



## D2.2 Classification and Systematization of the High TRL Industrial Biobased Systems

November, 2025

Muhammad Zeeshan Khan, Omar Hijazi, Gabriele Weber-Blaschke, Cristian Pérez Hernández

## Document Information

Work package and deliverable number	WP2 - Identification of industrial biobased systems and benchmark scenarios, D2.2
Authors	Muhammad Zeeshan Khan, Omar Hijazi, Gabriele Weber-Blaschke, Cristian Pérez Hernández
Involved organizations	All consortium partners
Reviewers	All consortium partners
Document date/version	Revised version; 06.11.2025

## Project Information

Project acronym	ESCIB
Project title:	Developing environmental sustainability & circularity assessment methodologies for industrial biobased systems
Project number:	101135071
Coordinator	WIP Renewable Energies
Project website	<a href="http://www.escib.eu">www.escib.eu</a>
Start date:	1 January 2024
Duration:	48 months

## Dissemination level of this document

<input checked="" type="checkbox"/>	Public
<input type="checkbox"/>	Sensitive

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The ESCIB project has received funding from the European Union's Horizon Europe Framework Programme under grant agreement No.101135071.

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## List of Abbreviations

BBS:	Biobased System
BBPs:	Biobased Products
IBBS:	Industrial Biobased System
LCA:	Life Cycle Assessment
TRL:	Technology Readiness Level
NACE:	Statistical classification of economic activities
PRODCOM:	Community Production
EoU:	End of Use
EoL:	End of Life

# 1 Abstract

This study introduces a thorough and systematic classification of the biobased system (BBS), organizing it into five key areas, keeping in view sustainability and circularity considerations. These areas encompass biobased products (BBPs) and biobased industries, including biorefineries, biomass feedstock, LCA system boundaries, and end-of-life (EoL). A comprehensive classification process was adopted for each category based on a multifaceted approach and key criteria based on literature to offer a detailed and well-organized understanding of the complex classification of BBS from various perspectives. BBPs were classified based on five pivotal criteria: application use, Statistical classification of economic activities (NACE) classification, market integration, certification scheme for biobased content, and transformation level. Biobased industries were broadly categorized into forest-based industries and biorefineries, with a specific focus on biorefineries classification regarding processing technology, platform, technology readiness level (TRL), biobased pathway, and conversion process. Feedstock was comprehensively classified based on origin, and detailed sources were provided for each category. A classification based on supply chain consideration and modeling approach was adopted regarding LCA system boundaries. Finally, EoL classification was adopted to classify the end-of-route pathway into open loop recirculation, closed loop recirculation, and end-of-life treatment. This classification will help to understand the BBS and further use it in its sustainability and circularity assessment.

## 2 Introduction

### 2.1 Background and Objectives of the Project ESCIB

Worldwide, organizations and countries are making policies to reduce the environmental impacts caused by fossil-based products and support the sustainable transition towards innovative and environmentally friendly products. This sustainable transition has pushed toward more innovative products made of biological origin that can offer alternative sources to replace fossil-based products. However, a life cycle and circularity assessment are required to assess if such products are more environmentally friendly and provide better utilization of resources. The results of such assessments will enable us to evaluate the environmental impacts of the products under development or already on the market. Furthermore, such an assessment will provide guidelines for formulating policies toward sustainable development and using alternative biomass products.

The ESCIB project aims to support the sustainability of the biobased economy in Europe by developing assessment methodologies to standardize the evaluation of sustainability. The goal is to create a comprehensive and robust methodology to assess the sustainability of BBS at various TRLs. This methodology will take a holistic life-cycle approach to evaluate the environmental impacts and circularity within biobased value chains. It will also address potential socio-economic trade-offs and align with the objectives of the European Green Deal (EGD) and the Circular Economy Action Plan (CEAP).

The ESCIB project also involves industrial partners in the consortium, who produce biobased products (BBPs). Such involvement will ensure the high applicability of the sustainability methods, which can be used by certification organizations for labeling and certifying BBPs. Finally, the results will give orientations for research and innovation programmes in the biobased sectors.

## 2.2 Objectives of this Report

Work package (WP)2 of the ESCIB focuses on identifying the EU's best practice industrial biobased systems (IBBS) regarding environmental sustainability and circularity assessment. Therefore, the consortium works on several tasks in WP2, including the classification and systematization of IBBS. The objectives of this report are the following,

- Identifying key areas for classification of IBBS.
- Classification of key criteria based on the multifaceted approach identified in the literature.
- Comprehensive systematized classification matrix for IBBS.

## 2.3 Deliverable D2.2 of WP2

This report presents the deliverable D2.2 of WP2 as shown in Table 2-1.

*Table 2-1: Deliverable D2.2 of the ESCIB project*

### **Deliverable D2.2 – Systemization of bio-based systems**

<b>Deliverable Number</b>	D2.2	<b>Lead Beneficiary</b>	4. TUM
<b>Deliverable Name</b>	Systemization of bio-based systems		
<b>Type</b>	R — Document, report	<b>Dissemination Level</b>	PU - Public
<b>Due Date (month)</b>	9	<b>Work Package No</b>	WP2

<b>Description</b>
Systematic matrix for the classification of the manifold bio-based systems (Related Tasks: T2.2)

### 3 Material and Methodology

#### 3.1 Identification of Key Elements of IBBS for Classification Systematization

To classify complex biobased systems (BBS), a systematic approach is essential. This approach involves categorizing the BBS into key distinct elements that are related to sustainability and circularity principles as part of the scope of ESCIB. Furthermore, identifying multifaceted classification criteria for each element of IBBS. As part of this approach, four key elements were identified for the classification from (D2.1) (Khan et al. 2024), including biomass feedstocks, biobased industries, biobased products (BBPs) and end-of-life (EoL) (Figure 3.1). Furthermore, LCA system boundary classification is integrated for systematization of the classification framework for IBBSs from the sustainability assessment perspective.

#### 3.2 Systematization of the Classification Framework

For the systematization of the classification framework, a top-down sustainability assessment approach was adopted, where a reference BBP is evaluated for sustainability assessment across key elements i.e., biomass feedstocks, industrial processing, EoL approaches, and system boundaries. In alignment with this approach, the classification framework was developed in a hierarchical manner. The classification framework commenced with the classification of BBPs, followed by the biobased industries, biomass feedstocks and end-of-life routes of BBPs. Finally, the framework integrates the LCA system boundary classification, ensuring systematization of IBBS classification framework based on key elements.

Table 3-1: Main sources used for classification of each element of industrial biobased system.

Element of Classification	Main Sources Used
Biobased Products	(Tobisch et al. 2023; CIRCE 2022; Platt et al. 2021; DIN EN 16575 D 2014; EUROSTAT 2023; Wagenführ et al. 2023)
Biobased Industries	(Platt et al. 2021; Tobisch et al. 2023; Cherubini et al. 2009b; Wagemann and Tippkötter 2019; IEA Bioenergy Task 42 2022)
Biomass feedstocks	(CIRCE 2022; Tursi 2019a)
End of Life	(Pérez-Hernández et al. 2024) WP (4)
LCA System boundaries	(ISO 14040; ISO 14044; Bjørn et al. 2018a; Gaffey et al. 2024; Egas et al. 2023; Schaubroeck et al. 2021; Heijungs et al. 2021; Life Cycle Initiative 2013)

Multifaceted classification criteria were identified and further systematized for the IBBS including industrial system with and without component separation as described in D2.1 (Khan et al. 2024). The inclusion criteria of classification were based on the classification that can be adopted for BBPs. Classifications that were only specific to energy purposes or related to food and feed were not considered for classification in this study. The main source for information collection regarding the classification of the industrial biobased system (IBBS) was collected from JRC and European Commission reports and webpages. Furthermore, extensive information was collected from peer-reviewed articles, handbooks, and grey literature (Table 3-1). Similarly, the ISO and European standards were also reviewed for classification, especially LCA system boundaries. Although it is impossible to classify the BBS in all dimensions, this study identified and presented the main industrial-related classifications that are easy to understand and adapt to industrial classifications. The classification involves the

high TRL and also low TRL system classification in the case of biorefineries. At last, a comprehensive matrix of classification is presented (Table 10-1) that shows the systematized classification framework adopted for each element of IBBS in this study. This approach is based on selecting the unique criteria of classification that presents the whole range of IBBSs, and is unique to the element of IBBS.

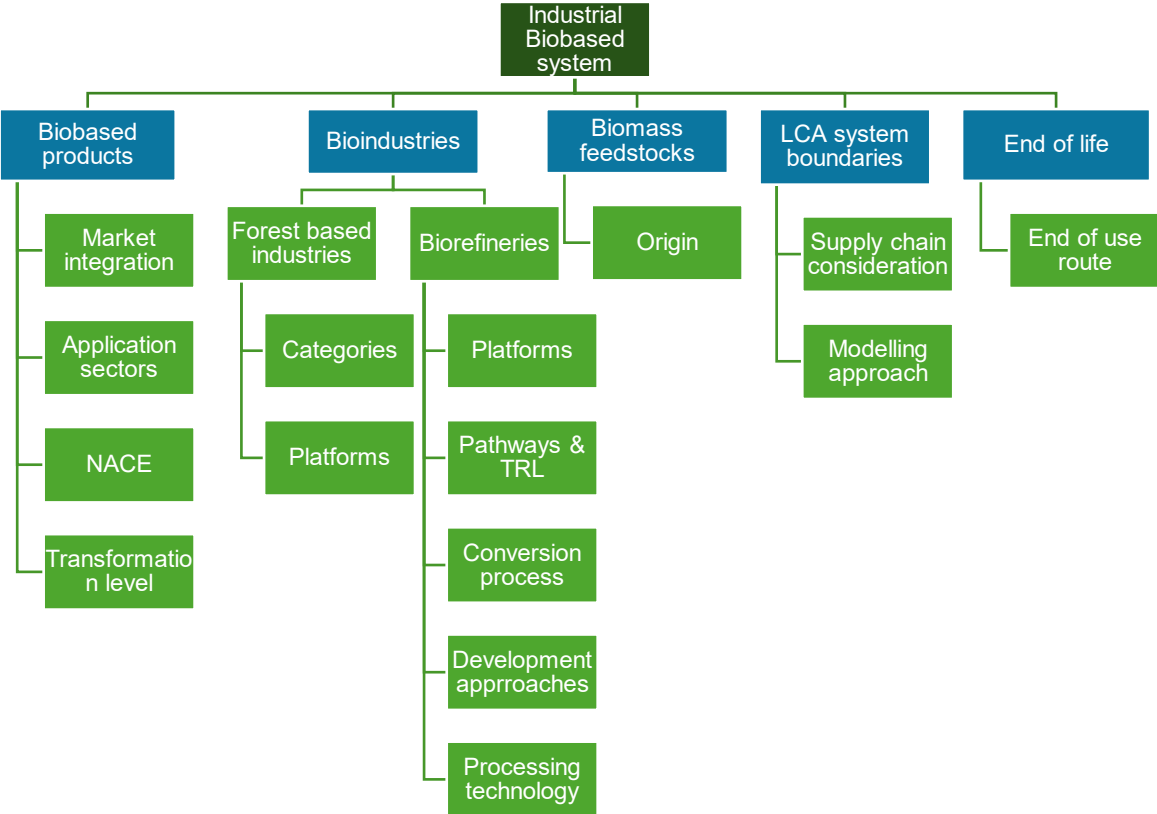


Figure 3.1: Key elements (blue boxes) and criteria (light green boxes) used for classification of industrial biobased system in this study.

### 4 Classification Concept for Industrial Biobased System

The industrial biobased system as defined in the ESCIB project includes a complete system from cradle to grave with the stages biomass feedstock production, bioindustry /wood/fiber industry, biorefinery), end products production, and end-of-life management. Therefore, according to this system definition, the following main elements are identified from mapping of IBBS in (Khan et al. 2024), which are used for the classification of IBBS:

- biobased products (BBPs),
- biorefineries resp. bioindustries,
- biomass feedstock
- end-of-life management

Due to the focus on environmental and sustainability assessment in the ESCIB project, this study also includes classification based on life cycle assessment (LCA) system boundaries. These elements can be further classified based on various categories described in the following chapters. BBPs were mainly classified based on market integration criteria, application or sector use, NACE classification, and transformation level. Furthermore, bioindustries classification mainly focuses on processing technology, development approaches, platforms, TRL, and conversion processes. Feedstock classification is based on origin, while LCA system boundaries classification is based on data consideration and modeling approaches. Lastly, end-

of-life route classification is adopted for BBPs. The criteria for selecting parameters for classification adopted in this study mainly focus on BBPs identified from the literature and do not include classifications specific to bioenergy, food or feed applications. Furthermore, the classification is mainly focused on BBPs, and this inclusion criterion was implemented. However, in certain cases, it is presented as a whole classification to also give an overview of potential sources. For example, aquatic biomass is also presented in the case of feedstock origin, although it is out of the ESCIB scope.

## 5 Classification of Biobased Products

As defined in ESCIB project D2.1 (Khan et al. 2024), BBPs are derived partially or fully from biobased feedstock. These products are seen as sustainable alternatives to fossil- or mineral- and metal- based products. BBPs can be classified in different ways, and it is not easy to classify them as a single classification; therefore, in this chapter, detailed classifications from literature and reports are examined to understand the types of classification that can be incorporated to understand BBPs.

### 5.1 Classification based on Integration into the Market.

It is important to differentiate the BBPs based on the integration into the market and use of the already developed infrastructure. Biobased chemicals or materials can be classified into two main groups: drop-ins, and novel (Felix et al. 2021; Spekrijse et al. 2019; M. Sara et al. 2016; Carus et al. 2019; Platt et al. 2021; US Department of energy 2018).

Platt et al. (2021) differentiate biobased chemicals based on the position of biobased chemicals production in the value chain. The differentiation is made between drop-in, smart drop-in, and dedicated products mainly, but also mixed products that are combination of drop-ins and dedicated biobased chemicals. Accordingly, drop-in products are classified as biobased products that can directly replace the fossil chemicals in the early production value chain (Platt et al. 2021). Biobased drop-in chemicals are chemically identical to their fossil counterparts, and they are the biobased versions of existing fossil-based chemicals or petrochemicals that have established markets (Carus et al. 2019; Spekrijse et al. 2019). Biobased drop-in chemicals are usually more expensive, hence less competitive, but are more environmentally friendly as compared to their fossil counterparts (Carus et al. 2019). They are relatively easy to produce technically as the existing infrastructure, machinery and methodology can be used (Carus et al. 2019; Bioplastics News 2018). Drop-ins bioplastics are simply the biocopy of the existing fossils based plastics but made of biomass instead of fossil oil (Bioplastics News 2018). (M. Sara et al. 2016) reveal that the drop-in biofuels are regarded as alternative biobased fuels. They are biomass-derived liquid hydrocarbons that can meet the current petrol distillate fuel specification and are ready to be integrated into the existing fuel supply and infrastructure. These biobased replacements are unrecognizable in terms of performance and structure compared to their petrochemical counterparts (M. Sara et al. 2016). Some drop-in biofuels and biochemicals are butanol, liquified biomass, sugar hydrocarbons, syngas complexes, ethanol, lactic acid, biobased ethylene, polyethylene (PE), Polyethylene terephthalate (PET), propylene (PP) (Carus et al. 2019; M. Sara et al. 2016). However, the (US Department of energy 2018) used different classifications, although similar in connection with the classification of BBPs. One classification is the “direct replacement”, when the biobased and its counter fossils based product are chemically identical. Another one is “functional replacement” when the BBP and its fossils-based counterpart are different chemically but have identical functions or properties (US Department of energy 2018). The term “replacement” means the same as “drop-in products” that can either be chemically identical or not and can replace the fossils-based product as chemically identical or only replace its function or properties. The third classification made by the US Energy Department (2018) is “novel products” that don’t have a resemblance to

existing fossil-based products in structure, function, or chemically but offer a unique advantage over existing products.

Smart drop-ins, on the other hand, are introduced at a later stage close to the end product in the value chain, but they are a subcategory of drop-ins and can directly replace fossil-based products (Carus et al. 2019). Smart drop-in products are also chemically identical to their fossil counterparts, but due to their unique production pathway, they have many advantages. Drop-ins can use the existing infrastructure from fossil based and hence easy to implement. The smart drop-ins are first processed in a new form and then fed back to the conventional or fossils pathway at later stages, hence making the process efficient, shorter, and less toxic (Carus et al. 2019). Smart drop-ins have to fulfil at least two of the following criteria (Carus et al. 2019),

- The biomass utilization factor from feedstock to product is higher compared to other drop-ins.
- The production is energy efficient and require less energy.
- They have fast and less complex production pathway as compared to other drop-ins or counter fossils-based products.
- During the production process, low toxic chemicals are used or formed in comparison to other drop-ins or replacing fossils-based products.

An example of the smart drop in is epichlorohydrin. Its production from glycerol based on biomass feedstock is much more efficient and less toxic than the conventional fossil based propylene production (Carus et al. 2019).

On the opposite side, dedicated biobased chemicals are those products that have completely different functionalities, which not only make them much superior to fossil products but also ensure to have a unique market advantage over the fossil-based counterparts (Platt et al. 2021). They have their own dedicated pathway of production (Figure 5.1) and having no equivalent or identical fossils-based counterparts (Carus et al. 2019; Spekrijse et al. 2019). These products offer superiors and unique properties that is almost unachievable using fossils based alternatives (Carus et al. 2019) such as biodegradability (Felix et al. 2021). They have high biomass utilization efficiency because they utilize the whole biomass consisting of carbon, oxygen, hydrogen, and nitrogen and not just only carbon hence making them more efficient (Carus et al. 2019). New synthetic strategies which are based on biomass can benefit by utilizing the complex structure and functional groups that are already present in the nature. Hence, instead of breaking down the naturally grown molecules into simple molecules (i.e., syngas) and then building them again, advantage can be taken from existing functional groups resulting in the greater efficiency. Therefore, dedicated biochemicals are also called novel chemicals (Carus et al. 2019). So dedicated or novel products usually need own dedicated and specific manufacturing technologies that make them more superior and efficient to their counter parts and can't be replaced by fossils-based products, hence need more research and development (R&D) (Felix et al. 2021). Examples of the dedicated biobased chemicals are Glycerol and derivatives, itaconic acid, farnesene, furans, levulinic acid, PEF, PHA, PLA, PA10, biobased lubricants and surfactants such as sphero and rehamnolipids, alkylpolyglycosides. Similarly, cellulose fibers, especially nano and micro cellulose, are also examples of dedicated biobased materials (Carus et al. 2019).

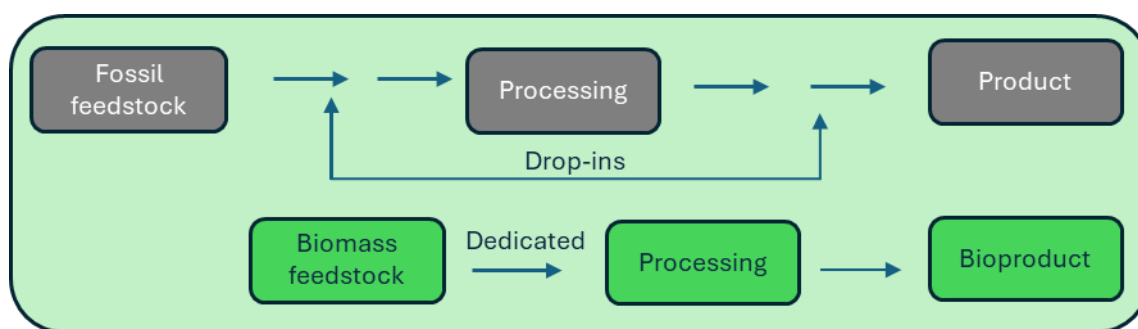


Figure 5.1: Differentiation of pathways for drop-ins, smart drop-ins and dedicated biobased products (Adapted from (Carus et al. 2019).

Based on the above discussion, the BBPs can be classified overall in to two main categories drop-ins or direct replacements and dedicated or novel BBPs as discussed in Table 5-1.

Table 5-1: Classification of biobased products based on market integration (Based on Platt et al. 2021, Spekreijse et al. 2019, P. 17, US Department of Energy, 2018).

Type of product	Description of type of biobased product	Infrastructure development
<b>Drop-in products/Direct replacements</b>	<ul style="list-style-type: none"> <li>Products that are direct replacements of fossils-based products having same chemical or functional properties.</li> <li>Bio-copy of existing fossils-based products that have well established markets.</li> <li>Unrecognizable in terms of structure and performance with respect to its fossil-based counterparts.</li> <li>Examples are Butanol, liquified biomass, sugar hydrocarbons, syngas complexes, ethanol, lactic acid, ethylene, polyethylene (PE), polypropylene, polyethylene terephthalate (PET) etc</li> </ul>	<ul style="list-style-type: none"> <li>Existing fossils-based infrastructure (machinery, equipment) is used completely or partially as shown in Figure 5.1.</li> <li>Economically cheap replacement due to use of existing infrastructure and less R&amp;D.</li> </ul>
<b>Novel/Dedicated products</b>	<ul style="list-style-type: none"> <li>Products that have completely different production pathway and are not the replacements of existing fossil-based products.</li> <li>They don't have an identical or equivalent fossils-based counterparts.</li> <li>Completely different structure and function and offer unique properties such as biodegradability.</li> <li>Examples of chemicals: e.g., levulinic acid, succinic acid, polyhydroxy-alkanoate (PHA), polylactic acid (PLA)). Similarly, biobased products such as lignin based phenolic resins, microfibrillated cellulose are dedicated materials(Platt et al. 2021).</li> </ul>	<ul style="list-style-type: none"> <li>Completely new infrastructure is needed as shown in Figure 5.1.</li> <li>More R&amp;D is needed hence can be economically expensive.</li> </ul>

## 5.2 Classification based on Certification Scheme for Biobased Content

BBPs can be partially or fully derived from biological origin materials. Therefore, BBPs are characterized by biobased carbon content or the biobased content (Knowledge4policy and EC). The measurement for the biobased content (C,H,N,O) is based on the standard EN 16785-1, for the biobased carbon content EN 16575 (Stahl 2024), and for the biogenic carbon content in wood and wood products (EN 16449:2014-06).

Biobased content is a fraction or proportion of a product that is derived from biomass (DINEN16785-1 2015; DIN EN 16575 D 2014) and expressed as a percentage of the total mass of the product. However, this information does not provide by any means information about the sustainability or environmental impact of a product (DINEN16785-1 2015).

It is important to note, that the biobased content and biobased carbon content are relative terms but they have different concepts (Tuv austria). Biobased content is based on the amount of biomass in a product considering four key components i.e., carbon, hydrogen, oxygen and nitrogen. While the biobased carbon content is only focused on the carbon (organic or total carbon), the product contains (Tuv austria). The biobased carbon content is the fraction of carbon in a product derived from biomass (DIN EN 16575 D 2014). For example, bio-ethyl acetate has 51.1% biobased content but 27.2% biobased carbon content (DINEN16785-1 2015).

The biobased content is equally applicable to all biomass-containing materials and products including raw materials, intermediates, and finished products (measurlabs 2024). Biobased products can be divided into three main groups for certification based on biobased content (EN 16785).

### 5.2.1 Group I Products

Chemicals and materials obtained through chemical or biological reactions (NCS 16785 2023) and mixed with other materials to manufacture various products fall in the category of Group I products. A single chemical formula is used for such products, for example a polymer is a group I product (NCS 16785 2023).

### 5.2.2 Group II Products

Products that are manufactured by mixing group I products without further chemical or biological reactions are Group II products (DINEN16785-1 2015). Most of the products belong to this category (measurlabs 2024). Instead of chemical processing the group I products are physically mixed. Example are laundry detergent manufacturing by mixing different biobased products such as surfactants and salts with fossils-based chemicals or similar modification of PET plastic by adding softeners and additives (measurlabs 2024). These products may contain additives. Similarly, plastic is also a group II product (NCS 16785 2023).

### 5.2.3 Natural Products

Products wholly derived from biomass, that do not go through any chemical modification or additives and are obtained completely from natural sources are natural products. Examples are unmodified saw dust (measurlabs 2024), wood (including pulp), bamboo, flax, sisal, rice and coconut etc. (DINEN16785-1 2015). These products can be used in the manufacturing of Group I products (substance, mixture of substance, material or object resulting from a production process (NCS 16785 2023)) or as components (part of the finished product that can be separated by hand or physical means (NCS 16785 2023)) of Group II products (DINEN16785-1 2015).

### 5.3 Classification based on the Product/Application Categories

BBPs traditionally include wood, cork, natural rubber, paper, textiles, and wooden construction materials. Nowadays, within the bioeconomy, the scope is extended with biobased chemicals, bioplastics, and biofuels, etc. (Galanakis 2020). (Shikha et al. 2020a) classified the BBPs into the three main categories biomaterials, biochemicals and biofuels/bioenergy. Biochemicals include a wide range of chemicals (e.g., volatile fatty acids, biosolvents, succinic acid). Materials are mainly further subcategorized into bioplastics, biocomposites, cellulose fibers and bioadhesives (Shikha et al. 2020a).

The scope of ESCIB is based on the materials and chemicals applications of the biomass, excluding food, feed and energy. Therefore, (Platt et al. 2021) provide a detailed range of biobased products adopted and further enhanced from IEA task 42 (IEA Bioenergy Task 42 2022), classifying BBPs into the five main categories chemicals, materials, food, animal feed, and energy. Thus, this classification and examples were adopted to this study focusing on biochemicals and biomaterials including wood based products (Figure 5.2). Further studies (Di Lorenzo and Androsch 2019; Lucy Nattrass et al. 2016; Ahmed et al. 2023; J. Jefferson and H.N. Dhakal 2021; Wojciech 2016) were used to include additional information. The detailed classification and description of the materials and chemical products are discussed in the following subchapters.

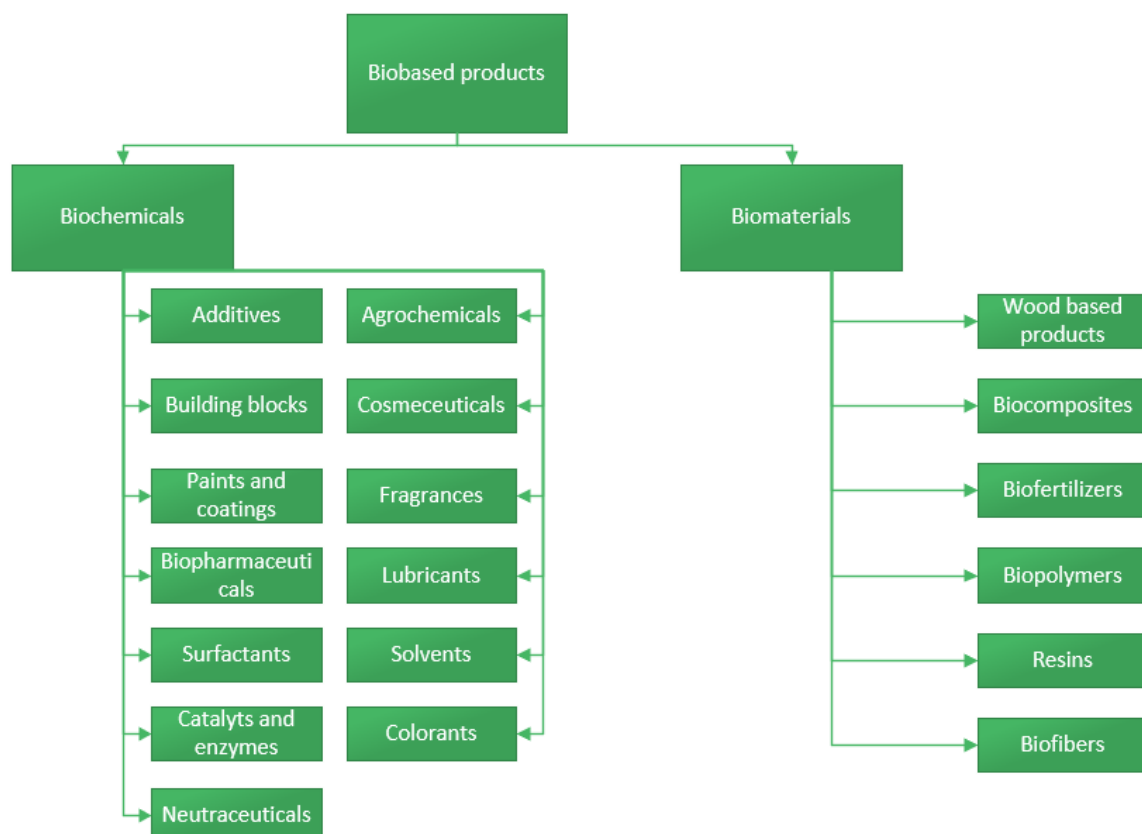


Figure 5.2: Classification of biobased products based on application (Based on (Platt et al. 2021)).

#### 5.3.1 Biochemicals

Biochemicals are used in many industries and different applications and are further classified into different categories based on their market applications (Platt et al. 2021). Although some chemicals, such as methanol, can be categorized into two or more classes, for example, it is

used as a solvent and a building block (Platt et al. 2021). Therefore, this category also includes building blocks.

#### 5.3.1.1 Additives and Adhesives

Additives are chemical substances added in small amounts into another product or chemical substance to enhance its properties and achieve desirable characteristics. Examples include epoxidized vegetable oils and epoxidized fatty acid esters (Platt et al. 2021). This includes the biobased derived plasticizers, thickeners, stabilizers, inhibitors, fillers and flame retardants (Platt et al. 2021). Adhesives are the materials that are used to connect two or more materials through adhesion or cohesion interface. Adhesives have many applications in wood-based products, such as wood processing, furniture, construction, etc. There is a wide range of biobased adhesives, such as protein adhesives, lignin-based adhesives, and starch adhesives (Yufeng et al. 2023).

#### 5.3.1.2 Agrochemicals

These chemicals are used in agricultural practices to improve plant and crop growth, increase production yield, and protect against insects and other diseases (Platt et al. 2021).

#### 5.3.1.3 Building Blocks

Building blocks or platform chemicals are starting materials to produce other chemical compounds and a wide range of products (Platt et al. 2021). Examples are ethylene, lactic acid, propylene, biomethanol, serine, acetoin, fumaric acid, succinic acid, aconitic acid, citric acid, levulinic acid, glucaric acid, etc (Wojciech 2016; Platt et al. 2021).

#### 5.3.1.4 Colorants

This category includes dyes, pigments, and inks. Dyes are water-soluble compounds typically used in textiles. Water-insoluble pigments are used in paints, ceramics, and plastics, and they are applied by dispersion in a suitable medium. Inks are more complex and can be liquid or paste containing dyes or pigments (Platt et al. 2021).

#### 5.3.1.5 Cosmeceuticals

Cosmeceuticals include essential oils, vitamins, antioxidants, hormones, and alpha-hydroxy acids (AHAs) intended to be applied to the human body as a function to clean, perfume, or alter the appearance of external body parts and protect and maintain them in good condition (Platt et al. 2021).

#### 5.3.1.6 Fragrances

Fragrances are chemical compounds that impart a smell (Platt et al. 2021). Some of the biobased fragrances are fragrance precursors, sandalwood oil, etc. (European Commission 2020).

#### 5.3.1.7 Lubricants

Lubricants are substances (liquids, solids, or semi-solids) used to facilitate the motion of solid bodies by minimizing friction and wear between interacting surfaces. Biobased lubricants are typically triglyceride esters (fats from plants) derived from vegetable oils like high oleic canola oil, castor oil, palm oil, sunflower seed oil, rapeseed oil, and tall oil from trees. These vegetable oils are often hydrolyzed to yield acids selectively combined to form specialist synthetic esters (Platt et al. 2021).

#### 5.3.1.8 Nutraceuticals

Nutraceuticals are substances derived from food sources that provide extra health benefits beyond basic nutrition. They are used to enhance health and well-being in humans or animals

and are sold in forms such as pills, powder, or other medicinal formats not usually associated with food. Examples are amino acids, proteins, vitamins and antioxidants etc. (Platt et al. 2021).

#### 5.3.1.9 Paints & Coatings

The main components of paints and coatings are solvents, binders, pigments, and additives. Biobased paints and coatings contain at least some biobased elements. Depending on the type of paint, a minimum biobased content of about 12.5% to 60% is required to be classified as a biobased product (Platt et al. 2021).

#### 5.3.1.10 Biopharmaceuticals

Chemical substances consumed by humans for medical purposes. They are used to restore or modify the physiological functions of the body. Examples are insulin, L-lysine, N-acetyl glucosamine, artemisinic acid, gallic acid, and caffeic acid etc. (Platt et al. 2021).

#### 5.3.1.11 Solvents

Solvents are substances capable of dissolving other materials without altering their chemical structure such as methanol, toluene, ethanol, acetone, ethyl acetate etc. (Platt et al. 2021).

#### 5.3.1.12 Surfactants

Surfactants are substances made up of organic compounds that have both hydrophobic and hydrophilic groups. They reduce the surface tension of the medium in which they are dissolved and/or the interfacial tension with other phases. This category includes soaps, wetting agents, and detergents (Platt et al. 2021).

#### 5.3.1.13 Catalysts & Enzymes

A catalyst is a substance that speeds up a reaction without being consumed in the process. Enzymes are highly specific biological catalysts. Plant-derived enzymes such as amylase, invertase, papain, bromelain, ficin, and lipoxygenase have been crucial in food production for items like syrups, baked goods, alcoholic beverages, and dairy products. New biobased catalysts like activated carbon can also be produced from renewable biomass (Platt et al. 2021).

### 5.3.2 Biomaterials

The category biomaterials include all other BBPs that are not in the chemicals application category and are further classified into traditional wood-based materials, biocomposites, biopolymers, fertilizers, resins, etc. (Platt et al. 2021). In novel use wood is also used as raw materials for composites, fibers, chemicals and adhesives etc. therefore traditional wood-based products is described as separate category.

#### 5.3.2.1 Traditional Wood-based Materials

This sector includes traditional materials, that are mainly used in construction, furniture, packaging and outdoor applications. This can further be classified in to;

##### 5.3.2.1.1 *Solid Wood and Veneer Wood Products*

This sector includes the sawn timber products such as solid timber for construction, glue laminated timber (rod shaped wood product that contain multiple laminations of sawn timber glued together), cross laminated timber (plate shaped bonded layers of sawn timber), solid wood panels, and timber trusses. Solid wood panels are made up of sawn timber pieces that are glued together, either edge to edge for single layer panels or face to face for making multilayered solid wood panels. Timber truss is a material used in construction industry made of sawn timber in triangular shape to bear high loads (Teischinger et al. 2023b). Furthermore, laminated veneer lumber and plywood also lies in this sector. Veneers are thin sheets of wood that are used for coating wood-based panels for decoration purposes. Furthermore, veneer sheets are glued

together to make engineered products like plywood, laminated veneer lumber or molded plywood (Wagenführ et al. 2023).

#### *5.3.2.1.2 Wood Particle/Chip Products*

This includes particle or chip based wood products such as particleboard, oriented strand board (OSB), molded particle board and cement-bonded wood based-panels. Particleboard are made from wood particles with application of pressure and heat and/or other particle form lignocellulosic fiber with addition of an adhesive (polymer). OSB is wood based multilayered panel, made from wood strands of specific shape and thickness, with application of high pressure and heat in combination with binder. OSB is used in construction sector, and particle boards find its application in furniture and buildings sector (Krug et al. 2023b).

#### *5.3.2.1.3 Wood Fiber Products*

Wood based products that are made up of wood fiber pulp belongs to this category such as medium density fiberboard (MDFB), insulation boards and molded fiberboards. These products are produced through mechanical, thermomechanical, or thermo-chemo-mechanical processes. Fiber board is produced from lignocellulosic fibers using heat and pressure. Fiberboard bonding depends on either natural felting of the fibers, or by adding a bonding agent. Based on the method used it can either be dry or wet. MDFB is produced using dry method, from lignocellulosic fibers from wood using pressure and heat. Fiber board that is produced using dry method, has a fiber moisture content less than 20% in board formation stage and of density less than or equal to 450 kg/m<sup>3</sup>. MDFB is also referred as fiberboards, hardboard, medium board, or soft board and is used in furniture, buildings, and packaging applications. Insulation boards are made of wood fiber and is used for heat and sound insulation. Molded fiberboard are the molded parts that are made from wood pulp and other natural fibers (Krug et al. 2023a).

#### *5.3.2.1.4 Wood Based Composites*

Composite wood based materials are made of wood in combination with other inorganic materials or plastics to achieve targeted enhanced properties (Tobisch et al. 2023). Mostly wood-based composites are made in combination with plastic or polymers hence it is also called wood plastic composites (WPC). WPCs are materials made from a mix of wood fiber or wood flour and virgin or recycled thermoplastics like HDPE, LDPE, PVC, PP, ABS, PS, and PLA. Polyethylene-based WPCs are the most common. The primary use of WPCs is in building materials, especially for outdoor deck floors, railings, fences, park benches, and window and door frames, among other applications (Lucy Natrass et al. 2016).

#### *5.3.2.1.5 Pulp and Paper Products*

This includes all kind of pulp obtained through different manufacturing process and papers products such as graphic paper, tissue paper, packaging paper and specialty paper. Pulp is a fibrous material that is obtained from wood or lignocellulosic materials by chemical or mechanical processes. Specialty paper has broad range of uses and applications in different fields such as electrical papers, release papers, filter papers, security papers, and building papers (wallpaper, barrier paper) etc. (Heinemann et al. 2023). Furthermore, this category include all other type of papers and article of papers, such as printing or writing paper, carbon papers, corrugated paper and paper board, folding paper board containers, bags of papers, office box files etc. (EUROSTAT 2008).

#### *5.3.2.2 Biocomposites*

Composites are materials made from combining two or more materials, either natural or synthetic, to achieve enhanced properties. These typically involve a fibrous or particulate material within a matrix or continuous phase, which can be a polymer, metal, or ceramic. Examples include natural composites like wood, mud bricks (a mix of mud and straw), and

bones, as well as biobased composites made with natural fibers and synthetic fossil-derived polymers or vice versa (such as PLA/flax composites and paper) (Platt et al. 2021). Various biobased materials are used to produce biobased composites, such as wood decks, sound-absorbing wooden materials, bathroom interiors, window frames, consumer products, decorative trim, automotive panels, and industrial applications (Shikha et al. 2020a). Biocomposites are also widely used in the healthcare and engineering sectors, and significant research interest in electronics has recently been gained (Ahmed et al. 2023). This category also includes the panels used in various applications such as countertops in kitchen areas, house interior and exterior, and floor and roof areas (USDA 2024). Packaging materials are also usually made of composites of cellulose fibers and biopolymers (Wojciech 2016).

Biocomposites can further be classified into two main groups identified from industrial data in EU – Natural fiber reinforced plastic composites (NFPCs) and wood plastic composites (WPCs) (Lucy Natrass et al. 2016). WPC are already discussed in wood products here only NFPC are discussed.

#### 5.3.2.2.1 *Natural Fibre Plastic Composites*

NFPCs are an eco-friendly and cost-effective alternative to composites reinforced with synthetic fibers. NFPCs can include non-cellulose-based fiber fillers such as pulp fibers, peanut hulls, bamboo, straw, and digestate (Lucy Natrass et al. 2016).

#### 5.3.2.3 Biofibers

Biofibers are substances, either natural or synthetic, with a thread-like appearance, significantly longer than they are wide (diameter less than 1 mm). Examples include natural fibers like wool, jute, hemp, sisal, abaca, coir, silk, and microfibrillated cellulose, as well as biobased fibers such as polycaprolactam (Nylon 6), Polyhexamethylene adipamide (Nylon 66), and polyamid-11 (Nylon 11) (Platt et al. 2021).

#### 5.3.2.4 Organic Fertilizers

Organic fertilizers are materials derived from animal products and plant residues that contain sufficient nitrogen. Naturally occurring organic fertilizers include green manure, slurry, worm castings, peat, seaweed, greensand (anaerobic marine deposits), humic acid, guano, sewage sludge, compost, bloodmeal, bone meal, and digestate (Platt et al. 2021).

#### 5.3.2.5 Biopolymers

Biopolymers are natural or synthetic substances composed of macromolecules with high relative molecular mass, consisting of repeated structural units. Examples include natural polymers such as starch, natural rubber (bioelastomers), lignin, cellulose, chitin, and pectin, as well as biobased polymers like polyethylene (PE), polyethylene terephthalate (PET), polyethylene 2,5-furandicarboxylate (PEF), polyhydroxyalkanoates (PHA), polylactic acid (PLA), and polybutylene succinate (PBS) (Platt et al. 2021). Biobased polymers could have significant applications in replacing conventional liquid electrolytes in battery applications because of biodegradable and biocompatible nature of biobased polymers (Ahmed et al. 2023). Biopolymers has a range of end sector application that includes packaging, textiles, construction materials, adhesives, cosmetics, biomedical, water barrier and purification, etc. (J. Jefferson and H.N. Dhakal 2021).

Recent studies further classify biopolymers into three main categories – The first class, The second class, The third class (Di Lorenzo and Androsch 2019) renamed to natural, bioengineered and polymers from monomers to understand it easily.

#### 5.3.2.5.1 *The first class/ Natural polymers*

Polymers belonging to the first class are natural polymers directly derived from biomass, which can include chemically modified versions such as starch, modified starches, chitin, chitosan, cellulose, cellulose acetate, and natural rubber (Di Lorenzo and Androsch 2019).

#### 5.3.2.5.2 *Second class/ Bio-engineered Polymers*

Polymers belonging to the second class are bioengineered polymers that are synthesized by microorganisms and plants, such as polyhydroxyalkanoates (Di Lorenzo and Androsch 2019).

#### 5.3.2.5.3 *Third class/ Polymers from Renewable Monomers:*

Polymers belonging to the third class are polymers which are synthesized from monomers obtained from renewable resources, including polylactide, poly(butylene succinate), bio-poly(ethylene terephthalate), and bio-polyolefins (Di Lorenzo and Androsch 2019). Monomers for such polymers are obtained from naturally synthesized molecules having diverse structure and characteristics. This category has the most promising and diverse range of products and is further classified into biodegradable and non-biodegradable biopolymers (Di Lorenzo and Androsch 2019).

#### 5.3.2.6 Resins

Resins are solid or highly viscous substances, composed of a complex mix of organic compounds, originating from either natural or synthetic sources, and are practically insoluble in water. These materials or substances are in an uncured state, meaning they have not undergone any chemical or physical processes to make them harder, tougher, or more stable. Natural resins include rosin, shellac, copal, and biobased derived resins i.e., polyurethane resins, epoxy resins, and alkyd resins (Platt et al. 2021).

### 5.4 Classification based on the Transformation Level

Biomass is a material of biological origin, excluding material embedded in geological formations or transformed into fossil material, while a product is a substance, a mixture of substances, materials, or objects resulting from a production process. It can be a primary product, intermediate product, semi-finished product, or finished product. Therefore, the definition of a BBP establishes a direct connection between the biomass and the final product. Intermediate steps are necessary to create a BBP from biomass (DIN EN 16575 D 2014).

After harvesting or collection, biomass can be a raw material in various processes and products. It can be processed mechanically, chemically, or biologically, leading to biobased materials or substances. These materials or substances may be processed alone or in combination with other materials (such as fossil or mineral origins) to create BBPs derived wholly or partially from biomass (DIN EN 16575 D 2014).

During the production of BBPs, biomass can undergo different levels of transformation, resulting in BBP of varying complexity. According to (DIN EN 16575 D 2014), the classification can be based on the transformation level, described as follows.

#### 5.4.1 Primary Products

Primary products are materials that result from simple physical or mechanical processes, such as sawn timber, hemp fibers used as insulation, etc.

#### 5.4.2 Extracted Products

Extracted products are materials that are obtained through extraction or fractionation processes. Examples are pulp, starch, and vegetable oils.

### 5.4.3 Intermediate Products

Intermediate products are products that are obtained from chemical, physical, or biological processing. They are referred to as intermediates, if they are further used for the manufacturing of final products. Examples include ethanol, chemical building blocks, and monomers.

### 5.4.4 Semi-finished or Finished Products

This category includes semi-finished and finished products that are ready to use and usually need no further processing. Examples are biopolymers, biochemicals, biocomposites, biosolvents, biolubricants, sawn wood, engineered wood like glue laminated timber, particle boards, etc.

## 5.5 Classification based on Sector and Product Classes

The Horizon EU project CIRCE (2022) classified the BBPs based on the statistical classification of economic activities in the European community (NACE) (EUROSTAT 2008) and on product classes from community production (PRODCOM) (EUROSTAT 2019) (Table 5-2). NACE (EUROSTAT 2008) is a classification system in the EU for economic activities in the economic, social, environmental, and agricultural domains. PRODCOM provides statistics on the production of manufactured goods and cover economic activities of mining, manufacturing, quarrying and material recovery which refers to the section B, C and E of NACE (EUROSTAT 2019).

In the project CIRCE (2022), the NACE classification (EUROSTAT 2008) was first used to identify the product that can potentially replace the fossil base materials in the sectors of construction, woodworking, textiles, pulp and paper, chemicals, and plastics (renamed to polymers in this work). After that, the PRODCOM (EUROSTAT 2019) product list was viewed in detail to identify the product or group of products that are already partially or fully biobased using the author's knowledge, market experience, product heading and literature search (CIRCE 2022). The PRODCOM (EUROSTAT 2019) product groups that do not have a biobased alternative were excluded from this classification (CIRCE 2022).

The finding from the CIRCE (2022) project was updated for the ESCIB project with new versions for NACE and PRODCOM currently available. The NACE classification applied in CIRCE (2022) was Rev2 used for statistics for the period of 2008 till 2024. The newest version is NACE Rev2.1 (EUROSTAT 2023), which will be used for EU statistics from 2025 onward. The version of PRODCOM used in the CIRCE project was from 2021 (EUROSTAT 2019), and the new version is 2024 (EUROSTAT 2025). The PRODCOM codes are still yet not developed with the NACE Rev2.1, so in this study we adapted the code for PRODCOM 2024 to link it to NACE Rev 2.1. However, this study recommends to update the PRODCOM codes when they are updated for Rev2.1, i.e., PRODCOM-2025. Furthermore, this study included a category, if it was a biobased category from the general description. If there is NACE activity that is energy-related, it is not included in our ESCIB classification due to our focus on material application of the BBPs, i.e., neither the NACE Rev2.1, 16.26 activity, which is “Manufacturing of solid fuels from vegetable biomass,” nor activities related to food, tobacco, and beverages are included in our classification. However, new categories were included from NACE Rev2.1 based on product description and market research of the product if any BBPs are available in the category no matter on low or high TRL. Furthermore, new divisions and sectors were included based on market and literature research. For example, the division “manufacture of motor vehicles” was included, as the automotive industry already sees a huge potential for biobased materials in car manufacturing such as biobased plastic, fibers and biocomposites due to a focus on sustainability and customer demand (BMBF 2015). Also the division,

“manufacturing of electronic components and boards” was added due to the potential of biobased materials for biobased electronic components (Kamble et al. 2022; Wang et al. 2023; Soon et al. 2024; Ahmed et al. 2023). However, the current list of products in PRODOM does not have more details, so it is not included in the main list, but only in the general division.

Table 5-2: Classification of biobased products based on NACE Rev2.1 2025 and PRODCOM (2024) product divisions and classes (Mainly Adapted from (CIRCE 2022) with addition of extra product categories and revising for NACE Rev 2.1 (Detail classification in Annex I).

Division (NACE Rev2.1)	Class (NACE Rev 2.1)	Sector
13.Manufacturing of Textiles	13.10: Preparation and spinning of textile fibers 13.20: Weaving of textiles 13.91: Manufacture of knitted and crocheted fabrics 13.92: Manufacture of household textiles and made-up furnishing articles 13.93: Manufacture of carpets and rugs 13.94: Manufacture of cordage, rope, twine and netting 13.95: Manufacture of non-woven and non-woven articles 13.96: Manufacture of other textiles for technical and industrial uses 13.97: Manufacturing of other textiles	Textile
14.Manufacturing of wearing apparel	14.10 Manufacturing of knitted and crocheted apparel 14.21: Manufacture of outerwear 14.22: Manufacture of underwear 14.23: Manufacture of work wear 14.24: Manufacture of leather clothes and fur apparel 14.29: Manufacture of other wearing apparel and accessories	Textile
15.Manufacture of leather and related products	15.20: Manufacture of footwear	Textile
16.Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood 16.24: Manufacture of wooden containers 16.28: Manufacture of other products of wood; and articles of cork, straw and plaiting materials	Wood working
	16.21: Manufacture of veneer sheets and wood-based panels 16.22: Manufacture of assembled parquet floors 16.23: Manufacture of other builders' carpentry and joinery 16.25: Manufacture of doors and windows of wood	Construction
17.Manufacture of paper and paper products	17.11: Manufacture of pulp 17.12: Manufacture of Paper and paperboard 17.21: Manufacture of corrugated paper, paperboard and containers of paper and paperboard 17.22: Manufacture of household, sanitary goods and toilet requisites 17.23: Manufacture of paper stationery 17.24: Manufacture of Wallpaper 17.25: Manufacture of other articles of paper and paperboard	Pulp and paper
20.Manufacture of chemicals and chemicals products	20.12: Manufacture of dyes and pigments 20.14: Manufacture of other organic basic chemicals 20.15: Manufacture of fertilisers and nitrogen compounds 20.16: Manufacture of plastics in primary forms 20.20: Manufacture of pesticides, disinfectants and other agrochemical products	Chemicals

Division (NACE Rev2.1)	Class (NACE Rev 2.1)	Sector
	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics 20.41: Manufacture of soap and detergents, cleaning and polishing preparations 20.42: Manufacture of perfumes and toilet preparations 20.51: Manufacture of liquid biofuels (it includes ethanol, bioethanol that can potentially be used in materials so included). 20.59: Manufacture of other chemical products n.e.c. 20.60: Manufacture of man-made fibres	

Table 5-2 (continued)

21.Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.10: Manufacture of basic pharmaceutical products 21.20: Manufacture of pharmaceutical preparations	Chemicals
22.Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres 22.12: Manufacture of other rubber products 22.21: Manufacture of plastic plates, sheets, tubes and profiles 22.22: Manufacture of plastic packing goods 22.23: Manufacture of doors and windows of plastic 22.24: Manufacture of builders' ware of plastic 22.26: Manufacture of other plastic products	Polymers
23.Manufacturing of other non-metallic mineral products	23.65: Manufacture of fiber cement 23.91: Manufacture of abrasive products	Construction
26.Manufacture of Computer, electronic and optical products	26.11: Manufacture of electronic components	Electronics
29.Manufacture of motor vehicles, trailers and semi-trailers	29.32: Manufacture of other parts and accessories for motor vehicles	Automotives/ Composites
30.Manufacture of other transport equipment	30.99: Manufacturing of other transport equipment	Transport
31.Manufacture of furniture	31.00: Manufacture of furniture	Wood working
32.Other manufacturing	32.30: Manufacturing of sport goods 32.40: Manufacturing of games and toys 32.50: Manufacturing of medical and dental instruments and supplies 32.91: Manufacturing of brooms and brushes 32.99: Other manufacturing n.e.c.	Woodworking and Composites and Polymers or other sectors

## 5.6 Comprehensive Overview of the Classification of Biobased Products

BBPs classification was made according to the different industrial perspectives for easy understanding from all perspectives. Product categories or application wise BBPs are classified into two main groups i.e., biochemical and biomaterials. Biochemicals includes bioadhesives, pharmaceuticals, agrochemicals and other chemical based products. While biomaterials consist of traditional wood-based products, biofertilizers, resins, etc. Similarly, BBPs classification was made based on the biobased content certification scheme standard adopted in EN 16785. Another classification approach is based on the transformation level i.e., primary, intermediate, or finished products (Table 5-3). Furthermore, BBPs were classified into drop-ins and dedicated BBPs, a concept adopted from biobased chemicals that are adopted based on the integration of the BBPs into the market. Lastly, a detailed classification was made for the BBPs from the NACE Rev2.1 classification and PRODCOM 2024 and listed all the potential BBPs.

Table 5-3: Classification of the biobased products considering different aspects.

Product Categories	Standards	Transformation level	Market integration	Product Sector NACE Rev2.1
Chemicals	Group I products	Primary products	Drop-ins / Direct Replacements	Construction
Biomaterials	Group II products	Extracted products	Novel or dedicated	Woodworking (incl. Furniture, Packaging, etc.)
	Natural products	Intermediate products		Pulp and Paper
		Semi-finished and Finished products		Textiles
				Chemicals and Chemical products
				Polymers (Plastics)
				Automotives and transport
				Electronics

## 6 Classification of Biobased Industries

Biobased industries and biorefineries are the facilities that process feedstock into various BBPs. Therefore, different classifications can be used to classify biobased industries based on feedstock, platforms, processing technology/conversion process, end products sectors, and technology readiness level (TRL) (Platt et al. 2021; Cherubini et al. 2009a; Parisi et al. 2020; Baldoni et al. 2021; IEA Bioenergy Task 42 2022; Wagemann et al. 2018).

Therefore, classification of biorefineries is mainly focused on platforms, pathway, processing technology and development approach. Most of the literature regarding the classification of BBS is focused on biorefineries, hence in this study the focus is on biorefineries. However, such classifications can also be implemented equally for traditional wood based industries i.e., platforms, development approaches. In this study, the forest-based industries classification is made separately based only on the sector and platforms.

### 6.1 Classification of Forest-based Industries

Forest based industries utilize the forest resources for producing wide range of wood based products, such as sawn timber, wood based materials, chemicals, and energy (Teischinger et al. 2023a). The forest based industry can be classified in to four main sectors according to the EU clusters namely, woodworking industry, furniture industry, pulp and paper industry and printing industry. Furthermore, forest based industries also include wood biorefinery (Teischinger et al. 2023a), which will be discussed in the classification of biorefinery in the section 6.2.4.

#### 6.1.1 Woodworking Industry

This industry includes the production of sawn timber, veneer, wood-based panels, and wooden construction materials and products (European Commission 2024). Sawn timber is produced by sawmilling of the round timber wood of a defined shape and quality. Sawn timber products include glue laminated timber, cross laminated timber and solid wood panels etc. Veneer based products includes laminated veneer lumber, plywood and molded plywood (Wagenführ et al. 2023). Similarly, it contain the particle based materials such as oriented strand board, extruded particle board, molded particle board, cement-bonded particle board (Krug et al. 2023b), and fiber base materials such as medium density fiber boards, insulation boards etc. (Krug et al. 2023a).

#### 6.1.2 Furniture Industry

Furniture industry includes all type of furniture used in homes and offices, seats made of wooden frames, and furniture for shops. Furniture industry is depended on the forest resources i.e., wood as primary material along with other materials such as textiles, additives, and adhesives etc.

#### 6.1.3 Pulp and Paper Industry

This industry includes the pulp, paper and paper products manufacturing such as paper board, solid board etc. Pulp is a fibrous intermediate material produced from the wood or other lignocellulosic material through different conversion process i.e., chemical, alkaline sulfate process (kraft process), mechanical etc. Paper machine is used then to convert the wood pulp into paper products by passing the pulp through different sections i.e., distributing stock suspension, wire section, press section, drying section and reeling part. Depending on the grade of the paper produced in paper machine specific unit operation are installed to obtain specific features of the paper. For finishing process coating is also used for surface finishing of the paper, by application of mineral pigments i.e.,  $\text{CaCO}_3$ , kaolin or silicates in combination with starch or synthetic based binders. This industry includes the graphic paper, packaging paper

(corrugated cardboard etc.), tissue paper and other papers including specialty papers (electrical papers, filter papers, silicon raw paper etc.) (Heinemann et al. 2023).

#### 6.1.4 Printing Industry

Printing industry uses products particularly paper from forestry resources, to produce wide range of printed papers. End products in this industry are books, newspapers, packaging, brochures, etc. All these products use paper as a primary material in combination with printing inks, binders etc., that can be obtained from biobased or also fossil based resources.

## 6.2 Classification of Biorefineries

Biorefineries are already defined in Khan et al. (2024), and in this study, a detailed classification was made for the biorefineries. Extensive literature review was conducted to classify biorefineries based on different approaches including processing technology, platform, pathway, and conversion processes.

### 6.2.1 Classification based on Refining Process.

(Wagemann et al. 2018) differentiates refining processes in biorefinery into primary (involves pretreatment and separation into intermediates) and secondary (intermediates are converted to final products, i.e., chemicals, polymers, etc.). This concept was extended to classify the biorefineries based on the refining process into three main classifications – primary, secondary, and full-scale and is described as follows.

#### 6.2.1.1 Primary Biorefineries

Primary refineries involve basic refining processes such as the pretreatment of biomass and then separation or further refining into useful intermediates. Such biorefineries are not involved in manufacturing final-end products such as paper, polymers, or chemicals. Examples include the production of pulp, lignin, chemical building blocks, sugar, etc. An industrial example is LXP group that produce cellulose and lignin.

Primary biorefineries can use a bottom-up approach (see section 6.2.2) to extend or upgrade their existing biomass-converting traditional facilities (pulp, starch, sugar, oil, etc.). An example is the Roquette Lestrem biorefinery which was a simple starch mill that was gradually developed, and the product spectrum increased to native and modified starches, proteins, polyols, organic acids and specialty chemicals (Platt et al. 2021). After using further processing of the starch into a variety of chemicals and products, this industry will be transformed into full-scale biorefinery.

#### 6.2.1.2 Secondary Biorefineries

Secondary biorefineries take the intermediate products/platforms created in primary facilities to make semi-finished or finished biobased products. Such types of facilities use chemical or thermochemical, biological, etc., processing to make final products. For example, making a vast range of chemicals and polymers from chemicals building blocks, making paper or packaging materials from pulp, etc.

#### 6.2.1.3 Full-scale Biorefineries

Full scale biorefineries are integrated facilities in terms of combining both primary and secondary refining processes to start the refining process from biomass feedstock processing and to get a final semi-finished or finished biobased product. Such biorefineries directly make a final product, i.e., first make intermediates and then, in the same facility, produce end products, such as polymers and chemicals.

Full scale biorefineries can be developed by using top-down approach, which is focused on developing a new and highly developed integrated system to manufacture wide range of products.

## 6.2.2 Classification of Biorefineries based on Development Strategies

Biorefineries can be classified based on a development strategy (how the biorefineries develop) into two types – bottom-up and top-down approaches (Wagemann et al. 2018).

### 6.2.2.1 Bottom-up Development Approach

In the bottom-up development approach, existing or already established biomass processing facilities broaden their range of operations and enhance their traditional production portfolio. This can involve enhancing current processes to extract additional valuable substances from the same feedstocks, utilizing or repurposing waste by-products, or integrating further processing steps to develop new products from traditional ones (Wagemann et al. 2018). Examples includes one platform sugar, one platform starch, one platform oil and pulp mill etc. (IEA Bioenergy Task 42 2022). The bottom-up approach is always a brownfield strategy, meaning that an existing facility is upgraded or expanded into a biorefinery at the same location (Platt et al. 2021).

### 6.2.2.2 Top-down Development Approach

The top-down development approach aims to establish new, fully integrated biorefinery systems from the ground up. Thereby own specialized logistics and proprietary conversion technologies have to be developed to handle the entire biorefining process independently and cohesively (Wagemann et al. 2018). Examples includes two platform oil and biogas, two platform C5 sugars, C6 sugar and lignin etc. (IEA Bioenergy Task 42 2022). It typically involves the creation of specialized processes designed to convert different biomass fractions efficiently, aiming for zero waste and producing a wide variety of products for diverse markets. The systems for both primary and secondary refining are specifically engineered to transform the feedstock into multiple products (Platt et al. 2021).

The top-down approach can follow either a brownfield or greenfield strategy. In a brownfield scenario, a new biorefinery is established at the same location as an existing facility, leveraging the existing industrial infrastructure, such as biomass supply, auxiliary systems, and downstream processing facilities, along with current regulations and permits. This approach can reduce deployment time due to factors like lower overall investments, shared facilities, and existing environmental permits (Platt et al. 2021).

In contrast, the greenfield approach involves building a new biorefinery from the ground up at a different location. This typically requires higher investments, new permits, and other considerations, which can significantly increase the time to market. Both approaches are evident in the bioethanol sector, where some advanced lignocellulosic biorefineries are being developed on the sites of existing ethanol plants to utilize current infrastructure and expertise, while other advanced bioethanol demo plants are being built at entirely new, stand-alone sites within feedstock cultivation areas (Platt et al. 2021).

## 6.2.3 Classification of Biorefineries based on Processing Technology

Biorefineries can be classified into phase I (single feedstock biorefinery), phase II (advanced single feedstock biorefinery), and phase III (advanced multi feedstock biorefinery) biorefineries (Figure 6.1) based on processing technology, the number of feedstocks they use, and the potential to produce final BBPs (Shahid et al. 2021; Kamm and Kamm 2004; Takkellapati et al. 2018; Clark and Fabien E. I 2008).

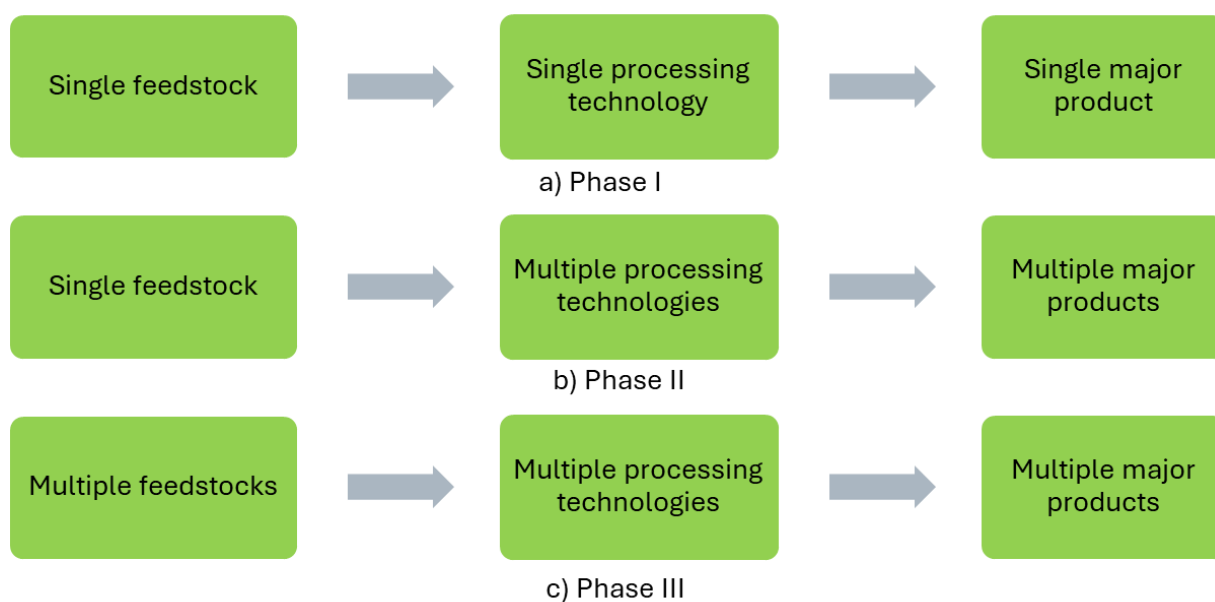


Figure 6.1: Phase I a), Phase II b) and Phase III c) biorefineries (Based on (Shahid et al. 2021; Clark and Fabien E. I 2008; Kamm and Kamm 2004) ).

### 6.2.3.1 Phase I/Single Feedstock Biorefinery

Phase I biorefinery relies on a single feedstock material, features fixed processing capabilities (single process), and generates one primary product. It exhibits minimal flexibility in its processing operations. Examples include; biodiesel production as a single major product from sunflower oil using single processing process (transesterification) (Shahid et al. 2021; Clark and Fabien E. I 2008). Another example is dry-milling ethanol plant which consumes grain as a feedstock, has fixed processing capability and produces a fixed amount of ethanol (means almost fixed production capacity), feed co-products and carbon dioxide. Such biorefineries has almost no flexibility in processing (Kamm and Kamm 2004). Similarly paper and pulp mills are also phase I biorefineries (Clark and Fabien E. I 2008; Takkellapati et al. 2018). Such biorefineries are not economically very feasible and have little flexibility to develop according to the demand and recover operation and investment cost efficiently (Clark and Fabien E. I 2008).

### 6.2.3.2 Phase II/Advanced Single Feedstock Biorefineries

Phase II biorefineries are similar to phase I biorefineries in a sense that they also use single feedstock, but they are capable of producing variety of major end products (i.e., polymers, chemicals, energy etc.) by multiple processing technologies (biochemical, enzymatic, fermentation etc.) (Shahid et al. 2021; Clark and Fabien E. I 2008). Such biorefineries are flexible to market demand, prices and operating limits hence providing higher return on investment (Clark and Fabien E. I 2008).

Examples reported by Shahid et al. (2021) and Clark and Fabien E. I (2008) include a phase II Plant of Novamont in Italy, which produce thermoplastics and biodegradable polyesters derived from starch feedstock. Another example of a phase II biorefinery is the Roquette site at Lastrem, which employed biochemical catalysis to transform cereal grain feedstock into a variety of key products, including organic acids, modified starches, and proteins.

Biofuels or energy refineries are mostly classified into phase II biorefineries. However, in the future, all phase I biorefineries will be converted into phase II biorefineries if methods of

upgradation are identified. For example phase I biodiesel biorefinery could be converted in to phase II biorefinery if the operator started to convert crude glycerol into valuable energy or chemical products (Clark and Fabien E. I 2008).

### 6.2.3.3 Phase III/Advanced Multi-feedstock Biorefineries

Phase III biorefineries are the most advanced form of biorefineries, that are capable of producing wide range of BBPs by utilizing a wide range of feedstocks using multiple processing technologies. Such biorefineries are market driven and can scope well with the market and price demand. The flexibility of utilizing multiple feedstocks is an important factor for adaptability towards changes in demand and supply for feed, food and industrial commodities (Kamm and Kamm 2004). (Shahid et al. 2021) report that currently phase III biorefineries can be classified into seven different systems based on nature of feedstock, applied techniques and intermediates such as syngas and sugar platforms. Seven phase III biorefineries systems such as lignocellulosic feedstock biorefinery, two platform concept biorefinery, thermochemical biorefinery, conventional biorefinery, whole crops biorefinery, green biorefinery and marine biorefinery are currently categories of phase III biorefineries that use multiple feedstocks, use multiple processing technologies to produce variety of biobased products (Shahid et al. 2021). Phase III biorefineries are very flexible in terms of market demands to achieve maximum return on investment and profits because of its diverse and most advanced nature of processing various feedstocks and producing various end products (Clark and Fabien E. I 2008).

### 6.2.3.4 Overview about Biorefinery Classification by Process Technology

Phase I biorefineries are not market and demand flexible as they have almost fixed capacity to produce one major product. It cannot compete price wise with phase II industries that produce multiple products by using single feedstock therefore being more flexible in demand and price for the end products. Phase III biorefineries are the future because they cannot only adopt to the market demand but are also more profitable. They can use various feedstock which can be used for manufacturing high value but low-price BBPs. Therefore, they are higher flexible in terms of market demand but also in term of price of the BBPs (Figure 6.2).

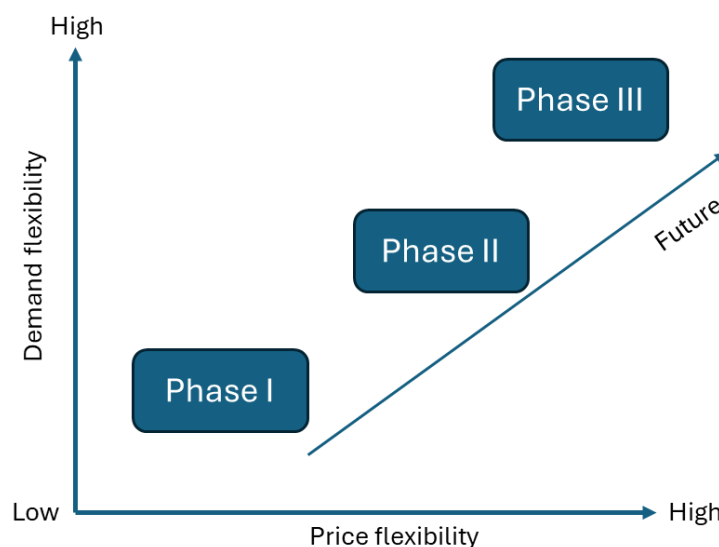


Figure 6.2: Price and demand flexibility of phase I, II and III biorefineries.

Furthermore, biobased paths identified in the study of Platt et al. (2021) were categorized in to phase I, phase II and phase III biorefineries (Table 6-1). This categorization was done based on the description provided for each biobased path, feedstocks used, and the case studies where it mainly identified the number of feedstocks used and the end products. Based on the description, the biobased paths were classified into phase I, phase II, and phase III biorefineries as follows.

Table 6-1: Categorization of biobased paths into Phase I, II, and Phase III biorefineries (Adapted from (Platt et al. 2021)).

Processing technology categorization	Biorefinery pathway name	
Phase I/Phase II	A	One platform (C6 sugars) biorefinery using sugar crops
Phase I/Phase II	B	One platform (starch) biorefinery using starch crops
Phase I/Phase II	C	One platform (oil) biorefinery using oil crops, wastes and residues
Phase I/Phase II	D	Two-platform (pulp and spent liquor) biorefinery using wood
Phase III	E	Three platform (C5 sugars, C6 sugars and lignin) biorefinery using lignocellulosic biomass
Phase II/Phase III	F	Two-platform (organic fibres and organic juice) biorefinery using green biomass
Phase II	G	Two-platform (oil and biogas) biorefinery using aquatic biomass
Phase II	H	Two-platform (organic fibres and oil) biorefinery using natural fibres
Phase III	I	One platform (syngas) biorefinery using lignocellulosic biomass and municipal solid waste
Phase III	J	Two platform (pyrolytic liquid and biochar) biorefinery using lignocellulosic biomass
Phase III	K	One platform (bio-crude) biorefinery using lignocellulosic, aquatic biomass, organic residues

#### 6.2.4 Classification of Biobased Industries based on the Platforms

Platforms are intermediate products derived from various biomass feedstocks, which can undergo further processing through the conversion processes (biochemical, chemical, mechanical, thermomechanical and thermochemical) to produce a wide array of final products. These platforms also offer insight into the potential for integrating different facilities into more complex biorefineries (Platt et al. 2021). It can also be a linkage between different biorefineries concepts or final products of the biorefinery (Hingsamer and Jungmeier 2019).

Classification of biorefineries based on the platforms is the most related feature used for classification (Hingsamer and Jungmeier 2019). (Platt et al. 2021) made an extensive review of the biorefinery classification and provided a detailed classification for biorefineries. This classification is focused only on chemical and materials-driven biorefineries either as a major product or as side products, and the focus was made on the BBPs available in the NACE classification. From NACE classification, agrochemicals, pesticides, paints and coatings, fertilizers, pharmaceuticals, fibers, inks, dyes, soaps, detergents, plastics, etc., were taken as references. This study proposed the biorefineries into 16 platforms. Platforms in biorefineries are according to Platt et al. (2021), are listed in Table 6-2.

Table 6-2: Platforms in material and chemicals biorefineries (Platt et al. 2021).

Platform	Description
Biochar	Biochar is a solid material produced through biomass carbonization and thermochemical conversion. It is mainly applied as a soil amendment to enhance soil health. Suitable biomass for biochar production includes crop residues, yard waste, food scraps, forestry by-products, and animal manures.
Bio-coal	Solid material with a higher energy content compared to the original biomass feedstock produced via torrefaction. It is usually converted into pellets for easy transportation and to avoid problems associated with decomposition during storage. Wood and bark are used as raw materials.
Bio-crude	A complex mixture of oxygenated organic compounds. It is produced using hydrothermal liquefaction or hydrothermal upgrading.
Biogas	Anaerobic digestion gas composed mainly of CH <sub>4</sub> and CO <sub>2</sub> and lower levels of impurities such as H <sub>2</sub> S. It is manufactured using anaerobic digestion of organic residues. After use it can be used for power and heat generation. The digestate associated to this process can be processed to be used as biological fertilizer.
Bio-hydrogen	Hydrogen is produced from biomass in photoreactors or fermenters, mostly catalyzed by enzymes. Biogenic hydrogen and carbon dioxide can be used to produce hydrocarbons or other chemicals.
Bio-naphtha	Bio-naphtha is a blend of volatile and flammable C <sub>5</sub> -C <sub>10</sub> hydrocarbon compounds that can replace petroleum-derived naphtha due to its similar physical and chemical properties. It can be produced from a range of biomass feedstocks, including palm oil, rapeseed oil, soybean oil, jatropha oil, camelina oil, waste animal fat, and vegetable oil residues.
Bio-oils	Oils derived from biomass, such as vegetable oil, microalgae oil, tall oil, fatty, grease and used oil.
C <sub>5</sub> /C <sub>6</sub> sugars	C <sub>5</sub> sugars (such as xylose and arabinose) and C <sub>6</sub> sugars (such as glucose, fructose, and galactose) are found in various feedstocks and are relatively easy to extract. These sugars are released through the hydrolysis of sucrose, starch, cellulose, hemicellulose, and from food and feed by-products. Extraction is particularly straightforward from sugar crops like sugarcane, sugar beet, and sweet sorghum.
Carbon dioxide	Carbon dioxide produced from biomass, whether entirely or partially, can be captured and processed to create higher value products such as chemicals.
Lignin	Lignin is primarily used for generating process steam and electricity in wood processing facilities. However, it is also utilized in other applications, such as dispersants in cement and gypsum, emulsifiers and chelating agents in industrial effluent treatments, tire additives, resins, and chemicals like vanillin and phenolic compounds.
Organic fibers	Fibers such as lignocellulose, press cake, and hulls are generated from biomass processing. These fibers can be employed in making building materials, insulation, packaging, biocomposites, biofuel feedstock, and various other products.
Organic juice	Organic juice is a liquid mixture obtained from pressing wet biomass, such as grass, alfalfa, or immature cereals. The processing involves dewatering the biomass to produce two separate intermediates: a nutrient-rich organic juice and a press cake. The organic juice contains valuable compounds, including carbohydrates, proteins, free amino acids, organic acids, minerals, hormones, and enzymes, which can be utilized in various valorization pathways.
Protein	Plant-based proteins can be extracted from a range of sources including crops, agro-residues, press cakes, algae, and grass. After processing and purification, protein isolates and concentrates, which contain essential amino acids, can be used to create specialized

Platform	Description
	formulated food. It is also used in other industrial applications such as adhesives, coatings, surfactants, and plastics.

Table 6-2 (continued)

Pyrolytic liquid	Pyrolysis liquid is produced from the thermochemical decomposition of solid biomass in a low-oxygen environment to prevent combustion. These liquids are complex mixtures containing water, guaiacols, catechols, syringols, vanillin, isoeugenol, pyrenes, various carboxylic acids, and a range of other compounds.
Starch	Modified and regular starch finds diverse application such in cosmetics, pharmaceutical, adhesives, bioplastics.
Syngas	A mixture of mainly carbon monoxide and hydrogen, as well as methane, CO <sub>2</sub> and nitrogen produced from biomass gasification. Syngas can be fermented to produce methanol, ethanol, ammonia, and potentially other chemical building blocks.
Other platforms	Any other new platforms, technologies or concepts.

The concept of platform is used mostly for biorefineries in the literature, but as for the definition it is the intermediate product which can then further be transformed into final product. Based on this concept, the same platform classification is also adopted for wood-based materials. Most of the wood based materials are produced by disintegration by cutting and other means to convert it first to intermediate products which then is processed further by joining parts together by adding other substances (organic and inorganic binders etc.) (Tobisch et al. 2023). Based on this wood based industries are also classified based on the platforms/intermediate products Table 6-3 as reported by (Tobisch et al. 2023).

Table 6-3: Classification of wood based industries based on platforms (Mainly adapted from (Tobisch et al. 2023) with further description of each platform).

Platforms/Intermediate products	Description	Wood-based products
Lamellas, Rods	Lamella is a thin wood strip used in production of solid wood panels.	<ul style="list-style-type: none"> <li>▪ Single-layer solid wood panel</li> <li>▪ Multilayer solid wood panel</li> <li>▪ Blockboard</li> <li>▪ Furniersperrholz</li> <li>▪ Veneer plywood</li> <li>▪ Veneer-strip plywood</li> </ul>
Veneers	Thin sheets of wood made by slicing, peeling or sawing from log, root of tree.	<ul style="list-style-type: none"> <li>▪ Star plywood</li> <li>▪ Laminated veneer lumber (LVL)</li> <li>▪ Parallel strand lumber (PSL) “parallam”</li> <li>▪ Artificial-resin compacted wood</li> <li>▪ Veneered particleboard</li> </ul>
Wood wool	Wood based materials made by shredding logs in to thin and long strands having specific dimension.	<ul style="list-style-type: none"> <li>▪ Mineral-bonded wood wool lightweight board</li> <li>▪ Lightweight particleboard with wood wool decks</li> <li>▪ Cement-bonded particleboard</li> <li>▪ Gypsum-bonded particleboard</li> <li>▪ Extruded board</li> </ul>
Particles, strands	Component of particle board made from wood. Include small subdivisions of wood such as chips, flakes, sawdust etc. Strand is type of wood flake used in OSB and laminated strand lumber.	<ul style="list-style-type: none"> <li>▪ Flat-pressed board</li> <li>▪ Calendered particle board</li> <li>▪ OSB</li> <li>▪ Particleboard with fiber surface layers</li> <li>▪ Hard fiberboard</li> </ul>
Fibers	Long narrow cell (or bundle of cells) of which wood is largely composed.	<ul style="list-style-type: none"> <li>▪ Medium fiberboard</li> <li>▪ Porous fiberboard</li> <li>▪ MDF</li> </ul>
Pulp	Fibrous materials made from pulpwood, wood chips, particles or residues of wood.	<ul style="list-style-type: none"> <li>▪ Paper</li> <li>▪ Paperboard</li> <li>▪ Fiberboard</li> </ul>

### 6.2.5 Classification of Biorefineries based on Pathway and TRL Scale

To understand the platform more easily, it is important to look into the complete biorefinery pathway. Biorefinery as a whole is composed of four main elements - feedstocks, platforms, conversion processes, and products. These four elements are combined in a biorefinery pathway. The biorefinery pathway includes the preprocessing or pretreatment of biomass

feedstocks, separation into components or intermediates/platforms, also known as primary refining, and then further conversion and processing of the intermediates into more intermediates products, semifinished or finished production (Platt et al. 2021). As an important factor in biorefinery specification, the platform is used to define and distinguish the biorefinery pathways (Platt et al. 2021). Furthermore, this pathway classification is only related to primary biorefining and not secondary refining. (Platt et al. 2021) also merged the development approaches (bottom-up and top-down) of the biorefinery that exists today and is used by biorefineries for its development or further increase of its operation or capabilities. Biorefinery pathways include an integrated development approach identified for material and chemical-driven biorefineries, as well as TRL for each pathway, from pathway description (Platt et al. 2021). Furthermore, the category of feedstock was added, which is identified in this study in the section classification of biobased feedstocks. The end products were adopted only to show material and chemicals, and food feed and energy products were removed (Table 6-4).

Table 6-4: Biobased pathway classification of biorefineries, categorization into bottom-up and top-down development approach and TRL (Platt et al. 2021).

	Biorefinery pathway name	Feedstocks	Feedstock category	Conversion Processes	Platforms	Products	TRL	
Bottom-up approach	A	One platform (C6 sugars) biorefinery using sugar crops	Sugar crops	Primary dedicated	Extraction, fermentation, (chemical conversions)	C6 sugars	Chemicals, polymers, ethanol (building block or fuel), CO2	9
	B	One platform (starch) biorefinery using starch crops	Starch crops	Primary dedicated	Extraction, fermentation, (hydrolysis, chemical conversions)	Starch	Chemicals, (modified) starches, polymers, ethanol (building block or fuel) and CO2	9
	C	One platform (oil) biorefinery using oil Crops, wastes and residues	Oil crops, waste/residue fats, oil and greases	Primary dedicated, Processing residues and Primary waste	Pressing, transesterification, (hydrolysis, chemical conversions)	Oil	Chemicals (fatty acids, fatty alcohols, glycerol), fuels (biodiesel and renewable diesel).	9
	D	Two-platform (pulp and spent liquor) biorefinery using wood	Lignocellulosic wood/forestry	Primary dedicated	Mechanical processing, pulping, combustion, (separation, extraction, gasification)	Pulp, spent liquor	Materials (pulp and paper, specialty fibres), chemicals (turpentine, tall oil, acetic acid, furfural, ethanol, methanol,	9

						vanillin), lignin.	
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Table 6-4 (continued)

Top-down approach	E	Three platform (C5 sugars, C6 sugars and lignin) biorefinery using lignocellulosic biomass	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry	Primary dedicated and Primary/harvest residues	Pre-treatment, hydrolysis, fermentation, combustion, (thermo- chemical conversions)	C5 sugars, C6 sugars, lignin	Chemicals, lignin products (materials, aromatics, pyrolytic liquid, syngas), ethanol (building block or fuel).	7-8
	F	Two-platform (organic fibres and organic juice) biorefinery using green biomass	Green biomass	Primary dedicated	Pressing, fibre separation, anaerobic digestion, combustion, (upgrading, separation)	Organic fibres, organic juice	Materials, chemicals (lactic acid, amino acid), animal feed, organic fertilizer, fuels (biomethane, ethanol).	5-7
	G	Two-platform (oil and biogas) biorefinery using aquatic biomass	Aquatic biomass	Primary dedicated	Extraction, anaerobic digestion, combustion, esterification, (hydrolysis, chemical conversions)	Oil, biogas	Chemicals (fatty acids, fatty alcohols, glycerol), nutraceuticals, organic fertilizer, biodiesel.	5-6
	H	Two-platform (organic fibres and oil) biorefinery using natural fibres	Natural fibres (e.g. hemp, flax)	Primary dedicated,	Fibre separation, extraction, (chemical conversions)	Organic fibres, oil	Materials, chemicals (fatty acids, fatty alcohols, glycerol), nutraceuticals, cannabinoids, food and biodiesel	4
	I	One platform (syngas) biorefinery using lignocellulosic biomass and municipal solid waste	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry, MSW	Primary dedicated, Primary/harvest residues, Primary waste	Pretreatment, gasification, gas conditioning, chemical conversions	Syngas	Chemicals (methanol, hydrogen, olefins), waxes and fuels (F-T biofuels, gasoline, LNG, mixed alcohols)	7-8
	J	Two platform (pyrolytic liquid and biochar) biorefinery using lignocellulosic biomass	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry	Primary dedicated, Primary/Harvest residues	Pyrolysis, separation, combustion, (gasification, cracking, extraction)	Pyrolytic liquid, biochar	Pyrolysis oil (for materials, chemicals, food flavorings,	4-5

							syngas, biofuels), biochar.	
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Table 6.4: (Continued)

	K	One platform (bio-crude) biorefinery using lignocellulosic, aquatic biomass, organic residues	Lignocellulosic crop, wood/forestry, residues from agriculture and forestry, organic residues and aquatic biomass	Primary dedicated, Primary/Harvest residues, Primary waste	Hydrothermal liquefaction, upgrading	Bio-crude	Chemicals and fuels	5
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(Platt et al. 2021) reports from the biorefineries status in EU according to the biorefinery pathway. Among operational chemical and material-driven biorefineries, 56% are based on the C6 sugar and starch platforms (Pathways A, B) and the oil platform (Pathway C), which utilize food and feed crop feedstocks such as oil, sugar, and starch crops. The two-platform pulp and spent liquor pathway (Pathway D), which focuses on pulping wood feedstocks (lignocellulosic wood/forestry), represents nearly 20% of these biorefineries. This pathway has the highest number of biorefineries using secondary feedstocks, such as residues from forestry and forest-based industries. The remaining pathways, E through K, constitute the rest, with the three-platform C5 sugars, C6 sugars, and lignin pathway (Pathway E) and the two-platform natural fibers and oil pathway (Pathway H) each accounting for around 10%.

Classification by TRL scale reveals that the biorefineries bottom-up pathways from A-D is all commercial scale with TRL scale 9. While the top-down pathways E-K vary from pilot and demonstration scale to commercial scale, overall, there is a lower TRL scale than A-D biorefinery pathways. (Platt et al. 2021) find that this is related to the technical barriers that still need to be tackled to achieve a high TRL scale.

#### 6.2.6 Classification of Biorefineries based on the Conversion Process

Conversion process is used to transform feedstock and /or intermediate products into a stream of final products in biorefinery (Platt et al. 2021). (Platt et al. 2021) made an extensive review of the conversion processes in biorefineries also adopted by IEA task 42. Therefore, this classification will be adopted for the ESCIB study. Furthermore, for each conversion process, corresponding end products were also adapted in this study. Four main processes can be used to transform biomass into a variety of BBPs – the biochemical conversion process, chemical conversion process, mechanical and thermomechanical conversion process, and thermochemical conversion process (Platt et al. 2021). Each of these conversion processes has subcategories of processes explained in Annex III.

##### 6.2.6.1 Biochemical Process

Biochemical conversion processes enable the breakdown of biomass into accessible carbohydrates, which can then be transformed into liquid fuels, biogas, and various bio-products through the use of biological agents like bacteria and enzymes (Tursi 2019b). The main conversion processes in the category are aerobic conversion, anaerobic digestion, enzymatic process, fermentation and insect based bioconversion (Platt et al. 2021). End products include biofuels, biochemicals, biopolymers, and materials (Figure 6.3).

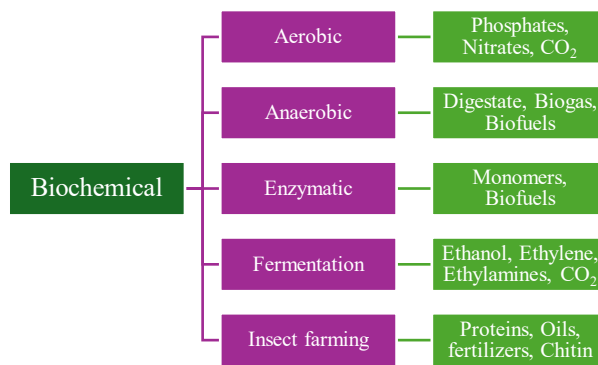


Figure 6.3: Biochemical conversion processes in refinery and end products (Based on (Platt et al. 2021), (Shabbir et al. 2021; Tursi 2019b; Gavrilescu 2014).

### 6.2.6.2 Chemical Process

Chemical processes are processes that alter the chemical structure of a molecule through reactions with other substances. Examples of such processes include hydrolysis, transesterification, hydrogenation, oxidation, electrolysis and pulping (Platt et al. 2021). End products include biochemicals, polymers, biofuels, and materials (Figure 6.4).

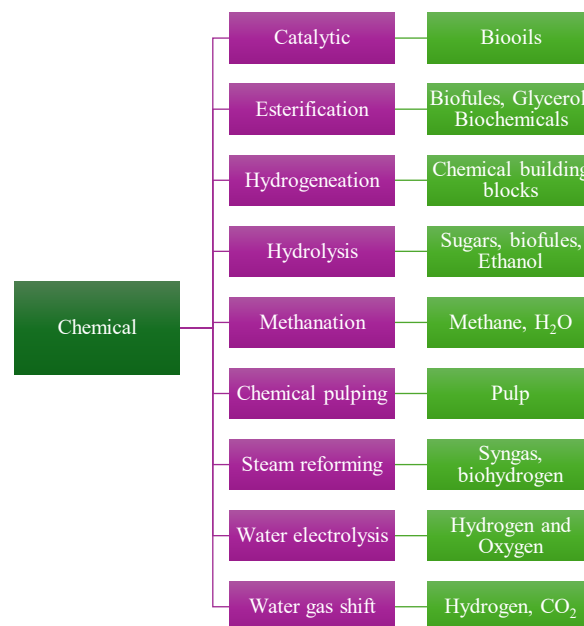


Figure 6.4: Chemical conversion processes in biorefineries and its end products (Based on (Platt et al. 2021; Tursi 2019b; Gavrilescu 2014).

### 6.2.6.3 Mechanical and Thermomechanical Process

Mechanical processes alter the physical characteristics of biomass, such as size, density, and composition, without changing its chemical structure. These processes, like size reduction and densification, are crucial for preparing feedstock to meet the quality standards needed for subsequent biochemical, thermochemical, or fiber processing (Platt et al. 2021). Some of the examples of mechanical processes are blending, extraction, fibre separation, mechanical pulping and separation. end products include fibres, oils, biofuels (Figure 6.5).

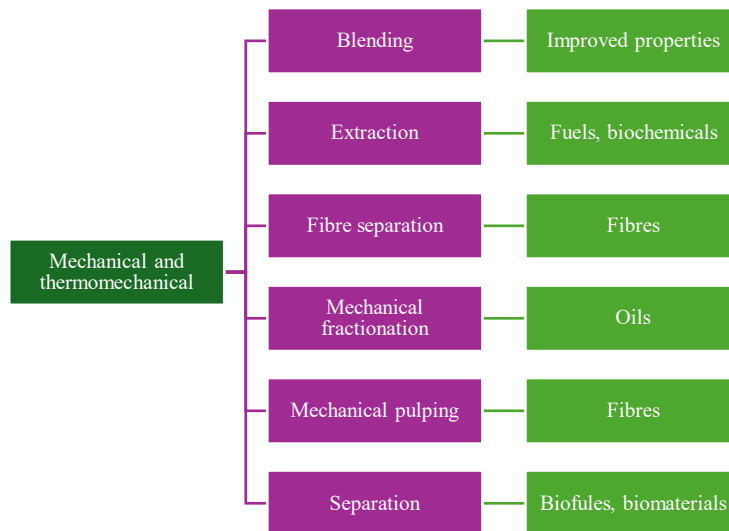


Figure 6.5: Mechanical and thermomechanical conversion processes in biorefineries and its end products (Based on (Platt et al. 2021; Gavrilescu 2014; Mboowa 2021)).

#### 6.2.6.4 Thermochemical

In thermochemical conversions heat, along with chemical reactions and catalysts, is used to break down biomass into sustainable fuels, materials, and value-added chemicals through thermochemical processes like pyrolysis, gasification, and liquefaction (Jha et al. 2022). End products include biochemicals, biofuels, biomaterials, etc. (Figure 6.6). Combustion end products are heat and electricity which is not in the scope of ESCIB project, hence not considered in this study.

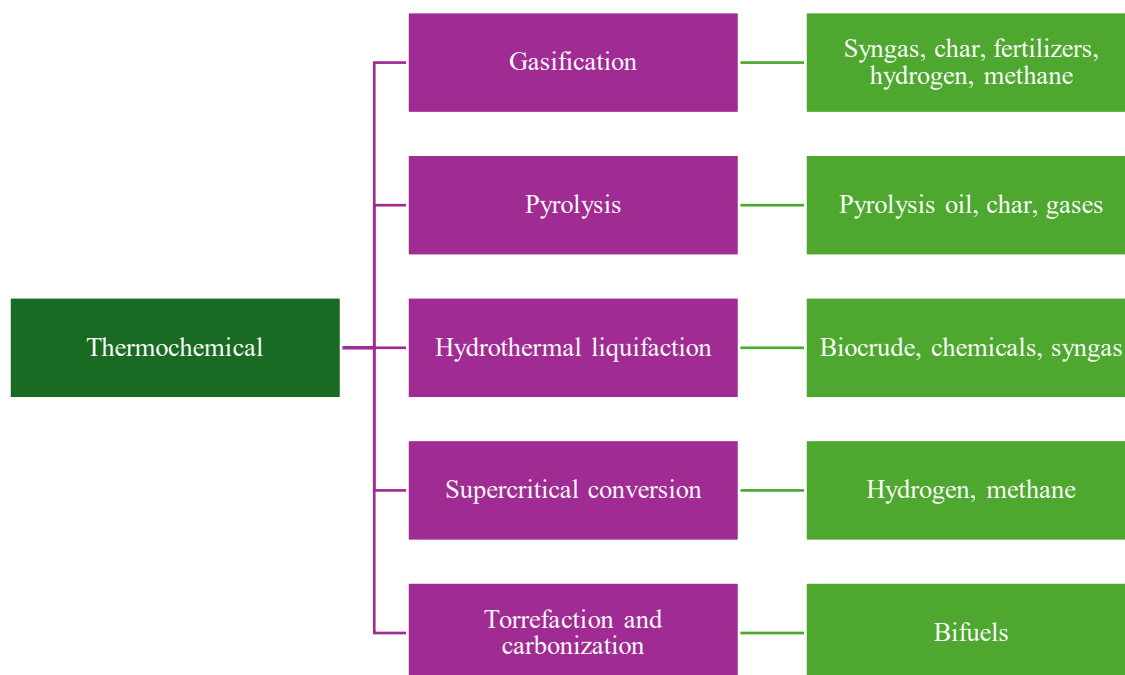


Figure 6.6: Thermochemical conversion process in biorefineries and its end products (Based on (Platt et al. 2021; Tursi 2019b; Gavrilescu 2014)).

## 7 Classification of Biomass Feedstocks

### 7.1 Definition of Biomass

Biomass is defined by the EU Renewable Energy Directive (RED) (EC 2018) as follows:

*“Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin.”*

Biomass can be classified and grouped differently based on its scope and purpose because of its unique characteristics in terms of verity, composition, source, etc. (Tursi 2019b). However, the most used classification for biomass feedstock is developed based on two main characteristics (Tursi 2019b):

1. Classification based on types of biomasses existing in nature or origin.
2. Classifications based on use and application.

### 7.2 Biomass Classification by Origin

A review by Tursi (2019b) reveals that classification based on the origin is the most used classification for biomass feedstock. Since our ESCIB study already provides a classification of BBPs based on the application sector in chapter 5.3, only an origin-based classification will be adapted for biomass feedstocks. However, the classification of biomass feedstock also varies depending on the purpose and scope of the studies. For example, biomass feedstock can be classified into primary, secondary, and tertiary feedstock reported by Cherubini et al. (2009a) based on Speight G (2008). Primary feedstock includes feedstock that is harvested from forestry or agriculture. Secondary feedstock is the process residue from industries such as sawmill residues or black liquor generated in wood and paper industry, while tertiary feedstock is post-consumer industry waste such as waste greases, wastewater, municipal solid waste, etc.

(CIRCE 2022) under Horizon Europe fund provides a detailed classification of biomass feedstock based on its position in the IBBS supply chain. The main categories of this classification are primary dedicated, primary residues, secondary residues and last tertiary residues and waste. These classifications are very detailed and perfectly align with the ESCIB project, which is focused on the complete IBBS. Hence identifying the biomass feedstock at each step in the supply chain is necessary. The last category, “Tertiary residues and waste,” was changed to “Primary waste” to make a distinctive differentiation between the term residue and waste. The reason is that this category include waste from consumption and production residues and includes materials that are discarded or intended to be discarded, and hence, it aligns more with the definition of waste. (Vassilev et al. 2011) used the word industrial biomass waste for municipal solid waste, demolition wood, sewage sludge, hospital waste, paper-pulp sludge, waste papers, paperboard waste, wood pallets, and boxes, etc., which are almost the same categories identified in CIRCE (2022), but termed as tertiary residues and waste. Additionally, a further category of secondary waste is integrated into the classification, which is the waste that is generated in waste treatment operations/facilities during the processing of waste (EC 2023; EUROSTAT and EC 2013). Therefore, the classification of biomass categories adapted from CIRCE (2022) for our ESCIB project is presented in Table 7-1.

Table 7-1: Classification of categories of biomass feedstock based on origin and source (Mainly adapted from (CIRCE 2022) with an addition of extra category 'secondary waste' from (EC 2023; EUROSTAT and EC 2013)).

Feedstock Categories identified	Description
Primary dedicated feedstock	Biomass that is grown purposely or which constitutes the primary result of production.
Primary residues or Harvest residues or Field residues	Biomass produced as part of production or management processes, but not intended as the main product, includes primary residues. These residues consist of biomass remnants left in the field or forest after the main harvesting activity.
Secondary residues or Production residues or Industrial residues	Secondary residues are biomass forms that result from industrial processing of primary biomass. They are not intentionally created during production but are by-products of the processing activities. These residues are usually found in significant amounts at processing sites like agro-food industries, sawmills, and paper mills.
Primary waste	This includes residues and waste from consumption in private households and businesses. It also includes the waste from the production residues. Primary wastes are the post-consumer and post-production waste and are intended to be discarded, such as municipal solid waste (MSW), waste and demolition wood, sludges, etc. This waste goes to a waste treatment facility for treatment (EUROSTAT and EC 2013).
Secondary waste	Waste and waste treatment residues that are generated by the waste treatment facility during waste processing. This includes waste for disposal and recovery. It includes residual materials from recycling and disposal operations such as incineration and composting residues (EUROSTAT and EC 2013; EC 2023).

### 7.3 Extended Classification by Type and Source

CIRCE (2022) also provided an extended classification by type of biomass feedstock and divided into three main categories: plant (feedstocks sourced of any type of plants or plant parts irrespective of its origin/type), animal (feedstocks from animals or its parts), and microbial (feedstocks sourced from any kind of microorganisms). Furthermore, for each feedstock, the origin of feedstock was identified include marine (feedstock sourced from oceans, seas or any other water masses), agriculture, forest, industry and urban (feedstock sourced from urban environment) (CIRCE 2022). The classification based on all aspects, which is used for the ESCIB project is presented in Table 7-2.

Table 7-2: Classification of biobased feedstock based on source and origin (Adapted from (CIRCE 2022), with addition of 'secondary waste' category from (EUROSTAT and EC 2013; EC 2023)(Detail classification in Annex II).

FEEDSTOCK CATEGORY	SUB-	TYPE	FEEDSTOCK SOURCE	DEFINITION
<b>PRIMARY DEDICATED</b>				
Aquatic biomass		Plant	Marine	Aquatic biomass consists of a variety of species, including microalgae, cyanobacteria, macroalgae, and aquatic plants. It offers high oil and biomass yields, is widely available, and faces minimal (or very limited) competition with agricultural land.
Lignocellulosic from croplands and grassland		Plant	Agriculture	These crops, cultivated in cropland areas, encompass short rotation coppice species (such as poplar and willow), various types of grasses (including Miscanthus, switchgrass, reed canary grass, rye, and giant reed grass), as well as other grass-like and herbaceous plants.
Wood		Plant	Forestry	This refers to lignocellulosic biomass, which includes both softwood and hardwood, and is produced on woodland areas (forests, short rotation coppices, agro-forestry).
Oil crops and plants		Plant	Agriculture	Oil plants refer to seeds, fruits, and nuts that are used to extract edible or industrial oils. In addition to well-known oil crops like palm, soybean, rapeseed, and sunflower, other plants such as canola, olive, jatropha, and coconut also serve as valuable sources of oil.
Starch crops		Plant	Agriculture	Starch-based feedstocks consist of grains like corn and wheat, as well as tubers such as sweet potatoes and cassava. These feedstocks are characterized by their long, complex chains of sugar molecules.
Sugar crops		Plant	Agriculture	Sugar crops are grown mainly for sugar production. The two principal sugar crops are sugar beets and sugarcane. Additionally, sugar and syrups can also be produced from the sap of certain maple tree species, sweet sorghum (when specifically cultivated for syrup production), and sugar palm.
Other primary biomass		Plant	Agriculture / Forestry / Marine	This category includes natural resins, which are derived directly from plants, as opposed to synthetic resins, which are produced through chemical synthesis.

FEEDSTOCK SUB-CATEGORY	TYPE	FEEDSTOCK SOURCE	DEFINITION
Livestock-based biomass	Animal	Agriculture	Animal fibers are the second most commonly used natural fibers, following plant fibers. These fibers are primarily made up of proteins and can serve as potential reinforcements in composites. Examples include wool from sheep, goats, llamas, rabbits, and musk oxen. Additionally, silk, feathers, and hair are also sources of animal fibers.

Table 7-2 (continued)

Marine animals	Animal	Marine	Marine animals encompass fish and marine arthropods, such as crabs, shrimp, and lobsters. These arthropods have jointed appendages that are both strong and flexible.
Microbial biomass	Microbial	Industry	Microbial biomass primarily consists of bacteria and fungi. These microbes break down crop residues and organic matter in the soil, releasing nutrients such as nitrogen (N), sulfur (S), and, to a lesser extent, phosphate (P), which become available for plant absorption.
<b>PRIMARY/HARVEST RESIDUES</b>			
Residues from agriculture	Plant	Agriculture	Agricultural residues encompass materials such as wheat straw, sugarbeet leaves, and sugarcane trash, which are often left in the fields after harvest. These residues are commonly utilized as fodder, landfill material, or are burned in various regions. They share similar structural, compositional, and property characteristics with other plant fibers, making them suitable for use in composites, textiles, and pulp and paper applications.
Residues from forestry	Plant	Forest	Forest residues are by-products resulting from forest harvesting activities. This category includes logging residues, thinning by-products, remnants from cutting stands for timber or pulp, and materials from land clearing for construction or other purposes, such as tops and branches.
Residues from nature and landscape management	Plant	Urban	Landscape residues refer to biomass generated from vegetation management across various landscapes. This includes material from managing roadside vegetation, pastures, and semi-natural environments like floodplains.
Residues from aquatic biomass cultivation	Plant	Marine	Aquatic biomass residues, such as those from seaweeds, are increasingly utilized in experimental projects for producing food, feed, pharmaceuticals, and cosmetics. Additionally, they are used to develop biomaterials, biofuels, and to enhance the efficiency of water treatment processes.

Animal-based residues	Animal	Agriculture	Animal-based residues are linked to the raising of animals, including those generated from livestock farming, meat production, animal testing, and fur breeding. This primarily includes wet and dry manure, which have significant potential, particularly in regions with high livestock concentrations such as the Netherlands. These animal wastes can be utilized as valuable sources, especially in the production of bio-fertilizers.
<b>SECONDARY/PRODUCTION/PROCESSING RESIDUES</b>			

Table 7-2 (continued)

Residues from agro-food industry	Plant	Industry	Residues from the agro-food industry consist of by-products from fruit, vegetable, and crop processing. These side streams are typically used as feed, energy, or fertilizers, but they also present significant opportunities for further valorization in new biobased applications and markets. Examples include sugar beet pulp, sugarcane bagasse, and empty fruit bunches.
Residues from wood-based industry	Plant	Industry	Secondary wood residues include by-products from sawmills, such as sawdust and cutter shavings, as well as residues from other wood processing industries, like panel manufacturing. They also encompass residues from the pulp and paper industry, including black liquor, bark, and tall oil.
Residues from fish and arthropods processing	Animal	Industry	Fish processing yields valuable by-products rich in proteins and lipids, including viscera, skin, tails, heads, and frames. Edible parts like heads, milt, and stomachs are occasionally collected and sold, while some fish skin is processed into gelatin or fish leather. These by-products can also be utilized to produce fertilizers and other products.
Residues from meat processing industry	Animal	Industry	Residues from the meat processing industry are by-products from slaughterhouses and include inedible parts such as skin, bones, blood, the gastrointestinal tract, tendons, and visceral organs.
<b>PRIMARY WASTES</b>			
Post-consumer wastes/Consumption residues	Mix	Urban Industry +	Post-consumer sources are categorized into four groups: organic fraction of municipal solid waste, separately collected biowaste, recyclable materials (such as paper, plastic, and textiles), and used cooking oil.
Post-consumer and industrial waste wood	Mix	Urban Industry +	Post-consumer wood refers to all types of wooden materials that are available at the end of their use as wooden products. This includes demolition wood, timber recovered from construction sites, and used wood from residential activities collected by municipalities.

Sewage and wastewater sludge	Mix	Urban Industry +	This category includes sewage sludge and wastewater from municipal and industrial sources. Sewage sludge is a mud-like by-product generated during the treatment of industrial or municipal wastewater. Municipal wastewater refers to water that has been used in homes or businesses in urban and suburban areas for activities such as washing, bathing, and flushing toilets.
<b>SECONDARY WASTE</b>			

Table 7-2 (continued)

Sorting waste	Mix	Industry	This encompasses waste from mechanical sorting processes, refuse-derived fuels, non-composted residues from composting, and similar by-products.
Sludges and liquid waste from waste treatment	Mix	Industry	It comprises wastes resulting from the chemical-physical treatment of hazardous waste, as well as liquids and sludges from anaerobic waste treatment, landfill leachates, and similar by-products.

## 8 Classification of End-of-use Routes for Biobased Products

Unlike abiotic resources, BBPs are derived from biomass, which involves biogenic carbon sequestered by living organisms like plants and animals as part of the natural carbon cycle as defined by ISO 21930:2017, and which possesses unique characteristics that differentiate them from fossil-based or mineral materials, such as their ability to participate in both biological and technical cycles, their role in carbon sequestration, and their potential for cascading use throughout their lifecycle.

Some BBPs present biodegradability, which allows them to close the biological loop through processes such as composting or anaerobic digestion, thereby returning nutrients to the soil and supporting the regeneration of ecosystems (Fleitas Girett et al. 2023; Briassoulis et al. 2021).

In relation to the cascading use of BBPs, secondary biomass can be utilized in different value chains via recirculation cascades. Originally developed as a framework to optimize natural resource use (Sirkin and Houten 1994), the cascading concept has gained relevance through the years, particularly in the forestry sector (Keegan et al. 2013). Nevertheless, now is being applied across various BBP value chains (Gursel et al. 2022; Navare et al. 2021; Olsson et al. 2018). Thus, BBPs can follow multiple pathways at the end of their initial application.

In the after-use stage of a BBP, the distinction between end-of-use (EoU) and end-of-life (EoL) is essential for accurately assessing material flows. The EoU refers to the stage after the use phase of a material in a product, where it still holds value and is potentially and technically feasible to be repurposed, recycled, or otherwise re-integrated into a production cycle, thereby extending its functional life defined by (Pérez-Hernández et al. 2024).

On the other hand, the EoL represents the ultimate fate of the material, marking the point at which it can no longer be reused or recycled and must be disposed or treated of through landfilling, incineration, or biodegradation (Pérez-Hernández et al. 2024). A systematic review by Pérez-Hernández et al. (2024) reveals that there are three primary pathways that biobased products can follow from the EoU stage;

### 8.1 Closed-loop Recirculation.

A closed-loop (CL) recirculation is where materials are recovered and taken back into the same value chain they took part in the previous cycle.

### 8.2 Open-loop Recirculation

In an open-loop (OL) recirculation, materials are recovered and taken into a different value chain.

### 8.3 End-of-life Treatment

The EoL treatment options include disposal or treatment methods such as landfilling, incineration, or biodegradation. A material may undergo several EoU stages, including both CL and OL recirculation, before ultimately reaching its EoL. Figure 8.1 presents a visual representation of these pathways, illustrating the flow of materials through various stages of use and their eventual end-of-life treatment.

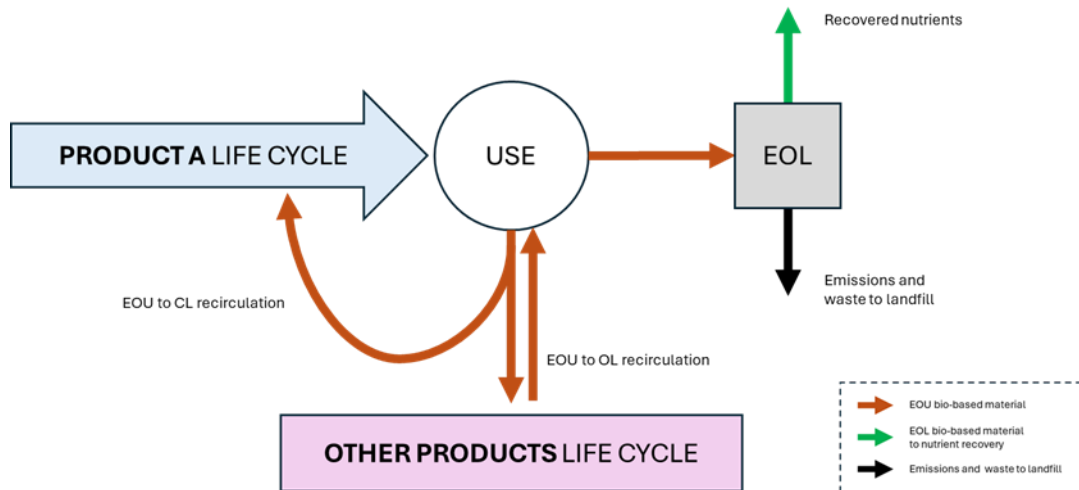


Figure 8.1: Different pathways that a biobased product can undergo after the EOU stage (Adapted from (Pérez-Hernández et al. 2024).

(Pérez-Hernández et al. 2024) developed a BBS flowchart that captured the various routes that BBP may take throughout one (or several) lifecycles. Considering the complex interactions that occur after a material has completed its initial use phase, the pathways that BBPs can follow after EoU stage are summarized in (Table 8-1).

Table 8-1: Classification of the potential routes after EoU phase for biobased products (Adapted from (Pérez-Hernández et al. 2024)).

Following stage after EoU	Strategy	Description
Secondary material, component and product recovery for CL recirculation	CL recirculation	Biobased materials, components, or products are recovered and/or reprocessed to be used within the same value chain, maintaining their original or similar function and/or application.
Secondary material, component and product recovery for OL recirculation	OL recirculation	Biobased materials, components, or products are recovered and/or reprocessed to be used in a different product value chain, often with a change in their properties or functional value. It often involves a downgrading of such original properties or functional value.
Composting	EoL	Biodegradable biobased materials are broken down by microorganisms into simpler organic matter forms, producing a compost that can be used to enrich soil. Thus, nutrients can be returned to close the biological loop.
Anaerobic digestion	EoL	Biodegradable biobased materials are broken down by microorganisms into simpler organic matter forms in the absence of oxygen, producing biogas (energy carrier) and a digestate, which can be used to enrich soil. Thus, both energy and nutrients to close the biological loop can be recovered.
Biofuel production and use	EoL	Biobased materials are converted into biofuels, which are (renewable) energy carriers. The process often involves the fermentation, distillation, or other chemical processes to produce fuels like ethanol or biodiesel, which can replace or supplement fossil fuels.
Incineration with energy recovery	EoL	Burning of biobased materials to generate heat and/or electricity. This process allows for the recovery of energy from materials at their EoL, although it does release (biogenic) CO <sub>2</sub> and other emissions into the atmosphere.
Incineration without energy recovery	EoL	Burning of biobased materials without capture of the energy and heat produced. It is typically considered a less desirable EoL option due to the loss of potential energy and the release of greenhouse gases and pollutants.
Landfill	EoL	Disposal of biobased materials in a designated site where they decompose after long retention times or simply become permanently stored. This option is generally seen as the least sustainable EoL strategy, although some positive trade-offs related to carbon storage for non-biodegradable biobased materials can be considered.

## 9 Classification based on LCA System Boundaries

According to ISO standards 14040 and 14044 (ISO 14040; ISO 14044), life cycle assessment (LCA) is used to assess the environmental impacts of a product system throughout the life cycle from raw material acquisition through production to end-of-life management.

LCA has four phases – goal and scope definition, inventory phase, impact assessment, and interpretation phase. Scope definition in LCA includes product system, functional unit, defining the system boundaries of a product system under study, and other methodological decisions (ISO 14040; ISO 14044).

*A system boundary is a set of criteria determining which specific unit processes are included in a product system (ISO 14040; ISO 14044).*

A unit process is the smallest component in life cycle inventory (LCI) analysis, where input and output data are measured and quantified. A product system is a group of interconnected unit processes that involve elementary and product flows, working together to perform specific functions and represent the entire life cycle of a product (ISO 14040; ISO 14044).

Criteria for defining which unit processes to include in the system boundaries of a product system depend upon (ISO 14040);

- Goal and scope definition of the study
- Intended application and audience
- Assumptions included in the study
- Data and cost constraints
- Cutt-off criteria

When defining the system boundary, it is important to consider various life cycle stages, unit processes, and flows, such as (ISO 14040):

- Raw material acquisition.
- Inputs and outputs during the primary manufacturing or processing stages.
- Distribution and transportation.
- Production and consumption of fuels, electricity, and heat.
- Product use and maintenance.
- Disposal of process waste and products.
- Recovery of used products, including reuse, recycling, and energy recovery.
- Manufacture of ancillary materials.
- Manufacture, maintenance, and decommissioning of capital equipment.
- Additional operations, such as lighting and heating

The system boundaries defined at the initial stages of the study are not final, and often, the established system boundary will need to be adjusted and refined as the study progresses. This system boundary refining is done by cutoff criteria established in the initial scope of the study (ISO 14044). The outcomes of refining the system boundary and conducting sensitivity analysis must be documented. Sensitivity analysis may lead to (ISO 14044):

- Excluding life cycle stages or processes that are shown to be insignificant.
- Removing inputs and outputs that do not affect the study's results.
- Adding new processes, inputs, or outputs that are found to be significant.

The system boundaries of an LCA study of the BBP should include the entire product and not only the biobased portion. LCA for BBP also covers the four phases described in ISO standards (DIN EN 16760 2016) from raw materials acquisition from biomass feedstocks till the end of life of the BBPs. Therefore, the exact definition and consideration regarding the system boundaries are applied to BBPs as provided in ISO standards 14040 and 14044. However, in

the scope of the LCA of BBPs, further guidance is provided by (DIN EN 16760 2016) for some aspects that are typical in BBPs, which can be considered while defining the system boundaries of BBPs. These include;

- Geographical and temporal scope
- Allocation procedure
- Consideration of resource-related elementary flows
- Data collection regarding the land use, water use, fossil and biogenic carbon fluxes.
- Agricultural, forestry and aquaculture system modelling
- Modelling end-of-life of BBPs

These standards and guidance provided by DIN EN 16760 (2016) are typical for BBPs that do not include food, feed, and energy products, hence according to the scope of ESCIB products, but it may also be applied to all BBPs regardless of their application.

## 9.1 Classification of System Boundaries into Ideal and Realistic System Boundaries

### 9.1.1 Ideal System Boundaries

While defining system boundaries, decisions should be made regarding the unit processes to be included in the study. Any assumption or decision regarding the excluding the lifecycle stages, processes, input, or outputs shall be clearly stated, including the reason and implication for such decisions. Similarly, the unit process that is included in the study and also the level of detail shall be clearly stated in defining system boundaries, preferably in a flow chart (ISO 14044). Ideally, system boundaries of the product system should be modeled so that the inputs and outputs at its boundary are elementary and product flows (ISO 14040; ISO 14044). In other words, system boundaries are set in such a way that all the flows crossing them are elementary flows (resources and emissions) and no material, energy, product, or waste flows should pass outside the system boundaries (Bjørn et al. 2018b). An elementary flow is a material or energy entering the system under study directly from the environment without prior human transformation, or a material or energy leaving the system that is released into the environment without further human modification (ISO 14044). Ideally, these boundaries should encompass all unit processes involved in delivering the reference flow, including generating energy and products (materials for other unit processes) from extracted resources, and treating waste flows until the only outputs are emissions (Bjørn et al. 2018b). As according to the DIN EN 16760 (2016) standards for LCA of BBPs, system boundaries consideration is exactly as per ISO standards (ISO 14040; ISO 14044) so the ideal BBP system boundary should also consider this approach.

The ideal system boundary for a BBP includes all the inventory data that is needed to deliver the reference flow and also end of life waste management till all the output flows remain are elementary flows (Figure 9.1). At input the reference flows include CO<sub>2</sub> absorbed by plants from air during photosynthesis, sunlight, natural nutrients, and natural water i.e., rainwater. At output reference flow emissions (air, water, soil) occur along with the waste that can't be transformed by human and goes to the ecosphere (Bjørn et al. 2018a).

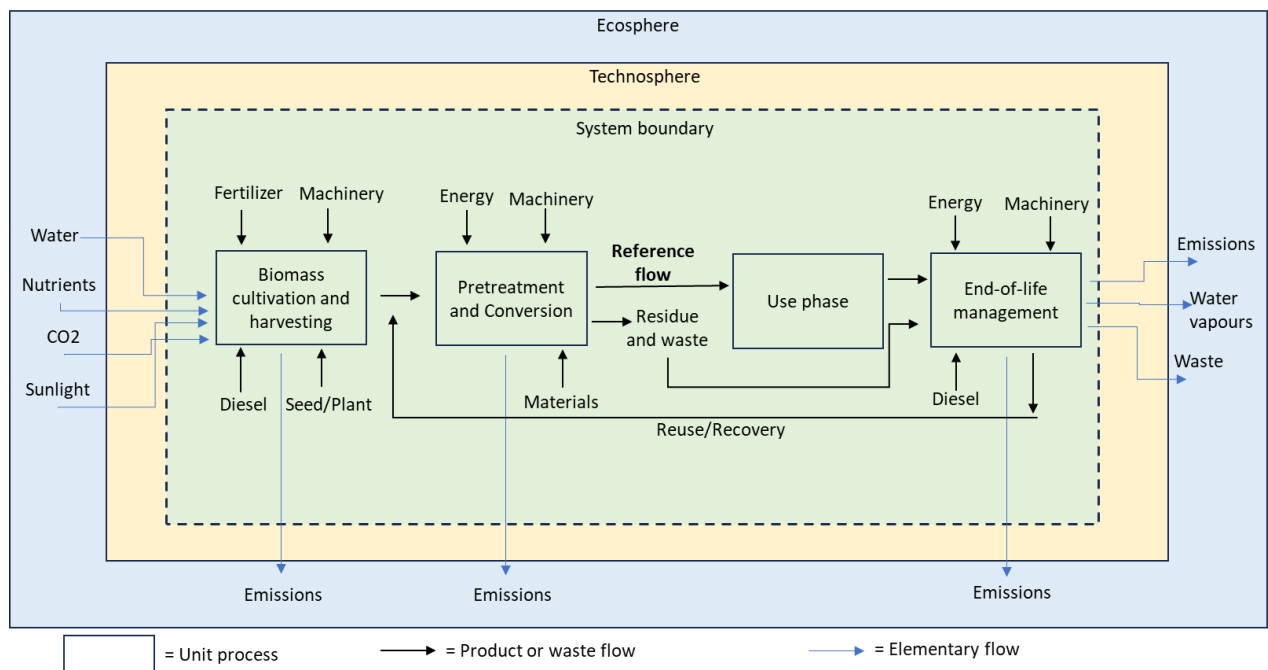


Figure 9.1: Ideal or hypothetical system boundaries for conducting LCA of biobased products (Adapted from the work of (Bjørn et al. 2018b)).

### 9.1.2 Realistic System Boundaries

Practically it is difficult to work with ideal system boundaries, specifically, due to the vast number of unit processes that are required to build a product system (Bjørn et al. 2018b). Realistic system boundaries could include the main processes that are relevant to the LCA practitioner or the goal and scope the desired study. Furthermore, since the biobased processes are sometime multioutput or multifunctional therefore allocation (also called partitioning (European Commission and JRC 2010)) or substitution approach (also called system expansion, avoided burden, or crediting approach (European Commission and JRC 2010)) is also needed to be include in the realistic system boundaries for the unit processes that are part of the study (Figure 9.2).

In case of LCI modelling, switching from realistic or traditional system boundaries to idealistic system boundaries requires a substantial amount of data, since it involves expanding the system to capture a wider range of processes and flows (Tillman et al. 1994). As a result, most practical studies adopt realistic system boundaries that apply cut-off approaches and omitting processes or flows considered to have limited influence or insufficient data availability (Bjørn et al. 2018a; Tillman et al. 1994) or processes are modelled in a simplified way. For example in the case of biogenic carbon accounting, the carbon neutrality approach (0/0, treating carbon uptake and release as balanced) is often adopted due to it's simplicity and land use changes from biomass is often disregarded in life cycle assessments of bio-based products (Zuiderveen et al. 2023).

Expanding the system boundaries from realistic to idealistic implies, however, that these processes are considered in the sustainability assessment of products. For example, for wood-based products associated to forestry biomass, it is known that biogenic carbon sequestration and release, carbon stocks and land use changes play a significant role in sustainability assessments. Therefore, to accurately reflect the true sustainability of wood-based products, it is necessary to look beyond realistic or traditional system boundaries and include the elementary flows i.e., exchanges between a product system and the environment. This includes the biogenic carbon sequestration and release, carbon stocks and land use and land use change. In ESCIB project WP(3), Deliverable (D3.3) this is of center importance in the sustainability

assessment methodological framework for biobased products more specifically wood based products.

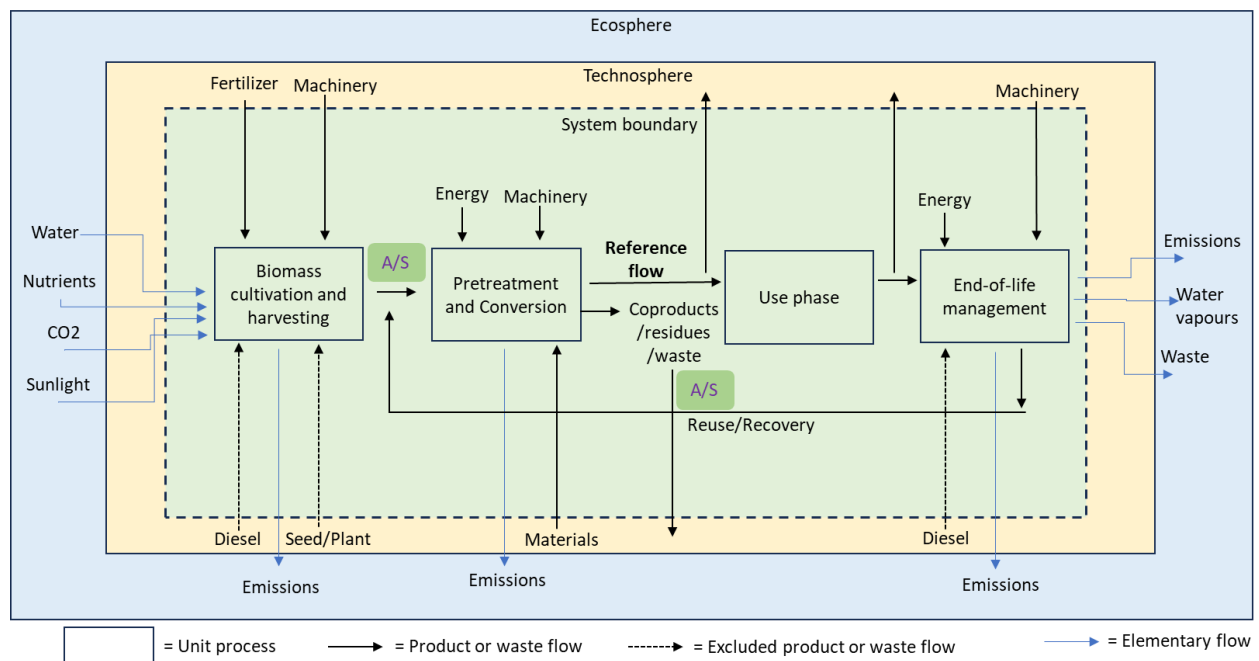


Figure 9.2: Realistic system boundaries for biobased products. Some processes are excluded or cut off from the system boundaries. Exact system boundaries depend on whether allocation or substitution is used in handling the multifunctionality in biobased products (Adapted from (Bjørn et al. 2018b)).

## 9.2 Classification based on the Data Composition in the System Boundaries

Modelling the LCI of the product system LCA practitioner need to define the system boundaries to accurately evaluate the impacts of the given system. Usually, hundreds of unit processes are required for conducting an LCA of the given product. It is although difficult to get all the data for the respective product and might need of some background data that is average data from the database and used in the modelling. Th distinction between the foreground and background system is necessary for planning data collection for the inventory analysis (Bjørn et al. 2018b).

### 9.2.1 Foreground System

The foreground system refers to the specific processes within a product system, often including some direct suppliers (tier-one) and possibly further suppliers (tier-two or tier-three) if known by the producer, such as through material certification. This system is usually modeled using primary data, which is firsthand information collected by the LCA practitioner, often provided by the study's commissioner (company or organization that request the LCA study) (Bjørn et al. 2018b). From a management standpoint, the decision-maker commissioning the study (e.g., a company) can typically alter the processes in the foreground system. The foreground processes hence are under direct control of the producer of the good or the operator of the service or user of the good where he has decisive influence (Bjørn et al. 2018b; European Commission and JRC 2010). These changes could involve selecting a different supplier or modifying how a process operates, thereby altering its qualitative and quantitative inputs and outputs (Bjørn et al. 2018b).

For example, in cottonid production, which is a biopolymer, LCA practitioner has access to the industrial data provided by industrial partner which requested LCA. But they don't have control over the tier 1 or tier 2 suppliers and hence it is directly taken from the LCA databases. This can also be changed depending on the goal and scope of the study, that the tier 1 suppliers are

also included in the foreground system i.e., changing paper supplier or using another paper manufacture cottonid production (Figure 9.3).

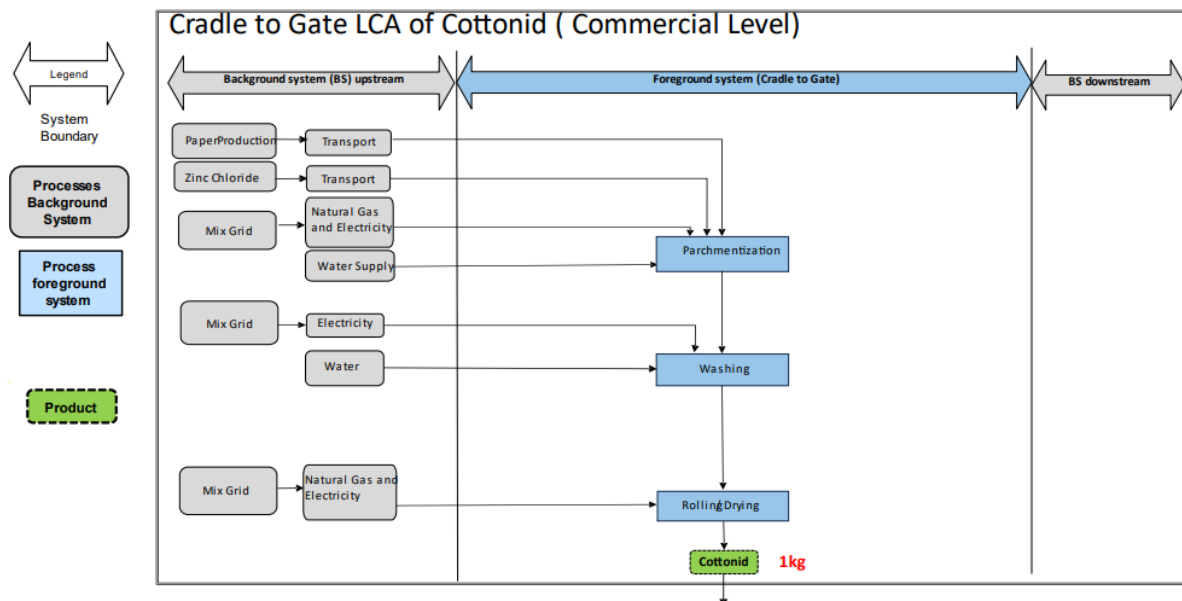


Figure 9.3: Cradle to gate system boundary of 1kg cottonid production and division of system boundary in to foreground and background system (Alam and Hijazi 2024).

### 9.2.2 Background System

The background system refers to the processes in a product's life cycle that are not specific to it. These processes are shared across many different product systems, such as the general electricity supply, production of materials, or waste management services. These processes are not specific to the product being studied and are usually sourced from the market without the ability to select specific suppliers. The background system is typically modeled using data from LCI databases such as ecoinvent, which provide average industry data for different regions or countries. From a management perspective, the company or person conducting the study (the study commissioner) generally cannot change these background processes because the decision maker has no limited power being a minor customer or because the suppliers are anonymous (Bjørn et al. 2018b).

In case of cottonid production, raw paper, electricity mix are the background system. As they are not changed by the commissioner of the study and hence taken from the LCI databases directly (Figure 9.3).

### 9.3 Classification based on Supply Chain Consideration.

System boundaries for conducting LCA for BBPs can be extended till the recovery of materials and energy (cradle-to-cradle) or only to limit it till the manufacturing of biobased product (cradle-to-gate). Establishing suitable system boundaries and a clear functional unit is essential for obtaining accurate and reliable comparisons of the environmental impacts between the studied systems (Shikha et al. 2020a). LCA review studies of biorefinery system by Gaffey et al. (2023), biobased platform chemicals by Jorge et al. (2023) and biobased fertilizers by D.Egas et al. (2023) reveals that there are four main system boundaries used in BBS named – Cradle-to-grave, Gate-to-grave, Cradle-to-gate and Gate-to-gate system boundaries. Similarly, review by Shikha et al. (2020b) reveals there is another system boundary cradle-to-cradle used in LCA studies which is a closed loop system boundary. Therefore, in this study five system boundaries are considered for BBS (Figure 9.4).

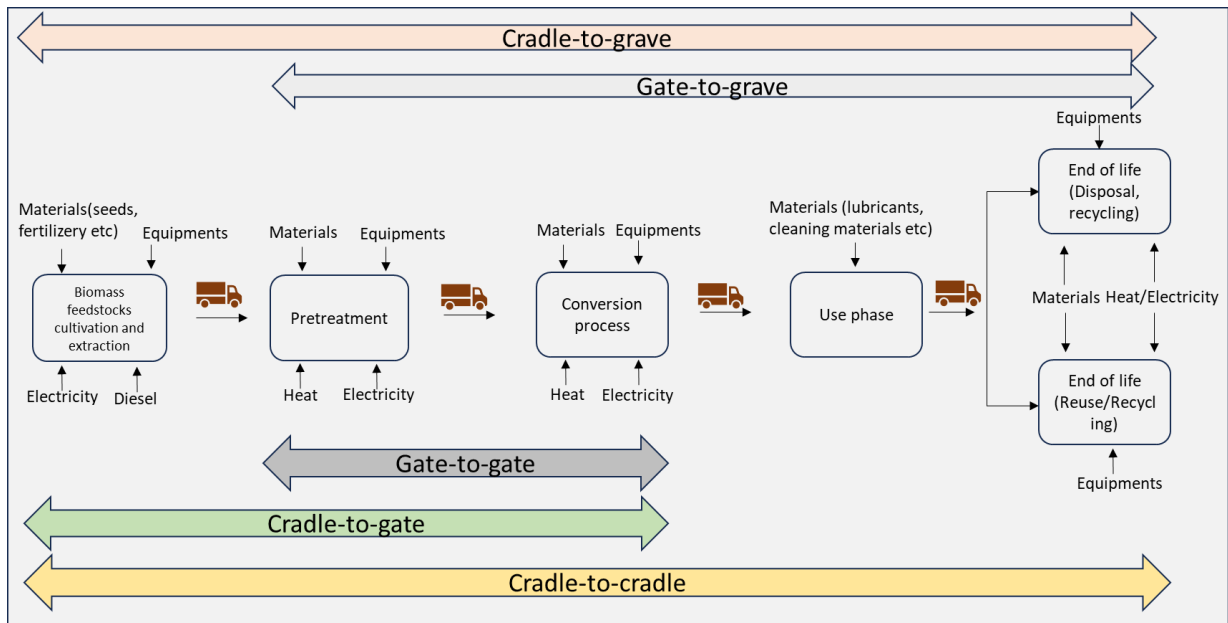


Figure 9.4: Classification of system boundaries based on supply chain consideration.

### 9.3.1 Cradle-to-gate System Boundary

This boundary system includes the extraction of raw materials i.e., feedstock production (cradle) till the final product manufacturing in biorefinery (gate) before reaching to the user. The end stage for calculating emissions in this system boundary is when the product leaves the biorefinery gate before transporting the product further to the customer.

### 9.3.2 Cradle-to-grave System Boundary

This boundary system includes the production of feedstocks (cradle), conversion in to BBPs in bioindustries and also the end of life disposal (grave) phase (Shikha et al. 2020a; Gaffey et al. 2023) of BBPs such as recycling, landfill and incineration.

For example study by Moretti et al. (2021) for cradle-to-grave LCA of polylactide PLA cup, end of life phase is considered as recycling, incineration, landfill and composting. Similarly, LCA study Adom et al. (2017) of biobased polymer grade lactic acid (PGLA) considers landfill, materials recovery (carbon sequestration and converting to polymer based plastics) in cradle-to-grave system boundaries.

### 9.3.3 Gate-to-gate System Boundary

This system boundary focuses on the activities within biorefinery (Gaffey et al. 2023). It starts at the entrance of biomass feedstock into bioindustry (gate) and ends when the BBP leaves the bioindustry (gate).

This system boundary includes only input (materials and energy) and output (emissions) that are specific to the production process within bioindustry. For example, in case of biosurfactant production gate-to-gate system boundaries only include the material and energy input in the process of pre-inoculum, inoculum and biosurfactant (sophorolipids and rhamnolipids) and the associated emissions (Kopsahelis et al. 2018).

### 9.3.4 Gate-to-grave System Boundary

This system boundary include activities of BBPs production in biorefinery, use phase and end of life disposal of BBPs (Gaffey et al. 2023). It starts at the entrance (gate) of the biorefinery and end at disposal (grave) of the BBP.

However review study by Adi et al. (2022) defines this system boundary as post production of a product manufacturing in bioindustry. It means this boundary start when the BBP leaves the biorefinery (gate) till end-of-life disposal. Due to this contradicting definition, it is critical for LCA practitioner of BBPs to specify this in the system boundary that either the system boundary is pre-production or post-production at biorefinery.

### 9.3.5 Cradle-to-cradle or Closed Loop System Boundary

This system boundaries also incorporate the recycling process along with disposal phase (Shikha et al. 2020a). It start from the production of biomass feedstock (cradle), include biorefining, use phase and end of life management i.e., recycling and upcycling so that the material is used for another product means closing the loop of the system boundary (Ecochain 2024; Shikha et al. 2020a). It is a variation of cradle-to-grave system boundary and uses circular approach (Ecochain 2024). However, (Suppipat et al. 2022) describes that the end of disposal operation is recycling process to get new, identical and distinct products.

Therefore, the cradle-to-grave system boundaries examples discussed above can also be considered as cradle-to-cradle system boundaries if the end-of-life management only include recycling. Therefore, it is very critical to define the system boundaries based on end-of-life management. But since it is closed loop means it only include recycling and reuse as main end of life approaches and therefore no waste or materials should leave the system boundary i.e., landfill.

In case of BBPs manufacturing from the residues or waste, the same system boundaries will be assumed. When a product is manufactured from waste, practically there is no cradle boundary as there is no raw material extraction. In LCA although credits are given for example in cut-off system model, waste producer has the responsibility to treat waste and then it is available burden free for the next product system. But in case of system boundaries, it is assumed that since at one point there is already an extraction of raw materials from which this residue or waste is produced. Hence the system boundaries in case of BBS will remain the same.

## 9.4 Classification of System Boundaries based on the Modelling Approach

System boundaries of LCA study can also vary according to the modelling approach used in LCA study which is dependent of the goal and scope of the study. These modelling approaches use different consideration for modelling while modelling system boundaries. System boundaries will change in terms of unit processes consideration and dealing with multifunctionality or multioutput biobased activities. Multifunctional activities sometimes demands not only change in functional unit but also in system boundaries of the study. (Heijungs et al. 2021) proposed a solution for solving this problem and how to change the system boundaries and functional unit associated to it (Table 9-1).

Table 9-1: Multifunctional activities and the proposed solution for system boundaries and functional unit changes (Heijungs et al. 2021).

Multifunctionality problem	Multifunctionality approach	Functional Unit	System boundaries
Avoiding substitution/ allocation	Subdivision	Remain consistent with goal and scope	Remain consistent with goal and scope
	System expansion	Extra functions added	Include coproducts
Performing substitution/allocation	Substitution	Remain consistent with goal and scope	Extra processes data added
	Allocation	Remain consistent with goal and scope	Remain consistent with the goal and scope

Multifunctionality is also treated differently based on these two different modelling approaches and will be discussed in each modelling approach in detail.

### 9.4.1 Attributional Approach System Boundary

A system modeling approach where inputs and outputs are assigned to the functional unit of a product system by connecting and/or dividing the unit processes according to a specified standard or guideline (Life Cycle Initiative 2013).

#### 9.4.1.1 System Boundary Consideration

In attributional system modelling, all the processes and material flows that are directly involved in the production, use, and disposal of the product are considered in system boundary (Brander et al. 2009). In other words, attributional modeling aims to accurately model system boundary that represent the real-life processes and life cycle stages of a product system, much like a supply chain. Any process that is physically involved in the product system, that contributes to its production, use, or disposal, should be included within the system boundaries (European Commission and JRC 2010). In case of multifunctionality, allocation based on mass, economic or energy content is applied (Brander et al. 2009), and hence the system boundaries remain same in the study and is associated to main reference product (Heijungs et al. 2021). System boundary is modelled using average emissions data (Figure 9.5) i.e. average emissions of electricity mix (Brander et al. 2009). In attributional system boundaries only direct land use (dLUC) is considered for evaluation (Moretti et al. 2022). dLUC refers to the recent changes in the use of land on which specific feedstock is grown (Ahlgren et al. 2015). Furthermore, regarding the absolute time perspective, (Schaubroeck et al. 2021) concludes that ALCA might

be used to access the impacts of a product in the absolute past, present or in future depending on the goal and scope of the study and must be specified.

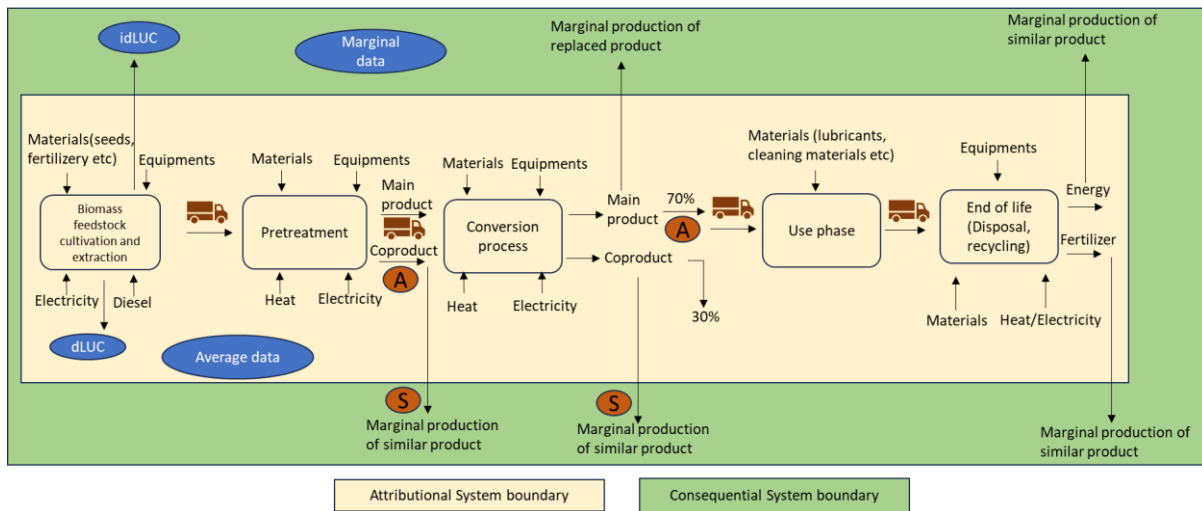


Figure 9.5: Attributional and consequential system boundaries of biobased system. dLUC(Direct land use change, idLUC (indirect land use change), A(allocation), S(substitution).

## 9.4.2 Consequential System Boundary

A system modeling approach where activities within a product system are included based on the extent to which they are expected to be affected by changes in demand for the functional unit (Life Cycle Initiative 2013).

### 9.4.2.1 System Boundary Consideration

All processes and material flows that are directly or indirectly influenced by a marginal change in the output of a product (Figure 9.5), such as through market effects, substitution, or the use of limited resources makes system boundary in consequential LCA (Brander et al. 2009). In case of multifunctional activity system expansion or substitution is used to quantify the impacts of co-products on emissions (Brander et al. 2009; Moretti et al. 2021; Moretti et al. 2022). System expansion, substitution, crediting and avoided burden are similar concepts (European Commission and JRC 2010), however (Heijungs et al. 2021) view is that these are two different terms and need to be considered by ISO standards. Therefore, it is also needed in the harmonization of the LCA approach that will be done in next tasks of ESCIB. System boundary is changed in system expansion or substitution and also consider coproducts or to add extra activities (Heijungs et al. 2021). The data consideration in the system boundary of such modelling approach uses marginal data i.e, the marginal impacts of electricity mix (Heijungs et al. 2021). Marginal suppliers are the most competitive one having the ability to respond to marginal increase in demand for the product (Weidema 2003). Similarly, review by (Schaubroeck et al. 2021) reveals that marginal can be viewed as very small change in amount or effect or it is a result from a small change or unit change. In consequential system boundaries both dLUC and indirect land use change (iLUC) are considered for environmental impacts evaluation (Schaubroeck et al. 2021). iLUC change are the indirect effects that have been occurred in the market due to changes in the feedstock production somewhere else (Gaffey et al. 2023). When there is an increase product demand it will lead to displacement of conventional agricultural production hence including iLUC (Gaffey et al. 2023). For example, if the agricultural crops are diverted to manufacture BBPs, the resulting human food or animal feed deficit will either be filled by expansion of more cropland across the world or by intensifying the crop production elsewhere resulting in emissions, an iLUC effect (Overmars et al. 2015). CLCA not only include the substitution or system expansion consideration for coproducts or byproducts but also the direct market consequences or impacts that occurred due to decision of

changing market demand should also be considered (European Commission and JRC 2010) as illustrated in Figure 9.5. CLCA can be implemented to assess the impacts of a product system in the present, past and also future and hence it should be defined in the scope and goal of the study (Schaubroeck et al. 2021).

(Schaubroeck et al. 2021) analysis reveals that system boundaries in ALCA and CLCA are assumed to be infinite, but practically there are always leakages. For example, in a close loop system, the flows that goes out of the boundary system may be very small but not equal to zero hence the system can be assumed as infinite. However, in practical considerations, in both ALCA and CLCA cutoff approaches is used to make the system boundary finite due to data shortage or less impacts associated to such processes (Schaubroeck et al. 2021).

## 10 Systematized Classification Matrix of Industrial Biobased Systems

This study did an extensive literature review for the classification of BBS. The classification focused on BBPs, bioindustries, feedstocks, LCA system boundaries, and end-of-life. This study identifies different classifications used in different studies for each element of IBBS. Systematization in previous studies is based on key elements, i.e., biomass feedstocks, conversion process, platforms and BBPs within scope of biorefineries. However, there is no single classification approach for each element of IBBS, and further lack the EoL element and LCA system boundaries element in the scope of sustainability and circularity assessment. Therefore, this study identified the main elements of IBBS, identified multifaceted classification criteria for each element, and presented key classification criteria for each element as a systematized classification framework for the IBBS (Table 10-1).

For the classification of BBPs, five different classification approaches were used: classification based on integration to market, transformation level, application sector, certification schemes for biobased content, and NACE and PRODCOM classification. Although, each classification provide significance information for classification of BBPs, the scope of the classification is different. Some classifications i.e., integration to market is mostly used for biochemicals perspective, and does not specifically include wood based products. In this regard, classification based on application sectors and NACE provides useful insights into BBPs classification and is systematized for the whole range of IBBS. These classifications are comprehensive and can further be used in the context of sustainability assessments. Thereby, defining product categories (Annex I) for sustainability assessment or benchmarking require careful consideration of different product systems. This classification (Annex I) is also employed in the PEFCR of apparel and footwear (Quantis 2021) that leads to creation of benchmarks for specific product categories and can be used for sustainability benchmarking.

Furthermore, biobased industries classification was made based on development approaches, processing technology, platforms, pathways and TRL scale and conversion processes used in biorefineries. Among the multifaceted classifications, using platform or intermediate product is the most adopted classification in the literature and review articles. Therefore, this study further extended the platform classification approach for forest-based industries and is reported in this systematized classification matrix. Although biorefinery classification frameworks often integrate the conversion processes element in the classification framework, the platform-based classification offers a distinct and standalone criterion for classifying biobased industries. Therefore, this is included in systematization framework developed in this study (Table 10-1).

Regarding feedstock, classification based on origin is mainly used in the literature. Origin based classification of biomass feedstocks varies by its categories in different classification studies (Cherubini et al. 2009b; IEA Bioenergy Task 42 2022; German Federal Government 2012; Vassilev et al. 2012). However, the classification provided by CIRCE (2022) in this regard is more comprehensive, categorizing the biomass feedstocks along the supply chain and clearly differentiating between the waste and residue boundaries. Such differentiation is not only important for clear communication, but also for fair comparisons in sustainability assessment to deal biomass feedstock as a waste or residue and how to allocate the impacts. Hence, this study proposes the origin based classification developed along the supply chain for the systematization of IBBS classification (Table 10-1).

BBS was further classified based on LCA system boundaries. First, a classification was made of the ideal and realistic system boundaries. Furthermore, classification was adopted for the BBS based on the supply chain consideration and LCA modeling approach to comprehend the environmental impacts associated with the supply chain and also due to different

methodological considerations in the LCA studies. Since, all these system boundaries classifications plays significant role in comparable sustainability assessment, they are integrated into the systematized classification framework. In the last stage, classification based on EoL was made, open-loop recirculation, closed-loop recirculation, and EoL treatment, identifying the routes a BBP can take after it has already achieved its useful life. Since the EoL classification developed in WP4 is mainly formulated in the context of BBPs. Therefore, this classification is integrated as part of the classification systematization. Therefore, this work extensively classifies the whole BBS based on the important factors in the supply chain and regarding the sustainability and circularity approaches.

Table 10-1: Systematized classification matrix presenting key criteria of classification for each element of an industrial biobased system.

Biobased products		Biobased industries	Biomass feedstock	LCA system boundaries		Circularity
Application categories	NACE Rev 2.1 Divisions	Platforms	Origin	Supply chain consideration	Modeling approach	EoL
<b>Biochemicals</b>	13-Manufacturing of Textiles	<b>Biorefineries platforms</b>	<b>Primary dedicated feedstock</b>	Cradle to gate	Attributional system boundary	Open loop recirculation
Additives and adhesives	14-Manufacturing of wearing apparel	Biochar	Aquatic biomass	Cradle to grave		Closed loop recirculation
Agrochemicals	15-Manufacture of leather and related products	Bio-coal	Lignocellulosic from croplands and grassland	Cradle to cradle	Consequential system boundary	EOL treatment
Building blocks	16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	Bio-crude	Wood	Gate to gate		
Colorants	17-Manufacture of paper and paper products	Biogas	Oil crops and plants	Gate to grave		
Cosmeceuticals	20-Manufacture of chemicals and chemicals products	Bio-hydrogen	Starch crops			
Fragrances	21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	Bio-naphtha	Sugar crops			
Lubricants	22-Manufacture of rubber and plastic products	Bio-oils	Other primary biomass			
Nutraceuticals	23-Manufacturing of other non-metallic mineral products	C5/C6 sugars	Livestock-based biomass			
Paints and coatings		Carbon dioxide	Marine animals			
Biopharmaceuticals		Lignin	Microbial biomass			
Solvents		Organic fibers	<b>Primary residues or Harvest residues or Field residues</b>			
Surfactants		Organic juice	Residues from agriculture			
Catalyst and enzymes		Protein	Residues from forestry			
<b>Biomaterials</b>		Pyrolytic liquid	Residues from nature and landscape management			
Traditional wood-based products		Starch	Residues from aquatic biomass cultivation			
Biocomposites		Syngas	Animal-based residues			
Biofibers		Other platforms	<b>Secondary residues or Production residues or Industrial residues</b>			
Fertilizers		<b>Forest industries platforms</b>				
		Lamellas, Rods				

<p>Biopolymers Resins</p>	<p>26: Manufacture of Computer, electronic and optical products 29-Manufacture of motor vehicles, trailers and semi-trailers 30-Manufacture of other transport equipment 31-Manufacture of furniture 32-Other manufacturing</p>	<p>Veneers Wood wool  Particles, strands Fibers Pulp</p>	<p>Residues from agro-food industry Residues from wood- based industry Residues from fish and arthropods processing Residues from meat processing industry <b>Primary waste</b> Post-consumer wastes/Consumption residues Post-consumer and industrial waste wood Sewage and wastewater sludge <b>Secondary waste</b> Sorting waste Sludges and liquid waste from waste treatment</p>			
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## 11 Conclusions

This deliverable of the ESCIB project is focused on the classification and systematization of high TRL industrial biobased systems. This study made a detailed systematic classification for the BBS, including the classification for BBPs, biobased industry, feedstock, LCA system boundary, and end-of-life (EoL). The systematic approach adopted in this study provides a detailed, comprehensive, multifaceted, and easy understanding of the BBS classification, hence providing a structured approach to addressing the complexity of BBS.

BBPs were classified based on five main approaches: classification based on integration to market, application, and classes, and its end products based on NACE and PRODCOM code. However, the most comprehensive classification for BBPs at the EU scale that can be adopted is from the NACE and PRODCOM lists, which include the sector and end product categories. The current drawback is that the classification does not provide a detailed classification for products, whether biobased or fossil-based and hence, the current classification is based on the general description of the sector and products. Similarly, PRODCOM does not provide more details about some products, i.e., biobased electronic components, which are already found in the literature but are not specified in PRODCOM products description. Therefore, further updating and detailed descriptions for NACE and PRODCOM will provide a more accurate classification of BBPs available in the EU market.

Furthermore, this study found that the current classification of biorefineries is mostly focused on biorefineries and does not include forest industries classification. Considering that the EU's largest sector by quantity is forestry-based BBPs, this study classifies bioindustries into traditional bioindustries, i.e., forest-based industries and biorefineries. Forest-based industries have four major types: woodworking, furniture, pulp and paper, and printing. Review studies reveal that platforms or intermediate products are the most important classification adopted in the literature for biorefineries. Therefore, this study also further identifies the platforms for forestry-based industries. Accordingly, sixteen platforms were identified for biorefineries, while six were identified for wood-based industries. Biorefineries classification identifies the multi feedstock or phase III biorefineries as the most sustainable one as they can not only adopt different feedstock based on their easy and sustainable availability but also can change their production lines based on increase or decrease in demand. Furthermore, pathway classification of biorefineries reveals that pathways A-E and I are high TRL (8-9) biorefineries while pathways F-K except I are low TRL biorefineries ranging from 4 to 7 TRL.

Biomass feedstock classification is made based on the origin as it is the most adopted classification in the literature, categorizing each feedstock type into its origin from which it is derived. The origin-based classification was extended by type and source, and this classification also takes care of the differentiation of the wastes and residues and provides a detailed stepwise classification of the biomass feedstock. The biorefinery classification based on the pathway reveals that most of the biorefineries use the primary or dedicated feedstock and harvest residues as the feedstock for the production of BBPs.

LCA system boundaries were classified based on two distinctive approaches: supply chain consideration and LCA methodological choice. Supply chain consideration as identified in the literature is the most important classification used in the LCA studies. This systematic classification approach offers a framework for comprehending the targeted, accurate and related environmental impacts of the BBS. This approach significantly highlights the importance of the implication in a specific supply chain but also considers the broader system boundaries in the case of different modeling approaches, leading to a more precise and accurate assessment of the environmental impacts in LCA studies.

The EoL of the BBP reveals that three main routes can be adopted by BBPs after its useful life comes to an end namely, closed-loop recirculation, open-loop recirculation, and EoL treatment. A closed-loop recirculation route is when materials are recovered and used in the same supply chain. In contrast, open loop considers materials recovery but does so in other supply chains of the product system. EoL treatment includes landfill and incineration as disposal methods at its end of life.

This study recommends expanding and refining this classification to include new technologies, product sectors, and feedstocks. Furthermore, besides technical classification, classifying the IBBS based on sustainability criteria, i.e., classifying the biorefinery pathways and platforms based on sustainability criteria, is an important future scope that can be adopted in the classification of IBBS. Furthermore, defining criteria to identify and classify the sector of BBPs based on sustainability and circularity criteria will help to focus more on the sustainable pathways and products. This classification approach supports the consistent, comparable assessment framework of WP3 and 4 essential for advancing a sustainable circular BBPs bioeconomy across the EU and will guide the development of the certification scheme in WP6.

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Annex I: Classification of biobased products according to NACE Rev 2.1 and PRODCOM-2024 (Mianly adapted from (CIRCE 2022) with an addition of extra divisions and revising for NACE Rev2.1 and PRODCOM 2024).

<b>Division-NACE Rev 2.1</b>	<b>Class-NACE Rev.2.1</b>	<b>PRODCO M 2024</b>	<b>Products description</b>	<b>Sectors</b>
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.10	Wool grease and fatty substances derived therefrom, including lanolin	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.21	Raw silk (not thrown)	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.22	Wool, degreased or carbonised, not carded or combed	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.23	Noils of wool or fine animal hair	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.24	Wool or animal hair, carded or combed (including wool tops)	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.25	Cotton, carded or combed	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.26	Jute and other textile fibres (except flax, true hemp and ramie), processed but not spun	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.29	Other vegetable textile fibres, processed but not spun	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.31	Synthetic staple fibres, carded, combed or otherwise processed for spinning	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.32	Artificial staple fibres, carded, combed or otherwise processed for spinning	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.40	Silk yarn, and yarn spun from silk waste	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.50	Yarn of wool (carded and combed) or fine animal hair, n.p.r.s.	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.61	Cotton yarn for woven, knitted fabrics and other uses	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.62	Cotton sewing thread	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.71	Flax yarn	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.72	Yarn of jute, vegetable or bast fibres, paper yarn	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.81.30	Multiple or cabled yarn of artificial filaments, n.p.r.s. (excluding sewing thread)	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.81.50	Man-made filament yarn, p.r.s. (excluding sewing thread)	Textile

Annex I (continued)

13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.84	Yarn of artificial staple fibers	Textile
13. Manufacturing of Textiles	13.10: Preparation and spinning of textile fibres	13.10.85	Sewing thread and yarn of artificial and synthetic filaments and fibres	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.11	Woven fabrics of silk or of silk waste	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.12	Woven fabrics carded or combed wool or fine animal hair or of coarse animal hair or of horsehair	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.13	Woven fabrics of flax	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.14	Woven fabrics of jute and other textile bast fibres (except flax, true hemp and ramie)	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.19	Woven fabrics of other vegetable textile fibres; woven fabrics of paper yarn	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.20	Woven fabrics of cotton	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.31.30	Woven fabrics of man-made filament yarns obtained from high tenacity yarn, strip or the like (including nylon, other polyamides, polyester, viscose rayon)	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.31.70	Woven fabrics of artificial filament yarns (excluding those obtained from high tenacity yarn)	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.33	Woven fabrics of artificial staple fibres	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.41	Woven pile fabrics and chenille fabrics (other than terry towelling and narrow fabrics)	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.42	Terry towelling and similar woven terry fabrics (other than narrow fabrics) of cotton	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.43	Other terry towelling and similar woven terry fabrics (other than narrow fabrics)	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.44	Gauze (other than narrow fabrics)	Textile
13. Manufacturing of Textiles	13.20: Weaving of textiles	13.20.45	Tufted textile fabrics, other than carpets	Textile
13. Manufacturing of Textiles	13.91: Manufacture of knitted and crocheted fabrics	13.91.11	Pile fabrics, terry fabrics, knitted or crocheted	Textile
13. Manufacturing of Textiles	13.91: Manufacture of knitted and crocheted fabrics	13.91.19.10	Knitted or crocheted fabrics (excluding pile fabrics)	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.11	Blankets and travelling rugs, except electric blankets	Textile

Annex I (continued)

13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.12	Bed linen	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.13.30	Table linen of knitted or crocheted textiles	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.13.53	Table linen of cotton (excluding knitted or crocheted)	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.13.55	Table linen of flax (excluding knitted or crocheted)	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.14.30	Toilet linen and kitchen linen, of terry towelling or similar terry fabrics of cotton	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.14.50	Woven toilet linen and kitchen linen, of textiles (excluding terry towelling or similar terry fabrics of cotton)	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.15	Curtains (including drapes) and interior blinds; curtain or bed valances	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.16	Furnishing articles n.e.c.; sets of woven fabric and yarn for making up into rugs, tapestries and the like	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.21	Sacks and bags, of a kind used for the packing of goods	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.22	Tarpaulins, awnings and sunblinds; sails for boats, sailboards or landcraft; tents and camping goods (including pneumatic mattresses)	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.24	quilts, cushions, pouffes, pillows ,sleepings bags, internally fitted with any materials or of cellular rubber or palstics	Textile
13. Manufacturing of Textiles	13.92: Manufacture of household textiles and made up furnishing articles	13.92.29	Other made-up textile articles (including floor cloths, dish- cloths, dusters and similar cleaning cloths, life-jackets and life-belts)	Textile
13. Manufacturing of Textiles	13.93: Manufacture of carpets and rugs	13.93.11	Carpets and other textile floor coverings, knotted	Textile
13. Manufacturing of Textiles	13.93: Manufacture of carpets and rugs	13.93.12	Carpets and other textile floor coverings, woven, not tufted or flopped	Textile
13. Manufacturing of Textiles	13.93: Manufacture of carpets and rugs	13.93.13	Carpets and other textile floor coverings, tufted	Textile
13. Manufacturing of Textiles	13.93: Manufacture of carpets and rugs	13.93.19	Other carpets and textile floor coverings (including those offelt)	Textile
13. Manufacturing of Textiles	13.94: Manufacture of cordage, rope twine and netting	13.94.11.30	Twine, cordage, rope or cables, of sisal or other textile fibres of 'agave', of jute or other textile bast fibres and	Textile

			hard leaf fibres (excluding binder or baler twine)	
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*Annex I (continued)*

13. Manufacturing of Textiles	13.94: Manufacture of cordage, rope twine and netting	13.94.11.53	Sisal binder or baler (agricultural) twines	Textile
13. Manufacturing of Textiles	13.94: Manufacture of cordage, rope twine and netting	13.94.12.33	Made-up fishing nets from twine, cordage or rope of man-made fibres (excluding fish landing nets)	Textile
13. Manufacturing of Textiles	13.94: Manufacture of cordage, rope twine and netting	13.94.12.59	Knotted netting of textile materials (excluding made-up fishing nets of man-made textiles, other made-up nets of nylon or other polyamides)	Textile
13. Manufacturing of Textiles	13.94: Manufacture of cordage, rope twine and netting	13.94.12.80	Articles of twine, cordage, rope or cables	Textile
13. Manufacturing of Textiles	13.95: Manufacture of non-woven and non-woven articles	13.95.10	Non-wovens and articles made from non-wovens, except apparel	Textile
13. Manufacturing of Textiles	13.96: Manufacture of other textiles for technical and industrial uses	13.96.13	Rubber thread and cord, textile covered; textile yarn and strip, impregnated or covered with rubber or plastics	Textile
13. Manufacturing of Textiles	13.96: Manufacture of other textiles for technical and industrial uses	13.96.14	Textile fabrics, impregnated, coated or covered n.e.c.	Textile
13. Manufacturing of Textiles	13.97: Manufacture of other textile products	13.97.11	Tulles and other net fabrics, except woven, knitted or crocheted fabrics; lace in the piece, in strips or in motifs	Textile
13. Manufacturing of Textiles	13.97: Manufacture of other textile products	13.97.12	Embroidery in the piece, in strips or in motifs	Textile
13. Manufacturing of Textiles	13.97: Manufacture of other textile products	13.97.13	Felt, coated, covered or laminated	Textile
13. Manufacturing of Textiles	13.97: Manufacture of other textile products	13.97.15	Gimped yarn and strip; chenille yarn; loop wale-yarn	Textile
14-Manufacturing of wearing apparel	14.10: Manufacturing of knitted and crocheted apparel	14.10.10	Jerseys, pullovers, cardigans, waistcoats and similar articles, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.10: Manufacturing of knitted and crocheted apparel	14.10.11	Panty hose, tights, stockings, socks and other hosiery, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.11	Men's or boys' overcoats, car coats, capes, cloaks, anoraks, windcheaters, wind-jackets and similar articles, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.12	Men's or boys' suits, ensembles, jackets, blazers, trousers, bib and brace overalls, breeches and shorts, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.13	Women's or girls' overcoats, car coats, capes, cloaks, anoraks, windcheaters, wind-jackets and similar articles, knitted or crocheted	Textile

Annex I (continued)

14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.14	Women's or girls' suits, ensembles, jackets, blazers, dresses, skirts, divided skirts, trousers, bib and brace overalls, breeches and shorts, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.21	Men's or boys' overcoats, raincoats, car coats, capes, cloaks, anoraks, wind-cheaters, wind-jackets and similar articles of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.22	Men's or boys' suits and ensembles of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.23	Men's or boys' jackets and blazers, of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.24	Men's or boys' trousers, bib and brace overalls, breeches and shorts of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.31	Women's or girls' overcoats, car coats, capes, cloaks, anoraks, wind-cheaters, wind-jackets and similar articles of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.32	Women's or girls' suits and ensembles of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.33	Women's or girls' jackets and blazers of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.34	Women's or girls' dresses, skirts and divided skirts of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.21: Manufacture of outerwear	14.21.35	Women's or girls' trousers, bib and brace overalls, breeches and shorts of textile fabrics, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.11	Men's or boys' shirts, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.12	Men's or boys' underpants, briefs, nightshirts, pyjamas, bathrobes, dressing gowns and similar articles, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.13	Women's or girls' blouses, shirts and shirt-blouses, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.14	Women's or girls' slips, petticoats, briefs, panties, nightdresses, pyjamas, dressing gowns, negligees, bathrobes and similar articles, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.21	Men's or boys' shirts, of textile fabric not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.22	Men's or boys' singlets and other vests, underpants, briefs, nightshirts, pyjamas, bathrobes, dressing gowns,	Textile

			of textile fabric not knitted or crocheted	
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*Annex I (continued)*

14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.23	Women's or girls' blouses, shirts and shirt-blouses, of textile fabric not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.24	Women's and girls' singlets and other vests, slips, petticoats, briefs, panties, nightdresses, pyjamas, negligees, bathrobes, dressing gowns and similar articles, of textile fabric not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.25	Brassieres, girdles, corsets, braces, suspenders, garters and similar articles and parts thereof, whether or not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.22: Manufacture of underwear	14.22.30	T-shirts, singlets and other vests, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.23: Manufacture of work wear	14.23.11	Men's ensembles, jackets and blazers, industrial and occupational	Textile
14-Manufacturing of wearing apparel	14.23: Manufacture of work wear	14.23.12	Men's trousers, bib and brace overalls, breeches and shorts, industrial and occupational	Textile
14-Manufacturing of wearing apparel	14.23: Manufacture of work wear	14.23.21	Women's ensembles, jackets and blazers, industrial and occupational	Textile
14-Manufacturing of wearing apparel	14.23: Manufacture of work wear	14.23.22	Women's trousers, bib and brace overalls, breeches and sorts, industrial and occupational	Textile
14-Manufacturing of wearing apparel	14.23: Manufacture of work wear	14.23.30	Other workwear	Textile
14-Manufacturing of wearing apparel	14.24: Manufacture of leather clothes and fur apparel	14.24.10	Articles of apparel of leather or of composition leather (including coats and overcoats) (excluding clothing accessories, headgear, footwear)	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.11	Babies' garments and clothing accessories, of textile fabric, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.12	Tracksuits, ski suits and swimwear; other garments of textile fabric, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.13	Gloves, mittens and mitts, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.19	Other made-up clothing accessories and parts of garments or of clothing accessories, knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.21	Babies' garments and clothing accessories, of textile fabric, not knitted or crocheted	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.22	Tracksuits, ski suits and swimwear; other garments of textile fabric, not knitted or crocheted	Textile

Annex I (continued)

14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.23	Handkerchiefs, shawls, scarves, veils, ties, cravats, gloves and other made-up clothing accessories; parts of garments or of clothing accessories, of textile fabric, not knitted or crocheted, n.e.c.	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.32	Garments made up of felt or non-wovens, textile fabrics impregnated or coated	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.41	Hat forms, hat bodies and hoods of felt; plateaux and manchons of felt; hat shapes, plaited or made by assembling strips of any material	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.42	Hats and other headgear, of felt, or plaited or made by assembling strips of any material, or knitted or crocheted or made up from lace or other textile fabric in the piece; hairnets	Textile
14-Manufacturing of wearing apparel	14.29: Manufacture of other wearing apparel and accessories	14.29.43	Other headgear, except headgear of rubber or of plastics, safety headgear and asbestos headgear; headbands, linings, covers, hat foundations, hat frames, peaks and chinstraps, for headgear	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.11	Waterproof footwear, with outer soles and uppers of rubber or plastics, other than footwear incorporating a protective metal toe-cap	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.12	Footwear with outer soles and uppers of rubber or plastics, other than waterproof or sports footwear	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.13.30	Footwear with a wooden base and leather uppers (including clogs) (excluding with an inner sole or a protective metal toe-cap)	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.13.70	Slippers and other indoor footwear with rubber, plastic or leather outer soles and leather uppers (including dancing and bedroom slippers, mules)	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.13.80	Footwear with wood, cork or other outer soles and leather uppers (excluding outer soles of rubber, plastics or leather)	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.14	Footwear with uppers of textile materials, other than sports footwear	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.21	Tennis shoes, basketball shoes, gym shoes, training shoes and the like	Textile
15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.31	Footwear incorporating a protective metal toe-cap ( with	Textile

			outer soles and uppers of rubber or of plastics)	
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*Annex I (continued)*

15-Manufacture of leather and related products	15.20: Manufacture of footwear	15.20.32	Wooden footwear, miscellaneous special footwear and other footwear n.e.c.	Textile
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.11	Wood, sawn or chipped lengthwise, sliced or peeled, of a of coniferous wood thickness > 6 mm,	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.12	Wood, sawn or chipped lengthwise, sliced or peeled, of a thickness > 6 mm, of non-coniferous wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.13	Railway or tramway sleepers (cross-ties) of wood, not impregnated	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.21	Wood, continuously shaped along any of its edges or faces (including strips and friezes for parquet flooring, not assembled, and beadings and mouldings), of coniferous wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.22	Wood, continuously shaped along any of its edges or faces (including strips and friezes for parquet flooring, not assembled, and beadings and mouldings) of bamboo	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.23	Wood, continuously shaped along any of its edges or faces (including strips and friezes for parquet flooring, not assembled, and beadings and mouldings), of other wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.24	Wood wool; wood flour	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.25	Wood in chips or particles	Woodworking

Annex I (continued)

16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.31	Wood in the rough, treated with paint, stains, creosote or other preservatives	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.32	Railway or tramway sleepers (cross-ties) of wood, impregnated	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.39	Other wood in the rough, including split poles and pickets	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.11: Sawmilling and planing of wood	16.11.91	Drying, impregnation or chemical treatment services of timber	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.11	Plywood, veneered panels and similar laminated wood, of bamboo	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.12	Particle board	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.13	Oriented strand board (OSB)	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.14	Other board of wood or other ligneous materials	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.15	Fibreboard of wood or other ligneous materials	Construction

Annex I (continued)

16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.16	Other plywood, veneered panels and similar laminated wood, of coniferous wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.17	Other plywood, veneered panels and similar laminated wood, with at least outer ply of tropical wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.18	Other plywood, veneered panels and similar laminated wood, of other wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.21	Densified wood, in blocks, plates, strips or profile shapes	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.22	Veneer sheets and sheets for plywood and other wood sawn lengthwise, sliced or peeled, of a thickness $\leq 6$ mm of coniferous wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.23	Veneer sheets and sheets for plywood and other wood, sawn lengthwise, sliced or peeled, of a thickness $\leq 6$ mm, of tropical wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.21: Manufacture of veneer sheets and wood-based panels	16.21.24	Veneer sheets and sheets for plywood and other wood sawn lengthwise, sliced or peeled, of a thickness $\leq 6$ mm of other wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.22: Manufacture of assembled parquet floors	16.22.10	Assembled parquet panels of wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.23: Manufacture of other builders carpentry and joinery	16.23.12	Shuttering for concrete constructional work, shingles and shakes, of wood	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.23: Manufacture of other builders carpentry and joinery	16.23.19	Builders' joinery and carpentry, of wood, n.e.c.	Construction

straw and plaiting materials				
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*Annex I (continued)*

16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.23: Manufacture of other builders carpentry and joinery	16.23.20	Prefabricated wooden buildings	Construction
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.24: Manufacture of wooden containers	16.24.11	Pallets, box pallets and other load boards of wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.24: Manufacture of wooden containers	16.24.12	Barrels and cooper's' products of wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.24: Manufacture of wooden containers	16.24.13	Other wooden containers and parts thereof	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.25: Manufacture of doors and windows of wood	16.25.11	Windows, French windows and their frames, doors and their frames and thresholds, of wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.11	Tools, tool bodies, tool handles, broom or brush bodies and handles, blocks for the manufacture of smoking pipes, boot or shoe lasts and trees, of wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.12	Tableware and kitchenware, of wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.13	Wood marquetry and inlaid wood, cases for jewellery or cutlery and similar articles of wood, statuettes and other ornaments, of wood	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.14	Wooden frames for paintings, photographs, mirrors or similar objects and other articles of wood	Woodworking

Annex I (continued)

16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.15	Pellets and briquettes, of pressed and agglomerated wood and vegetable waste and scrap	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.21	Natural cork, debarked or roughly squared or in blocks, plates, sheets or strip; crushed, granulated or ground cork; waste cork	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.22	Articles of natural cork	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.23	Blocks, plates, sheets and strips, tiles of any shape, solid cylinders, of agglomerated cork	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.24	Agglomerated cork; articles of agglomerated cork n.e.c	Woodworking
16-Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles, of straw and plaiting materials	16.28: Manufacture of other products of wood and articles of cork, straw and plaiting materials	16.28.25	Manufactures of straw, of esparto or of other plaiting materials; basket ware and wickerwork	Woodworking
17-Manufacture of paper and paper products	17.11: Manufacture of Pulp	17.11.11	Chemical wood pulp, dissolving grades	Pulp and paper
17-Manufacture of paper and paper products	17.11: Manufacture of Pulp	17.11.12	Chemical wood pulp, soda or sulphate, other than dissolving grades	Pulp and paper
17-Manufacture of paper and paper products	17.11: Manufacture of Pulp	17.11.13	Chemical wood pulp, sulphite, other than dissolving grades	Pulp and paper
17-Manufacture of paper and paper products	17.11: Manufacture of Pulp	17.11.14	Mechanical wood pulp; semi-chemical wood pulp; pulps of fibrous cellulosic material other than wood	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.11	Newsprint, in rolls or sheets	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.12	Handmade paper and paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.13	Paper and paperboard used as a base for photo-sensitive, heat-sensitive or electro-sensitive paper; carbonising base paper; wallpaper base	Pulp and paper

Annex I (continued)

17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.14	Other paper and paperboard for graphic purposes	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.20	Toilet or facial tissue stock, towel or napkin stock, cellulose wadding and webs of cellulose fibres	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.31	Kraftliner, unbleached, uncoated	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.32	White top kraftliner; coated kraftliner	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.33	Semi chemical fluting	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.34	Recycled fluting and other fluting	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.35	Testliner (recycled liner board)	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.41	Uncoated kraft paper; sack kraft paper, creped or crinkled	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.42	Sulphite wrapping paper and other uncoated paper (other than that of a kind used for writing, printing or other graphic purposes)	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.43	Filter paper and paperboard; felt paper	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.44	Cigarette paper not cut to size or in form of booklets or tubes	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.51	Uncoated, inside grey paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.59	Other uncoated paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.60	Vegetable parchment, greaseproof papers, tracing papers and glassine and other glazed transparent or translucent papers	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.71	Composite paper and paperboard, not surface-coated or impregnated	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.72	Paper and paperboard, creped, crinkled, embossed or perforated	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.73	Paper and paperboard of a kind used for writing, printing or other graphic purposes, coated with kaolin or with other inorganic substances	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.74	Kraft paper (other than that of a kind used for writing, printing or other graphic purposes), coated with kaolin or with other inorganic substances	Pulp and paper

Annex I (continued)

17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.75	Kraft paperboard (other than that of a kind used for writing, printing or other graphic purposes), coated with kaolin or with other inorganic substances	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.76	Carbon paper, self-copy paper and other copying or transfer paper, in rolls or sheets	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.77	Paper, paperboard, cellulose wadding and webs of cellulose fibres, coated, impregnated, covered, surface coloured or printed, in rolls or sheets	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.78	Inside grey paperboard (other than that of a kind used for writing, printing or other graphic purposes), coated with kaolin or with other inorganic substances	Pulp and paper
17-Manufacture of paper and paper products	17.12: Manufacture of paper and paperboard	17.12.79	Other paperboard (other than that of a kind used for writing, printing or other graphic purposes), coated with kaolin or with other inorganic substances	Pulp and paper
17-Manufacture of paper and paper products	17.21: Manufacture of corrugated paper and paperboard; manufacture of containers and packaging of paper and paperboard	17.21.11	Corrugated board, in rolls or sheets	Pulp and paper
17-Manufacture of paper and paper products	17.21: Manufacture of corrugated paper and paperboard; manufacture of containers and packaging of paper and paperboard	17.21.12	Sacks and bags of paper	Pulp and paper
17-Manufacture of paper and paper products	17.21: Manufacture of corrugated paper and paperboard; manufacture of containers and packaging of paper and paperboard	17.21.13	Cartons, boxes and cases, of corrugated board or corrugated paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.21: Manufacture of corrugated paper and paperboard; manufacture of containers and packaging of paper and paperboard	17.21.14	Folding cartons, boxes and cases, of non-corrugated paper or paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.21: Manufacture of corrugated paper and paperboard; manufacture of containers and packaging of paper and paperboard	17.21.15	Box files, letter trays, storage boxes and similar articles of a kind used in offices, shops or the like, of paper	Pulp and paper
17-Manufacture of paper and paper products	17.22: Manufacture of household, sanitary goods and toilet requisites	17.22.11	Toilet paper, handkerchiefs, cleansing or facial tissues and towels, tablecloths and serviettes, of paper pulp, paper, cellulose wadding or webs of cellulose fibres	Pulp and paper

Annex I (continued)

17-Manufacture of paper and paper products	17.22: Manufacture of household, sanitary goods and toilet requisites	17.22.12	Sanitary towels and tampons, napkins and napkin liners for babies and similar sanitary articles and articles of apparel and clothing accessories, of paper pulp, paper, cellulose wadding or webs of cellulose fibres	Pulp and paper
17-Manufacture of paper and paper products	17.22: Manufacture of household, sanitary goods and toilet requisites	17.22.13	Trays, dishes, plates and cups and the like, of paper or paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.23: Manufacture of paper stationery	17.23.11	Carbon paper, self-copy paper and other copying or transfer papers; duplicator stencil and offset plates of paper	Pulp and paper
17-Manufacture of paper and paper products	17.23: Manufacture of paper stationery	17.23.12	Envelopes, letter cards, plain postcards and correspondence cards of paper or paperboard; boxes, pouches, wallets and writing compendiums of paper or paperboard, containing paper stationery	Pulp and paper
17-Manufacture of paper and paper products	17.23: Manufacture of paper stationery	17.23.13	Registers, account books, binders, forms and other articles of stationery, of paper or paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.23: Manufacture of paper stationery	17.23.14	Other paper and paperboard, of a kind used for writing or printing or other graphic purposes, printed, embossed or perforated	Pulp and paper
17-Manufacture of paper and paper products	17.24: Manufacture of wallpaper	17.24.11	Wallpaper and similar wall coverings; window transparencies of paper	Pulp and paper
17-Manufacture of paper and paper products	17.24: Manufacture of wallpaper	17.24.12	Textile wall coverings	Pulp and paper
17-Manufacture of paper and paper products	17.25: Manufacture of other articles of paper and paperboard	17.25.11	Labels of paper or paperboard	Pulp and paper
17-Manufacture of paper and paper products	17.25: Manufacture of other articles of paper and paperboard	17.25.12	Filter blocks, slabs and plates, of paper pulp	Pulp and paper
17-Manufacture of paper and paper products	17.25: Manufacture of other articles of paper and paperboard	17.25.19	Cigarette paper; bobbins, spools, cops and similar supports; filter paper and paperboard; other articles of paper and paperboard n.e.c.	Pulp and paper
20-Manufacture of chemicals and chemicals products	20.12: Manufacture of dyes and pigments	20.12.22	Tanning extracts of vegetable origin; tannins and their salts, ethers, esters and other derivatives; colouring matter of vegetable or animal origin	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.11	Acyclic hydrocarbons	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.12	Cyclic hydrocarbons	Chemicals

Annex I (continued)

20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.21	Industrial fatty alcohols	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.22	Monohydric alcohols	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.23	Diols, polyalcohols, cyclical alcohols and derivatives thereof	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.24	Phenols; phenol-alcohols and derivatives of phenols	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.31	Industrial monocarboxylic fatty acids; acid oils from refining	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.32	Saturated acyclic monocarboxylic acids and their derivatives	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.33	Unsaturated monocarboxylic, cyclanic, cyclenic or cycloterpenic acyclic	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.34	Aromatic polycarboxylic and carboxylic acids with additional oxygen functions; and their derivatives, except salicylic acid and its salts	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.41	Amine function compounds	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.42	Oxygen-function amino-compounds, except lysine and glutamic acid	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.43	Ureines; carboxymide-function compounds, nitrile function compounds; derivatives thereof	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.44	Compounds with other nitrogen functions	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.51.39	Other organo-sulphur compounds	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.13	Ethanal (acetaldehyde)	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.15	Butanal (butyraldehyde; normal isomer)	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.19	Acyclic aldehydes, without other oxygen function (excluding methanal (formaldehyde), ethanal (acetaldehyde), butanal (butyraldehyde; normal isomer))	Chemicals

20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.20	Cyclic aldehydes; without other oxygen function	Chemicals
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*Annex I (continued)*

20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.30	Aldehyde-alcohols	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.35	Aldehyde-alcohols, Aldehyde-ethers, aldehyde-phenols and aldehydes with other oxygen function	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.61.30	Aldehyde-alcohols	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.62	Ketone and quinone function compounds	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.63	Ethers, organic peroxides, epoxides, acetals and hemiacetals and their derivatives	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.64	Enzymes and other organic compounds n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.71	Derivates of vegetable or resin products	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.72	Wood charcoal	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.73	Oils and other products of the distillation of high temperature coal tar, and similar products	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.74	Undenatured ethyl alcohol of alcoholic strength by volume of $\geq 80\%$	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.75	Ethyl alcohol and other spirits, denatured, of any strength	Chemicals
20-Manufacture of chemicals and chemicals products	20.14: Manufacture of other organic basic chemicals	20.14.80	Residual lyes from the manufacture of wood pulp, excluding tall oil	Chemicals
20-Manufacture of chemicals and chemicals products	20.15: Manufacture of fertilisers and nitrogen compounds	20.15.80	Animal or vegetable fertilisers n.e.c	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.10.35	Linear polyethylene having a specific gravity $< \dagger 0,94$ , in primary forms	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.10.39	Polyethylene having a specific gravity $< \dagger 0,94$ , in primary forms (excluding linear)	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.10.50	Polyethylene having a specific gravity of $\geq \dagger 0,94$ , in primary forms	Chemicals

Annex I (continued)

20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.40.80	Unsaturated polyesters, in primary forms (excluding liquid polyesters, polyacetals, polyethers, epoxide resins, polycarbonates, alkyd resins, polyethylene terephthalate)	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.51.30	Polypropylene, in primary forms	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.59.45	Other plastics, in primary forms, n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.59.50	Cellulose and its chemical derivatives, in primary forms, excluding sodium carboxymethyl cellulose and n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.59.55	Natural polymers and modified natural polymers, not elsewhere specified or included, in primary forms . Alginic acid, its salts and esters	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.59.65	Natural polymers and modified natural polymers, e.g. hardened proteins, chemical derivatives of natural rubber, n.e.s., in primary forms (excl. alginic acid and its salts and esters)	Chemicals
20-Manufacture of chemicals and chemicals products	20.16: Manufacture of plastics in primary forms	20.16.59.70	Ion-exchangers based on synthetic or natural polymers, in primary forms	Chemicals
20-Manufacture of chemicals and chemicals products	20.20: Manufacture of pesticides, disinfectants and other agrochemicals products	20.20.11	Insecticides	Chemicals
20-Manufacture of chemicals and chemicals products	20.20: Manufacture of pesticides, disinfectants and other agrochemicals products	20.20.12.40	Herbicides based on amides, put up in forms or packings for retail sale or as preparations or articles (excluding hazardous pesticides)	Chemicals
20-Manufacture of chemicals and chemicals products	20.20: Manufacture of pesticides, disinfectants and other agrochemicals products	20.20.13.50	Anti-sprouting products put up in forms or packings for retail sale or as preparations or articles	Chemicals
20-Manufacture of chemicals and chemicals products	20.20: Manufacture of pesticides, disinfectants and other agrochemicals products	20.20.14.90	Disinfectants put up in forms or packings for retail sale or as preparations or articles (excluding those based on quaternary ammonium salts, those based on halogenated compounds and those being hazardous pesticides)	Chemicals
20-Manufacture of chemicals and chemicals products	20.20: Manufacture of pesticides, disinfectants and other agrochemicals products	20.20.19	Other pesticides and other agrochemical products	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.11.70	Other paints, varnishes dispersed or dissolved in an aqueous medium	Chemicals

Annex I (continued)

20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.12.25	Paints and varnishes, based on polyesters dispersed/dissolved in a non-aqueous medium, weight of the solvent >†50†% of the weight of the solution including enamels and lacquers	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.12.29	Paints and varnishes, based on polyesters dispersed/dissolved in a non-aqueous medium including enamels and lacquers excluding weight of the solvent>†50†% of the weight of the solution	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.12.70	Paints and varnishes: solutions n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.22.13	Oil paints and varnishes (including enamels and lacquers)	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.22.20	Prepared driers	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.22.40	Pigments, including metallic powders and flakes, dispersed in non-aqueous media, in liquid or paste form, of a kind used in the manufacture of paints; colorants and other colouring matter, n.e.c. put up for retail sale	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.22.55	Painters' fillings	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.22.60	Non-refractory surfacing preparations for facades, indoor walls, floors, ceilings or the like	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.22.79	Organic composite solvents and thinners used in conjunction with coatings and inks (excluding those based on butyl acetate)	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.23	Artists', students' or signboard painters' colours, modifying tints, amusement colours and the like	Chemicals
20-Manufacture of chemicals and chemicals products	20.30: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	20.30.24	Printing ink	Chemicals
20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.10	Glycerol	Chemicals
20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.20	Organic surface-active agents, except soap	Chemicals
20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.31	Soap and organic surface-active products and preparations for use as soap; paper, wadding, felt and non-wovens, impregnated, coated or covered with soap or detergent	Chemicals

Annex I (continued)

20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.32	Detergents and washing preparations	Chemicals
20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.41	Preparations for perfuming or deodorising rooms	Chemicals
20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.43	Polishes and creams, for footwear, furniture, floors, coachwork, glass or metal	Chemicals
20-Manufacture of chemicals and chemicals products	20.41: Manufacture of soap and detergents, cleaning and polishing preparations	20.41.44	Scouring pastes and powders and other scouring preparations	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.11	Perfumes and toilet waters	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.12	Lip and eye make-up preparations	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.13	Manicure or pedicure preparations	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.14	Powders for cosmetic or toilet use	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.15	Beauty, make-up or skin-care preparations (including sun tan preparations) n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.16.30	Shampoos	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.17	Lotions and other preparations for use on the hair n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.18	Preparations for oral or dental hygiene (including denture fixative pastes and powders), dental floss	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.19.15	Soap and organic surface-active products in bars, etc., for toilet use	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.19.30	Organic surface-active products and preparations for washing the skin; whether or not containing soap, p.r.s.	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.19.45	Pre-shave, shaving and after-shave preparations (excluding shaving soap in blocks)	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.19.60	Personal deodorants and anti-perspirants	

Annex I (continued)

20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.19.75	Perfumed bath salts and other bath preparations	Chemicals
20-Manufacture of chemicals and chemicals products	20.42: Manufacture of perfumes and toilet preparations	20.42.19.90	Other personal preparations (perfumeries, toilet, depilatories)	Chemicals
20-Manufacture of chemicals and chemicals products	20.51: Manufacture of liquid biofuels		Manufacture of ethanol, bioethanol, liquid biofuels (NACE)	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.41	Lubricating preparations	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.42	Anti-knock preparations; additives for mineral oils and similar products	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.43	Hydraulic brake fluids; anti-freezing preparations and prepared de-icing fluids	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.51	Peptones, other protein substances and their derivatives n.e.c.; hide powder	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.54	Activated carbon	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.55.50	Finishing agents, etc., with amylaceous basis	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	29.59.57.70	Sorbitol (excluding D-glucitol)	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.58	Biodiesel	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.59.57	Mixtures of mono-, di- and tri-, fatty acid esters of glycerol (emulsifiers for fats)	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.60	Gelatines and gelatine derivatives, including milk albumins	Chemicals
20-Manufacture of chemicals and chemicals products	20.59: Manufacture of other chemical products n.e.c.	20.59.59.63	Products and preparations for pharmaceutical or surgical uses	Chemicals
20-Manufacture of chemicals and chemicals products	20.60: Manufacture of man-made fibres	20.60.21.40	Artificial filament tow, of acetate	Chemicals
20-Manufacture of chemicals and chemicals products	20.60: Manufacture of man-made fibres	20.60.22	Viscose high tenacity filament yarn	Chemicals

Annex I (continued)

20-Manufacture of chemicals and chemicals products	20.60: Manufacture of man-made fibres	20.60.23.20	Yarn of viscose rayon filament, including monofilament of <†67 decitex, single, n.p.r.s. (excluding sewing thread and high-tenacity yarn)	Chemicals
20-Manufacture of chemicals and chemicals products	20.60: Manufacture of man-made fibres	20.60.23.40	Filament yarn of cellulose acetate, including monofilament of <†67 decitex, single, n.p.r.s. (excluding sewing thread and high-tenacity yarn)	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.10	Salicylic acid, O-acetylsalicylic acid, their salts and esters	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.20	Lysine, glutamic acid and their salts; quarternary ammonium salts and hydroxides; phosphoaminolipids; amides and their derivatives and salts thereof	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.31	Lactones n.e.c., heterocyclic compounds with nitrogen hetero-atom(s) only, containing an unfused pyrazole ring, a pyrimidine ring, a piperazine ring, an unfused triazine ring or a phenothiazine ring system not further fused; hydantoin and its derivatives	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.32	Sulphonamides	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.40	Sugars, chemically pure, n.e.c.; sugar ethers and esters and their salts n.e.c.	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.51	Provitamins, vitamins and their derivatives	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.52	Hormones, derivatives thereof; other steroids, used primarily as hormones	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.53	Glycosides, vegetable alkaloids, their salts, ethers, esters and other derivatives	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.54	Antibiotics	Chemicals
20-Manufacture of chemicals and chemicals products	21.10: Manufacture of basic pharmaceutical products	21.10.60	Glands and other organs; extracts thereof and other human or animal substances n.e.c.	Chemicals
21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.11	Medicaments, containing penicillins or other antibiotics	Chemicals
21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.12	Medicaments, containing hormones, but not antibiotics	Chemicals

Annex I (continued)

21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.13	Medicaments, containing alkaloids or derivatives thereof, but not hormones or antibiotics	Chemicals
21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.21	Antisera and vaccines	Chemicals
21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.22	Chemical contraceptive preparations based on hormones or spermicides	Chemicals
21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.23	Diagnostic reagents and other pharmaceutical preparations	Chemicals
21-Manufacture of basic pharmaceutical products and pharmaceutical preparations	21.20: Manufacture of pharmaceutical preparations	21.20.24	Adhesive dressings, catgut and similar materials; first-aid boxes	Chemicals
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.11	New pneumatic tyres, of rubber, of a kind used on motor cars	Polymers
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.12	New pneumatic tyres, of rubber, of a kind used on motorcycles or bicycles	Polymers
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.13	New pneumatic tyres, of rubber, of a kind used on buses, lorries or aircraft	Polymers
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.14	Agrarian tyres; other new pneumatic tyres, of rubber	Polymers
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.15	Inner tubes, of rubber	Polymers
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.16	Camel-back strips for retreading rubber tyres	Polymers
22-Manufacture of rubber and plastic products	22.11: Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	22.11.20	Retreaded pneumatic tyres, of rubber	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.10	Reclaimed rubber in primary forms or in plates, sheets or strip	Polymers

Annex I (continued)

22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.20	Unvulcanised rubber and articles thereof; vulcanised rubber, other than hard rubber, in thread, cord, plates, sheets, strip, rods and profile shapes	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.30	Tubes, pipes and hoses, of vulcanised rubber other than hard rubber	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.40	Conveyor or transmission belts or belting, of vulcanised rubber	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.50	Rubberised textile fabrics, except tyre cord fabric	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.60	Articles of apparel and clothing accessories, of vulcanised rubber other than hard rubber	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.71	Hygienic or pharmaceutical articles (including teats), of vulcanised rubber other than hard rubber	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.72	Floor coverings and mats, of vulcanised rubber other than cellular	Polymers
22-Manufacture of rubber and plastic products	22.12: Manufacture of other rubber products	22.12.73	Other articles of vulcanised rubber n.e.c.; hard rubber in all forms and articles thereof; floor coverings and mats, of vulcanised cellular rubber	Polymers
22-Manufacture of rubber and plastic products	22.21: Manufacture of plastic plates, sheets, tubes and profiles	22.21.21	Artificial guts, of hardened proteins or of cellulosic materials; tubes, pipes and hoses, rigid, of plastics	Polymers
22-Manufacture of rubber and plastic products	22.21: Manufacture of plastic plates, sheets, tubes and profiles	22.21.29	Other tubes, pipes hoses and fittings of plastics	Polymers
22-Manufacture of rubber and plastic products	22.21: Manufacture of plastic plates, sheets, tubes and profiles	22.21.30	Plates, sheets, film, foil and strip, of plastics, not supported or similarly combined with other materials	Polymers
22-Manufacture of rubber and plastic products	22.21: Manufacture of plastic plates, sheets, tubes and profiles	22.21.41.50	Plates, sheets, film, foil and strip of cellular polyurethane	Polymers
22-Manufacture of rubber and plastic products	22.21: Manufacture of plastic plates, sheets, tubes and profiles	22.21.41.70	Plates, sheets, film, foil and strip of regenerated cellular cellulose	Polymers
22-Manufacture of rubber and plastic products	22.21: Manufacture of plastic plates, sheets, tubes and profiles	22.21.41.80	Plates, sheets, film, foil and strip of cellular plastics (excluding of polymers of styrene, of polymers of vinyl chloride, of polyurethanes, of regenerated cellulose)	Polymers

Annex I (continued)

22-Manufacture of rubber and plastic products	22.22: Manufacture of plastic packing goods	22.22.11	Sacks and bags (including cones), of polymers of ethylene	Polymers
22-Manufacture of rubber and plastic products	22.22: Manufacture of plastic packing goods	22.22.12	Sacks and bags (including cones), of other plastics than polymers of ethylene	Polymers
22-Manufacture of rubber and plastic products	22.22: Manufacture of plastic packing goods	22.22.13	Boxes, cases, crates and similar articles of plastics	Polymers
22-Manufacture of rubber and plastic products	22.22: Manufacture of plastic packing goods	22.22.14	Carboys, bottles, flasks and similar articles of plastics	Polymers
22-Manufacture of rubber and plastic products	22.22: Manufacture of plastic packing goods	22.22.19	Other plastics packaging goods (plastic stoppers, lids, caps cops, spools etc)	Polymers
22-Manufacture of rubber and plastic products	22.23: Manufacture of doors and windows of plastic	22.23.14	Doors, windows and frames and thresholds for doors; shutters, blinds and similar articles and parts thereof, of plastics	Polymers
22-Manufacture of rubber and plastic products	22.24: Manufacture of Builders ware of plastic	22.24.11	Floor, wall or ceiling coverings of plastics, in rolls or in the form of tiles	Polymers
22-Manufacture of rubber and plastic products	22.24: Manufacture of Builders ware of plastic	22.24.12	Baths, wash-basins, lavatory pans and covers, flushing cisterns and similar sanitary ware, of plastics	Polymers
22-Manufacture of rubber and plastic products	22.24: Manufacture of Builders ware of plastic	22.24.13	Reservoirs, tanks, vats and similar containers, capacity > 300 l, of plastics	Polymers
22-Manufacture of rubber and plastic products	22.24: Manufacture of Builders ware of plastic	22.24.15	Linoleum and hard non-plastic surface floor coverings, i.e. resilient floor coverings, such as vinyl, linoleum etc.	Polymers
22-Manufacture of rubber and plastic products	22.26: Manufacture of other plastic products	22.26.10	Apparel and clothing accessories (including gloves), of plastics	Polymers
23-Manufacturing of other non-metallic mineral products	23.65: Manufacture of fibre cement	23.65.11	Boards, blocks and similar articles of vegetable fibre, straw or wood waste, agglomerated with mineral binders	Construction
23-Manufacturing of other non-metallic mineral products	23.65: Manufacture of fibre cement	23.65.12	Articles of asbestos-cement, cellulose fibre-cement or the like	Construction
23-Manufacturing of other non-metallic mineral products	23.91: Manufacture of abrasive products	23.91.12	Abrasive powder or grain, on a base of textile fabric, paper or paperboard	Construction
26: Manufacture of Computer, electronic and optical products	26.11: Manufacturing of electronic components	-	Manufacture of capacitors, electronic - manufacture of resistors, electronic - manufacture of microprocessors - manufacture of electron tubes - manufacture of electronic connectors - manufacture of cables, printer cables, monitor cables, universal serial bus (USB) cables etc (NACE Rev2.1)	Electronics

Annex I (continued)

29-Manufacture of motor vehicles, trailers and semi-trailers	29.32: Manufacturing of other parts and accessories for motor vehicles	29.32.10	Seats for motor vehicles	Composites/ Polymers
29-Manufacture of motor vehicles, trailers and semi-trailers	29.32: Manufacturing of other parts and accessories for motor vehicles	29.32.20.90	Parts and accessories of bodies (including cabs and windows)	Composites/ Polymers
29-Manufacture of motor vehicles, trailers and semi-trailers	29.32: Manufacturing of other parts and accessories for motor vehicles	29.32.30.10	Bumpers and parts thereof (including plastic bumpers)	Composites/ Polymers
30. Manufacture of other transport equipment	30.99: Manufacturing of other transport equipment	30.99.10	Vehicles not mechanically propelled including industry trolleys, barrows, luggage trucks, hopper-trucks, hand pulled golf trolleys, shopping trolleys	Composites/ Polymers/ Wood working
31-Manufacture of furniture	31.00: Manufacture of furniture	31.00.12	Seats, primarily with wooden frames (cane, osier, bamboo or similar materials)	Woodwork ing
31-Manufacture of furniture	31.00: Manufacture of furniture	31.01.12	Wooden furniture of a kind used in offices	Woodwork ing
31-Manufacture of furniture	31.00: Manufacture of furniture	31.01.13	Wooden furniture for shops	Woodwork ing
31-Manufacture of furniture	31.00: Manufacture of furniture	31.03.11	Mattress supports	Woodwork ing
31-Manufacture of furniture	31.00: Manufacture of furniture	31.03.12.30	Mattresses of cellular rubber (including with a metal frame) (excluding water-mattresses, pneumatic mattresses)	Woodwork ing
31-Manufacture of furniture	31.00: Manufacture of furniture	31.03.12.70	Mattresses with spring interiors (excluding of cellular rubber or plastics)	Woodwork ing
32-Other manufacturing	32.30: Manufacturing of sport goods	32.30.14	Gymnasium, fitness centre or athletics articles and equipment	Wood working/co posites/Pol ymers
32-Other manufacturing	32.30: Manufacturing of sport goods	32.30.15.10	Leather sports gloves, mittens and mitts	Textiles
32-Other manufacturing	32.30: Manufacturing of sport goods	32.30.15.50	Articles and equipment for table-tennis (including bats, balls and nets)	Wood working
32-Other manufacturing	32.30: Manufacturing of sport goods	32.30.15.60	Tennis, badminton or similar rackets, whether or not strung	Wood working
32-Other manufacturing	32.30: Manufacturing of sport goods	32.30.15.90	Other articles and equipment for sport and open-air games, n.e.c	Wood working
32-Other manufacturing	32.40: Manufacturing of games and toys	32.40.11	Dolls representing only human beings	Polymers/Te xtiles
32-Other manufacturing	32.40: Manufacturing of games and toys	32.40.12	Toys representing animals or non-human creatures	Polymers/Te xtiles
32-Other manufacturing	32.40: Manufacturing of games and toys	32.40.20	Toy trains and their accessories; other reduced-size models or construction sets and constructional toys	Polymers/W ood working

Annex I (continued)

32-Other manufacturing	32.40: Manufacturing of games and toys	32.40.31	Wheeled toys designed to be ridden by children; dolls' carriages	Polymers/Composites/Wood working
32-Other manufacturing	32.40: Manufacturing of games and toys	32.40.39.00	Games and toys	Polymers/Composites/Wood working
32-Other manufacturing	32.40: Manufacturing of games and toys	32.40.42.70	Tables for casino games, automatic bowling alley equipment, and other funfair, table or parlour games, including pinteables (excluding operated by coins, banknotes 'paper currency', discs or other similar articles, billiards, video games for use with a television receiver, playing cards and electric car racing sets, having the character of competitive games)	Wood working/Polymers
32-Other manufacturing	32.50: Manufacturing of medical and dental instruments and supplies	32.50.23	Parts and accessories of prostheses and orthopaedic appliances	Polymers/Composites
32-Other manufacturing	32.50: Manufacturing of medical and dental instruments and supplies	32.50.30	Medical, surgical, dental or veterinary furniture; barbers' chairs and similar chairs and parts thereof	Polymers/Composites
32-Other manufacturing	32.50: Manufacturing of medical and dental instruments and supplies	32.50.41	Contact lenses; spectacle lenses of any material	Polymers/Composites
32-Other manufacturing	32.50: Manufacturing of medical and dental instruments and supplies	32.50.42	Spectacles, goggles and the like, corrective, protective or other	Polymers/Composites
32-Other manufacturing	32.50: Manufacturing of medical and dental instruments and supplies	32.50.43.90	Plastic frames and mountings for spectacles, goggles or the like	Polymers/Composites
32-Other manufacturing	32.50: Manufacturing of medical and dental instruments and supplies	32.50.44	Parts of frames and mountings for spectacles, goggles or the like	Polymers/Composites
32-Other manufacturing	32.91: Manufacturing of brooms and brushes	32.91.11.10	Brooms and brushes of twigs or other vegetable materials, bound together	Polymers/Composites
32-Other manufacturing	32.91: Manufacturing of brooms and brushes	32.91.11.90	Brushes, n.e.c	Polymers/Composites
32-Other manufacturing	32.91: Manufacturing of brooms and brushes	32.91.12	Tooth brushes, hair brushes and other toilet brushes for use on the person; artists' brushes, writing brushes and brushes for cosmetics	Polymers/Composites
32-Other manufacturing	32.91: Manufacturing of brooms and brushes	32.91.19.30	Paint brushes, distempering brushes, paper-hanging brushes and varnishing brushes	Polymers/Wood working
32-Other manufacturing	32.99: Other manufacturing n.e.c	32.99.11.30	Protective gloves, mittens and mitts for all trades, of leather or composition leather	Textiles
32-Other manufacturing	32.99: Other manufacturing n.e.c	32.99.11.60	Protective face shields/visors of plastics	Polymers

Annex I (continued)

32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.12	Ball-point pens and sliding pencils etc	Polymers
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.13	Fountain pens, stylograph and other pens	Polymers
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.14	pen or pencil sets and inks	Wood working
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.15.10	Pencils and crayons with leads encased in a sheath (excluding pencils for medicinal, cosmetic or toilet uses)	Wood working
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.30	Products of human or animal hair; similar products of textile materials (en)	Textiles
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.52	Scent sprays and mounts and heads	Chemicals
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.59.20	Articles of gut (excluding silkworm gut), goldbeater's skin, bladders or tendons	Art/Antiques
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.59.30	Carvings from animal material such as ivory, bone, tortoise shell, horn, antlers, coral, mother-of-pearl	Art/Antiques
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.59.40	Worked vegetable or mineral carving material and articles of these materials n.e.s; moulded or carved articles of wax, of paraffin, of stearin, of natural gums or natural resins or of modelling pastes, and other moulded or carved articles n.e.s; worked, unhardened gelatin, and articles of unhardened gelatin, n.e.s	Art/Antiques
32-Other manufacturing	32.99: Other manufactruing n.e.c	32.99.59.91	Wooden coffins	Wood working

Annex II: Classification of biomass feedstocks (Mainly adapted from (CIRCE 2022) with an addition of ‘secondary waste’ category).

CATEGORY	TYPE	FEEDSTOCK SUB-CATEGORY	SOURCE	SUB-TYPE FEEDSTOCK	EXAMPLES
<b>Primary dedicated</b>	Plant	Aquatic biomass	Marine	Aquatic plants and macroalgae	Seaweed, duckweed
				Microalgae and cyanobacteria	Spirulina, chlorella
		Lignocellulosic from croplands and grassland	Agriculture	Short rotation coppice (SRC)	Willow, poplar
				Agricultural fibres	Cotton, Flax, Hemp, Jute, Sisal, Coir
				Herbaceous perennials and grasses	Miscanthus, Giant reed, Reed canary grass, Switchgrass
		Lignocellulosic wood/forestry	Forest	Softwood	Pine, Spruce, Fir
				Hardwood	Oak, Birch, Beech
				Cork	Cork (cork oak)
		Oil crops and plants	Agriculture	Oil crops	Soybean, Rapeseed, Sunflower, Canola, Castor beans, Linseed
				Oil plants (fruit, nut)	Coconut, Olive, Jatropha curcas
	Starch crops	Agriculture	Edible grains	Wheat, corn, barley, rye, oat, rice	
			Tubers	Potato, Cassava	
	Sugar crops	Agriculture	Sugar crops	Sugar cane, sugar beet	
	Other primary biomass	Agriculture/ Forest/ Marine	Natural resins	Natural latex (rubber tree), natural dyes, amber	
	Animal	Livestock-based biomass	Agriculture	Fibres of animal origin	Wool, silk
				Marine animals	Marine
		Marine arthropods	Crab, shrimp, lobster		
	Microbial	Microbial biomass	Industry	Enzymes	Xylanases, amylases, proteases, cellulases
				Bacteria	Nocardioides nitrophenolicus, Rhodococcus opacus
Protist				Heterotrophic protist	
Fungi				Fungal biomass	
<b>Primary/Harvest residues</b>	Plant	Residues from agriculture	Agriculture	Agricultural field residues	Straw (wheat, rice), Leaves (sugar beet), Stover (corn), Sugarcane trash, Oil palm fronds

Annex II (continued)

		Residues from forestry	Forest	Forest field residues	Logging residues, branches, stumps, foliage, roots
		Residues from nature and landscape management	Urban	Biomass from nature and landscape management	Green biomass (grass clippings), Tree pruning, felling
		Residues from aquatic biomass cultivation	Marine	Residues from aquatic biomass cultivation	Residues from aquatic biomass cultivation
	Animal	Animal-based residues	Agriculture	Animal manure	Dry manure (poultry, sheep & goat, cattle), Wet manure (pig, cattle)
<b>Secondary/Production/Processing residues</b>	Plant	Residues from agro-food industry	Industry	Sugar crop processing residues	Sugar beet pulp, Sugarcane bagasse
				Starch crop processing residues	Potato peels, Rice husks, Corn cobs
				Oil crop and plant processing residues	Empty fruit bunch, Mesocarp fibre, Palm kernel shell & meal, Soy hulls, Nut shells, Olive stones
				Other industry residues using agricultural products	Cotton acorn, coffee silverskin
				Residues from fermentation	Distiller's dried grains with solubles (DDGS)
	Residues from forest-based industry (woodworking, pulp & paper)	Industry	Secondary forestry residues	Sawdust, bark, brown and black liquor, fibre sludge, lignin and tall oil, cutter shavings	
	Animal	Residues from fish and arthropods processing	Industry	Secondary marine residues	Arthropods shells, fish scales and bones, muscles and oils
Residues from meat processing industry				Industry	Animal by-products from slaughterhouses
<b>Primary wastes</b>	Mix	Post-consumer wastes/Consumption residues	Urban + Industry	Organic fraction municipal solid waste (MSW)	Food waste, garden waste and other fermentable materials
				Biowaste (separately collected)	Food and kitchen waste from households, restaurants, retail
				Recyclable materials	Textiles and clothing, Paper and cardboard & Plastics

				Used cooking oil	Used cooking oil (from restaurants, households and others)
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*Annex II (continued)*

		Post-consumer and industrial waste wood	Urban	Post-consumer wood	Used furniture
			Industry	Industrial waste wood	Demolition wood, bulk transport packaging
		Sewage and wastewater sludge	Industry	Sewage and wastewater sludge from industry	Industrial wastewater and sludge
			Urban	Sewage and wastewater sludge from municipalities	Sewage sludge and wastewater from municipalities
<b>Secondary waste</b>	Mix	Sorting residues	Industry	Waste from mechanical sorting process of waste, combustible waste, non-composted fraction of biodegradable waste	Sorting residues, uncomposted residues.
		Sludges and liquid waste	Industry	These wastes comprise different types of sludges and liquid wastes from waste treatment facilities. They include wastes from the physico/chemical treatment of hazardous wastes, liquids and sludges from the anaerobic treatment of waste, landfill leachate and effluent treatment sludges from oil regeneration. Sludges and liquid wastes from waste treatment are hazardous and non-hazardous.	Sludges generated from chemical treatment

Annex III: Classification of biorefineries based on conversion processes (Mainly adapted from (Platt et al. 2021) with addition of end products related to each conversion process.

Conversion process category	Conversion process	Description	End products
Biochemical	Aerobic conversion	The aerobic process is a method that depends on microorganisms that flourish in environments with sufficient oxygen and an adequate supply of nutrients(Platt et al. 2021).	CO <sub>2</sub> , nitrate, phosphate(Shabbir et al. 2021)
	Anaerobic digestion	Process in which microorganisms break down biodegradable materials in the absence of oxygen. It is also called methanization(Platt et al. 2021).	Digestate (fertilizer), Biogas, liquid biofuels(Platt et al. 2021; Tursi 2019b)
	Enzymatic process	Enzymes are biocatalysts, meaning that any chemical reaction or series of reactions catalyzed by an enzyme is referred to as an enzymic or enzymatic process. An enzyme is a protein that functions as a highly selective catalyst, allowing reactions to occur quickly within living cells under physiological conditions(Platt et al. 2021).	Monomers, Biofuels(Platt et al. 2021)
	Fermentation	This is an anaerobic process that breaks down glucose within organic materials. It involves a series of biochemical reactions that convert sugars into alcohol or acid. Yeast or bacteria are introduced to the biomass material, where they consume the sugars and produce ethanol and carbon dioxide as by-products(Platt et al. 2021).	Ethanol, Ethylene,ethylamines, CO <sub>2</sub> (Platt et al. 2021; Gavrilescu 2014)
	Insect-based Bioconversion (Insect farming)	This process involves the selection and cultivation of specific insect species, such as Black Soldier Fly (BSF) larvae, house fly maggots, mealworms, and grasshoppers or crickets, using various rearing substrates. The primary advantages of this conversion process include waste reduction and the production of high-quality proteins and valuable by-products such as oil, natural fertilizer, and chitin can be extracted(Platt et al. 2021).	Byproducts (Oil, Fertilizers, Chitin) (Platt et al. 2021)
Chemical	Catalytic	A chemical process using catalysts to selectively speed up reactions by lowering the required energy and targeting specific chemical breakdowns(Platt et al. 2021).	Biooil(Gavrilescu 2014)
	Esterification	Esterification is the reaction between alcohols and carboxylic acids, acyl chlorides, or acid anhydrides to form esters(Platt et al. 2021).	Liquid fuels, Glycerol, esters(solvents, pharmaceuticals, fragrances, plasticizers)(Tursi 2019b; Platt et al. 2021).
	Hydrogenation	Hydrogenation is a reaction where hydrogen atoms are added to an unsaturated compound to reduce double and triple bonds. Molecular hydrogen or transfer hydrogenation compounds serve as the hydrogen source, and this process is important for upgrading bio-intermediates into chemical building blocks(Platt et al. 2021).	Chemical building blocks(Platt et al. 2021)
	Hydrolysis	Hydrolysis is a chemical reaction where water breaks down bonds in a substance. It involves separating chemicals by adding water and occurs in three main forms: salt, acid, and base hydrolysis(Platt et al. 2021).	Fermentable sugars, biofuel, ethanol(Gavrilescu 2014)
	Methanation	Methanation is a chemical reaction where carbon oxides and hydrogen are converted into methane and water using a catalyst(Platt et al. 2021).	Methane, H <sub>2</sub> O(Platt et al. 2021)
	Chemical Pulping	The process of separating cellulose fibers from biomass, primarily wood, can be achieved through mechanical, chemical, or thermomechanical/chemical methods. The most common chemical pulping method is the Kraft process, which uses sodium sulfate and is favored for its	Pulp

		strong pulp and suitability for all wood types. Sodium sulfite is also used, and newer, more environmentally friendly methods, such as those involving ionic solvents or supercritical CO <sub>2</sub> , are emerging(Platt et al. 2021).	
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*Annex III (continued)*

	Steam reforming	Steam reforming is a common method to produce hydrogen-rich syngas from light carbohydrates, including biomass and its derivatives. This process is promising for bio-hydrogen production, but the key challenge lies in identifying suitable catalysts and optimal operating conditions for each type of feedstock to maximize hydrogen yield(Platt et al. 2021).	Syngas, Biohydrogen(Platt et al. 2021)
	Water electrolysis	During electrolysis, electricity splits water into oxygen and hydrogen. The hydrogen can be used as fuel or combined with biogenic carbon dioxide to create hydrocarbons through synthesis. This process is often integrated with gasification and pyrolysis to produce hydrogen(Platt et al. 2021).	Hydrogen and Oxygen(Platt et al. 2021)
	Water gas shift	The water gas shift process adjusts the CO/H <sub>2</sub> ratio in syngas from gasification by reacting it with steam. This reaction splits water into hydrogen and oxygen, with the oxygen reacting with some CO in the syngas to form CO <sub>2</sub> . This adjusts the H <sub>2</sub> /CO ratio, but excess CO <sub>2</sub> may need to be removed(Platt et al. 2021).	Hydrogen, Co <sub>2</sub> (Platt et al. 2021)
Mechanical and thermomechanical	Blending	Blending is used to adjust the specifications of materials for various purposes, such as combining feedstocks to meet emission standards, reduce ash production during power generation(Platt et al. 2021).	Improved or enhanced products(Platt et al. 2021).
	Extraction	Extraction is a recovery and purification technique that involves separating impurities or valuable compounds from a bulk phase using a solvent that selectively binds to the desired substance. This process includes liquid-liquid and solid-phase extraction. It's often used for compounds with higher boiling points than water, which makes it more energy-efficient than distillation(Platt et al. 2021).	Fuels, oleochemicals(Gavrilescu 2014)
	Fibre separation	Fibre separation involves extracting fibres from non-fibrous tissues and the woody part of the stem by dissolving and decomposing pectins, gums, and other substances. Bacteria and moisture may be used to break down these substances, loosening the fibres for easier extraction. The fibres are then mechanically separated, washed, dried, and prepared for market, in a process known as retting(Platt et al. 2021).	Fibres(Platt et al. 2021)
	Mechanical and thermomechanical disruption and fractionation	This process modifies the shape, particle size, bulk density, and moisture content of biomass. These processes use mechanical energy to separate raw biomass into liquid fractions, such as green juice, and solid fractions. They also include techniques like mechanical pressing for extracting seed oils, screw pressing, biomass spraying, and steam explosion(Platt et al. 2021).	Oils,(Platt et al. 2021)
	Mechanical pulping	Mechanical pulping involves breaking down wood into individual fibers through processes such as refining, grinding, shearing, and disintegration(Mboowa 2021).	Fibers(Mboowa 2021)
	Separation process	This involves dividing a substrate into its individual components using methods such as distillation, evaporation, crystallization, filtration, and membrane separation.	Biofuels, heat and electricity, biomaterials(Gavrilescu 2014)
	Thermochemical	Combustion	This is a chemical reaction in which a fuel reacts with an oxidizer (typically oxygen) and heat. The interaction between the fuel and the oxidizer results in the formation of new chemical substances(Platt et al. 2021).
Gasification		Process used to produce syngas and char at high temperatures/pressure in presence of controlled amount of oxygen (or air) and steam(Jha et al. 2022; Platt et al. 2021). This process can be performed through either conventional gasification or hydrothermal gasification (HTG).  Conventional gasification transforms biomass into hydrogen-rich syngas at temperatures exceeding 800 °C, utilizing a gasifying agent such as air, steam, CO <sub>2</sub> , or a combination of these. On the other hand, HTG takes place in the presence of water at temperatures and pressures above the critical point of water (temperature over 374 °C and pressure greater than 22.1 MPa)(Jha et al. 2022).	Syngas, Char, fertilizers, pure hydrogen, methane, biofuels(Tursi 2019b; Platt et al. 2021).

Annex III (continued)

	Pyrolysis	<p>Pyrolysis is the thermal breakdown of lignocellulosic biomass in the absence of oxygen at temperatures between 300 and 550 °C (Jha et al. 2022).</p> <p>There are generally three types of pyrolysis, each producing different ratios of the three main products: slow pyrolysis (primarily yielding char), medium pyrolysis (producing both char and pyrolysis oil), and fast pyrolysis (mainly producing pyrolysis oil). Slow pyrolysis is also known as carbonization(Platt et al. 2021).</p>	Pyrolysis oil, Char, gases(Platt et al. 2021)
	Hydrothermal liquefaction (HTL)	<p>HTL is a process that increases the energy content of wet organic streams, converting biomass into a heavy oil (biocrude) without the need for drying. Feedstocks like black liquor, lignin, and sawdust sludge can be transformed into bio-crude through HTL, which can then be hydrogenated to produce diesel, kerosene, or other chemical products(Platt et al. 2021).</p>	Biocrude, chemical products, Syngas(Platt et al. 2021; Tursi 2019b)
	Supercritical conversion	<p>Supercritical conversion occurs at temperatures and pressures above the critical point of water. The main processes include supercritical water gasification (SCWG) and supercritical water oxidation. SCWG is a promising method for converting wet biomass and waste streams into hydrogen or methane, while supercritical water oxidation is particularly useful for degrading harmful and toxic materials(Platt et al. 2021).</p>	Hydrogen, Methane(Platt et al. 2021)
	Torrefaction and carbonization	<p>Processes that convert biomass into a coal-like material with higher energy density and hydrophobic properties compared to the original biomass(Platt et al. 2021).</p> <p>These are two branches of the pyrolysis(Amer and Elwardany 2020).</p>	Biofuels(Gavrilescu 2014)



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