Wood → Woody biomass	**Aquatic biomass** → Algae	**Biogenic residual- & waste materials** → Agricultural and forestry residues (e.g. straw, manure, wood residues, fruit peel, slurry) → Biogenic residual materials from processing (e.g. whey, pulp, stillage, spent grains) → Biogenic waste materials (e.g. yellow grease, waste wood)
Platform	→ Low molecular weight carbohydrates (e.g. lactose, sucrose) → Polymeric carbohydrates (e.g. starch, inulin, pectin) → Lignocellulose components (lignin/cellulose/ hemicellulose) → Proteins → Plant fibres → Vegetable oils, lipids → Pyrolysis oil → Press juice → Biogas → Syngas		
Products	**Materials** → Chemicals → Materials → Feedstuff* → Foodstuff*	**Bioenergy** → Solid, liquid, gaseous sources of bioenergy → Electricity → Heat	
Processes	→ Physical, including mechanical processes → Thermochemical processes → Chemical processes → Biotechnological processes		

* as a co-product

Figure 6: The elements of biorefinery classification (BMELV 2012)

[1] International Energy Agency Task42 provides an international platform for collaboration and information exchange between industry, SMEs, GOs, NGOs and universities concerning biorefinery research, development, demonstration and policy analysis.

A wide range of technologies and processes are required for biorefining. There are basically no specific developments which are exceptional only in biorefineries. The focus lies on the innovative adaptation of the well-known production techniques to the specific biomass properties. However, this in turn requires the development of new and specific processes and methods as well as intelligent technical solutions for the provision, conditioning and conversion of biomass. A distinction can be made between four main groups, which - without claiming completeness - can be assigned to the following processes:

- **Physical, including mechanical processes**
  - Basic operations to change material properties (e.g. milling, drying, heating, cooling, compacting)
  - Cleaning and separation processes (e.g. filtration, distillation, extraction, crystallisation, adsorption, sieving)
  - Extraction processes
  - Dissolution and shaping processes
- **Thermochemical processes**
  - Combustion (burning of biomass in the presence of oxygen)
  - Gasification (a thermochemical process in which biomass is transformed into a combustible gas known as syngas or synthesis gas)
  - Pyrolysis (thermal degradation of a substance in the absence of oxygen)
  - Thermolysis (chemical decomposition caused by heat)
  - Hydrothermal processes
- **Chemical processes**
  - Basic operations for material transformation (e.g. oxidation, hydrogenation, esterification, etherification, isomerisation, hydrolysis, polymerisation)
  - Chemically catalysed conversions
- **Biotechnological processes**
  - Enzymatically catalysed conversions
  - Fermentation and decomposition processes (e.g. anaerobic digestion) (Agrela et al. 2019, BBJ Group 2018, BMEVL 2012).

These processes can be operated as integrated processes, too, e.g. through the combination of separation and reaction technologies or as a combination of chemical and biotechnological processes. A process does not only have products and educts. All processes require additional additives/media and energy which need to be taken into account in process development and accounting for biorefineries. When using biomass, other factors (such as nutrient cycles and competing uses of biomass between food and non-food uses and within non-food applications between energy and materials) must be considered, too. In order to assess a conversion process, a technological development and a utilisation pathway, a material and energy balance of the biorefinery needs to be implemented and analysed (BMELV 2012, Gerssen-Gondelach et al. 2014).

3 Options for the use of biomass in a regional bioeconomy

The development of a bioeconomy requires process innovations that allow an efficient utilization and valorisation of raw and residual materials. Process innovations in the bioeconomy encompass processes and technologies that use biogenic raw materials and residues as a starting substrate, as well as bio-based processes that use the metabolic activities of living organisms such as microorganisms, bacteria or algae. In both cases, the goal must be to develop environmentally friendly, flexible and economically feasible processes that can be industrially scaled up quickly (Bioeconomy BW n.d.).

3.1 Energy uses of biomass

3.1.1 Solid biomass for heating and cooling

Solid biomass fuel is an umbrella term for all solid organic components to be used as fuels. In the context of BE-RURAL, solid biomass refers mainly to log wood (firewood), wood chips, pellets and briquettes from the forestry and agricultural sectors (Figure 7).

Log wood © VTT

Wood chips © HFA

Pellets © GEMCO ENERGY

Briquettes © HFA

Figure 7: Different types of solid biomass fuels

Log wood generally refers to wood logs, that have been split and cut into lengths for direct use in wood stoves or boilers, coming directly from agricultural or forestry companies. In Europe, hardwood has a higher relevance for combustion than softwood. The most common wood species for log wood in Europe are beech, maple, oak, ash and birch. But there are also some softwood species which are used for combustion, like spruce, fir and larch. The usual lengths for log wood are 0.25 m, 0.33 m and 0.50 m. It is common to buy log wood in cubic meters of stacked wood, normally consisting of 70%

wood and 30% air. For a high combustion performance, the moisture content should be lower than 15-20%. Typically, fresh harvested wood will have a moisture content of approximately 50%. For reaching the suitable moisture content adequate storage is required. The time for drying varies between six months and two years, in respect to the specific species and storage place. A perfect place for storage is outdoors, in a windy and sunny place, but covered from rain (ETIP n.d. a).

Wood chips are woody biomass that are chopped with the intention of being burned afterwards. The quality of the wood chips depends on the used raw material and the chipper. With respect to the raw material, wood chips can be divided into the following groups:

- Forest chips (produced from logs, whole trees, logging residues, or stumps)
- Wood residue chips (produced from untreated wood residues, recycled wood, offcuts)
- Sawing residue chips (produced from sawmill residues)
- Short rotation coppice chips (produced from energy crops)

Because of the chipping process, wood chips are a relatively uniform fuel, which can flow and be fed into a boiler automatically. The average dimension of a wood chip is from 16 to 45 mm.

Besides being a small, electrically operated garden device, woodchippers are used as attachments on tractors from agriculture or forestry industries. They are also used as build-on aggregates on trucks, self-propelled forestry machines and self-propelled chipping units. In Europe, three construction types of woodchippers are available: the disc-chipper, drum-chipper and screw-chipper.

A **disk woodchipper** features a flywheel made of steel and chopping blades with slotted disks (Figure 8). The blades slice through the wood as the material is fed through the chute. Knives located in the body of the chipper cuts the wood in the opposite direction. The design is not as energy efficient as other styles but produces consistent shapes and sizes of woodchips.

A **drum woodchipper** has a rotating parallel-sided drum attached to the engine with reinforced steel blades attached in a horizontal direction (Figure 8). Wood is drawn into the chute by gravity and the rotation of the drum where it is broken up by the steel blades. The drum type is noisy and creates large uneven chips but is more energy efficient than the disk type.

A **screw-type woodchipper** contains a conical, screw-shaped blade (Figure 8). The blade rotation is set parallel to the opening, so wood is pulled into the chipper by the spiral motion. Screw-type, also called high-torque rollers, are popular for residential use due to being quiet, easy to use and safer than disk and drum types (Greengain 2015).

Flywheel with chipping knife of a disc-chipper ©greengain

Drum-chipper with hydraulic forced infeed ©greengain

View into the grinding device of a screw-chipper ©greengain

Figure 8: Different types of woodchipper

In order to control and verify the quality of wood chips, the European Standard DIN EN ISO 17225-4:2014-09: “Solid biofuels – Fuel specification and classes – Part 4: Graded wood chips”, defines four different quality classes for wood chips (A1, A2, B1, B2) and three different grain size fractions (P16S, P31S, P45S). The quality classes A1 and A2 are intended for use by private households (small scale) and the classes B1 and B2 are usually used by the industry (large scale). For plants larger than 1MW, specific quality agreements are defined. The grain size fractions indicate the maximum fine portion, the permissible coarse portion, the maximum particle length and the maximum cross-sectional area of the particles. The use of this standard is not mandatory, but voluntary (ETIP n.d. b).

The mobile wood chipping unit from Erpék Ind[2]

Erpék Ind offers a mobile wood chipping unit which can be fed with wood based raw material from forest industry, agriculture and municipalities. The woodchipper is mounted on a trailer chassis why it is highly flexible and suitable for different surfaces. Since the woodchipper is driven by an integrated 60 HP diesel engine, it can work autonomously without any external power. The feeding of the chipper is done manually, and the unit is basically designed for branches from orchards, forest residuals, Christmas trees from urban areas, branches from urban parks and so on. In one hour, up to 15 m^3 of chipped biomass can be produced. The volume of the raw materials can be reduced to 25% whereby the transport and logistic process of wood materials becomes simpler and cheaper. The performance of the machine depends strongly on the quality, size and type of input material, as well as on the labour force involved in the wood chipping process (Colmorgen and Khawaja 2019).

Mobile wood chipping unit © IPE

Pellets with or without additives are compressed feedstock material, normally cylindrical with broken ends, with a length of typically 5 mm to 40 mm and a diameter of maximum 25 mm. The moisture content of wood pellets normally is less than 10% and they have an ash content of up to 3%. The pellets are usually produced with a pellet mill.

The common pellets are made from woody biomass, like sawdust, wood chips or forest residues, but there are a variety of raw materials which can be pelletised. Some examples are paper products, waste

[2] The info boxes attached to several options for the use of biomass in regional bioeconomies contain relevant best practice technologies for regional bioeconomies from the deliverable “D2.1 Small-scale technology options for regional bioeconomies” of the BE-Rural project.

biomass, corn, cotton seed, hemp, miscanthus, reed canary grass, straw, cereal spillage, low-grade hay etc. The fuel properties of pellets made from alternative raw materials differ from pellets made from woody biomass. For example, wood pellets contain a maximum of 15% water, otherwise they will fall apart. In contrast, the water content of alternative pellets varies between 7% (corn cobs) and 56% (hemp). Certain fuel properties can be set by mixing different raw materials together in suitable amounts.

The process of pelletising includes the following steps (Figure 9):

- Initial size reduction (chipping) if it is not already in a small size (e.g. sawdust)
- Drying until a moisture content of 8-12%
- Fine grinding using a hammer mill which will grind the raw materials into smaller pieces with a diameter under 5 mm
- Pelletising where pellets are extruded using special dies. High pressure and temperatures are needed in this process, which softens lignin in the wood and binds the material in the pellet together
- Cooling which allows the pellets to become rigid
- Bagging and truck loading

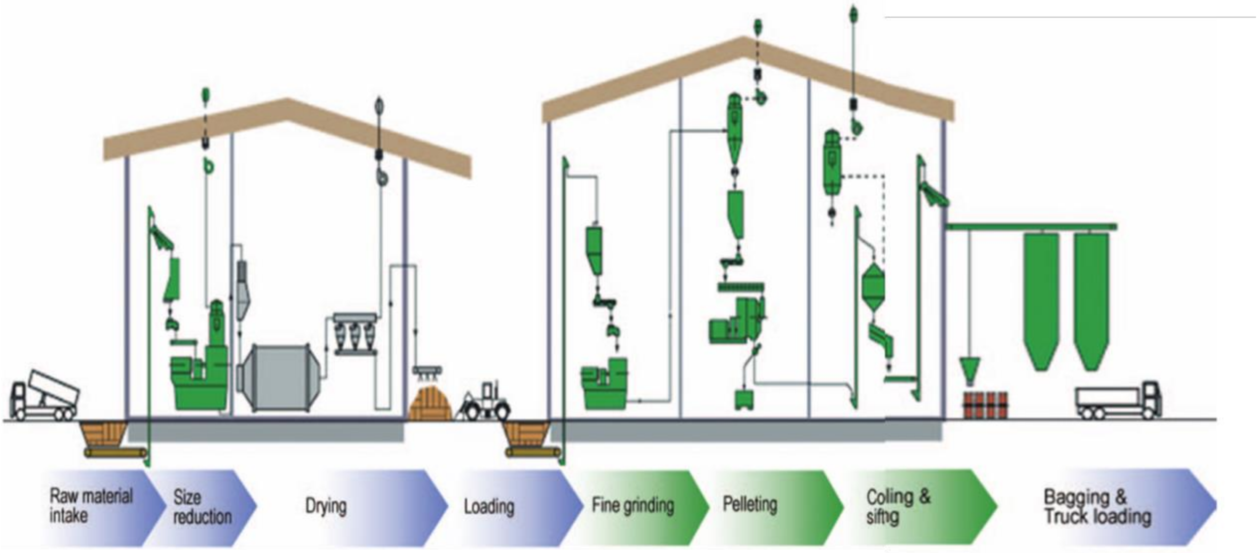


Figure 9: Pelletisation process (Coford 2007)

The advantages of pellets compared to log wood or wood chips are among others: the possibility to optimise the combustion because of the uniform fuel, the reduced costs for transportation because of the increased fuel bulk density and the improvement of thermal and combustion properties.

In order to control and verify the quality of wood pellets, the European standard (ISO 17225-2:2014 "Solid biofuels – Fuel specifications and classes – Part 2: Graded wood pellets") defines the quality standards of pellets. There are three different classifications for pellets: A1, A2 and B. The differences regard the used raw materials and their quality. The relevant wood pellet class for end users is A1, A2 and B are used in industrial applications like power plants.

Briquettes are densified solid biofuels made with or without additives in the form of cubic, polyhedral, polyhydric or cylindrical units with a diameter of more than 25 mm, produced by compressing biomass (ISO 2014). Generally, there are a wide range of materials that can be used to make briquettes, such as wastepaper, cardboard, agricultural residues, charcoal dust, and wood wastes like sawdust, etc.

The briquetting process starts with size reduction or mechanical fragmentation of raw materials by a crushing machine, drying of the crushed materials when the moisture content is too high, and compaction or pressing using various types of briquetting machines such as the screw pressing machines, stamping pressing machines and hydraulic briquetting machines. The briquettes are made in the process of pressure agglomeration, in which the loose materials are moulded into a permanent, geometrical and defined dimensions by the compaction pressure and intermolecular forces and bonds when necessary (Renewable Energy World 2014).

At **household level**, biomass for heating purposes is traditionally used in stoves where log wood or briquettes are fired to generate heat in a decentralised way at typically low efficiency between 10% and 30%. Besides stoves, small scale boilers can also use similar types of fuel for small, household central heating systems. These systems can usually also use smaller sized fuels like pellets or wood chips, which enable automatic feeding. In recent years, with the development of modern condensing wood pellet boilers, the efficiency of these systems has increased to almost 90%. **Middle-sized centralised systems** dedicated to heat generation in small networks use fuels which enable automatic feeding, like pellets or wood chips, and usually use hot water boilers to generate heat with up to 90% efficiency. **Larger district heating systems** and industrial plants fuelled with solid biomass fuels usually use cogeneration technologies for heating purposes. When cooling is needed, absorption (COP between 0.5 and 2.2) or adsorption (COP 0.5-1.5) systems can be used to convert the available heat for cooling purposes. Most of this cooling is produced by traditional mechanical compression systems, often electricity driven. When renewable or waste heat is available, thermal cooling by absorption or adsorption are interesting options (SETIS 2016).

Power plants can also use solid biomass as a source for electricity production. Most of them use direct-fired combustion systems. Direct combustion systems feed a biomass feedstock into a combustor or furnace, where the biomass is burned with excess air to heat water in a boiler to create steam which is then expanded through a steam turbine that spins to run a generator and produce electricity (WBDG 2016).

A combined heat and power (CHP) plant is a facility for the simultaneous production of thermal and electrical respectively mechanical energy in one process. As compared to power plants using solid biomass fuels with efficiencies of 20-45%, the overall process efficiency is significantly higher, 80-90%, as the otherwise rejected heat is also transferred to consumers (ETIP n.d. c).

3.1.2 Biomass for biogas production

Biomass can be converted to biogas though a process called **anaerobic digestion (AD)**. It is a multistep biological process in which a variety of microorganisms decompose digestible biomass in the absence of oxygen. The biomass is converted into biogas, which consists mainly of methane (CH_4) and carbon dioxide (CO_2) and in much smaller quantities of hydrogen (H_2) and hydrogen sulphide (H_2S). At the end of the process, the digestate which remains is often high in nutrients such as ammonium and phosphate. Therefore, it can be used as fertiliser in agriculture or in landscaping. The methane producing microorganisms are found in different places in nature such as in the stomach of ruminants (cows). In order to initiate the anaerobic digestion process in a biogas plant, an inoculum (cow faeces) must be introduced to the feedstock.

A wide variety of biomass resources can be used as a feedstock for anaerobic digestion including agro-industrial waste, organic food waste, sludge from wastewater treatment plants, animal manure, agricultural residues and energy crops (e.g. maize, miscanthus, sorghum). The agricultural sector produces significant amounts of waste, which could be used for anaerobic digestion. It helps farmers:

- produce their own power and heat, and therefore save money;
- reduce greenhouse gases related to livestock manure and energy consumption;

- reduce the strong odours associated with the use of untreated manure as fertiliser;
- minimize the need to transport the organic inputs for treatment to the proximity of the on-site facilities;
- benefit from the advantages of digestate: more liquid material and therefore easier to spread, fewer weeds and mineralized nitrogen, etc.

The feedstock or substrates for AD can be classified according to various criteria: origin, dry matter content, methane yield etc. Substrates with dry matter content lower than 20% are used for what is called wet digestion (wet fermentation). This category includes animal slurries and manure as well as various wet organic wastes from food industries. When the dry matter content is as high as 35%, it is called dry digestion (dry fermentation), and it is typical for energy crops and silages. The choice of types and amounts of feedstock for the AD substrate mixture depends on their dry matter content as well as on the content of sugars, lipids and proteins. Substrates containing high amounts of lignin, cellulose and hemicelluloses can also be co-digested, but a pre-treatment is usually applied in this case, in order to enhance their digestibility (Al Seadi et al. 2008).

The composition of gases contained in the biogas differs according to the feedstock used. After being collected, biogas is purified from water and H_2S. The latter is a toxic gas, with a specific, unpleasant odour, similar to rotten eggs, forming sulphuric acid in combination with the water vapours in biogas. The sulphuric acid is corrosive and can cause damage to the engines, pipes etc. In order to remove the water contained in the biogas, often a condensation process is used which consists on cooling the gas in the pipelines and collecting the water in a condensation separator, at the lowest point of the pipeline. For H_2S removal, different technologies can be used, and these can be biological, physical or chemical methods. An overview on purification and upgrading technologies are given in details in Awe et al. (2018).

Biogas is a very valuable renewable energy source and an important element of viable energy concepts for the future. It is an environmentally friendly fuel made from 100% local feedstocks that is suitable for a diverse set of uses. The circular-economy impact of biogas production is further enhanced by the organic nutrients recovered in the production process. Biogas is used mainly used today directly in combined heat and power (CHP) plants for the production of electrical and thermal energy or on traditional gas-powered domestic appliances, such as gas ovens or gas driers.

A further step to add value to the biogas is the upgrading of biogas to biomethane. Upgrading is targeted to the removal of CO_2 in order to adjust (increase) the heating value and the relative density of the biogas. CO_2 removal can also be done through different technologies. The most common ones are pressure swing adsorption, pressurised water scrubbing, physical absorption with organic solvents, chemical absorption with organic solvents, membrane process, cryogenic separation. Details about these technologies can be found in FNR (2013) and Awe et al. (2018). The final upgraded biogas is at least 95% and usually around 98% methane.

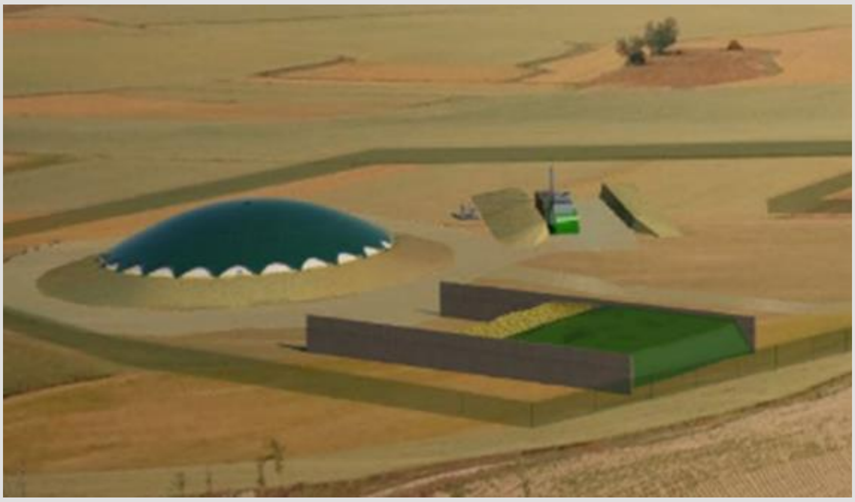
Once upgraded, biomethane has the same characteristics as natural gas. It can be injected into the natural gas grid and can be used in the following ways (FNR 2013):

- Fuel for natural gas vehicles. One possibility is to feed the biomethane into the natural gas network and subsequently to make it available on a virtual basis at natural gas fuelling stations. This is already happening at many fuelling stations in Germany, at which mostly natural gas/biomethane mixtures are offered.
- Domestic, industry, commercial uses as a substitute for natural gas in conventional natural gas burners and condensing boilers. There is no need for homeowners to replace their existing heating system for this.

- In the chemical industry as natural gas substitute. Natural gas is converted into synthetic gas (a mixture of carbon monoxide and hydrogen). Synthetic gas is an essential source for basic chemicals and thus one of the most important components for many chemical products.

The ADbag from Demetra

The Demetra ADbag is an example, that uses this process to convert different feedstocks to biogas and natural fertilizer. The Demetra ADbag consists of a plasticized fabric bag which works as reaction tank and a technical container which regulates the recirculation, the feeding and the heating of the digester. Depending on the energy type, the client wants to retrieve, the ADbag can be supplied with or without the CHP. The sludge within the reaction tank is agitated by the recirculation system to provide the perfect mixing of the feedstock and thus, to maximize the production of biogas. The entire process is monitored, and the automatized system can be controlled by onsite operators and remotely via an internet connection. The bag tank is partially embedded in the soil and the excavated material is used to build the shoulders all around the bag. The bag gets unpacked at the centre of the excavation before connecting it to the pipes in order to complete the circulation system. The storage pits for the digestate, the feeding tank and the screed for the container can be assembled on site from pre-casted concrete elements. The ADbag is available with a diameter of 12 m (ADbag12), 15 m (ADbag15) or 18 m (ADbag18) (Colmorgen and Khawaja 2019).



© Demetra

Biogas plants can be built in different sizes depending on the needs. A plant that is producing 1,000 MWe and more can be considered a large-scale biogas plant. If it is producing between 500 and 1,000 MWe, it can be referred to as medium-scale. Plants producing less than that can be considered small-scale (Collata and Tomasoni 2017). Although anaerobic digestion of small amounts of organic waste was considered unprofitable a few years ago, small-scale digestion is growing today (Biogas World 2019). Interest and public support in large scale biogas has been growing in most European countries. After a period of stagnation, caused by technical and economic difficulties, the environmental benefits and increasing price of fossil fuel have improved the competitiveness of biogas as an energy fuel (build a biogas plant n.d.).

3.1.3 Oil crops and used cooking oil for biodiesel production

Oil crops are those whose seeds, nuts, beans or fruits contain an important amount of oil. Beside the oil, they usually have a high protein content. After being extracted, the oil of these crops can be used to produce biodiesel and/or bio-based materials. The protein cake is often used for feed/food. In this section, biodiesel production will be reviewed, and the bio-based material production will be detailed in section 3.2.

There is a wide variety of oil crops. The most prominent ones are palm, soybean, rapeseed and sunflower (Figure 10) canola, mustard, flax, jatropha, coconut, hemp, and pennycress are also good resources of oil (ETIP n.d.). In the EU, concerns over ILUC (indirect land use change) and the food versus fuel debate have led to proposals to limit biofuel production from food crops to 7%. This has accelerated interest in drought-resistant oil crops that can be cultivated on marginal lands and do not compete with food crops such as cardoon, safflower and camelina (ETIP n.d. d) (Figure 11).

Biodiesel is produced through a chemical process known as transesterification from plant oils and animal fat with an alcohol (commonly ethanol or methanol) in the presence of a catalyst (e.g. sodium hydroxide).

$$\text{Oil} + \text{alcohol} \xrightarrow[]{\text{Catalyst}} \text{biodiesel} + \text{glycerine}$$

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Oil palm: *Elaeis guineensis, Elaeis oleifera*

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Soybean: *Glycine max*

© Pixabay

© Wikipedia

Rapeseed: *Brassica napus* subsp. *napus*

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Sunflower: *Helianthus annuus*

Figure 10: Most prominent oil crops

© Pixabay

© shawislandgatehouse

Cardoon: *Cynara cardunculus*

© Pixabay

© Caluna agrotrade

Safflower: *Carthamus tinctorium*

© ETIP

© Feepedia

Camelina: *Camelina Sativa*

Figure 11: Oil crops that could be grown on marginal lands

Since biodiesel can be produced from a wide range of oil crops, the fuels obtained have a greater variety in physical properties (viscosity and combustibility) than ethanol. Biodiesel can be blended with the commonly used diesel as fuel or used as it is in compression ignition engines. Its energy content is equivalent to 88-95% of that of diesel, but it improves its lubricity while improving its cetane number, in such a way that the two fuels are much the same (FAO n.d.). The higher oxygen content of biodiesel promotes more complete combustion of the fuel, which reduces emissions to the atmosphere of polluting particles, carbon monoxide and hydrocarbons. Like ethanol, biodiesel has a negligible sulphur content, which helps reduce sulphur oxide emissions from vehicles.

Beside from oil crops, used cooking oil which is usually handled as waste can be also converted to biodiesel. Despite the fact that used cooking oils are very cheap and sometimes even free, they present special challenges for biodiesel production because they contain contaminants such as water, meat scraps, and breading that must be filtered out before the oil is converted to biodiesel. Another challenge to biodiesel production from used oils is the high percentage of free fatty acids (FFAs). Fats and oils are composed of triglycerides – three fatty acid molecules attached to a glycerol molecule. In used oils, some of the triglycerides have broken down so that the fatty acids are separated from the glycerol molecule. These are called free fatty acids. These free fatty acids tend to react with the alkali catalyst in biodiesel production to form soap instead of biodiesel. This reduces the level of free catalyst and thus reduces the speed of the transesterification reaction. Soap formation tends to slow down the reaction. In addition, because the soap must be removed and discarded, more soap formation means less biodiesel (Farm Energy 2019).

When a feedstock contains less than 3% or 4% FFA, usually an extra catalyst is added and the FFAs are let to be converted to soap, and then the soap is removed. From 3% or 4%, up to 10% or 15% FFAs, a common approach is to use vacuum distillation to remove the FFAs from the oil. Then the oil can be processed normally, and the FFAs can be sold as animal feed or esterified separately (Farm Energy 2019). If the used oils contain more than 15% of FFAs, additional processing of these feedstock is needed before they can undergo traditional transesterification such as acid pre-treatment, glycerolysis, or solid acid catalysts etc.

3.1.4 Biomass for bioethanol production

Bioethanol is a biofuel which is produced by the fermentation process of sugars under anaerobic conditions in the presence of water and yeasts. Bioethanol is a clear colourless liquid, biodegradable, low in toxicity and causes little environmental pollution if spilt. It burns to produce carbon dioxide and water. Bioethanol is a high-octane fuel and has replaced lead as an octane enhancer in petrol. By blending it with gasoline, the fuel mixture can be also oxygenated so that it burns more completely and reduces polluting emissions. The most common blend is 10% ethanol and 90% petrol (E10). Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected also. Only flexible fuel vehicles can run on up to 85% ethanol and 15% petrol blends (E85) (Strathclyde n.d.).

Bioethanol can be classified based on the feedstock resources into first, second and third generation bioethanol.

First generation bioethanol fuels are made from sugar-containing crops such as sugarcane and sugar beet, and starch containing crops such as maize and wheat using standard processing technologies. For sugar crops, the process consists of first juice extraction; fermentation of the juice using yeasts, whereby the sugar is converted into bioethanol and CO_2; distillation and rectification, i.e. concentration and cleaning the ethanol produced by distillation and drying of the bioethanol. For grains, the process includes first milling or mechanical crushing of the cereal grains to release the starch components; heating and addition of water and enzymes for conversion into fermentable sugar; and then the process follows the same remaining steps as the sugar crops (crop energies n.d.). As it is the case for biodiesel made from food crops there are some sustainability concerns for first generation bioethanol production as it can compete with food production and other socio-economic and environmental issues (Kobak and Balcerek 2018).

Second generation bioethanol also known as advanced biofuels do not compete against food supplies as they are manufactured from non-food biomass. Second generation bioethanol is typically produced from lignocellulosic biomass (e.g. perennial grasses, agricultural crop residues such as wheat straw, forest residues) but it is also possible to use industrial by-products, such as whey or crude glycerol, as feedstock. Lignocellulose is considered a renewable and sustainable carbon source, but its conversion into reducing sugars is more difficult than the conversion of starch. Lignocellulosic materials contain a complex mixture of carbohydrate polymers from the plant cell walls known as cellulose, hemi cellulose and lignin. There are two processing routes by which lignocellulosic biomass can be converted into second generation ethanol: thermochemical and biochemical. The latter is a common technique for producing bioethanol, because of the high selectivity and efficiency of biomass conversion. The biochemical method involves pre-treatment of lignocellulosic material, enzymatic hydrolysis, fermentation of sugars by specific strains of microorganisms and distillation of bioethanol with dehydration (Figure 12). In the biochemical route, biomass is subjected to biological, physical (heat) or chemical catalysts during pre-treatment in order to break down the cellulose and the hemi cellulose portions into sucrose sugar. Additionally, biocatalysts such as enzymes are applied for the hydrolysis of polysaccharides, and fermentative microorganisms (yeast or bacteria) for fermentation of mixed sugar streams (Kobak and Balcerek 2018).

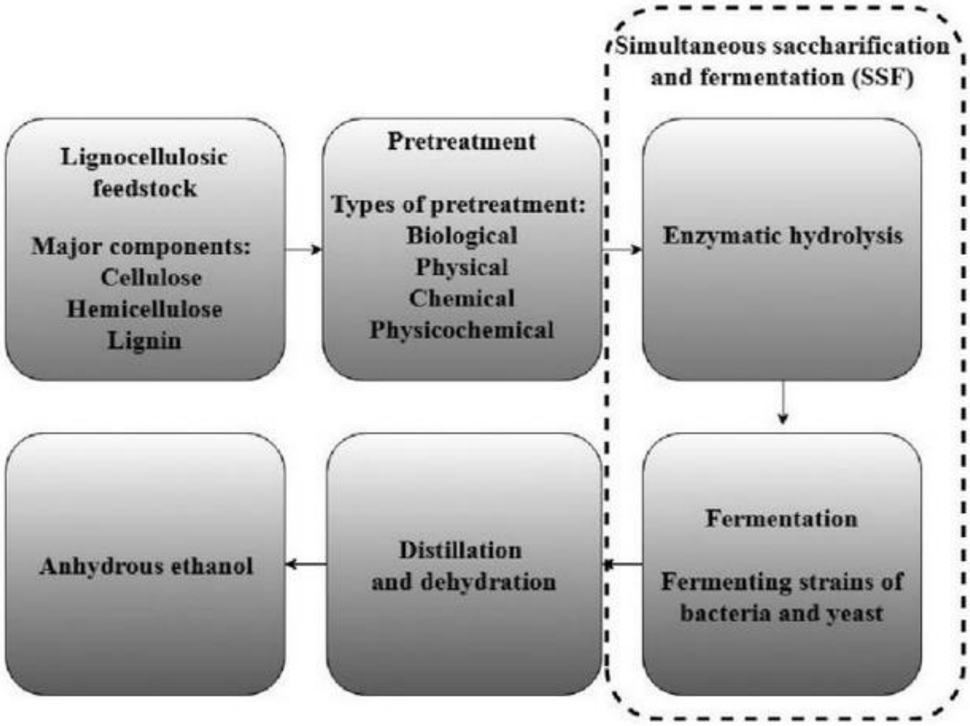


Figure 12: Major steps in bioethanol production (Kobak and Balcerek 2018)

The lignin which is also present in the biomass is normally used as a fuel for the ethanol production plants boilers.

Third generation bioethanol is based on the cultivation of microalgae or unicellular microorganisms derived from eukaryotes and prokaryotes. Live biocatalysts in the form of active microalgal biomass can use nutrients (carbon, nitrogen, phosphate or sulphur) from industrial waste streams as substrates to create high concentrations of biomass. These waste streams include effluent gases from industrial power plants, wastewater, products of hydrolysis of organic waste and digestate (waste from biogas production). Producing third generation biofuels can therefore help minimize waste streams from many industries. Biological sequestering of CO_2 from the combustion of fossil resources by microalgae and conversion of CO_2 to biofuels contributes to the reduction of levels of GHGs in the atmosphere, helping to meet global targets for preventing climate change (Robak and Balcerek 2018).

3.2 Material uses of biomass

According to the EU, Bio-based products are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised (European Commission n.d.). Following a strict definition, many common materials, such as paper, wood, and leather, can be referred to as bio-based materials, but typically, the term refers to modern materials that have undergone more extensive processing. Materials from biomass sources include bulk chemicals, platform chemicals, solvents, polymers (i.e. plastics), and biocomposites (some materials may fall under more than one category) (Curran 2010).

Cellulose, lignin, vegetable oils and sugars constitute the main bio-based raw materials for the development of a new chemical industry, all sectors combined. For the past 20 years, the growth of bio-based products has been stimulated by three drivers:

- The substitution of identical petrochemical molecules by bio-based molecules. Plant chemistry has historically developed in certain segments of the chemical industry (adhesives, surfactants, cosmetics, etc.) or in the paper sector. Most of this development was achieved through strict substitution of petrochemical molecules with molecules of plant origin (polyethylene from petrochemicals versus polyethylene produced from sugar cane, for example), imitation making it possible to access markets already in place, thereby limiting technical and regulatory risks.

- The substitution of use where a new bio-based molecule can replace a petrochemical or mineral product, a new approach which has been developing since the mid-2000s. In this context, a molecule of petrochemical origin (or a product) can be replaced by a molecule with a different molecular structure from plants, like polylactic acid for some bottles or glass wool replaced by hemp wool.
- The development of new uses based on the specific properties of plant molecules (ABGi n.d.).

3.2.1 Bioplastics

According to European Bioplastics, a plastic material is defined as a bioplastic if it is either bio-based, biodegradable, or features both properties. The term 'bio-based' means that the material or product is (partly) derived from renewable resources (Figure 13). Biodegradation is a chemical process during which microorganisms that are available in the environment convert materials into natural substances such as water, carbon dioxide, and compost (artificial additives are not needed). The process of biodegradation depends on the surrounding environmental conditions (e.g. location or temperature), on the material and on the application. 'Bio-based' does not equal 'biodegradable'. The property of biodegradation does not depend on the resource basis of a material but is rather linked to its chemical structure. In other words, 100% bio-based plastics may be non-biodegradable, and 100% fossil-based plastics can biodegrade (European Bioplastics n.d.).

Figure 13: Conventional plastics vs. bio-based plastics (European Bioplastics n.d.)

According to this definition, bioplastics can be classified into three main groups:

1. Bio-based or partly bio-based, non-biodegradable plastics such as bio-based polyethylene PE, PP, or polyethylene terephthalate PET (so-called drop-in solutions) and bio-based technical performance polymers such as numerous polyamides (PA), polyurethanes (PUR), polyesters (e.g. PTT, PBT) or TPC-ET. Usually, their operating life lasts several years. Therefore, they are referred to as durables, and biodegradability is not a sought-after property.

2. Plastics that are both bio-based and biodegradable, such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) or polybutylene succinate (PBS). They have been available on an industrial scale only for the past few years. So far, they have primarily been used for short-lived products such as packaging, yet this large innovative area of the plastics industry continues to grow due to the introduction of new bio-based monomers such as succinic acid, butanediol, propane diol, or fatty acid derivatives.
3. Plastics that are based on fossil resources and are biodegradable such as PBAT. They are a comparatively small group and are mainly used in combination with starch or other bioplastics because they improve the application-specific performance of the latter by their biodegradability and mechanical properties. These bio-degradable plastics are currently still made in petrochemical production processes. However, partially bio-based versions of these materials are already being developed and will be available in the near future (European Bioplastics n.d.)

Figure 14 depicts common types of bioplastics and how they are classified according to their biodegradability and bio-based content.

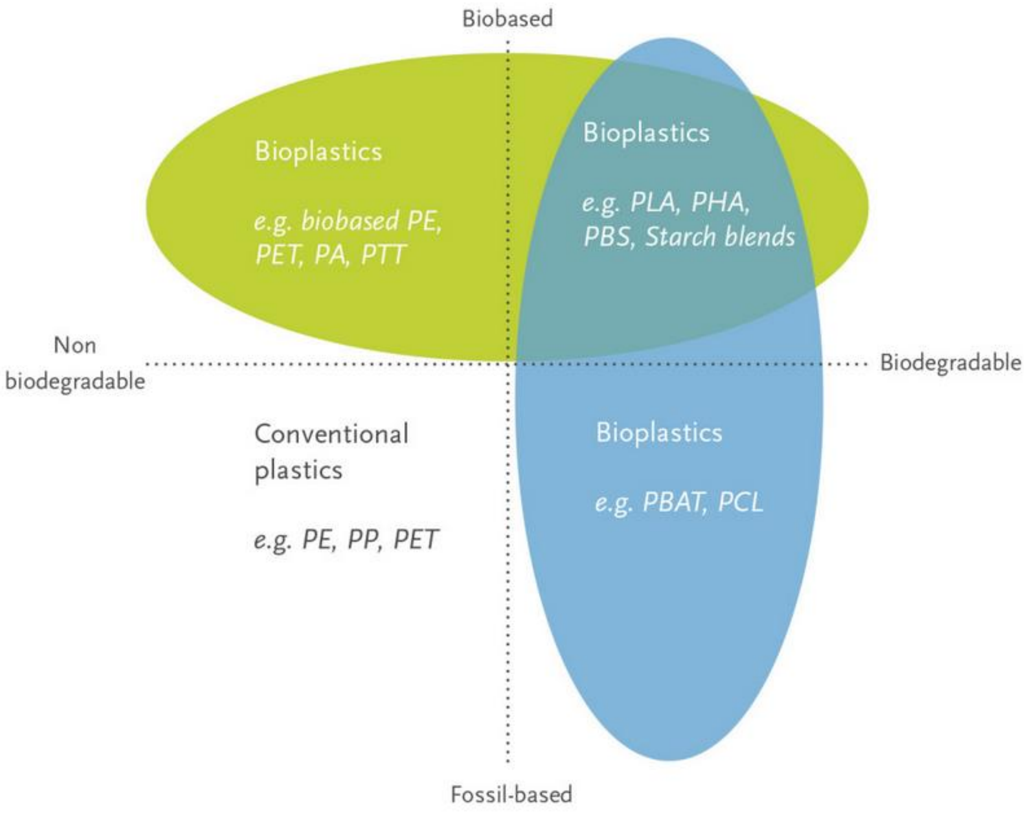


Figure 14: Classification of bioplastics (European Bioplastics n.d.)

Based on the permanence or impermanence of their form, bioplastics can be classified into two categories: Thermoplastics or thermosetting polymers (thermosets). **Thermoplastics** are the plastics that, when heated, do not undergo chemical change in their composition and so can be moulded again and again. Examples include polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC). **Thermosetting polymers,** in contrast to thermoplastics, remain in a permanent solid state after being cured one time. Polymers within the material cross-link during the curing process to perform an unbreakable, irreversible bond. This means that thermosets will not melt even when exposed to extremely high temperatures. Thermosets have low-viscosity and are easy to work with because they exist in liquid form at room temperature, meaning that no application of heat is required. Examples include polyurethane (PUR) (Romeorim n.d.).

Types of bioplastics

Another classification that seemed more fitted to the context of BE-RURAL is the one based on the raw material source. Bio-based plastics (not fossil-based) can be produced from a wide range of plant-based raw materials. Natural polymers (macromolecules) such as polysaccharides (e.g. starch, cellulose), proteins, lignin, natural rubber, monomers (glucose, fructose), dimers (sucrose) and fatty acids (plant oils), are used as the basic raw materials in the production of bio-based plastics. Based on the type of raw materials used, different types of bioplastics can be distinguished:

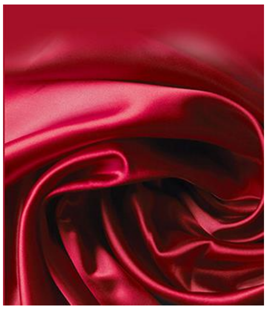
1. **Polysaccharide (multi-sugar) -based bioplastics** (Figure 15)

Polysaccharides are among the most important naturally occurring polymers. They are synthesised by living organisms and act as energy reserves or have a structural function for the cells or the whole organism. The most common natural polymers that can be transformed to bioplastics include the following:

Thermoplastic starch (TPS): It is produced by the destruction (extrusion) of starch through sufficient mechanical energy and heat in the presence of so-called plasticisers such as glycerine. TPS can be used for manufacture of any kinds of packaging, such as films, bags (for shopping or waste) and one-off products (e.g. catering equipment pieces) and in this area it can be an equivalent substitute of conventional materials like polyolefins or PVC (ŁUKASIEWICZ n.d.). It is also an alternative to gelatine and can be used as a material for pills and capsules.

Cellulose regenerate: Cellulose is the principal component of cell walls in all higher forms of plant life, at varying percentages. It is therefore the most common organic compound and the most common polysaccharide. If cellulose is chemically dissolved and newly restructured in the form of fibres or film, it is known as a cellulose regenerate. The most well-known members of this group of materials are viscose, viscose silk, rayon or artificial silk, and a few more in the area of fibres and textiles (FNR 2019).

Thermoplastic starch food packaging © John R. Dorgan



Viscose silk fabric © Rudolf group

Transparent dice made from cellulose acetate © Michael Thielen

Figure 15: Examples of products made from polysaccharide-based bioplastics

Cellulose esters: They are derived from natural cellulose and produced by the esterification of cellulose with organic acids, anhydrides, or acid chlorides. Cellulose acetate is the most important organic ester because of its broad application in fibres and plastics. Although cellulose acetate remains the most widely used organic ester of cellulose, its usefulness is restricted by its moisture sensitivity, limited compatibility with other synthetic resins, and relatively higher processing temperature (Edgar 2004).

Cellulose ethers: They are water-soluble polymers produced by chemical treatment of cellulose and the reaction of etherifying agents such as chlorinated ethylene, chlorinated propylene and oxidized ethylene. They are non-ionic, water soluble products. Cellulose ethers are used as functional and rheological additives and function as thickening agents, emulsifiers, protective colloids, stabilisers and for water retention (Vink Chemicals n.d.).

2. **Sugar-based bioplastics** (Figure 16)

Sugar (e.g. glucose, sucrose) is present in many plants and crops. After being extracted, it can be further processed into bioplastics. The starch contained in the starchy crops (e.g. corn, maize) can also be extracted, hydrolysed with enzymes to produce glucose and then further processed in the same way as sugar to produce bioplastics. Furthermore, some bioplastics can be produced by microorganisms using sugar as a substrate. The most common sugar-based bioplastics are listed below:

Polylactic acid (PLA): A bio-based polyester considered to be today's most important bioplastic on the market. The production process includes as a first step the fermentation of sugar to lactic acid by microorganisms (if starch is used, hydrolysis with enzymes takes place first). Then dehydration which transforms lactic acid to lactide and finally, the polymerisation of lactide (monomer) which leads to the production of PLA. It is a very versatile bioplastic. By varying composition and quality, it can be designed to biodegrade quickly or last for years. Additionally, PLA possesses an extraordinary stability, as well as an extremely high transparency. Nevertheless, PLA has some disadvantages: as its softening point is around 60 °C, the material is only to a limited extent suitable for the manufacture of cups for hot drinks. PLA blends have a wide range of applications including computer and mobile phone casings, biodegradable medical implants, foil, moulds, tins, cups, bottles and packaging devices. PLA and PLA copolymer plastics have already been used successfully for medical and pharmaceutical purposes such as the production of screws, nails, plates and implants that can be resorbed by the body (Innovative Industry 2010).

Polyhydroxybutyrate (PHB): One of the members of the polyhydroxyalkanoate (PHA) family. It is a bio-based polyester synthesised by microorganisms. By feeding on carbon rich sources such as sugar or starch and under limited nitrogen condition, the microorganisms accumulate PHB in their cells as reserves (up to 80% of their own body weight). After that, the biopolymer is isolated, compounded and granulated. It is used mainly in food packaging, biomedical and pharmaceutical industry. However, their use is currently limited owing to their high production cost (Tripathi 2015).

Polybutylene succinate (PBS): is a thermoplastic polyester made from polycondensation of succinic acid and 1-4 Butanediol (BDO). Succinic acid, a product coming from the fermentation of sugar by microorganisms, is one of the most important new chemicals of the bio-based economy. It is a very versatile building block, which is expected to develop into a platform chemical with a broad range of applications, from high-value niche applications such as personal care products and food additives, to large volume applications such as bio-polyesters, polyurethanes, resins and coatings (Nova Institut 2018). PBS is a crystalline polyester with a melting temperature exceeding 100 °C, which is important for applications that require a high temperature range.

Polyethylene terephthalate (PET): is a thermoplastic polyester that is produced by polycondensation of monoethylene glycol (or ethylene glycol, a bivalent alcohol, a diol) and terephthalic acid or dimethyl terephthalate. Sugar is used as raw material for the production of both components, but with different processes. PET can be partially bio-based when terephthalic acid comes from fossil resources. Regardless of whether PET is partially or totally produced from renewable resources, chemically the material is identical to conventional PET and the applications are also the same. Because it is an excellent water and moisture barrier material, it is widely used to make plastic bottles for mineral water and soft drinks (FNR 2019).

Polytrimethylene terephthalate (PTT): It is a polyester similarly to PET is produced by polycondensation of terephthalic acid or dimethyl terephthalate and a diol. PTT was first launched onto the market mainly in the form of spun fibres and textiles. Because they are particularly soft and yet can bear heavy wear the principal area of application was for domestic carpets and carpets for the automobile industry. With a high-quality surface finish, and low shrink and deformation performance, the material is ideal for, amongst other things, electrical and electronic components such as plugs and housings, or also for air breather out-lets on car instrument panels (FNR 2019).

Polyethylene (PE): is a polyolefin that is produced from the dehydration of bioethanol which itself comes from the fermentation of sugar by yeasts. It is the most popular plastic in the world. It has the same characteristics as fossil PE and therefore has the same applications, typically films (storage bags, pouches, packaging films), blow moulded hollow parts such as beverage containers, automotive fuel tanks, injection moulded parts, tubes and others.

Coffee capsule made by bioPLA © COEXPAN

Bottle made of 30% PET © Coca cola

Packaging made from (PBS) © Mitsubishi chemical

Figure 16: Examples of products made from sugar-based bioplastics

3. **Oil-based plastics**

The utilisation of plant oils is currently in the spotlight of the chemical industry, as they are one of the most important renewable platform chemicals due to their universal availability, inherent biodegradability, low price, and superb environmental credentials (i.e., low ecotoxicity and low toxicity towards humans) (Lligadas et al. 2013). These natural properties are now being taken advantage of in research and development, with vegetable oil derived polymers/composites being used in numerous applications including paints and coatings, adhesives, and biomedicine (surgical sealants and glues, pharmacological patches, wound healing devices, and drug carriers to scaffolds for tissue engineering). The most common oil-based plastics are polyurethane and certain polyamides.

Polyurethane (PUR): They are made by a reaction between isocyanates and polyols (produced by transesterification and epoxidation of plaint oil). They can be hard and brittle, elastic, foamed or compact. Bio-PUR has the same characteristics as the fossil ones and are non-biodegradable. Therefore, they have the same applications and are used mainly in the manufacture of high-resilience foam seating, rigid foam insulation panels, microcellular foam seals and gaskets, durable elastomeric wheels and tires, automotive suspension bushings, electrical potting compounds, high-performance adhesives, surface coatings and surface sealants, synthetic fibres (e.g., Spandex), carpet underlay, hard-plastic parts (e.g., for electronic instruments), condoms etc. (Howe 2018).

4. **Protein-based plastics**

Proteins are natural polymers built up of amino acids. Casein is a protein commonly found in animal milk and was already a significant player in the bioeconomy, used as a nutritional supplement and also as a binding agent or capsule for pharmaceutical tablets. Gelatine, another protein-based bioplastic is produced by the partial hydrolysis of collagen, a natural polymer present in animal protein (IfBB 2017).

5. **Lignin-based plastics**

Lignin is a natural matrix material which binds the strong and stiff cellulose units in, for example natural wood. Once separated, it can be chemically modified or blended to produce a thermoplastic-type polymer which can be heated and processed like synthetic thermoplastics. Lignin can be in the form of a brown powder, but more often it is a gummy mixture with a wide range of molecular weights. It is a by-product of the pulp industry and the volume created worldwide is about 50 million tonnes per year (Quarshie and Carruthers 2014).

3.2.2 Biocomposites

Composites are formed by combining materials to form an overall structure with properties that differ from that of the individual components. The common example of composites is the synthetic polymers reinforced with synthetic fibres such as glass fibres or carbon fibres. When the polymers and/or the fibres used to form the composite come from an organic origin, it can be referred to as biocomposite.

Composite materials derived from natural, renewable sources have received significant interest in recent years, in particular due to the increased awareness and drive towards more environmentally sustainable technologies. In many cases bio-based materials offer weight reduction, added functionality (e.g. damping / impact absorption) and occupational health benefits.

Natural fibres such as hemp, jute and bamboo fibres have good strength and stiffness properties, whilst being significantly lighter than conventional reinforcements such as glass fibres, and they have relatively a low cost and are biodegradable. In addition to their appealing mechanical properties, natural fibres are non-irritating which makes them safer and easier to handle and they tend to be non-abrasive resulting in reduced wear on tooling and manufacturing equipment. Natural fibres are also biodegradable and/or recyclable, depending on the desired end-of-life process route. The main shortcomings associated with natural fibres as composite reinforcements are the relatively high moisture uptake, which can lead to swelling, rotting and reduced mechanical properties, the low impact resistance, the relatively low temperature capability (decomposition usually occurs at approximately 200 ºC) and the maintenance of acceptable levels of quality control. Natural fibres are hydrophilic (‘water loving’) in nature which can lead to compatibility issues when combining with hydrophobic (‘water hating’) polymer matrix materials. Waxy compounds can also be present on the surface of the fibres, making it difficult to achieve strong fibre-matrix bonding. In order to overcome some of the disadvantages of natural fibres, in particular the poor bonding to polymers, the high moisture uptake and the limited thermal stability, a wide range of physical, chemical and additive treatments which modify the fibre characteristics can be done. One of the treatments is called acetylation and it is considered to have the most potential for natural fibres because it significantly improves the moisture resistance, continuous processing is possible, and the fibre strength and stiffness are not reduced (Quarshie and Carruthers 2014).

A number of bio-based polymers and resins have been launched commercially, the most notable being polylactic acid (PLA) from corn starch and polyfurfuryl alcohol resins from waste sugarcane biomass. However, many more types are currently under development, from sources including starches and crop oils (see section 3.2.1).

More recently, combinations of natural fibres and bio-based polymers have been shown to have appealing composite properties, offering the enticing prospect that fully bio-based composites are an increasing commercial reality.

Wheat gluten and soy protein are common examples of biopolymers which have been reinforced with natural fibres to produce a biocomposite with improved mechanical properties (Muneer 2015). Natural fibres, reinforced with synthetic polymers such as polypropylene (PP), are currently used in significant quantities, in particular in automotive interior components. It has been estimated that substituting glass fibres with natural fibres can reduce the weight of a composite by up to 40% which, in the automotive sector, can lead to substantial benefits in fuel efficiency (Quarshie and Carruthers 2014).

Biocomposites have not only been produced by combining the natural fibres and polymers but there are several examples where two natural polymers have been combined to make a biocomposite with improved mechanical and gas barrier properties. Wheat gluten, rice proteins and egg albumin have been combined with starch with an aim to improve functional properties of the composite (Muneer 2015).

Biocomposite BioLite™

The company Trifilon developed a process to create a biocomposite that has similar features to their conventional, petroleum-based counterparts. For the production, two types of feedstock are needed. In the first type, natural fibres like hemp or flax fibres, which can be provided by local or European framers, are required. In the second type of feedstock, thermoplastic polymers like polypropylene are used. Since the outcome of this process is a blended product and not free from fossil-based ingredients, it must be considered as a greener plastic, not as a bioplastic, even though recycled plastics are involved, too. The natural fibres undergo a mechanical cleaning, a chemical purification and an optimization process, before they are mixed with the polypropylenes and some additives. The outcome is the biocomposite BioLite™ in granulate form with different ratios of polypropylenes and natural fibres. BioLite™ AP21 consists of 10% natural fibres and 90% polypropylene and BioLite™ AP23 consists of 30% natural fibres and 70% polypropylene. The different ratios result in different product properties like bio-content, stiffness and weight. The latter can be even better than competing fossil-based compounds (30% stiffer and 10-25% lighter). Finally, both types of granulate can be fed into conventional injection moulding units (Colmorgen and Khawaja 2019, Ecologic Institute 2018).

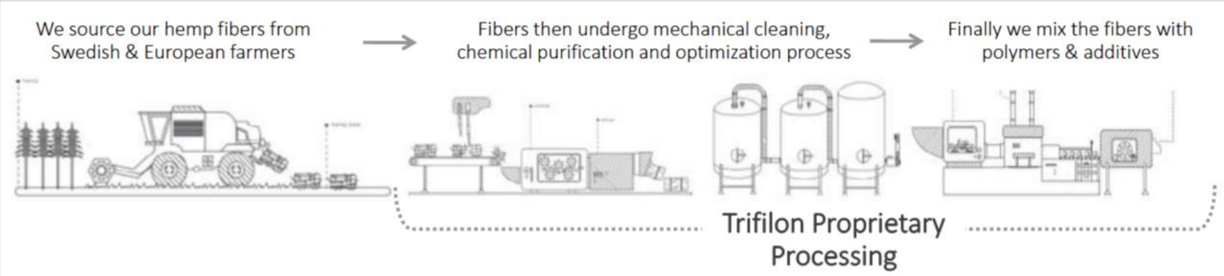


Illustration of the production stages of BioLite™ (Ecologic Institute 2018)

Hemp fibres and BioLite™ samples in different colours © Trifilon

3.3 Composting of biowastes

In a bioeconomy, biowaste is not supposed to be landfilled. It is no longer seen as waste but rather as a valuable resource for organic soil improvers, fertilisers, growing media component and bio-based products. An important prerequisite to produce high-quality compost is an exhaustive **source separated waste collection** in order to keep the number of undesired interfering materials as small as possible. Compared to new upcoming and innovative bioeconomy-related technologies and processes, composting is often associated with a rather simple and proven option, to make use of collected biowastes coming from different sources. However, composting can be technically very sophisticated, since composting facilities can range from low-technology operations, where piles of leaves are turned periodically with front-end loaders, to high-technology operations, where size reduction equipment, dedicated windrow turners, and screening equipment are used. One of the main advantages of the compositing treatment of organic waste is its scalability. This means that, the process is the same regardless of the quantity of organic materials which are converted. Thus, composting treatments can be applied on domestic as well as on municipal and even larger scales. Even though the biological process is the same one, its kinetics, evolution and the relevance of different parameters (e.g. physical structure, particle size, moisture, surface/volume ratio, C/N ratio, porosity, temperature), vary significantly depending on the applied scale. These parameters can be different in sensitivity depending on the scale (ACR+ 2014, ECN n.d., González-Sierra et al. 2019).

Small and medium-scale composting sites mostly focus on the treatment of waste of organic origin (often roughly divided into food waste and green waste) generated in limited catchment areas. Nonetheless, the variety of raw materials used is large and thus their origin and characteristics, which are highly important for the design of whole composting process (see exemplary EWC codes in Table 1). The variation of the characteristics and origin of the raw material are the result of different influencing factors such as seasonality, local gastronomy, weather conditions, etc. and condition of the organic waste in terms of moisture, consistency, granulometry and oxidisability C/N ratio (ACR+ 2014, González-Sierra et al. 2019).

Table 1: Extract of composting-relevant wastes from the EWC

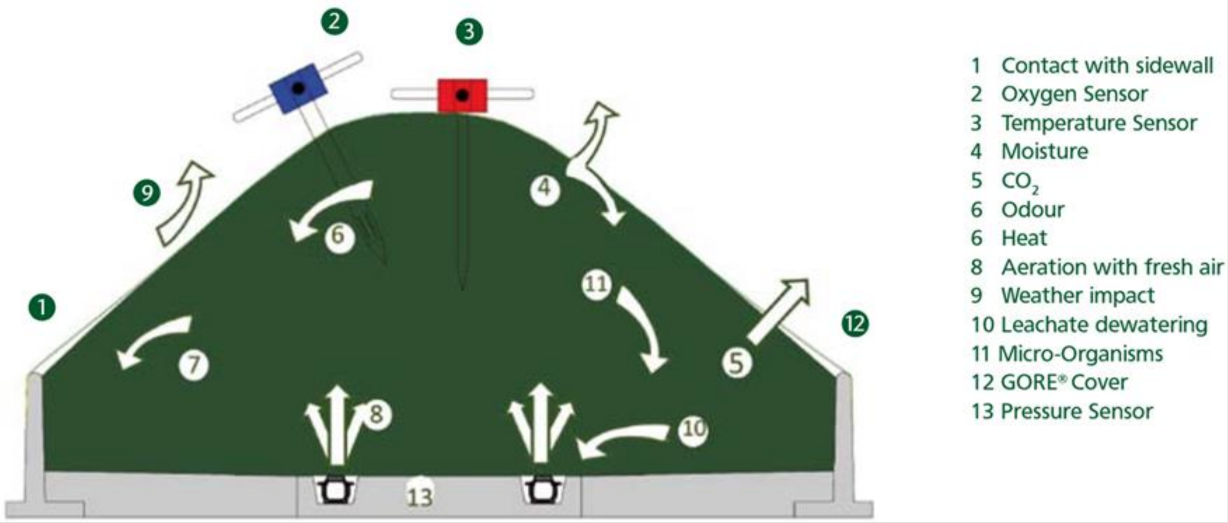
EWC code	Description
20	Municipal wastes (household waste and similar commercial, industrial and institutional wastes).
2001	Separately collected fractions.
200108	Biodegradable kitchen and canteen waste.
200138	Wood other than that mentioned in code 200137 (Wood containing dangerous substances).
2002	Garden and park wastes (including cemetery waste).
200201	Biodegradable waste.
2003	Other municipal wastes.
200302	Waste from markets.

When adapting the composting process to a certain level, the composting process phases depend on the design of the composting site (mainly on the number of modules) and, in turn, such design defines the working or operational functioning. Thereby, several design rules exist, which are described in the report from González-Sierra et al. (2019).

The composting solution from UTV AG

Composting is a process in which microorganisms, naturally present in organic matter and soil, decompose organic matter. In order to break down the organic matter into smaller particles the microorganisms require basic nutrients, oxygen and water. Organic matter is recycled naturally without human management, but since this process is under human control the end-product is called compost. Furthermore, the regulation and optimization of the composting process have a decisive influence on the time in which the composting takes place as well as on the quality of the compost (Chen et al. 2011).

With the GORE® Cover, UTV AG offers a retrofittable, cost efficient and flexible technology which suits for different types of waste. Within the membrane-covered heap the organic matter is decomposed in a pressure-aerated and oxygen-controlled environment, which is computer monitored. The optimized aeration and supply of oxygen through the fans and ventilation pipes result in an intensified decomposition in eight weeks. The end-product is a high-quality compost. Advantages of this technology are the short planning and installation (maximum three months), its mobility, its low construction and operating costs (compared to concrete installations) and the easy handling (trained staff necessary) (Colmorgen and Khawaja 2019).



UTV's composting system with a membrane-covered heap

3.4 Bio-based packaging solutions

For the transition to a bioeconomy, it is of utter importance that raw materials are used in the most sustainable way, as efficient and long as possible. That applies for biomass, too. In many cases, packaging materials have a relatively short lifespan during which they add value to products. In order to guarantee that raw materials are used for as long as possible, packaging materials must be used properly, be developed in a way that requires as few virgin materials as possible and finally they need to be suitable for reuse or recycling processes (KIDV 2018).

Packaging materials based on renewable raw materials have so far mainly been found in the paper and cardboard packaging sectors. They already have a very large share in the packaging market. The most important raw materials for industrial paper production are wood and wastepaper. In addition, certain annual plants are used as a source of raw materials. All cellulose-containing substances are basically suitable for paper production. Foil materials based on cellulose or starch can only be found in very small niche markets. A more recent development is the production of so-called drop-in materials. Here, conventional polymers such as polyethylene are produced from renewable raw materials, which can be fed into already existing value chains for plastic packaging materials (Sachverständigenrat Bioökonomie Bayern 2017). There are various processes by which conventional packaging polymers such as PE, PP, PET (approx. 80% market share) can be produced from renewable instead of fossil raw materials. More than 80% of bio-based PE from bioethanol and 30% of bio-based PET is already established in industry. Their production can be integrated into existing chemical value chains, e.g. through the chemical raw materials bio-naphtha and bio-methane. In addition, completely new synthetic routes are also possible. As bio-based raw materials, carbohydrate and oil-containing plants as well as residual and waste materials (wood-like components, old fats etc.) come into question. Bio- and fossil-based variants are chemically identical and the bio-based packaging materials can be but do not have to be recyclable in practice (Käb 2018). Forecasts give this strategy the greatest market opportunities, because existing structures and processing processes of established, petroleum-based plastics can be used, and no new technologies are needed. Thus, biogenic raw materials can also be processed into conventional polymers with good barrier properties. Nevertheless, they still lack few barrier properties, e.g. against water vapor. This is a fundamental shortcoming of purely biological polymers such as cellulose or starch. This also applies to polymers that can be obtained from natural raw materials through fermentative processes such as polylactic acid or polyhydroxyalkanoates (Sachverständigenrat Bioökonomie Bayern 2017).

Today, most of the biodegradable packaging materials can only be broken down in industrial composting facilities. The natural decomposition process of bio-based materials can be very long lasting. Thus, the use of biodegradable packaging is not necessarily a solution for the litter problem or the plastic soup. This will change once innovations result in the introduction of biodegradable materials that can be broken down in the natural environment. Bio-based plastics, in turn, are not compostable but can be recycled within the existing plastic waste collection system. Currently, this results in the highest added value for the bioeconomy, since they lead to a reduced demand for fossil fuels and thus have a positive impact on the emissions of greenhouse gases when kept in reuse and recycling loops as long as possible (KIDV 2018).

Beside the conventional packaging production from paper and cardboard and biodegradable and bio-based materials, there are some innovative companies that try to overcome the composting and deposition gaps with new innovative technologies. The start-up company BIO-LUTIONS takes up the challenge of creating two products out of one harvest. Together with the Brandenburg company Zelfo, BIO-LUTIONS developed a **mechanical process** to produce a sustainable packaging alternative from agricultural waste. The idea of BIO-LUTIONS was to develop an innovative and resource efficient technology which can use even the shortest fibres from numerous agricultural residues to produce valuable products worldwide. By extending the life cycle of these unused crop residuals they also aim to create a decentralized production network with local production units and regionalized distribution of the local raw material used. Beside adding value in the regions and strengthening the circular economy, they want to raise awareness on the issue of plastic waste, offer sustainable and affordable solutions and eliminate non-sustainable disposables (Colmorgen and Khawaja 2019).

Packaging materials from agricultural residues

BIO-LUTIONS provide a technology which enables them to produce disposable tableware and packaging from renewable raw materials like plant and crop residues. The process transforms previously unused crop residues into innovative and valuable products. So, the patented technology, developed by BIO-LUTIONS and Zelfo, can be described as an up-cycling procedure that can be applied worldwide. The plant fibres are broken down and blended into a cohesive pulp, which is conducted into a water tank. A mechanic rake is moving the humid mixture which is very similar to the one in the paper industry. Afterwards, the mass runs to the squeezing machine where the products are formed and pressed under high temperatures. There is no need for use of chemicals during the whole process. The process water is cleaned and recycled several times until it is disposed by using it for irrigation (BIO-LUTIONS 2019, Bioökonomie.de n.d.).

Banana stems as a raw material source in India and BIO-LUTIONS' current product range of disposables © BIO-LUTIONS

3.5 Bio-based insulating materials

In an era of energy-efficient construction and renovation as well as increasing energy tariffs, natural insulation materials are gaining in importance. Their production requires less energy and they have a positive impact on the living climate and thus on human health. In summer, the natural materials insulate well against heat. They can also absorb large amounts of moisture and are often allergy friendly. Bio-based insulation materials are made from renewable resources which means they are plant or animal based. The range of bio-based and sustainable materials that are suitable as insulation materials is large. Insulation materials from straw, meadow grass, hemp or cellulose flakes can already compete with conventional insulation materials such as mineral wool regarding material properties (Bioökonomie.de 2017, BMBF 2014). Further examples of raw materials which can be used to produce sustainable insulating materials are jute, cork, reeds, seagrass, meadow grass, cellulose, kenaf and cotton.

Bio-based insulating materials can replace conventional ones. In so far as, they do not come with a loss of performance, but often offer additional positive functionalities. Compared to mineral and fossil-based materials bio-based insulating materials provide heat and sound insulation properties which are just as good as the ones from fossil-based materials, such as rock wool, glass wool and polystyrene. The technical performance of renewable insulating materials such as cellulose and fibres from hemp, flax, kenaf and cotton, can be compared to the performance of the mineral benchmarks. The same applies for the good sound insulation or sound reducing properties that are comparable to those of standard materials of mineral origin. Moreover, bio-based insulating materials have a better moisture regulation performance and they offer excellent summer heat protection. The ability of an insulating material to regulate the temperature by storing and releasing heat to a cooler environment is highly important. This indicator is called specific heat capacity. When it comes to the regulation of temperature, natural insulation materials can be superior to conventional fossil or mineral based materials since their specific heat capacity is higher. This becomes very important when it comes to creating a more comfortable indoor climate and to preventing overheating of rooms that sit below the roof during the summer (BioCannDo n.d.).

Table 2 gives an overview of different insulating materials and their thermal conductivity and specific heat capacity. The heat-insulating effect is described by the thermal conductivity (λ). Small thermal conductivity correlates with a better insulating effect and a better thermal protection. Values for thermal conductivity below 0.5 W/(m × K) guarantee good thermal insulation properties. The specific heat capacity (c) indicates the amount of heat that a material can accumulate. High values for c indicate a higher heat storage capacity and a corresponding capacity to release heat to a cooler environment (BioCannDo n.d.).

Table 2: Overview on insulating materials, their thermal conductivity and specific heat capacity.

Insulating Material	λ (W/(m × K)	c (J/kg × K)
Bio-based materials		
Flax mats	0.036-0.040	1,600
Hemp mats	0.040-0.050	1,600-1,700
Hemp (loose)	0.048	1,600-2,200
Wood shavings	0.045	2,100
Wood fibre insulation board	0.040-0.052	2,100
Cork board	0.040	1,800
Sheep wool	0.0326-0.040	1,720
Straw bale construction	0.052-0.080	2,000
Cellulose flakes	0.040	2,200
Seagrass	0.037-0.0428	2,000
Conventional materials		
Polystyrol (PS) (Styrofoam)	0.035-0.040	1,400
Rock wool	0.033-0.040	840-1,000

Moreover, bio-based insulating materials contribute a healthy living environment. Already during the installation, they are much more user-friendly (non-irritating to the skin) than conventional insulating materials. In addition, natural insulating materials can accumulate and conduct moisture, resulting in a moisture-regulating effect and contributing to a balanced indoor climate throughout the year. Sheep wool has a particularly positive effect since it can absorb and neutralise a large variety of volatile organic compounds and thus has a strong air purification effect. Finally, bio-based insulating materials contain much less (mostly flame-retardant chemicals) or sometimes no chemical additives which is healthier for residents and the environment. Compared to fossil-based materials, sustainable insulating materials do not pose an increased risk of fire and they are just as durable. (BioCannDo n.d.)

The environment protection potential of sustainable insulating materials must be considered, too. Firstly, compared to fossil-based counterparts, much less energy is needed during the production process. Compared to the primary energy requirement of mineral wool, sheep wool insulation materials safe 130 kg CO_2/m^3. Furthermore, the GWP of sheep wool is negative (Figure 17). Secondly, natural insulating materials bin CO_2 during the growth phase and even store it. Since many natural insulating materials have their origin in the agricultural or forestry sectors, transport distances are short and import dependencies small. This can also stimulate development in rural areas. (BioCannDo n.d., Daemwool n.d.)

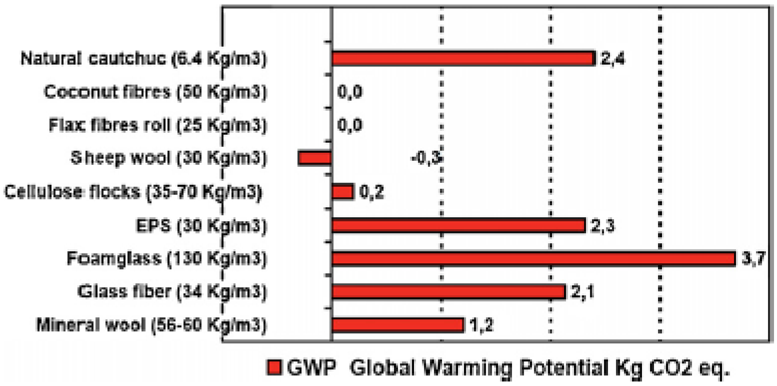


Figure 17: Global Warming Potential of different insulating materials (Daemwool n.d.)

One company that produces sustainable insulating materials is Daemwool from Austria. They produce eco-friendly sheep wool insulating materials from local and existing sheep wool resources that have been unexplored for a long time.

Daemwool's sheep wool insulating material

The starting material is raw wool with a high contamination level of up to 50% (sweat, skin scales, soil and plant remains and wool grease). Therefore, the wool is gently washed with soda and soap at 60 °C and degreased. Additionally, the pH value is adjusted, and the wool is treated with moth repellents. Now the wool consists of approx. 97% protein (keratin fibres). The treated wool is pressed in bales to transport them to the production site, where the bales are opened again to feed the wool to the carding machine. The carding machine produces a primary fleece which gets accumulated until it reaches the necessary weight. To generate the desired raw density, the fleece is compressed either mechanically by needling or thermally by solidifying with synthetic fibres in an oven. Finally, the insulating material is cut to size with a cutting machine. Leftovers are recycled. Since the wool fibres are not exposed to highly intensive UV radiation or constant moisture, chemical decomposition won't occur. Further characteristics of the flame-retarding and self-cleaning insulation wool are the natural ability of air conditioning and absorbing pollutants, the easy handling as well as its energy-saving potential and environmental friendliness (Colmorgen and Khawaja 2019).

There is already a large range of bio-based insulating materials available - ready for application. These materials have different advantages and disadvantages depending on their use. Several sustainable insulating materials can be found in online databases such as the ones provided by natureplus® or by the German Agency for Renewable Resources (FNR).

3.6 Bio-based textile solutions

The use of renewable raw materials is an everyday routine for the textile industry. Plant fibres such as linen and cotton, as well as animal products such as wool, silk and leather are used in many textile areas. To increase sustainability and resource efficiency, unconventional ideas are now being implemented. For instance, new high-tech fibres with previously unknown properties are created from residues from the food industry (BMBF 2017). Currently, polyester and other petroleum-derived fibres account for more than 60% of textiles. Therefore, consumers as well as the environment ask for a more sustainable textile production and consumption (biobridges n.d.). Therefore, one of the most important trends in innovation are sustainable textiles (Bioökonomie BW 2019).

Natural products have been used to produce clothing for thousands of years. Even the ancient Egyptians and Romans used flax to produce linen fabrics from its fibres. Leather was a popular material even in the Stone Age to make shoes or belts. In the past few decades, inexpensive petroleum-based synthetic fibres have increased their total market share. However, a return to traditional natural fibres has been observed in the recent past. Unlike cotton, the stems of other textile plants are further processed: for example, flax, hemp and jute. However, the global production of these bast fibres is much lower, at around two million tons each year. After the bast fibres have been separated, their processing is similar to that of cotton: yarn is spun from the individual fibres, which in turn can be further processed into fabrics. However, their areas of application differ: the bast fibres are mainly used as so-called technical textiles in industrial applications, less for the manufacture of clothing. Currently, cotton has a share of 31% (BMBF 2014).

Most materials used in industry sector are synthetic and chemical fibres made from synthetic polymers such as polyester, Teflon, Lycra, Trevira, nylon and others. In the meantime, there are also examples of natural polymers that are used as raw materials for fibres, but which are manufactured within chemical processes. This also includes viscose, the raw material of which is cellulose. In contrast to cotton fibres, viscose fibres are characterized by a greater variation in their fibre geometry (length, crimp, fineness, cross-sectional shape) and can therefore be used more widely. The energy and water consumption in the production and processing of viscose is lower than that in cotton, but during the production process, unhealthy and environmentally harmful poisons such as hydrogen sulphide (H_2S) and carbon disulphide (CS_2) arise. Other chemical fibres made from cellulose do not have this problem. To produce Tencel and Lyocell fibres, a direct dissolving process was developed that relies on a non-toxic solvent and works within the framework of a closed material cycle. In addition, the cellulose for Lyocell fibre is obtained from eucalyptus or beech wood. Since these plants grow faster and have a high yield per area, their environmental balance is better than for cotton. Recent research also shows that flax, hemp and bamboo as well as banana plants and soy are also suitable raw materials for the cellulose pulp (Bioökonomie.de 2016, BMBF 2014).

Currently, plants that have seldom been noticed have recently returned to the focus of interest - for example the fibre nettle. In addition to hemp and fibre flax, the nettle was one of the most important indigenous fibre plants until the Second World War. Thanks to new processing methods, fabrics can now be woven from their fibres with the fineness of cotton and quality textile properties. Additionally, they can be used as nonwovens for technical purposes. However, the usual propagation via cuttings is not very suitable for large-scale cultivation and increases in the fibre content of the existing varieties are still possible (BMBF 2014).

Beside potential raw materials for the textile production that are experiencing their renaissance, such as the stinging nettle, further new and innovative companies start to attract attention by using new raw materials and technologies. For instance, Swicofil produce a fibre which is made from casein, a protein in milk, coming from the dairy industry as an unused waste product. Milk fibre has a pH similar to human skin and is antibacterial and antifungal. As a very smooth and soft product, milk fibre is very suitable to produce textiles that worn close to the skin, like socks and underwear (AllThings.Bio 2017). Further companies use wood as raw material for the yarn and textile production.

Textiles from wood pulp

Spinnova developed a technology that allows them to turn wood fibres into yarn without using harmful chemicals. The whole process is built upon a mechanical treatment of the pulp, fibre suspension flows and rheology. Spinnova produces fibre out of micro fibrillated cellulose (made of FSC certified wood or waste streams) which can be described as a pasty mass of tiny wood fibres. This finely ground pulp mass then flows through a nozzle, where the fibres rotate and align with the flow, creating a strong, elastic fibre network. Using the patented spinning technology, the fibre is spun and dried. The outcome of this process is a fluffy but solid wool-like material, suitable for spinning into yarn and to use for textile production. The only by-product of the process is evaporated water, which is lead back into the process. The produced yarns are unexpectedly fire retardant, antimicrobial, warm as lamb wool and naturally biodegradable. This opens several interesting applications apart from the textile industry (Colmorgen, Khawaja 2019).

Micro fibrillated cellulose mixed in water and Spinnova's sustainable filament fibres © Spinnova

Efforts in the research, development and market uptake of new and innovative solutions is only one side. Especially in the field of clothing and home textiles, end consumers can make a decisive contribution to the further distribution of sustainable textiles. Since not every customer can verify the actual veracity of the products they buy. Therefore, brands and labels should transparently report on the value chains of their products in an easy to understand language. The same applies for industries which use industrial textiles along their value chains (biobridges n.d.).

3.7 Food and beverage industry

In a bioeconomy, food security always has priority over other uses of biomass. This applies for both, the use of biomass and the land required for the biomass production. This is why the food and beverage industry plays a prominent role in bioeconomy from a social and an economic perspective. In order to guarantee reliable food value chains, emerging challenges such as growing competition for biomass for food production and as a raw material energy and materials or the consequences of malnutrition or over-eating must be addressed. Thus, increased R&D along entire value chains from production to processing to consumption habits is needed (Bioeconomy Council 2012).

Figure 18 shows the development of turnover of the total bioeconomy in Europe between 2008 and 2016. Aside from the recession in 2009, the data show a continuous increase from less than 2 trillion

Euro (2008) to about 2.3 trillion Euro (2016). The food sector contributed significantly to the increase in turnover.

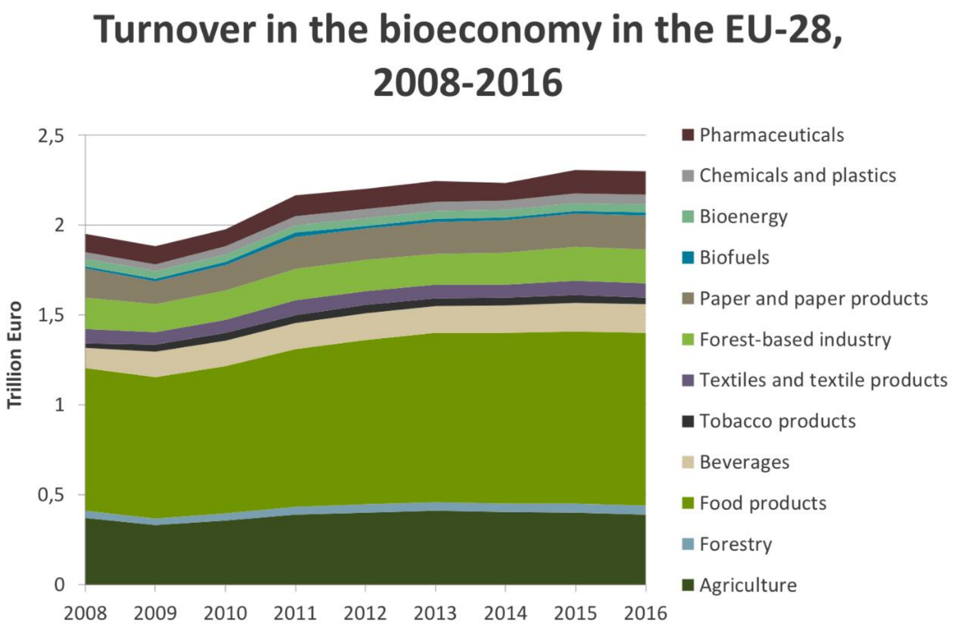


Figure 18: Turnover in the bioeconomy in the EU-28, 2008-2016 (nova Institute 2019)

As it is shown in Figure 19, roughly half of the 2.3 trillion Euro come from the food and beverages sector in 2016.

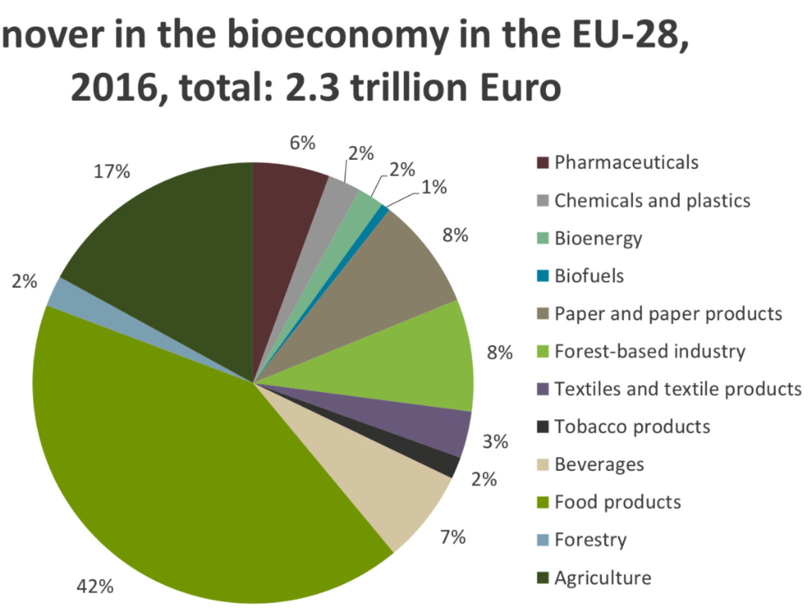


Figure 19: Turnover in the bioeconomy in the EU-28, 2016 (nova Institute 2019)

The food and beverage industry is responsible for the processing of agrarian materials to foods, beverages and animal fodder. Even today, resource efficient technologies facilitate the manufacturing of healthy, high-value and safe products. Strategies that recycle waste products from the human-food and animal-fodder industries are gaining increased importance. Thus, the food and beverage industry is not only a consumer of agrarian raw materials. In fact, this sector has the potential to be an important raw material supplier, too (BMBF 2017).

Even today, the biotechnology offers a plethora of different enzymes and microbes which are used in different production processes to give a product certain properties. For instance, they build the basis for the production of natural aroma agents, amino acids and enzymatically produced carbohydrates such as glucose and fructose that are used as sugar substitutes. Glucose can be obtained from plant starch by enzymatic cleavage. There is also a trend towards sweeteners that are less high in calories and thus trigger fewer civilization diseases such as obesity. Substances that taste sweet but do not contain sugar are currently heavily demanded. Such an alternative is an extract from the tropical plant Stevia rebaudia, which already sweetens food and beverages without calories (Bioökonomie.de 2016).

Another trend for which bio-based processes can be useful in the food and beverage sector are functional foods and drinks. These products have a positive and preventive effect on health due to their special bioactive ingredients. Functional ingredients include, for example, probiotic substances, which contain special ballast substances that have a positive effect on the intestinal flora (BMBF 2017). Such methods are already used, as shown in the following info box.

Gluten-free functional drink

Within the scope of Interreg Europe, the first gluten-free fibres enriched natural medicinal mineral water was investigated. The rather simple technology was developed by a cooperation of members of the Agrofood Regional Cluster in Romania. The product consists of Valcele medicinal mineral water, which is rich in Fe, Ca, Mg and several natural ingredients like aroma, fructose, natural colorants, soluble, gluten-free and prebiotic food fibres (Inulin). All ingredients are mixed at a controlled temperature regime. For preservation and packaging, the blending process is followed by pasteurization at 70 °C for 10 minutes. To manufacture the product with the required properties, several test series were needed (Colmorgen and Khawaja 2019).

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Further technologies facilitate the exploitation of alternative protein sources in order to reduce the share of animal proteins or the valorisation of unused food scraps coming from the food processing. Both are exemplary approaches to make the agriculture as well as downstream sectors more sustainable.

In the food and beverage industry, there is an enormous unused potential for the bioeconomy in processing residues. Much effort in R&D is made in using and valorising the underused raw materials and residues. Here, cross-sectoral approaches can stimulate new innovations, too. The use of residues of the food and beverage industry is thus an example for the bioeconomy how various sectors can interlink, increase resource efficiency and create added value by extending value chains (BMBF 2017).

High protein level drink from milk waste

SC Meotis SRL and IBA - National Institute of Research and Development for Food Bioresources, both members of the Agrofood Regional Cluster in Romania, found a way to valorise the dairy waste by using it for a new developed high protein level drink (Interreg Europe n.d.). The product consists of whey, aroma, amino-acids, fruit juice, fructose, and natural colorants, which are all agitated mechanically. Before arriving at the optimal composition of ingredients, which was preferred by various test persons, 35 recipes have been tested. For that, a sensory analysis was conducted that included colour, texture, taste, and aroma. To guarantee an optimal product with good storage and preservation properties, the mixture is pasteurized and homogenized (Colmorgen and Khawaja 2019).

© Revolve

3.8 Valorisation of aquatic biomass

The oceans provide a huge potential when it comes to facilitating sustainable growth. Given that the oceans' enormous resources are used wisely, oceans can contribute significantly to achieving the global sustainable development goals (Moilanen et al. 2019). This is where the blue bioeconomy, coming from blue biotechnology innovations for marine and aquatic applications, comes into play. The blue bioeconomy encompasses economic activities that are built upon the sustainable use of living aquatic biomass resources and their conversion into a large number of products and services such as food, feed, bio-based materials and bioenergy (Beyer at al. 2017). Benefits and products from living aquatic biomass resources are exemplary shown in Figure 20.

One of the most common ways of using residues and bycatches of the fishery sector nowadays is processing it to fish meal and fish oil. Nevertheless, there exist some more technologies which broaden the opportunities of valorising the valuable aquatic biomass. Using fish waste and bycatches for the energy production is an option, which recently attracts more and more public interest. The increasing interest is a result of the simplicity and replicability of the technology. Thus, with limited investments, energy can be produced at local fish farms at very little costs. This leads to a reduction in GHG emissions, additional income for fishers' and fish farmers' communities and thus to a positive impact on food security and energy security (FAO n.d. a).

Companies like Järki Särki from Finland follow another approach for the valorisation of aquatic biomass that fits within the scope of the blue bioeconomy. They aim to valorise cyprinid fishes by (re) integrating them in the food market and thus widening the variety of edible fish. Since fish are a unique source of protein, omega-3 oils, and vitamin D they contribute to a healthy diet which is an important topic within the bioeconomy approach, more precisely in the food-related guiding principle (Järki Särki n.d.).

Regardless of the type of valorisation of the fish processing residues or bycatches, environmental benefits can be achieved. By using the aquatic biomass, fossil-based products and energy can be substituted and disposal costs and its negative environmental effects reduced. Additionally, diets can be diversified and imported endangered species such as tuna replaced.

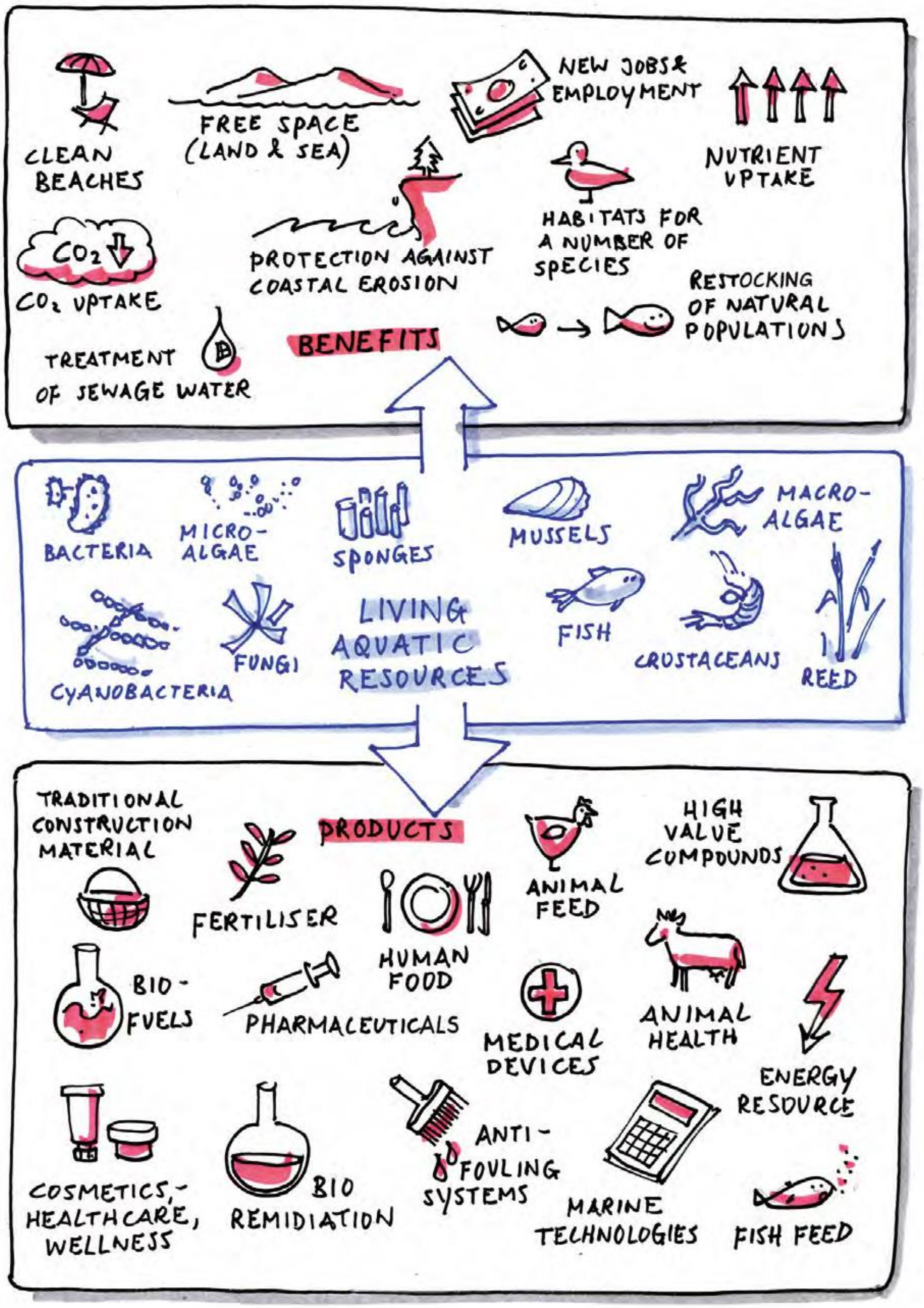

Figure 20: Summary of benefits and products that can be obtained from a sustainable use of living aquatic resources (Beyer at al. 2017)

Mobile lab for future fish waste-based applications

SINTEFF developed a mobile customized processing unit and laboratory that helps to investigate potential applications of numerous raw materials and process designs on small scale. Therefore, the processing units can be customized regarding the feedstock and the desired output. In this way, the customer can identify value streams that might be worth to invest in or not.

The Mobile Sealab contains a small, but complete, factory facility for the recovery of oil, protein-rich fractions, and other nutrients from waste raw materials, produced by the fishery industry. SINTEF's mobile customized facility enables customers, in cooperation with SINTEF, to develop new products and value streams as well as to optimize existing processes for a wide range of raw materials. In this way, SINTEF fills the gap between lab scale tests and production and full industrial facilities. Screen testing of enzymes and antioxidants can also be done. Currently, fish backbones, offal and off-cuts from fillet production are processed to make low-quality animal feed, even though it is possible to produce food quality Omega-3 fish oil and protein hydrolysates from the same raw materials. To preserve the potential and quality of the feedstock used, it is important to process the raw material when it is completely fresh. SINTEF's mobile processing unit can fulfil these requirements since it can be dispatched to production locations as a result of its high level of mobility. (SINTEF 2016, 2018)


Fish processing residues are a valuable resource for further applications. Heads from salmon, cod and herring can be used to produce Omega-3 fish oil, animal feed and powdery protein hydrolysates (SINTEF n.d.).

Variation in processing capacity

The capacity will vary depending on the chosen product and type of process used. For heat treatment the capacity is 500-1,000 kg/h and for one batch hydrolysis it is 400 kg/4-6 h (SINTEF 2016).

4 Business models for a regional bioeconomy

Coping with today's challenges and fulfilling the SDGs requires sweeping changes. These changes affect the development of businesses in bioeconomies, too. Resource efficiency and circularity, sustainable economic growth, environmental friendliness and social justice and inclusion are integral to development and establishment of future bioeconomy-related businesses (Karlsson et al. 2018).

Business models help to encompass certain elements which must be considered when planning and setting-up a business. A business model is "an abstract conceptual model that represents the business and money earning logic of a company" and further as "a business layer between business strategy and processes" (Osterwalder 2004). Beside the internal forces which define and shape the business model, external forces need to be considered when it comes to the continuous adjustment of business models. Thus, every company is responsible for altering their business model in a changing environment (business model innovation). Nevertheless, it is important to stress, that businesses in the 21st century do not only offer products and services, but also deliver social and environmental values (e.g. inclusiveness or reduction of GHG emissions), which can be important for businesses in a bioeconomy (Fogarassy et al. 2017). Consequently, the type of business model correlates with the value the organization or company wants to create for its customers or users of their products (Stratan 2017). Thus, a business model can be understood as a network of different influencing elements. This means that business models should take a network-centric perspective rather than a single-company-centric perspective. Such network-level business models can potentially unlock new competences, open new markets and promote new innovative and unique value proposition. Innovating a business model can be crucial in making radical improvements including an enhanced creation of environmental, social and economic values (Karlsson et al. 2018).

For the collection of primary data through first-hand observation, interaction and brainstorming, a template as it is shown in Figure 21 might be useful.

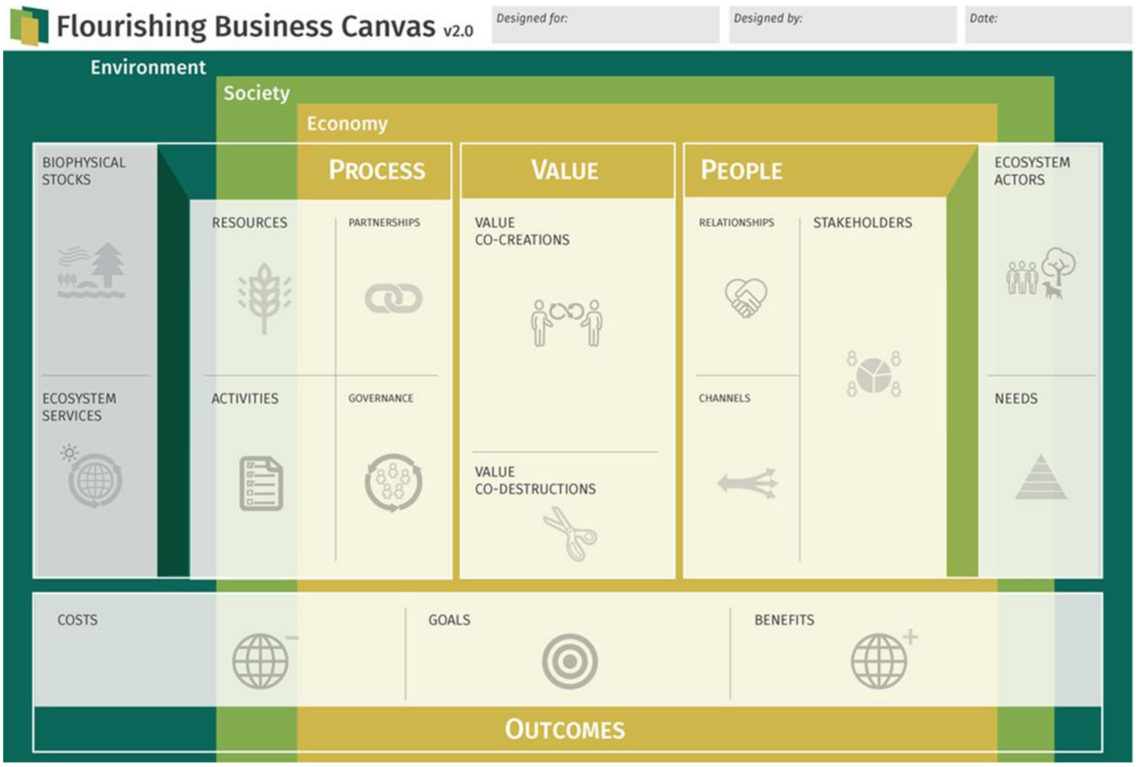

Figure 21: The flourishing business Canvas (Karlsson et al. 2018)

The **Flourishing Business Canvas (FBC)**, a significant extension of the widely used Business Model Canvas[3], identifies and describes the fundamental characteristics of BMs conceptualised in the context of real-world economic, environmental, and social systems. In order to describe a sustainable business model properly, the FBC consist of three contextual systems (environment, society and economy), four perspectives (process, people, value, and outcomes) and sixteen building blocks (topics intended to provoke stakeholder questions about a firm's past, current or future BM). Overall, the FBC is a tool which provides a consistent way for companies and stakeholders to record and analyse its business-modelling efforts (Karlsson et al. 2018).

4.1 Availability and identification of local biomass, technical and infrastructural resources

What is special about the bioeconomy is its renewable raw material base: biological resources - living organisms such as plants, animals and microorganisms – grow, thrive and produce a large variety of organic substances through their metabolism. The generic term under which such renewable resources of plant or animal origin can be summarised is biomass. In a regional bioeconomy, these resources need to be identified in order to develop new bio-based businesses but also to facilitate a potential re-orientation of existing businesses that are willing to shift their raw material base. In both cases, businesses based on fossil resources might be displaced in the short, medium and long term.

Thus, it is important to carefully check the availability of raw materials as well as the framework conditions for the provision of defined raw material qualities for selected biomass-based businesses. Therefore, different potential value chains and material flows from different sectors must be analysed and assessed regarding the biomass potential (EMEL 2014, Fehrenbach 2017). Widespread biomass resource pools and markets are:

- Agriculture and downstream processing industry
- Forestry and downstream processing industry
- Fishery and downstream processing industry
- Food processing industry
- Pulp and paper industry
- Municipalities

One of the main challenges for the proper assessment of the biomass potential is the identification of reliable data sources. These can vary significantly between different sectors. Nevertheless, the goal must be to gather the most reliable data set possible, which provides important information on the quality and quantity of the biomass resource (Griestop and Graf 2019). Therefore, several survey methods such as interviews, desk research, etc. should be considered. One exemplary and rather simple approach, to estimate the technical-sustainable biomass potential is presented below:

Availability = Presence - A - B

Where:

Availability = Biomass availability given what can be produced, harvested and collected with current or near future practices and known given state-the-art technologies and taking account of basic environmental sustainability requirements regarding soil and biodiversity conservation.

Presence = Presence of biomass now (and in future given land use change expectations)

[3] See deliverable "D2.4 Business models for regional bioeconomies" of the BE-Rural project.

A = has to be left behind for soil conservation/biodiversity/erosion control and other constraints that are not resulting from competitive use

B = conventional known competitive uses (feed, food, material and energy use) (Dees et al. 2017).

It is important to stress that the weighting of the different parameters may differ between different sectors. This can go so far that parameters might be neglected or added.

Based on the biomass type, the technology for the business can be chosen. Thereby, several factors, that play crucial roles in the decision-making process as well as in the following operational years, need to be considered. Table 3 shows a rough, overall checklist for the development of technology and infrastructure concepts for businesses in a regional bioeconomy (no guarantee of accuracy or completeness):

Table 3: Technical, economic and other criteria for the selection of technical equipment (adapted from Stein et al. 2017).

Technical criteria	Economic criteria	Other criteria
Local conditions Site (affecting design and sizing), traffic connection, load demand and capacity (time course: winter vs. summer), electrical and grid connections	**Capital demand** Investment, machines and plant equipment, buildings, planning, financing (equity, loan, leasing, contracting etc.)	**Organization & structure** Project partners (for erection and operational phase), ownership structures, contracts and responsibilities, legal aspects etc.
Biomass & biomass supply Biomass type, required/available quantity, characteristics and quality, supply type and intervals, biomass preparation and storage, delivery and transport, supply distance	**Operational Costs** Maintenance and repair, insurance, salaries, energy costs, process and control technic and monitoring, product development costs, process improvement costs, handling of waste and by-products	**Authorities** Verification of authorization requirements, emissions, health and safety, etc.
Technology concept & construction aspects capacity, existing equipment, electric installations, control equipment, buildings, outdoor facilities	**Economics** Outcome (e.g. price/unit or product), amortisation, expansion, trainings	**Acceptance** Internal and external
Risk assessment, future developments, Investment decision		

Logistics of biomass are a key part of the supply chain that must be taken into account since relative cost of collection are considerable (BioEnergy Consult 2020). Biomass logistics involve harvest, transport, (intermediate) storage, and processing of produced plant biomass and organic waste and residues. (Biomass Logistics n.d.). For instance, the bulk density affects the distance along which the biomass can still be trucked economically. Thereby, the batch capacity as well as the processing capacity of the processing unit need to be considered since they may vary significantly for different types of biomass (Scholwin and Fritsche 2007). For the transportation of biomass, it is advisable to scan and identify existing transportation structures including transportation companies as well as potential pre-processing operators. Especially the latter are of utter importance when it comes to increasing the bulk density of the biomass used.

4.2 Stakeholder involvement

The sustainability of an organisation or company and its business is determined, in large, by the extent to which it considers the interests of its stakeholders. Freeman defines a stakeholder as “any group or individual who can affect, or is affected by, the achievement of a corporation’s purpose” (Freeman 1984). A sustainable business has the advantage that it is not only a boundary-spanning economical resource-based concept. In addition, it considers social interaction and integrates internal and external resources of firms. In this way, stakeholders take over crucial roles for accessing and acquiring resources and capacities necessary for developing and implementing new businesses (Tiemann et al. 2018). Value creation should be mutually beneficial for all stakeholders involved (even though the type of value created may vary between stakeholders). Otherwise a business would lose its business partners and resources as well as its legitimacy (Freudenreich et al. 2019).

There are various stakeholders on different levels that need to be involved in order to create new bioeconomy businesses. These stakeholders participate in different forms and play different roles during the lifecycle of a project. For a bioenergy project, the stakeholder levels could look as follows (no guarantee of accuracy or completeness):

Local level

- Biomass suppliers
- Plant operators
- Energy suppliers
- Municipal administration

Regional level

- Financing and funding partners
- Engineers and planning offices
- Citizens, public, regional groups
- Local and regional SMEs (e.g. installers, electricians, designer)

National/Federal level

- Manufacturers of technical equipment
- Law makers
- Regional and state government (Stein et al. 2017).

A stakeholder analysis helps to identify local capacities that can be used as well as missing elements. This process helps to determine which experts can be involved locally, what resources they can provide, and which resources should be provided through and by external stakeholders. Major steps of a stakeholder analysis are listed below:

- Determine who your stakeholders are (executive staff, marketing, sales, finance, development/engineering/manufacturing, procurement, operations/IT, consultants)
- Group and prioritize these stakeholders (categorizing them in terms of their influence, interest, and levels of participation in your project)
- Figure out how to communicate with and win buy-in from each type of stakeholder

As mentioned above, the role of the involved stakeholders varies in the single phases of a business project, such as during the development, implementation and operational phases.

Some of the stakeholders only contribute in few phases of the business project, whereas others are involved during the complete planning, implementation and operation period (e.g. feedstock suppliers). This means, that stakeholders are linked by different relationships, formally and informally. Formal relationships are defined through contracts (see section 4.5).

4.3 Customer segments

Customer segments for bio-based products are very different. They range from single persons and stakeholder groups to industry branches. In some cases, consumers and producers of a bioproducts can be even the same party, as it is the case in some shared bioenergy businesses. Main driver for choosing bioproducts and establishing sustainable businesses are financial incentives or advantages compared to products based on fossil resources. Additionally, consumer awareness is rising since environmental threats receive increased attention nowadays. This applies for direct consumers of bio-based products as well as for industries and businesses that try to introduce renewable materials and products to their value chains and processes.

Table 4 summarises some bio-based products and their potential customers. This overview is based on the biomass conversion technologies and products presented in section 3.

Table 4: Bio-based products and their potential customer segments

Bio-based products	Potential customer segments
Solid biomass (for heating and cooling)	Private households, industry, municipalities (e.g. district heating plants)
Biogas	Gas and energy suppliers, industry (e.g. chemical industry)
Biodiesel	Commercial vehicle operators, transport and cargo industry, fuel industry
Bioethanol	Fuel industry (fuel is mainly used for commercial vehicles and aviation)
Bioplastics	Electrics industry, building and construction industry, automotive and transport industry, agriculture, consumer industry, textile industry, packaging industry
Biocomposites	Construction industry, automotive industry, consumer industry (e.g. casing and packaging, music instruments, medicine and hygiene products)
Compost	Farmers, private households, nurseries
Bio-based packaging	Food industry, packaging industry
Bio-based insulating materials	Construction industry, music industry
Bio-based textiles	Textile industry, organic) retailers, construction industry

Bio-based products	Potential customer segments
Food and beverages	Food industry, (organic) retailers, fitness industry
Omega-3 fish oil	Cosmetics industry, food industry, animal feed industry, health and medical industry

As it is shown in Table 4, there are certain bio-based products that are linked with specific customer segments. Therefore, different channels[4] are used to reach the customers but also to exploit new customer segments. It is a continuous screening of both, the supply and demand side, to identify and develop new business opportunities. On the one hand, the supply side tries to enter markets with bio-based products and offer a competitive alternative for petroleum-based products. On the other hand, the demand side tries to extend their range of options and replace fossil-based materials at the same time.

4.4 Planning, implementation and operation of technology options

There is no generally valid guideline for the planning, implementation and operation phases of a bioeconomy business, but there are some adjusting screws and steps, that play a role in most of the cases even though their weight might differ.

In the **initial planning phase**, main drivers and decisive stakeholders need to be identified. They are elementary when it comes to any further steps of the realisation of a business. The initiation of a business idea can come from:

- Citizen initiatives
- Associations
- Companies and entrepreneurs
- External consultants
- Politicians and key persons (mainly on local and regional level)

Furthermore, objectives of the business are defined during the initial phase of the project. Such objectives can be:

- Valorisation of untapped biomass resources
- Closing circuits
- Create added value in the region and thus strengthen the regional economy
- Facilitating regional development
- Realignment of socioeconomic and environmental foci
- Reduction of GHG emissions
- Increase the share of renewable products such as bio-based energy and materials and reducing dependencies from fossil resources

[4] Several potential channels for business models are depicted in the deliverable “D2.4 Business models for regional bioeconomies” of the BE-Rural project.

These general objectives can be refined by estimating rough quantitative indicators that are derived from existing plans, if possible, on municipal or regional level e.g. Sustainable Energy Action Plans, Climate Protection Concepts or strategies linked with the European Energy Award. In addition to that, different preconditions must be evaluated based on the existing framework conditions as well as on many quantitative and qualitative criteria for the development of a new business, such as legal conditions or subsidy and price structures. This **first phase** is elementary for roughly clarifying the suitability the potential business and for preparing the further steps. At this early stage of the project, socioeconomic, technical and environmental issues are addressed.

Some key questions might be:

- What is the starting point, the core idea of the project?
- Who are the key stakeholders and who are potential supporters? What are the potential intentions to join the project?
- What are the relationships between the relevant participants?
- What are the suitable communication channels within the first stage of the project?
- Who are the potential customers and what added value is generated for the customer?
- What are pros and cons for the project that must be addressed by the communication strategy?
- Who are potential local project partners (farmers, installers, etc.)?
- What resources do they have?
- Which options do exist in order to involve potential feedstock suppliers?
- What resources for biomass / renewable energy already exist in the region or can be used?
- What is the availability of resources? Is it sufficient for the new business? Is there competition on biomass resources?
- Which technologies are best suited for the business?

The initiators should compile all gathered information very accurately because that is the base for the further procedure and actions. Web-based clouds and other tools are very useful instruments to bundle all different information and to structure the data (Stein et al. 2017).

This data affects the **further planning**, since here, more detailed data on biomass availability and suitability (e.g. arable land, logistics, etc.), the technical composition of the business as well as on the potential implementation and operation is collected. Moreover, the demand side must be investigated in order to estimate the economic feasibility of the business (e.g. sufficient pool of customers). This is crucial for the calculation of the business case and the reliability of the economic results. This data can be collected by questionnaires, face to face meetings and working groups. The further planning should also include a **feasibility study** that delivers the decision basis for the real implementation of the business. It includes data bases, calculations and information from the previous planning. A life-cycle approach is a reliable tool for the calculation of the economic outcomes and additionally takes into account the dynamic development of the different cost's categories. At the end of the feasibility study stands a matrix of decision-making criteria. A decision-making matrix can have a strong impact on the selection of the technical measures as well as on the investment costs and the business model. This decision-making matrix can then be used to prepare the decision making for a technical concept and during the major steps of planning, design and implementation of the business. Decision making criteria can be technical, environmental and economic metrics.

After the planning phase and the approval of the planning, the **implementation of the measures** can begin. This work can be done by operating companies or contracted stakeholders and planners.

Subsequently, the **operational phase** of the project starts. There appear different tasks, that need to be managed during operation. These tasks naturally depend on the resources used, the technical equipment and the business model. Some tasks can be:

Use of biomass

- Biomass procurement and logistics
- Pre-processing of biomass
- Loading/feeding of biomass plants
- Disposal of waste products from biomass processing
- Quality assurance of the bio-based products

Management of technical equipment

- Operational monitoring of equipment
- Ongoing optimization of production processes
- Measurement and Verification
- Documentation
- Maintenance

Accounting and Controlling

- Procurement for and negotiations with contracting parties
- Insurance contracts
- Accounting and payment of employees, biomass suppliers and other companies
- Year planning and year contracts
- Payroll, taxes, banking
- Revenues from sales
- Dunning process
- Documentation
- Economic calculation and income statement

Communication and distribution

- Communication of results
- Press and public relations
- Acquisition of new customers (adapted from Stein et al. 2017).

4.5 Ownership models and contractual issues

4.5.1 Ownership model

In short, the ownership models can be categorised as municipality/state owned, a form of public-private partnership (PPP) or as a pure private market operation. These models vary in suitability for bioeconomy-related business. For instance, each of the mentioned ownership models could be applied to a biogas plant. Boldly put, this must not be the case for a start-up company that develops new high-tech technologies for the conversion of biomass.

The **public model** without any private participation, public entities take on most of the risk associated with the investment for the project. In case a project has a low internal rate of return (IRR), typically in the range of 2–6%, an internal department of the local authority can develop and operate the project to reduce administrative costs. Stable cities develop such projects via the public utility, and the low return can be spread across other projects that have higher IRRs. Projects with a higher IRR in less consolidated cities are being developed by creating e.g. a subsidiary (such as a new public utility) to reduce the administrative and bureaucratic burden on the local authority. This can provide additional benefits, such as limiting the city's financial liability in the event of project failure, increasing the flexibility and speed of decisions, and offering greater transparency and a more commercial operation. The public model may strengthen communities, make use of regional capacities and create regional jobs (Asian Development Bank 2015, Sunko et al. 2017).

A **PPP** is a long-term contractual agreement between a public sector authority and a private party, in which the private party provides a public service (e.g., electricity supply) and assumes a significant amount of the financial, technical, and operating requirements. The main function of a PPP is to allocate the tasks and risks to those parties, that manage them in the best possible and efficient way, notably to the private sector partners. The political responsibility for the provision remains with the public authorities. The participation of the private sector should provide long-term investment perspectives, enable access to additional investment sources and provide private sector experience and innovation. A main challenge for PPP is the management of many different stakeholders (and their needs) involved (Asian Development Bank 2015, Sunko et al. 2017).

The term PPP covers several more specified models with partnerships between the public and private sector. Some of them are shown in Table 5.

Table 5: PPP models (Sunko et al. 2017, Practical Law n.d.)

PPP model	Acronym	Description
Build Lease Transfer	BLT	A PPP in which a private organization designs, finances and builds a facility on leased public land. The private organization operates the facility for the duration of the lease and then transfers ownership to the public organization.
Build Own Operate	BOO	A government entity sells the right to construct a project according to agreed design specifications and to operate the project for a specified time to a private sector party. The private sector party owns the project and does not have to transfer it to the government entity at the end of the term.
Build Own Operate Transfer	BOOT	A government entity grants the right to finance, design, construct, own and operate a project for a specified number of years to a private sector party. The private sector party owns the asset during the term of the agreement.
Build Operate Transfer	BOT	A government entity grants the right to construct a project according to agreed design specifications and to operate the project for a specified time to a

PPP model	Acronym	Description
		private sector party. The private sector party does not own the project. In exchange for assuming these obligations, the private sector party receives payment from the government entity or the project's end users.
Design and Build	D&B	A method to deliver a project in which the design and construction services are contracted by a single entity known as the design-builder.
Design Build Finance Operate	DBFO	The private sector party designs, constructs, finances and operates a capital project and may be paid from fees or by the government agency which retains ownership of the project.
Private Finance Initiative	PFI	A way of financing public sector projects through the private sector. PFIs alleviate the government and taxpayers of the immediate burden of coming up with the capital for these projects.

Following PPPs, the multiparty ownership model can be named. Here, the projects are part public and part private, too. This ownership model can be suitable for multipurpose renewable energy projects, such as community-based biogas digester projects on a rather small scale, compared to many PPP projects. Key aspects of the multiparty ownership model, as applied to an energy project, are presented in Table 6.

Table 6: Multiparty Ownership Model for an Energy Project: Key Aspects (Asian Development Bank 2015)

Item	Features of the Model
Key Aspects	Renewable energy or energy efficiency projects may be technically complex and have high capital costs, requiring special models (to achieve economy of scale).
	In the case of biogas digester generation systems, the power-generating equipment is funded and installed by the utility, and the digester is owned and maintained by a third party (energy service company, user cooperative, or other entity).
	In the biogas digester generation example, funding is provided by a third-party installer or an outside source, freeing the farmer from any major liability. The equipment is installed at the farmer’s site.
	Revenues from the sale of the biogas to the utility are used to repay debt and interest.
Implementation	Biogas systems, micro- or minigrid systems
Benefits	Low risk for farmer; can incorporate donor funding for rural electrification
Disadvantages	High technical risk (particularly if third-party maintenance company does not properly support the farmer)

Finally, businesses can be **owned privately** by companies, associations, households, persons, etc. Models like the Lease or Hire Purchase Model (a leasing company (lessor) or equipment supplier provides the equipment to the end user for a contracted period of time in exchange for regular payments) or the Dealer Credit Business Model (equipment or system supplier provides technical equipment and the initial credit for the system) come into question here. In addition to that, it is of course possible to simply invest (through private savings or credits) in new technologies or develop them in certain cooperations. Operations, maintenance and management usually tends to more efficient within in private sector models.

4.5.2 Contracts with biomass suppliers

Biomass suppliers are an essential part along the value chains in regional bioeconomies. As it was already depicted in previous sections, biomass suppliers may come from the agricultural, forestry and fishery sectors as well as from biomass processing industry and municipalities.

Businesses that base on the conversion of different types of biomass require a continuous supply of biomass. In case the biomass is not produced and converted in one business, third parties come into play for the supply of raw material. Therefore, feedstock supply contracts are needed to agree on the specific supply conditions. These contracts may consist of different elements. Some of those elements are listed below:

- Type of the feedstock
- Quality of the feedstock (water content, dry matter content, energy content, ash content, applied standards and specifications, proofs of origin)
- Physical property of the product (pre-processing)
- Quantity of the feedstock: in tons, cubic meters
- Procedure of delivery: delivery to the processing site or independent collection from source(s) of origin
- Delivery intervals: depends on the storability of the feedstock, the storage capacity at the biomass conversion sites
- Monitoring and control measures: intervals, type and procedures for biomass samples
- Duration of the contract (typically 3-10 years: the longer the contract is, the lower is the risk and the better is the economic planning)
- Recycling of residues (e.g. agreements on return of digestate to farmers for fertilizing, national and local regulations need to be considered when agreements on the recycling on residues are made)
- Price: fixed price, index-related prices
- Conflict resolution: jurisdiction clauses, penalties, warranties, liabilities, general provisions, etc. (adapted from Stein et al. 2017).

Especially the specification of the quality of the feedstock is highly important, since the biomass properties have a direct impact on the technology and the manufactured product. Therefore, ISO standards exist for biomass types such as such as woodchips, pellets, briquettes and logwood (ISO 17225-1:2014 on “Solid biofuels -- Fuel specifications and classes”). That means that if contract with solid biofuel suppliers are made, the appropriate ISO standard should be applied and referred to in the contract (Stein et al. 2017).

Furthermore, markets and trade centres exist for different types of biomass. It is important to stress that the establishment of markets and trade centres strongly distinguish between regions and countries. For instance, in Germany there are biomass trade centres such as the "Biomassehof Achental", an association of different members from the forestry sector. Here, different wood fuels such as pellets, briquettes and log wood can be ordered and purchased in batches of different sizes for private and commercial customers. The biomass prices depend on the size of the batch. Due to their large storage capacity, the Biomassehof Achental can guarantee a continuous biomass supply and thus helps to overcome a bottleneck in everyday biomass supply (Biomassehof Allgäu n.d.). Such trade centres exist predominantly for woody biomass and biofuels.

For agricultural biomass, these trade centres are not common. But there are other approaches to deal with the biomass supply, also in different regional contexts. For instance, the start-up company BIO-LUTIONS produces disposable tableware and packaging from agricultural waste and residues. Here the company purchases its biomass feedstocks from contracted famers from the surrounding rural region (BIO-LUTIONS 2019).

4.6 Financing sources

The development and realisation of bioeconomy businesses requires investment as any other business. Therefore, several financing sources exist in order to facilitate the overall growth of the bioeconomy. A variety of approaches exist when it comes to the financing of bioeconomy project and businesses. Commonly used financing sources for bioeconomy businesses are equity, loan capital and grants. Each of those will be described briefly in the following.

Equity capital represents the personal investment of the owner in the business respectively project. It is also called risk capital because the investor incurs the risk of losing his money in case the business fails. Unlike the loan capital, equity capital does not have to be repaid with interest. Instead it is reflected in the ownership structure of the planned business. Sources for equity capital are the entrepreneur's own resources, private investors (from the private persons to groups of local business owners), employees, customers and suppliers, former employers, venture capital firms, investment banking firms, insurance companies, large corporations, and government-backed Small Business Investment Corporations. Thus, equity capital can be provided internally by those developing the project (e.g. municipality, company, cooperative, individuals) and externally. The most common sources of equity capital are summarised in Table 7 (Sunko et al. 2017).

Table 7: Source of equity capital (adapted after Sunko et al. 2017)

Source of equity capital	Description
Private equity	Provision of equity capital by project initiators or financial investors over the medium or long term. The private equity can be provided by external investors in form of ownership or in the form of a loan, which presents and expensive part of the financing structure (private equity loans can hold over 10% interest rates) and thus should be minimised. It is recommendable to use specialised private equity investors for the sector in which the investment will be executed, since they have knowledge and experience and the ability to support the investment in its lifespan.
Venture capital	Provision of capital by investors to start-up companies and small businesses that could have long-term growth potential. The investor risk is high, but the venture capitalists normally get a say in company

Source of equity capital	Description
	decisions. Venture capital generally comes from well-off investors, investment banks and any other financial institutions that pool similar partnerships or investments in specific industries with which they are familiar. Thus, this type of equity can provide a technical and managerial experience, too.
Crowdfunding / cooperative	Cooperatives are business enterprises that are democratically owned and controlled by the people who benefit from them and are operated collaboratively for the purpose of providing services to these beneficiaries or members. The funds provided by cooperatives can represent equity capital and can be translated into investment ownership. In addition to that, cooperative funds can be translated into loan capital which is than treated as described later.
Connection fees	Connection fees can be minor sources of equity in the investment structure. Here, the return of investment is entirely dependent on the customer base of a business, so it is imperative that a business targets customer who can pay. This makes public sector buildings, communal facilities and large manufacturers ideal customers because they should be able to pay their bills unlike individual households that might represent a greater risk. Connection fees can be negotiated, contracted and collected in the investment phase and thus represent a minor part of the investment equity capital.

Debt or loan capital is the capital that a business raises by taking out a loan. Usually it is repaid at a certain date. Since subscribers to debt capital do not become part owners of the business, but are merely creditors, debt capital differs from equity capital. The suppliers of debt capital usually receive a contractually fixed annual percentage return on their loan. This share of the investment must be repaid within a defined period with a fixed interest rate, irrespective of the company's financial position. Loan types can vary by different variables such as the calculation type of interest rates or their due dates. In the easiest version, interest is the costs of borrowing money which is usually a percentage of the overall loan. Thus, the borrower must repay the original amount of money borrowed plus the cost of borrowing money (interest). How much interest must be repaid on a given loan depends on the lending institution and the terms of loan. **Fixed interest rates** contain a fixed percentage on the loan that must be paid back during the life of the loan. It is rather easy to calculate the amount of money the borrower must repay at a certain time as the percentage never changes. **Variable interest rate** loans allow the lending institution to adapt the interest rate to changing market conditions at any time during the life of the loan. Thus, the borrower may benefit from future drops in market interest rates which leads to reduced monthly repayments. However, the exact opposite may occur, too, which could lead to serious financial difficulties for the project (Sunko et al. 2017).

Another variable of loan capital is the duration of the loan. Short term loans are usually loans with a validity period of three years or less. Short term financing is typically intended for financing continuing operations. Unlike short term loans, long term loans may have repayment periods from three to 30 years. Long term loans are suitable for financing projects. Loans can play an important role in stimulation regional development. Various state-owned institutions can provide different loans with subsidized interest rate in order to facilitate investments into new business projects.

A third financing source for new bioeconomy businesses are **grants**. Grants can be provided by several institutions at different levels. Thus, municipalities and cities, counties, federal states, national states as well as union of states, such as the EU, might provide capital grants. There is a variety of available grants for bioeconomy business projects. This overview focusses on financial instruments and sources on EU level, since regional and national grant programs may differ significantly:

- European Fund for Strategic Investments (EFSI)

  https://ec.europa.eu/growth/industry/innovation/funding/efsi_en
- European Investment Advisory Hub (EIAH)

  https://eiah.eib.org/
- European Investment Project Portal (EIPP)

  https://ec.europa.eu/eipp/desktop/en/index.html?2nd-language=en
- European Structural and Investment Funds (ESIF)

  https://ec.europa.eu/info/funding-tenders/funding-opportunities/funding-programmes/overview-funding-programmes/european-structural-and-investment-funds_en
  - European Regional Development Fund (ERDF)

    http://ec.europa.eu/regional_policy/en/funding/erdf/
  - European Agricultural Fund for Rural Development (EAFRD)

    https://ec.europa.eu/regional_policy/en/policy/what/glossary/e/european-agricultural-fund-for-rural-development
  - European Maritime and Fisheries Fund (EMFF)

    https://ec.europa.eu/fisheries/cfp/emff/
- Horizon 2020 (Horizon Europe)

  https://ec.europa.eu/programmes/horizon2020/en/
- NER 300 program

  https://ec.europa.eu/clima/policies/innovation-fund/ner300_en
- The EEA and Norway Grants

  https://eeagrants.org/
- European Investment Bank (EIB)

  https://www.eib.org/en/
- The Just Transition Mechanism

  https://ec.europa.eu/commission/presscorner/detail/en/fs_20_39
- Financing Energy Efficiency

  https://ec.europa.eu/energy/en/topics/energy-efficiency/financing-energy-efficiency
- European Energy Programme for Recovery (EEPR)

  http://ec.europa.eu/energy/eepr/projects/
- The European Bank for Reconstruction and Development (EBRD)

  https://www.ebrd.com/home (BIC 2017, Sunko et al. 2017).

5 Sustainability impacts of the bioeconomy

One could assume that as bio-based products are wholly or partly made from renewable resources, this could mean that they are automatically sustainable and have no negative environmental or socioeconomic impacts compared to the fossil fuel-based products. It just seems logical that it is much more sustainable to use resources that we can grow and maintain under sustainable practices. Bio-based products are part of the natural cycles on Earth, such as the carbon cycle, while fossil fuel-based products disrupt the natural systems (Contreras 2015). From a point of view that considers resource scarcity and climate change, of course, bio-based products can still be a great alternative to fuel-based materials. However, they are not intrinsically sustainable. The type and source of biomass feedstock, the energy used in the production process, the interdependency with other product value chains, recycling and waste scenarios play an important role in the level of sustainability (Maastricht University n.d.).

5.1 Environmental impacts

There is a long list of impacts to consider when determining the environmental sustainability of bio-based products (Table 8), but the main ones which are more often debated are greenhouse gas emissions (GHG) which has an effect on climate change, resource depletion, biodiversity, land use change and others.

Table 8: Review on environmental impacts of the bioeconomy (Hasenheit et al. 2016)

Impact	Possible indicator
GHG emissions	▪ Change in GHG emissions ▪ LULUCF carbon baseline
Reduced consumption of fossil resources	▪ Change in consumption level of fossil resources
Biodiversity loss & threats (including invasive species)	▪ Rate of biodiversity loss ▪ Habitat loss ▪ Forest fragmentation
Land use change	▪ Change in cropland/ grassland/ forest area, non-arable land use ▪ Short rotation plantations
Land use intensity	▪ Change in land use intensity ▪ Forest carbon content
Soil quality depletion	▪ Acidification ▪ Salinization ▪ Bulk density ▪ Soil carbon content
Decline in ecosystem services provision	▪ Change in ecosystem service provisioning
Water depletion	▪ Water scarcity ▪ Consumptive water use

Impact	Possible indicator
	▪ Water exploitation index ▪ Water use for agriculture ▪ Forestry ▪ Manufacturing ▪ Recycling
Water pollution	▪ Eutrophication ▪ Toxicity Level of water pollution ▪ Water pollution
Increased consumption of biomass	▪ Change in wood resource balance ▪ Consumption level of biomass
Increased re-use of biomass	▪ Organic waste diverted from landfills
Increased consumption of fish	▪ Change in fish stocks
Atmospheric pollution	▪ Level of emission ▪ Concentration of air pollutants
Material carbon pools	▪ Change in carbon stocks
Products characteristics	▪ Degree of the products' biodegradable parts ▪ Level of the products toxicity

Using renewable organic resources for the production of bioenergy and bio-based products play a positive role as they help reduce the dependence on fossil fuels which is a limited resource and are themselves non-depleted resources.

Concerning GHG emissions, biomass absorbs CO_2 during its growth, which is released again during the use phase or waste phase. That means bio-based products can be considered climate-neutral (Contreras 2015). Therefore, compared to fossil-based products, they can be considered to have less GHG emissions especially considering the end-of life impact. However, the production of biomass requires the use of fertilisers, which result in emission of nitrous oxide, a greenhouse gas 298 times stronger than CO_2. In addition, fossil fuels are needed to produce the fertiliser and bio-based fuels for agriculture, transport and processing (Contreras 2015). Therefore, a big attention should be given to these issues to determine whether the impact would be still considered positive. A study done by the European Commission assessed the environmental impact of bio-based products in comparison to petrochemical counterparts and showed that bio-based products could offer more than 65% GHG emissions savings (European Commission 2019).

The big dilemma which puts bioenergy and bio-based products in the frame of non-environmental sustainability questioning is the type of feedstock used and its effect on land use change and biodiversity. Biomass production requires land. Either the land needed to grow biomass needs to compete with the land required for food production or new land needs to be made ready for agriculture, causing a change in land use. This is called indirect land use change (ILUC) (see section 3.1.3). The impact of ILUC relates to the unintended consequence of releasing more carbon emissions due to land use changes around the world induced by the expansion of croplands. Because natural lands, such as rainforests and grasslands, store and sequester carbon in their soil and biomass as plants grow each year, clearance of wilderness for new farms in other regions or countries translates in a net increase in greenhouse gas emissions, and due to this change in the carbon stock of the soil and the biomass, indirect land use change has consequences in the GHG balance of a biofuel (Bathia 2014).

ILUC and food versus fuel/bio-based products impacts are questionable especially for the so-called first generation biomass feedstock, which uses food resources such as vegetable oils plants (e.g. soy, palm, sunflower, castor, rapeseed), starch-producing crops (e.g. corn, wheat, potato) and sugar-producing crops (e.g. sugar cane, beetroot). Second generation biomass, which uses non-food resources such as lignocellulosic biomass and waste is less likely subjected to these dilemmas. Concerning biofuels, the EU differentiated in the RED II directive between high ILUC-risk and low ILUC risks biofuels. High ILUC-risk biofuels are fuels that are produced from food and feed crops (first generation) that have a significant global expansion into land with high carbon stock such as forests, wetlands and peatlands. This expansion releases a considerable amount of GHG emissions and therefore negates emission savings from the use of biofuels instead of fossil fuel ones. These are set to be phased out in 2030. Low ILUC-risk biofuels are defined as fuels produced in a way that mitigate ILUC emissions, either because they are the result of productivity increases or because they come from crops grown on abandoned or severely degraded land (European Commission 2019a).

Many nominations fall under these types of land mainly marginal, underutilised or fallow and contaminated land. According to FAO, fallow land is an agricultural land that has had no signs of human activity (including grazing) over the last five years (FAO 2014). For Marginal lands, there are two different aspects for an area to be considered as marginal: 1) biophysical constraints: Soil constraints (low fertility, poor drainage, shallowness, salinity), steepness of terrain, unfavourable climatic conditions; or 2) socio-economic constraints: Absence of markets, difficult accessibility, restrictive land tenure, small holdings, poor infrastructure, unfavourable output/input ratios (FAO 1999).

Contaminated land is defined by EU regulation as any land which appears to be in such a condition - by reasons of substances in, on or under the land - that significant harm is being caused or there is a significant possibility of such harm being caused; or pollution of controlled waters is being, or is likely to be caused (European Commission 2003). These lands which are no longer used for agricultural purposes and therefore do not compete with food/feed still can be used to grow crops for the production of bioenergy and bio-based products in case they do not provide important ecosystem services such as provisioning (e.g. medicinal herbs, game species, timber), cultural (e.g. recreation, cultural setting, tourism), supporting (e.g. biomass production, oxygen production, soil production and retention) and regulating services (e.g. erosion regulation, water quality) (Wells et al. 2018).

The FORBIO project has demonstrated, after conducting a sustainability assessment on specific case studies, that value chains for bioenergy production on these lands can be indeed environmentally and socially sustainable and at the same time economically profitable (Colangeli et al. 2016).

Generally speaking, it cannot be said that the products of the bioeconomy are environmentally sustainable or not. A detailed Life Cycle Assessment (LCA) should be made for each specific value chain and for each specific region in order to determine the environmental sustainability of bioenergy and bio-based products. All stages in the life cycle of the product are considered in an LCA, from the mining and extraction of its raw materials, to the shipping, right on to the landfill. Data are not only considered for the initial product, but also for the full life cycles of other materials that are used in the making of the product (UNEP SETAC 2009).

Nonetheless, positive environmental impacts may occur on regional level. For instance, the full utilisation of cyprinid fish catch for food or bio-based products can have a positive impact on regional ecosystems since it helps mitigating eutrophication in (brackish) waters. In this case, the use of untapped fish resources in different forms aligns with benefits for regional ecosystems (Mäkinen and Halonen 2019). Another example is the production and use of renewable insulating materials. As it was depicted in section 3.5, there is a large environmental protection potential of sustainable insulating materials, due to lower energy needs during production and the sheep wool's carbon storage capacity. Thus, the bioeconomy can contribute to climate change mitigation by sequestrating CO_2 from the atmosphere in bio-based products (EESC 2018). This has a direct impact on the regional CO_2 footprint.

There exist many certifications and labels that would help consumers to identify if a bio-based product has certain environmental sustainability aspects. A non-exhaustive list of them exists (Table 9). According to the report from WWF assessing the different certification systems (WWF 2013), RSB was rated the best certification system for all kinds of biomass and RSPO and RTRS were the highest rated for single biomass types (soy and palm oil respectively) with Bonsucro following closely behind.

However, after analysing the current status of sustainability certification and standardisation in the bio-based economy, Majer et al. (2018) found that relevant gaps relating to existing criteria sets, the practical implementation of criteria in certification processes, the legislative framework, end-of-life processes, as well as necessary standardisation activities, exists and these require further research and development to improve sustainability certification and standardisation for a growing bio-based economy.

Table 9: List of different labels, certification schemes and standards that may be considered when purchasing bio-based products or services (adapted after InnProBio n.d.)

Sustainability aspect	Certification name	Label
Multi-issue ecolabels specifying bio-based products	▪ The Blue Angel, ▪ The EU Ecolabel, ▪ The Nordic Ecolabel	
Sustainable wood	▪ Forest Stewardship Council (FSC), ▪ Programme for the Endorsement of Forest Certification (PEFC)	
Sustainable agricultural biomass	▪ International System for Carbon Certification (ISCC), ▪ Roundtable on Sustainable Biomaterials (RSB), ▪ REDcert, ▪ Better Biomass, ▪ Roundtable on Sustainable Palm Oil (RSPO), ▪ Bonsucro, ▪ Roundtable Responsible Soy (RTRS)	

Sustainability aspect	Certification name	Label
Bio-based content	▪ OK bio-based ▪ DIN-Geprüft Bio-based ▪ Bio-based content	
End-of-life options	**Industrial compostability:** ▪ The Seedling ▪ DIN-Geprüft Industrial Compostable ▪ OK compost	
	Home compostability: ▪ OK compost HOME ▪ DIN-Geprüft Home Compostable	
	Biodegradability in soil: ▪ OK biodegradable SOIL ▪ DIN-Geprüft Biodegradable in soil	
	Biodegradability in sea water: ▪ OK biodegradable MARINE	

5.2 Social impacts

In the same way that bio-based products have different environmental impacts, there are also social impacts which need to be looked at to assess the social sustainability of the products (Table 10). Social impacts are consequences of positive or negative pressures on social endpoints, i.e. well-being of stakeholders. Environmental impacts are much more easily standardized and quantified than social and socio-economic ones, for obvious reasons. For example, emissions can be readily measured and given numerical data that can be used over and over whereas for a social assessment, methods for data collection and measuring of social impacts is much more complicated. They are challenging to conduct because qualitative data is often subjective and therefore must be handled by capable experts (SETAC-UNEP 2009).

Table 10: Review on social impacts of the bioeconomy (Hasenheit et al. 2016)

Impact	Possible indicator
Food security (including GMO crops)	▪ Use of agro-chemicals (& GMO crops) ▪ Change in food prices (& its volatility) ▪ Malnutrition ▪ Risk of hunger ▪ Macronutrient intake/availability

Impact	Possible indicator
Land access (incl. gender issues & tenure)	▪ Land prices ▪ Land tenure ▪ property rights ▪ Access to land
Employment	▪ Change in employment rate ▪ Full time equivalent jobs ▪ Job quality ▪ Need/lack for highly specialised workforce
Household income	▪ Income of employees in bioeconomy sector (total) ▪ Distribution of income
Workdays lost due to injury	▪ Number of workdays lost per worker & year
Quality of life	▪ Change in quality of life
Health	▪ Exposure to agri-chemicals ▪ Numbers of multi-resistant organisms ▪ Toxicity of “green” vs. “grey” industrial products

Food security is one of the most important social impacts which needs to be assessed when judging the sustainability of a bio-based product. This is especially important when the feedstock used for the production of bioenergy and bio-based materials is a first-generation feedstock. In places where their planting and use could affect for example the prices of the same crops used for food, the product would be considered socially unsustainable under this impact category.

In the same context, if growing crops for the bioeconomy affects the land used for food production purposes, for example through increased prices or accessibility for farmers, the products would be considered socially unsustainable from this point of view. Using second generation feedstock or crops grown on marginal lands are less likely to face such problems without forgetting to mention that the use of marginal land can be difficult as these lands are often fragmented and owned by different people making the decision of growing one type of feedstock sufficient for a certain value chain not easy to handle.

In general, a significantly larger bioeconomy will require new and greatly expanded production systems and networks to efficiently grow, harvest, and transport large quantities of sustainable biomass. The industry also needs technologies to more efficiently and economically convert biomass for a variety of end-use applications. These demands create employment opportunities and stimulate economic development in a broad range of fields, from scientific research to plant operations, farming, and equipment design. The bioeconomy will require skilled workers to build and upgrade infrastructures and develop new biomass resources and products. A study by JRC and the Nova Institute tested a methodology for the quantification of bioeconomy jobs and economic performance in the EU-28. Excluding the sectors of bioconstruction, waste management and bioremediation, the number of people employed in all other sectors of the bioeconomy in 2014 and 2015 were estimated to be more than 218 million and 220 million jobs respectively (JRC 2018).

The production of biofuels and bio-based materials, the same as any other product, can result in the spread of health-threatening products along the production process and it could expose workers to various health and safety issues. On the other hand, it has been proven that biofuels have less negative impacts on human health compared to fossil-based fuels (Prasad and Dhanya 2011). Similarly, bio-based products seem to be less harmful than comparable fossil-based ones. Fabbri et al. (2018) have cited many examples of bio-based products showing the positive impacts on human health. For instance, the beverages depicted in section 3.7, may have a positive regional impact on health, since they have the potential to diversify the nutrition and enhance health in the region where they are produced. This also applies for the use of fish-based bioproducts since they can influence human's health positively.

Even though the social aspects mentioned above seem in favour of the bio-based economy, a bio-based product cannot be considered socially sustainable without conducting a Social Life cycle assessment or other assessment methodologies to determine its social impact. An example on how Social life cycle assessments can be performed is given in UNEP-SETAC (2009).

5.3 Economic impacts

An important aspect that a product should acquire to be viable is to be economically feasible. Otherwise, even if it is environmentally and socially sustainable, it will not see the light. Therefore, the most important aspect to investigate for determining the economic sustainability on a product level would be the productivity which would be determined primarily by an economic feasibility study. On a bioeconomy level, other impacts could be measured to identify the influence of a bio-based product on the economy in general (Table 11).

Table 11: Review on economic impacts of the bioeconomy (Hasenheit et al. 2016)

Impact	Possible indicator
Change in GDP/GNI	▪ Change in GDP/GNI ▪ Rural development perspectives
New market for innovative bio-based products	▪ Change in turnover of bio-based sectors ▪ Business opportunities/challenges
Change in trade balance	▪ Change in trade (biomass (incl. wood) & animal-based products (incl. Fish) ▪ Energy diversification
Change in commodity prices	▪ Change in food prices ▪ Real wood & forest product prices
Change in demand for biomass products	▪ Change in cropland-based demand for products/energy ▪ Change in wood/wood fibre demand for forest products ▪ Change of biomass demand for energy use
Change in public cost	▪ Dependence on subsidies
Change in farmers revenue	▪ Yield/hectare ▪ Costs for agri-chemicals/year

Typical approaches that can be adopted to measure the bioeconomy contribution to a country's economy include the value added/GDP approach; Input-Output and Social Accounting Matrix (SAM) analysis; Computable General Equilibrium Model; Partial Equilibrium Model and other economic models and tools. Some countries do not adopt an economic model, but measure the contribution of bioeconomy by means of disaggregated indicators such as the turnover of the bioeconomy (revenue from sales); GDP of the total bioeconomy and its sectors, and the contribution of the bioeconomy to total country/region GDP; Employment in the total bioeconomy and its sectors, and the contribution of the bioeconomy to total employment etc. (FAO 2018).

Fuentes-Saguar et al. (2017) used a disaggregated SAM and provided a complete multisectorial database on the bio-based sectors and their economic links with the rest of the activities and institutional sectors for EU-28. Also, this database allows a useful and informative linear multiplier analysis to be computed to show the role of bio-based sectors in the economic development of the EU. The results of the study shows that for the EU Member States in 2014, there is still a low potential for creating wealth and the bioeconomy sectors have a quite low level of integration with the rest of the economy especially those that are considered at higher value added. Output multipliers show that many sectors related to the bioeconomy in the 2014 data were still underperforming compared to the EU average. Particularly, those with higher value-added content and that are considered more innovative are not yet able to produce more than average wealth.

It is estimated that the turnover and employment of the European primary and processing bio-based sectors will increase by at least 10%, resulting in 3 million extra jobs and an €80bn increase in turnover (Bio-based Industries consortium 2012). A number of independent studies corroborate the bio-based Economy's economical potential (Bio-based Industries Consortium 2012):

- The World Economic Forum has estimated the global revenue potential of the entire biomass value chain to be more than €200bn by 2020 (WEF 2010).
- According to Bloomberg New Energy Finance (BNEF), the revenue potential would be €78bn and 170,000 jobs would be created if 10% of cellulosic ethanol was used in gasoline cars in Europe by 2030 (BNEF 2012).
- 10% more forest biomass can be mobilised by 2030. This would lead to an additional revenue creation of €35bn and 350,000 extra jobs, based on the current employment and turnover figures for the forest and pulp and paper sectors (Bio-based Industries Consortium 2012).
- The EU-27 agricultural and forestry sectors will be able diversify their revenues and reinvigorate rural communities. According to BNEF, using only 17.5% of the EU27 residue resource for producing advanced biofuels has the potential to diversify farmers' revenue and provide them with additional margins by up to 40%.11 BNEF also claims that using only 17.5% of the EU-27 residue resource for producing advanced biofuels has the potential to displace between 52% to 62% of the EU-27's forecast fossil gasoline consumption by 2020, reducing the bill of EU oil imports by some €20bn to €24bn (BENF 2011).

Looking at the impact of new innovative bio-based products on the economy, it can be said that it would have the same impact as any other innovative product. Innovation is an essential driver of economic progress that benefits consumers, businesses and the economy as a whole (ECB 2017). In the regional context, it can play a big role in the waste management and valorisation, open markets for new products which locals among others could benefit from and increase environmental awareness. Regional added value, jobs and additional incomes may be created. For instance, BIO-LUTIONS creates additional incomes for farmers from the surrounding region. This also applies for biomass suppliers and users from the examples mentioned in the environmental and social impacts.

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