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**Forests and the Circular Economy**

AGENDA ITEM 4

# Circularity concepts in forest-based industries

UNEDITED VERSION

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## Abbreviations

| | |
|---|---|
| Btu | British Thermal Unit |
| CEPI | Confederation of European Paper Industries |
| CEI-BOIS | European Confederation of Woodworking Industries |
| CO2 | Carbon dioxide |
| CSCM | Circular Supply Chain Management |
| ECE | United Nations Economic Commission for Europe |
| EEA | European Environment Agency |
| EPA | United States Environmental Protection Agency |
| EU | European Union |
| EUROSTAT | Statistical office of the EU within the European Commission |
| FAO | Food and Agriculture Organization of the United Nations |
| FSC | Forest Stewardship Council |
| GHG | Greenhouse gases |
| IEA | International Energy Agency |
| ISIC | International Standard Industrial Classification of All Economic Activities |
| ITC | International Trade Centre |
| ITTO | International Tropical Timber Organization |
| kJ | Kilojoule |
| mm | Millimeters |
| Mt | Metric tonnes |
| NACE | Statistical Classification of Economic Activities in the European Community |
| OECD | Organisation for Economic Co-operation and Development |
| OSB | Oriented Strand Board |
| PACE | Platform for Accelerating the Circular Economy |
| PEFC | Programme for the Endorsement of Forest Certification |
| SDG | Sustainable Development Goals |
| SFM | Sustainable Forest Management |
| SME | Small and medium-sized enterprises |
| TCO | Total Cost of Ownership |
| UEA | European Federation of Furniture Manufacturers |
| VCA | Value Chain Analysis |
| WWF | World Wildlife Fund |

# Part 1
# Setting the Stage for a Circular Forest Sector

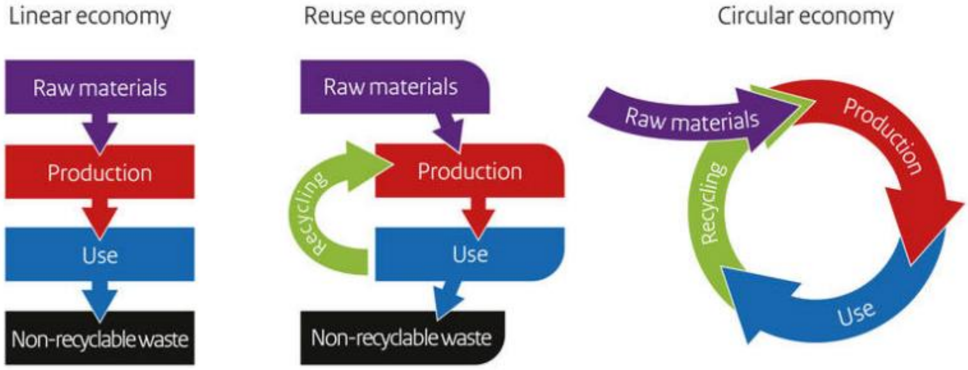
# 1. Introduction

In the face of pressing socio-economic and environmental challenges coupled with an extreme use of natural resources, the concept of a circular economy has emerged as a promising sustainable paradigm that is attracting significant public and private interests. This is reflected in policy instruments and strategies, research, as well as private sector commitments to circularity. Reference to circularity principles can be found, among others in Sustainable Development Goals (SDGs), in particular Goal 12[1], calling for responsible consumption and production, the European Union (EU) Circular Economy Action Plan (EC, 2020a), and the Platform for Accelerating the Circular Economy (PACE),[2] launched by the World Economic Forum. However, although the potential of a circular economy concept is recognized in policy, there is no clear and cross-cutting definition of what circularity means, often being mixed up with sustainability concepts and, at times, the bioeconomy (Kirchherr et al., 2017).

The concept of a circular economy is commonly characterized as a way to reduce resources consumption by slowing, closing and narrowing resource loops (Geissdoerfer et al., 2017). For instance, the Ellen MacArthur Foundation has defined a circular economy as an "*industrial economy that is restorative and regenerative by intention and design*", relying on three principles, namely, the (*i*) preservation and enhancement of natural capital, (*ii*) optimization of resource yields and (*iii*) fostering systems effectiveness (EMF, 2012, 2015).

On the other hand, the European Commission (EC) has defined a circular economy as a process by which "*the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised*" (EC, 2020a). From these different perspectives, a circular economy is fundamentally about the responsible and cyclical use of natural resources achieved by designing out waste, keeping materials and products in use for as long as possible, and regenerating natural systems (CGRI, 2019).

Figure 1. The linear, reuse and circular economy.




*Source:* Government of the Netherlands, https://www.government.nl/topics/circular-economy.

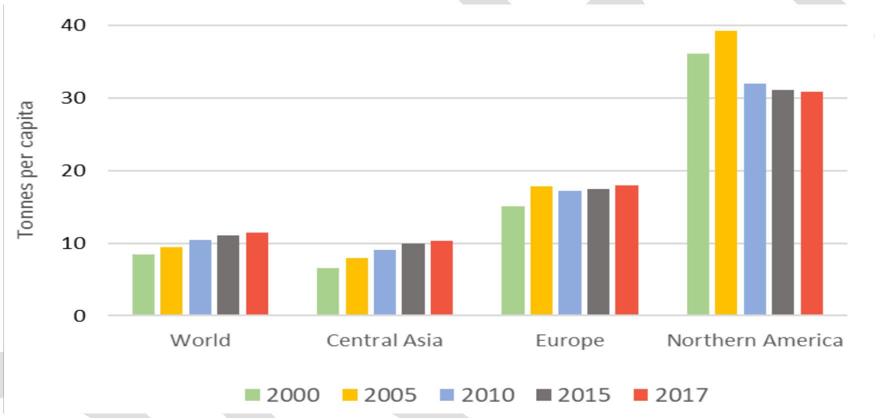
In a nutshell, circularity is based on the idea that economic growth needs to be decoupled from the growth in finite material consumption. The reason for considering circularity and the prospects of a circular economy resides in the fact that current linear economy model (take, make and dispose)

[1] See www.un.org/sustainabledevelopment/sustainable-consumption-production/.
[2] See https://pacecircular.org/.

depends on an unsustainable output of materials that are extracted and processed into goods, and, in the end, disposed of as non-recyclable waste (Figure 1).

This linear approach can be set against the background that global use of materials has almost tripled since 1970 and it is accelerating. For the ECE region, material production has increased from around 13 billion tonnes in 1970 to approximately 20 billion tonnes from 1998 (ECE, 2019). It can be noted that the average material footprint per capita generated by the ECE region has been at about 25 tonnes, annually, since 2010. However, there are significant variations within the region (Figure 2). Global consumption of materials, such as biomass, fossil fuels, metals and minerals are expected to double in the next forty years (OECD, 2019b). These trends are not sustainable. Moreover, material use contributes significantly to climate change, while the extraction and production of materials have negative effects on land use, ecosystems, eutrophication, and acidification, as well as affecting freshwater and terrestrial toxicity. These examples demonstrate why society and industry have been calling for systemic change.

Figure 2. Material footprint per capita, tonnes, 2000, 2005, 2010 and 2017, in the ECE.




*Source*: ECE (2019).

The current economic models, based on linear processes of production, consumption and disposal, cannot sustain the projected levels of natural resource use (Figure 3). The current rate of natural resource use means that 1.75 planets is needed to support current global demand for natural resources.[3] Moreover, it can be noted that 62 per cent of global greenhouse gas emissions (not including land use and forestry) come from the extraction, processing and manufacturing of goods while 38 per cent are emitted in the delivery and use of products (CGRI, 2020). This implies that the linear production cycle has led to an economic model that is not sustainable.

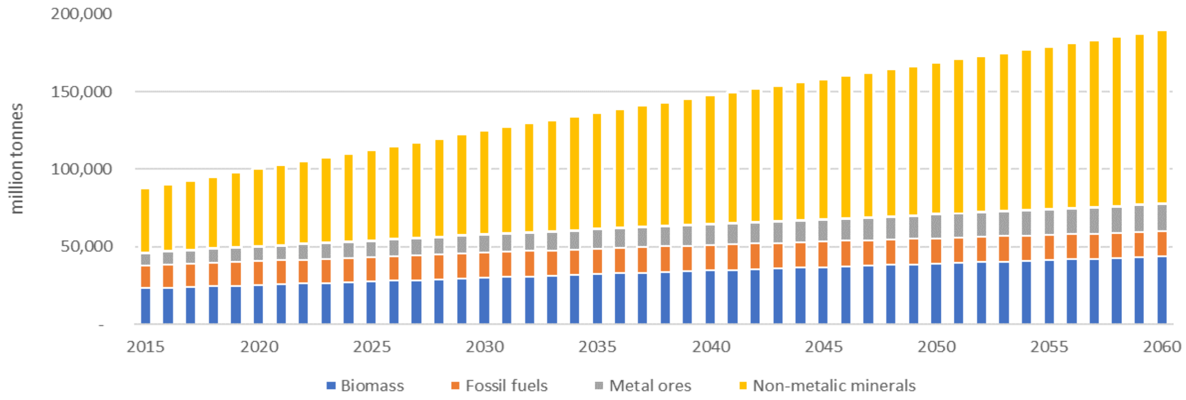
It can also be noted that, despite a recent surge of interest in circularity, the linear production model is still overwhelmingly present. For instance, the most recent Circularity Gap Report 2020 demonstrates that the global economy is presently only in 8.6 per cent circular (CGRI, 2020). This means that from all the minerals, fossil fuels, metals and biomass that enter the global economy every year, only 8.6 per cent is being cycled back (EMF, 2020).[4] In addition, the degree of circularity

[3] See www.overshootday.org.

[4] Cycled back implies that the material is collected, sorted and processed for use in the same, or other, manufacturing processes. This includes maintaining/prolonging, reusing/redistributing, refurbishing/remanufacturing and recycling but excludes incineration or discharges to land, water or air that threaten the environment or human health (EMF, 2020).

has dropped from 9.1 per cent when the first circularity report was launched in 2018. In contrast, the EU reported that the rate of circularity of material use was 11.2 per cent in 2017,[5] so marginally better, but still far away from being circular.

Figure 3. Projected global material extraction, 2015 to 2060.




*Source*: UNEP (2019).

In that context, there is a need to explore what circular economy means for the use of forest-based resources and how circularity concepts are already applied in forest-based industries; what good practice is already in place and where possible limitations are. While no reliable statistics are available concerning the degree of circularity in the forest-based sectors, forests have the potential to play an important role in a circular economy, mainly, because they provide a strategic natural resource that can be used for creating reusable and recyclable materials. Moreover, wood is renewable and biodegradable, has qualities that can store carbon, so even in instances where it cannot be reused or recycled, it can be returned to the biosphere (e.g., in the form of nutrients). For these reasons, forest-based sectors are unique in their capacity to offer solutions to global socio-economic and environmental challenges, as part of a circular economy.

## 1.1. Background and objectives

A circular economy concept is communicated as being a promising framework that has much to bring towards addressing some of our most pressing challenges, such as how to tackle climate change, while boosting resource efficiency and use. However, given the many definitions and applications associated with a circular economy framework and circularity (Kirchherr et al., 2017; Korhonen et al., 2018b; Reike et al., 2018), it is relevant to have a shared understanding. This study will consequently begin by describing some of the different concepts, ideas and paradigms underlying circularity. The general objective will be to bring some conceptual clarification.

The second objective will be to consider the potential for implementing a circular economy framework across different value chains of the forest-based sector. The reason for taking a value chain approach resides on the fact that opportunities for closing the loop on products and raw materials are fundamentally interlinked with the structure of the respective value chains. In other words, the prospects for a circular economy depend on how the sector is structured. It is therefore important to analyze the extent to which different sub-sectors could become circular. It can further

[5] See https://ec.europa.eu/eurostat.

be noted that material value and physical properties of the material have an influence on the prospects for circularity (e.g., higher valued material or lower recovery costs and rare materials may equate to more incentive while lower valued or higher recovery costs and plentiful materials equate to less incentive).

Finally, it is important to note that that circularity does not always equal sustainability, or economic viability. Although the consideration of these aspects falls outside the scope of this study, effort has been made to recognize, that successful implementation of circular approaches is related to their economic feasibility, their practicality, as well as their impact on environment and human health.

## 1.2. Structure of the study

- ⇒ Part 1 sets out the background and objectives of the study and provides an initial introduction to what a circular economy means.

- ⇒ Part 2 describes a circular economy framework. In addition, given the many definitions and applications associated with a circular economy framework, it proposes a conceptual understanding of circularity for the forest-based sectors.

- ⇒ Part 3 outlines the forest-based sectors (woodworking industry, furniture industry, paper and pulp industry, as well as cellulose-based fibers and plastics) and their respective values chains. Further, it considers how circularity could be implemented across different parts of the forest-based sectors value chains and what the implications and limitations for the respective sectors may be on the way to become more circular.

- ⇒ Part 4 considers possible implications, challenges and opportunities related to circular approaches in forest-based industries. It also summaries some of the key messages from the preceding sections.

- ⇒ Part 5 will present conclusions from the study.

# Part 2
# Defining a Circular Economy

# 2. What is a circular economy?

## 2.1. Origins of circularity

A circular economy framework is older and more diverse than what is commonly recognized. It can be seen as a continuation of ideas starting at the onset of modern industrial practices dominated by a linear production model and initial attempts to repurpose objects and materials. The initial ideas surrounding reuse mainly came from trying to optimize the use of resources, not necessarily from circular thinking. For instance, one economic driver in a circular economy stem from a possibility to use materials that are disposed in a linear economy model (Figure 1).

Circularity is not based on any particular economic model or theory; however, a circular economy concept is significantly rooted in ecological and environmental economics as well as industrial ecology (Kapur and Graedel, 2004; Lieder and Rashid, 2016). In the “spaceman economy”, which is often credited for providing the first reference to a circular system, Boulding (1966) introduced the concept of a closed system and noted that all outputs from consumption would need to be constantly recycled to become inputs for production. This, and other contributions, such as “Limits to Growth” (Meadows et al., 1972) and “Overshoot” (Catton, 1980), and more recently, “Cradle-to-Cradle” design (Braungart and McDonough, 2002)[6] and the “Performance Economy” (Stahel and Clift, 2016), have provided a background for a circular economy to develop as a concept. Formally, the circular economy was introduced by Pearce and Turner (1990) in their review of the traditional linear economic system. They drew their ideas from the principle that everything is an input to everything else when they developed their “circular economy” model. This was the metaphorical birth of the circle economy concept.

During the earlier stages of the circular economy, circularity was mostly about waste management and recycling for different waste streams (Reike et al., 2018). These efforts were focused on technological innovations and finding ways to turn waste into a valuable input for other processes. In contrast, practices of reusing or remanufacturing materials and systematically reducing material consumption remain rare to this day (Ghisellini et al., 2016; Ritzén and Sandström, 2017), in particular, as the implementation of a circular economy entails a major transformation of current production and consumption patterns.

In the last 20 years, circularity has moved beyond its focus on reducing waste and increasing recycling, towards a more comprehensive socio-economic approach. This builds more on a systems-perspective with regards to resource use, taking into account the objectives of the Rio Declaration, amongst other things (UN, 1992). Also, the 2030 Agenda for Sustainable Development (UN, 2015), while not explicitly addressing circularity (Box 1), highlights the importance of a transition to circularity for successfully achieving the SDGs (Schroeder et al., 2019).

[6] See www.c2ccertified.org/about/about.

Box 1. Circularity and the Sustainable Development Goals.


A circular economy does not per se imply sustainability, it has to be made sustainable. In fact, while the aim of a circular economy and the SDGs may appear to be the same, the term "circular economy" does not occur in the **2030 Agenda for Sustainable Development** (UN, 2015).

There are nevertheless important interlinkages between a circular economy and the SDGs. More specifically, circular economy practices can contribute (directly and indirectly) towards achieving a sizeable number of the SDG targets.

A recent study by Schroeder et al. (2019), highlighted that circular economy practices can contribute to achieving 21 of the 169 SDG targets and indirectly contribute to an additional 28 SDG targets. The study notes that the strongest relationships exist between a circular economy and targets of **SDG 6** (Clean Water and Sanitation), **SDG 7** (Affordable and Clean Energy), **SDG 8** (Decent Work and Economic Growth), **SDG 12** (Responsible Consumption and Production) and **SDG 15** (Life on Land). Circular economy practices furthermore offer the potential to create synergies between other SDGs, such as those aiming for biodiversity protection in the oceans (SDG 14) and on land (SDG 15) and those promoting economic growth and jobs (SDG 8), eliminating poverty (SDG 1), ending hunger and sustainable food production (SDG 2).

In summary, these results demonstrate that the implementation of a circular economy may be an important component for successful implementation of several SDGs.

Source: Schroeder et al. (2019).

Also, the EU has been considerably active in promoting circularity on the international stage. Its conceptual work on a circular economy has influenced international organizations, such as the United Nations Environment Programme (UNEP, 2018b) in defining targets, and in highlighting the importance of circularity in policymaking. The idea of transitioning to a circular economy has been articulated in the EUs action plan for a circular economy, as part of its strategy for industry in Europe, and the European Green Deal (EC, 2015, 2019, 2020a, b). In so doing, the EU has ensured that circularity will stay on the political agenda for the foreseeable future, at least in Europe.

The discourse on circularity has increasingly been followed by the business world (CGRI, 2020). The World Economic Forum and the World Business Council for Sustainable Development have been advocating for social, economic and environmental benefits via circular business models and policies. The work by the Ellen MacArthur Foundation[7] is another example of this trend (EMF, 2012, 2015).

[7] The Ellen MacArthur Foundation develops and promotes the idea of a circular economy. Its aim it to educate society on the merits and possibilities of building circularity into all economic activity (see www.ellenmacarthurfoundation.org).

## 2.2. Defining a circular economy

The idea behind circularity has been influenced by several concepts and ideas, over time, and remains a contested concept, with a diversity of conflicting approaches. In fact, a systematic analysis of circular economy definitions identified 114 different ones (Kirchherr et al., 2017). Conflicting perspectives on what a circular economy means on a conceptual level prevail in the literature. There is for example one strand of work that wants to operationalize circularity within the boundaries of the current economic system (Fullerton, 2015; Rifkin, 2011), while another strand of work seeks transformation of the socio-economic order (Latouche, 2009; Trainer and Alexander, 2019). They differ fundamentally in their views regarding the capacity of society to overcome resource limits and to decouple ecological degradation from economic growth (Calisto Friant et al., 2020). These opposing perspectives demonstrate that the concept is still fuzzy. This remains a key reason for criticism of the concept and reduces its overall appeal and impact. Despite milestone publications, such as the Circularity Gap Report (CGRI, 2020), the diversity of definitions makes it also difficult to measure it.

Notwithstanding the varied approaches to circularity, it can be noted that most definitions focus on **material use** and/or on **system change** to different degrees:

- Definitions that focus on material use commonly follow the three guiding principles of **reducing** (minimum use of raw materials), **reusing** (maximum reuse of products), and **recycling** (high quality reuse of raw materials). This is also known as the three Rs of sustainability or the **3R-approach**. (Korhonen et al., 2018b).
- Definitions that focus on system change concentrate on closing production cycles while using renewable energy and applying system thinking (Korhonen et al., 2018b).

Arguably, the 3R-approach may relate more to a reuse economy (Figure 1), while in a closed loop system it is not only important that materials are recycled properly, but that products and raw materials retain a high quality. There is also a more comprehensive **9R-approach**, developed by UNEP, which may be seen as combination of the two approaches. It includes: **R**efuse, **R**ethink, **R**educe, **R**euse, **R**epair, **R**efurbish, **R**emanufacture, **R**epurpose, **R**ecycle, and **R**ecover (Figure 4).

Another distinguishing factor of a circular economy is the recognition that certain materials are not recyclable. For instance, since it is not possible to recycle energy, there is commonly no consideration of energy cycles but rather the cascading use of certain materials. Examples include the co-production of heat and power by the paper and pulp industry using by-products such as black liquor.[8] Questions do however remain as to whether this can be considered as being a circular approach as energy production is a dead-end path for biomass.[9] In terms of system thinking, it is key to follow the example of an industrial ecosystem, where short- and long-term consequences must be considered and, more importantly, the impact across the entire value chain is taken into account (see page 22).

[8] Black liquor is the by-product from the kraft process when digesting pulpwood into paper pulp removing lignin, hemicelluloses and other extractives from the wood to free the cellulose fibers. It is the black liquor that can be burnt for heat and/or power.

[9] FAO defines biomass as organic material (both above-ground and below-ground) and both living and dead, (such as trees, crops, roots) (FAO, 2009) while the European Commission defines biomass as "*the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste*" (Directive 2009/28/EC).

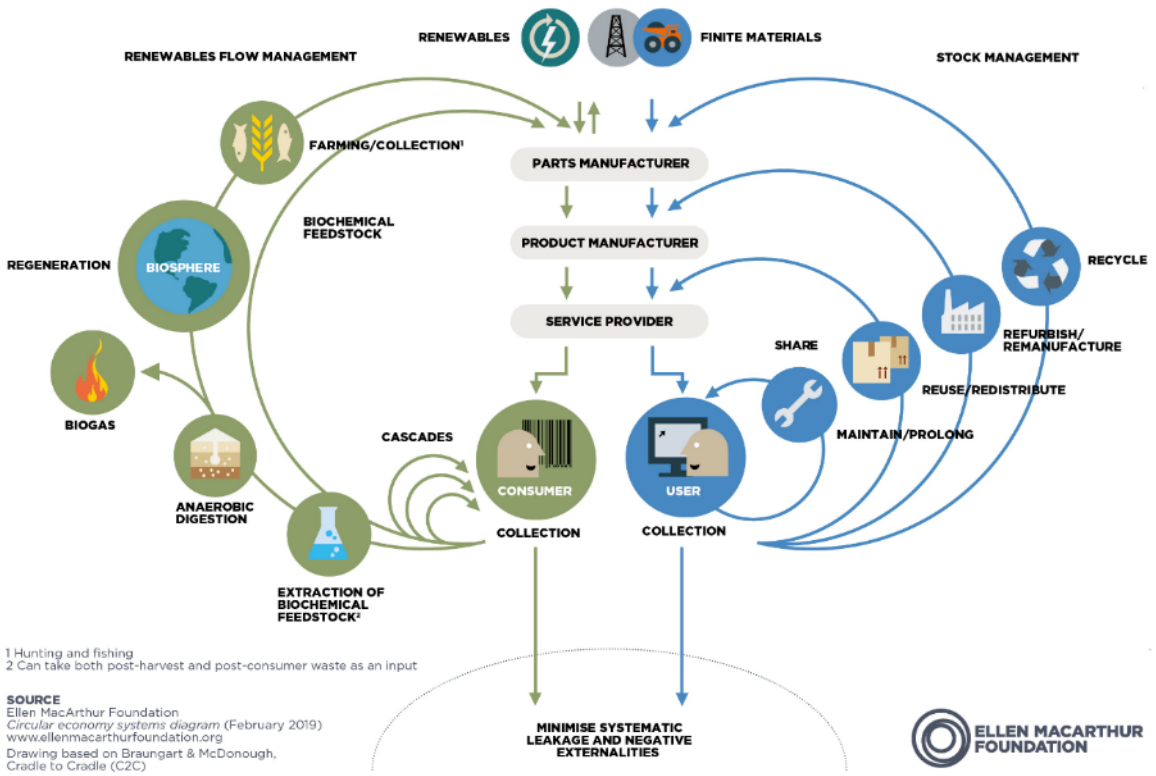
Figure 4. Circularity and the 9Rs.

| Circular economy ↑ Increasing circularity ↓ Linear economy | | | |
|---|---|---|---|
| | **Smarter product use and manufacture** | **R0 Refuse** | Make product redundant by abandoning its function or by offering the same function with a radically different product. |
| | | **R1 Rethink** | Make product use more intensive (e.g. by sharing product). |
| | | **R2 Reduce** | Increase efficiency in product manufacture or use by consuming fewer natural resources and materials. |
| | **Extend lifespan of product and its parts** | **R3 Reuse** | Reuse by another consumer of discarded product which is still in good condition and fufils its original function. |
| | | **R4 Repair** | Repair and maintenance of defective product so it can be used with its original function. |
| | | **R5 Refurbish** | Restore an old product and bring it up to date. |
| | | **R6 Remanufacture** | Use parts of discarded product in a new product with the same function. |
| | **Useful application of materials** | **R7 Repurpose** | Use discarded product or its parts in a new product with a different function. |
| | | **R8 Recycle** | Process materials to obtain the same (high grade) or lower (low grade) quality. |
| | | **R9 Recover** | Incineration of material with energy recovery. |

*Source*: Ellen MacArthur Foundation (see https://www.ellenmacarthurfoundation.org).

Although there is no commonly agreed definition of the circular economy, there are a few which are used more than others. For instance, the Ellen MacArthur Foundation describes a circular economy, both in terms of material use and from a systems perspective, as a global economic model that aims to minimize the consumption of limited resources. The focus is on the design of materials, products and systems (EMF, 2012, 2015), drawing on cradle-to-cradle principles and system thinking (Braungart and McDonough, 2002). The basic idea is that the circularity of products is considered at every stage of their lifecycle: during the conceptualization, design, development, use, and disposal of the product (Su et al., 2013). This forms the basis for the 3R-approach in a closed loop - 9R-approach (Figure 5). The overall goal is to minimize the resources and energy put into the system and turning what was once considered waste into inputs. In this model, it is assumed that emissions associated with resource extraction and waste management decrease in line with the reduction in resource extraction. This interpretation of circularity involves two different types of materials, namely, materials of biological origin that can return to the biosphere as feedstock, such as biomass products, and technical materials, which cannot biodegrade, but can circulate in closed loops, such as plastics and metals (Figure 5).

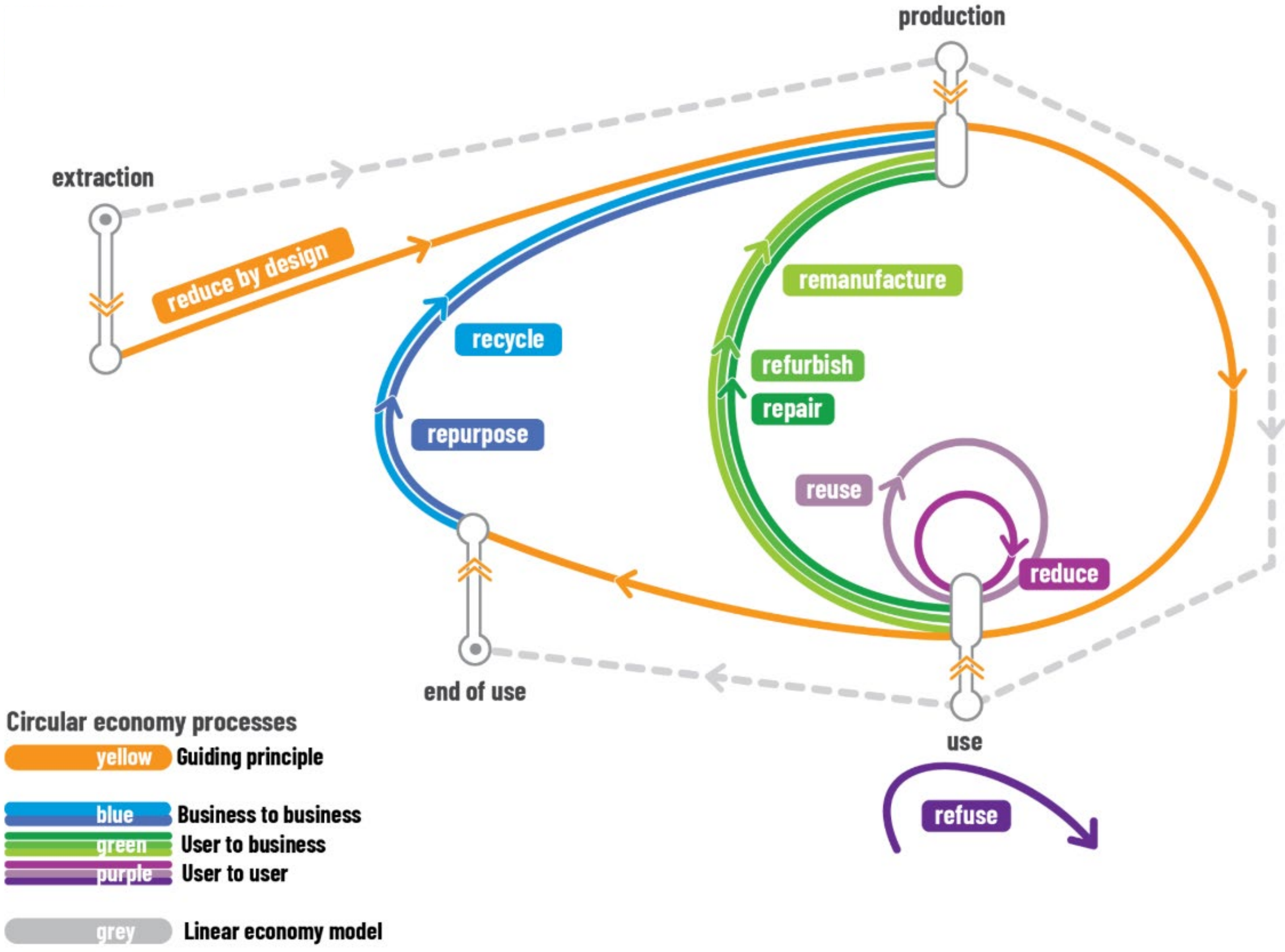
Figure 5. Circular economy model by Ellen McArthur Foundation.




*Source*: https://www.ellenmacarthurfoundation.org/circular-economy/concept/infographic. Copyright © Ellen MacArthur Foundation (2017).

At the EU level, the European Environment Agency (EEA) define a circular economy as a concept that can be "applied to all kinds of natural resources, including biotic and abiotic materials, water and land. Eco-design, repair, reuse, refurbishment, remanufacture, product sharing, waste prevention and waste recycling are all important in a circular economy" (EEA, 2016). However, it can be noted that EU policies on a circular economy focus, mainly, on resource efficiency and technological change as the way towards circularity. Most measures and targets are in fact geared towards the recycling of different types of waste (Friant et al., 2020). For instance, while there are repair and eco-design regulations for a few products, including extended producer responsibility, there are no set targets on repair and reuse activities. The same arguments apply to measures that aim at raising awareness and reducing consumption.

Figure 6. Circular economy model by UNEP.




*Source*: https://buildingcircularity.org.

For this study, the analysis of circularity in forest-based industries will be based, to the extent possible, on the concept put forward by Potting et al. (2017) and taken up by UNEP (Figure 6).[10] There, a circular economy is characterized as three **value retention loops**. These loops, covering the life cycle of a product and/or material from extraction to production and end-of-use (or end-of-life), include:

- The "*User-to-user*" loop – implying that the product and/or material remains close to its user and function (purple line). This can for example mean reusing furniture so that it is used as long as possible before being recycled.
- The "*User-to-business*" loop – implying that the product and/or material is upgraded, and producers are involved again (green line). This can for example mean used clothing given to businesses that make new clothing from the old textiles.
- The "*Business-to-business*" loop – implying that the product and/or material loses its original function (blue line). This can for example mean recycled pulp made out of used paper that is used as a raw material in paper manufacturing.

The UNEP circularity concept uses the 9R-approach (Figure 4) when considering ways for the economy to become more circular (Potting et al., 2017). More specifically, circularity can be achieved within the respective loops (user-to-user, user-to-business, and business-to-business) and, crucially, through design (Figure 6). In this model the number of materials used can mainly be reduced through design and this should be a guiding principle from the earliest stages of the production model to the end-of-life for products. Within the respective loops, it is further possible to encourage reducing and re-using within the user-to-user loop while the user-to-business loop focuses on repairing, refurbishing and remanufacturing (Potting et al., 2017). The business-to-business loop focuses mainly on repurposing and recycling. It should also be noted that dead-end pathways are not represented in this model. This includes, for instance, the production of energy from waste as it is only consumed once and not returned to the system.

## 2.3. Circularity, cascading use and the bioeconomy

Having characterized what a circular economy means for this study (Figure 6), it is also important to consider some of the similar concepts that may be associated or confused with circularity. This section will consider how the concepts of **bioeconomy** and the **cascading use** of biomass relate to a circular economy:

- **Biomass is the physical basis of the bioeconomy**. In fact, the bioeconomy refers to the production of biomass and the conversion of biomass into value added products, such as bioenergy. It includes sectors such as forestry, pulp and paper production, agriculture, fisheries and food. It also covers parts of the chemical, biotechnological and energy industries as well as the manufacturing of bio-based textiles. The circular economy is aimed at a sustainable, resource efficient and carbon-neutral economy. The bioeconomy offers the possibility to substitute fossil-based, non-renewable and non-biodegradable materials with renewable and biodegradable solutions.
- **Cascading use of biomass** also strongly overlaps with the concept of a circular economy, which refers to efforts to preserve products, materials and resources within the economy for as long as possible. The European Commission has defined the cascading use as the "*efficient utilization of resources by using residues and recycled materials for material use to extend*

[10] See https://buildingcircularity.org/.

*total biomass availability within a given system*" (Vis M. et al., 2016). Following this definition, cascading use essentially means a value-added hierarchical utilization of biomass (Box 2).

Box 2. Cascading use of biomass.

The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) has characterized the cascading use of biomass as either a **single-stage cascade**, where the bio-based product is directly used for energy after material use (e.g., on-site energy consumption at a sawmills) or a **multi-stage cascade**, where the bio-based final product is used at least once more as a material (UBA, 2017).

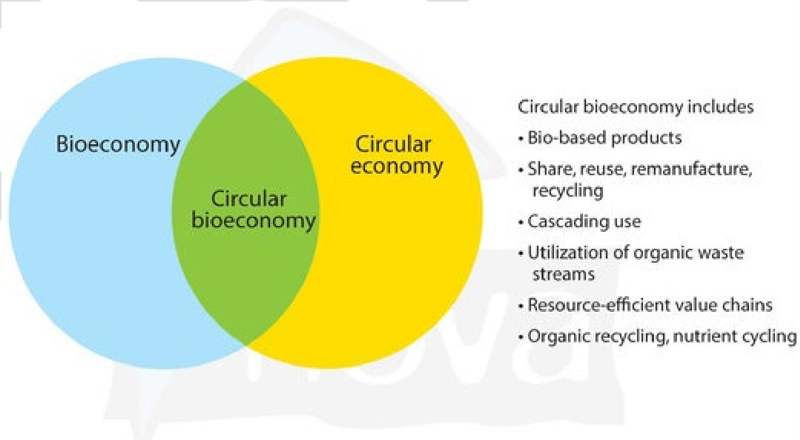
Examples of multi-stage cascading use of biomass include:

- Wastepaper recycling for paper, corrugated board and paperboard.
- Material waste wood recovery for particle board manufacture.
- Bioplastics obtained from renewable raw materials.
- Natural fibers[11] or recovered textiles.

For the present report, cascading use of wood is understood as the sequential use of one unit of a resource in various material applications with its energetic use as a final step (Risse et al., 2017).

Building on overlaps between a circular economy and bioeconomy, as two sustainability-oriented concepts, the term **circular bioeconomy** is also widely used both by industry and academia. The "circular bioeconomy" can be defined as the sum of all activities that are included in transforming biomass for use in different product streams, such as converting biomass into different materials, chemicals, biofuels and food (Figure 7).

Figure 7. Circular bioeconomy.




*Source*: Newton (2017).

[11] Natural fibres are fibres that are produced by plants, animals, and geological processes.

A circular bioeconomy includes processes and products of the traditional industries in the forest-based sector, such as timber, pulp and paper, along with new industries, such as biorefineries, that produce bioproducts from biofuels to fibers. It also includes the many ecosystem services that are necessary for a functional ecosystem (Box 3).

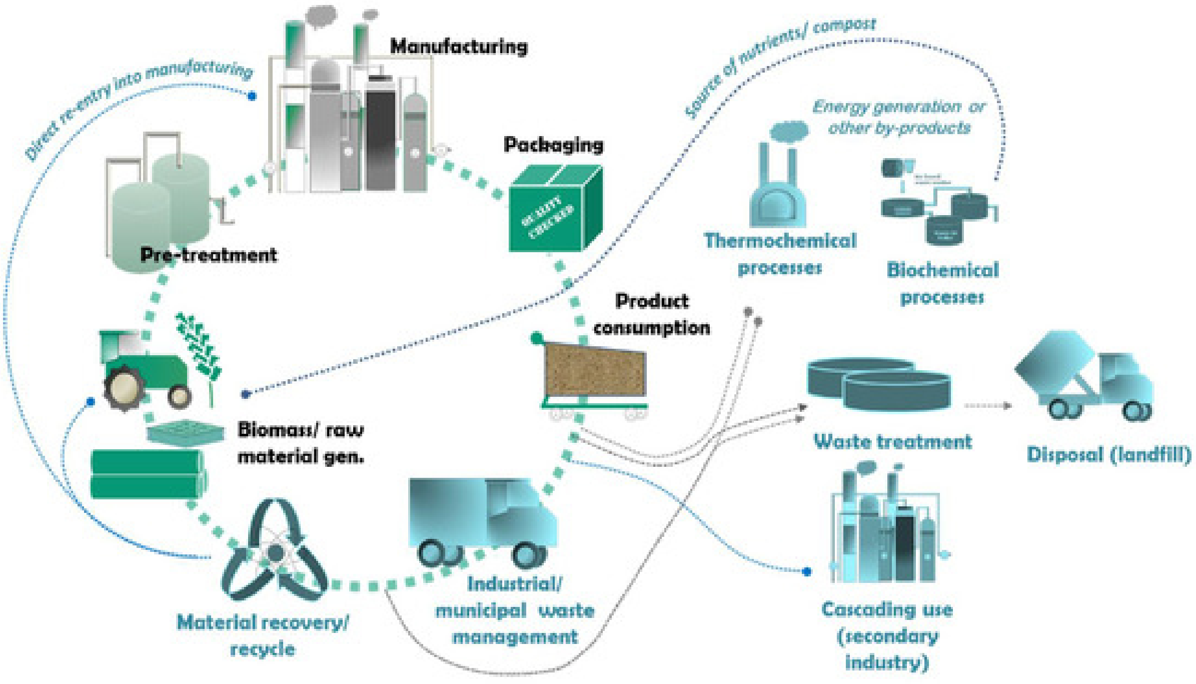
Box 3. A circular bioeconomy.

The European Commission Expert Group on the Bioeconomy (EC, 2017a, b) have indicated that a **circular bioeconomy** involves the following activities:

- Use of organic side and waste streams from agriculture, forestry, fishery, aquaculture, food and feed to applications such as aquaculture feed.
- Biodegradable products being returned to the organic and nutrient cycles.
- Successful cascading of paper, other wood products and natural fibers textiles.
- Innovations that enhance the recyclability of other materials, such as biodegradable oleochemicals used to de-ink paper.
- Linking different industrial sectors, such as forest-based industries and chemical industries.
- Collection and recycling of bioplastics.

Figure 8 illustrate some of the material flows that would make up a circular and bio-based value chain. The value chain can be complex and involve a wide range of actors. The main stages of the value chain are: (1) biomass availability, covering feedstock production and procurement, (2) pre-treatment, (3) conversion and formulation using different technologies, (4) packaging and distribution, (5) consumption, and (6) end-of-life management (Lokesh et al., 2018).

Figure 8. A circular and bio-based value chain.




Source: Lokesh et al. (2018). Figure under CC BY 4.0 license.

From a conceptual perspective, a circular bioeconomy implies the integration of circularity into a biological segment of the economy (e.g., forest-based industries, including wood construction, bio-based packaging and textiles or biofuels). However, there are limits to the amount of biomass that can be used for industrial processes as maximizing the production of biomass conflicts with other ecosystem services. This highlights inherent limitations and differences between circularity and the bioeconomy. For instance, certain elements of the bioeconomy go beyond the objectives of a circular economy, including the replacement of technical non-biodegradable materials by biological ones, which reintegrate into the biosphere. It is also recognized that some sectors of the bioeconomy cannot satisfy the principles of circularity. For example, bioenergy and biofuels are considered dead-end pathways for biomass.

## 2.4. Circular business models

The transition towards a circular economy implies a systemic transformation in a number of domains. One of them is the transformation of the current system of production and consumption, which includes, among others, redefining the relationship between consumers and products. The circular economy puts emphasis on constraints in resource availability and their impact on production processes. It shifts the focus from products to services by promoting access to goods over ownership.

In line with this paradigm, new business models are proposed. In these business models, companies retain the ownership over their products, acting as service providers and recovering products and materials after use. In some cases, products can be leased, rented and shared. These approaches involve greater level of collaboration among supply chain actors, from suppliers and manufacturers to distributors, customers, and recyclers.

The Organisation for Economic Co-operation and Development (2019a) identified the following types of circular business models:

- **Circular Supply Model** – in this business model, renewable, bio-based and recycled materials replace traditional inputs. Through cradle-to-cradle product design, material loops are closed, nutrients are cycled, and waste is designed out. This model is built upon marketing sustainable products, targeted at environmentally conscious consumers, and is especially relevant to companies that rely on scarce resource, as well as to those that cause major environmental impacts related to raw material sourcing. **Most of forest-bases industries should aspire to apply this model.**
- **Resource Recovery Model** – this business model produces secondary raw materials from waste streams. Waste is collected, sorted into its constituent materials and then transformed back into raw materials, thereby closing material loops. Variants include recycling, upcycling, and industrial symbiosis, where waste of one firm is used as input by another. This model is founded upon a valorization of materials contained in waste streams. It is particularly relevant for companies that generate large quantities of by-products during manufacturing processes, as well as for those with access to products at the end of their life. **In the forest sector, sawmills, for instance, generate wood chips and sawdust which are used for pulp and paper production, fiberboard manufacturing and energy use**.
- **Product Life Extension Model** – this model seeks to extend product life and retain products and embedded materials for as long as possible, thereby slowing material loops. Model variants are the classic long-life model, where products are designed for longevity, direct reuse, maintenance and repair, refurbishment, as well as remanufacturing. This model is

particularly suited to capital-intensive business-to-business segments such as industrial machinery, as well as to high-value consumer products such as luxury watches and cars.

- **Sharing Model** – this model aims at increasing the utilization of existing products, thereby narrowing resource loops. Under-utilized consumer assets are used more intensively through co-ownership (lending of physical goods) and co-access (pooling or allowing others to take part in an activity that would have otherwise occurred anyway). This is facilitated by new technologies such as online platforms that reduce transaction costs and associated risks. Transactions typically take place between consumers, are temporary rather than permanent, and seek to utilize assets more intensively rather than providing services. The business case rests on an online platform generating a small margin without high upfront investment and owners of assets gaining an additional income. Examples of such business models are Airbnb or BlaBlaCar.
- **Product Service System Model** – this model combines a physical product with a service component, thereby narrowing resource loops. Consumers purchase the service which a product provides. Its ownership thereby remains with the producer. This model is especially pertinent for companies that produce high-value goods such as cars or household appliances with a high Total Cost of Ownership[12] (TCO), and substantial requirements for product maintenance, and repair.

Unlike linear business models, which often calculate a premature obsolescence to increase sales, circular business models fundamentally change the way in which value is created. They focus on product design, production processes and product use which aim to drive businesses to minimize resource consumption and maintain products in use at their highest value for as long as possible.

## 2.5. Circular value chains

Value chains incorporate "the entire sequence of activities or parties that provide or receive value in the form of products or services (e.g., suppliers, outsourcers, workers, contractors, investors, R&D, customers, consumers, members)" (UNEP, 2014). In linear value chains, raw materials flow in, are changed into a product, then distributed and used until finally they are thrown away (Figure1). There, the value is created by selling products. That means that products have a relatively short lifespan in order to continuously create a need for their replacement.

In the context of a growing resources scarcity, pollution and related environmental and economic risks, described at the beginning of this study, circular value chains (Figure 9) are increasingly recognized as a better alternative to the dominant linear (take, make, and dispose) model. For most supply chains, the drive towards circularity relies heavily on government regulations. They make businesses adopt more circular attitudes by imposing what products are allowed to be sent to landfills, what products should be recycled and what methods are required for supply chains to limit their environmental impact. While some of the circular approaches across value chains, such as recycling, redistribution and sharing, have already been functioning with the support of specific policy measures, circularity in value chains is not yet managed in a systematic and coordinated way.

[12] Total Cost of Ownership is a calculation method that determines the overall cost of a product or service throughout its life cycle. This method combines both direct and indirect costs.

Figure 9. Life cycle of products.


*Source*: General Journal of Europe (www.journalgeneraldeleurope.org).

Following the importance of the value chain for many business models and the need for alignment of all the business actors for optimal economic and sustainability performance, the concept of Supply Chain Management (SCM), came into place. SCM being the management of the flow of goods and services, transforming raw materials into final products with a value to customers at a competitive advantage.[13] Further, building on the SCM, the Circular Supply Chain Management (CSCM) integrates the philosophy of a circular economy into supply chain management, and offers a new perspective to their sustainability.

Because closed loop supply chains still generate substantial amounts of waste, as it is rarely feasible to reuse and recycle all items within the same supply chain, the CSCM includes recovering value from waste by collaborating with other value chains within the industrial sector (open loop, same sector), or with different industrial sectors (open loop, cross-sector) (Weetman, 2016). Within the forest sector, wood and its residues can be used in a number of different ways. Many value chains overlaps create a complex system of dependencies: an industrial ecosystem, with numerous industrial symbioses which rely on circular approaches. Value chains across different industries and different service providers promote sectoral collaboration and support industrial clusters that share a mutual interest in resource efficiency.

CSCM also aims to minimize waste production across different industrial sectors, through system-wide approaches, to recover value from what was traditionally called waste (Scheel and Vasquez, 2013; Scheel and Vazquez, 2012). For example, wood buildings can be deconstructed and (not contaminated) wood reused for other purposed, or woodworking residues can be recycled into mulch for landscaping. Similarly, a manufacturer may recycle textile materials to produce insulation products for the construction industry (Nasir et al., 2017) while a food supply chain's waste cooking oil may be refined and utilized to produce biodiesel (Genovese et al., 2017). Food wastes can also be minimized at their sources and the remaining food wastes can be composted or anaerobically digested to produce methane as a renewable energy source, with the remaining organic matter used as a fertilizer in agriculture and horticulture (Farooque et al., 2019).

[13] See www.investopedia.com/terms/s/scm.asp.

At the level of individual value chains, the transition towards a circular economy requires considerable transformation of practices related to product and service design, production, consumption, waste management, reuse, and recycling (Hobson, 2015; Mendoza et al., 2017). The stage of product design has a crucial role in materials and energy recirculation. Circular design strategies also involve sustainable packaging design and product labelling (Bovea et al., 2018). The literature on design functions offers various design strategies based on the notion of product life extension and closed loop systems (Bakker et al., 2014; den Hollander et al., 2017; Moreno et al., 2016; Sumter et al., 2018). Bocken et al. (2016) introduced CSCM strategies of slowing, closing, and narrowing resource loops:

- Slowing resource loops means product-life extension through the design of long-life products (e.g., service loops to extend a product's life, for instance through repair, remanufacturing), the utilization period of products is extended and/or intensified, resulting in a slowdown of the flow of resources.
- Closing resource loops means closing the loops between post-use and production through recycling, resulting in a circular flow of resources.
- Narrowing resource loops means achieving resource efficiency by using fewer resources per product.

According to den Hollander et al. (2017), the waste hierarchy described in the European Waste Framework Directive (Directive, 2008/98/EC) which details a priority order for managing waste, e.g., moving from prevention of waste, to reuse, recycling, recovery, and disposal, can be used as one of the guiding principles of eco-design. Another CSCM strategy, the Design for Dismantling (DFD) has already been adopted by many sectors. It is partly motivated by technological advancements that offer cost savings besides extended product responsibility regulations. The DFD offers value to products not only at the end of life stage but also during the usage, lifetime and maintenance stages (Sabaghi et al., 2016).

Moving down the value chain to the production stage, a circular economy requires raw materials to be either technically restorative or biologically regenerative so that there are no negative impacts upon the environment (Genovese et al., 2017). There, the role of sustainable procurement for reducing raw material utilization and improving resource efficiency through recovery and lower waste generation comes into place. Reduction of resource consumption in the production processes has become essential for manufacturing industries not only to mitigate the environmental risks but first and foremost to maintain competitiveness in order to survive on the market. Many also recognize that adopting circular production practices not only offers long-term cost savings but improves brand image, regulatory compliance, and investors' interest (Dubey et al., 2015). Circular practices seek to prevent the use of non-renewable and harmful inputs (Ghisellini et al., 2016) and often involve not only manufacturing but also service activities.

Another important aspect of CSCM is the reduction of environmental impacts of various logistics and distribution strategies, including reducing energy requirements in logistics-related activities, reducing waste, and treatment of residual waste (Sbihi and Eglese, 2007) in transport, warehousing, and inventory management from suppliers to customers. The CSCM also gives special consideration to secondary markets in extracting the value from products at the end of life in a closed loop recovery system by integrating a concept of reverse logistics. That means moving goods from their final destination (consumer) for the purpose of capturing value, or proper disposal.

This includes returns from e-commerce and retail, as well as components for refurbishing and remanufacturing of products which may be resold or disposed of permanently.

Further, down the value chain, there is consumption stage. At that awareness campaigns and sustainability education play an important role in changing consumer attitudes and choices. Overall, there is a need for policy measures to enhance the awareness about circular consumption, noting that cultural differences play a significant role in framing consumer attitude towards circularity and nature in general (Gaur et al., 2019; Lakatos et al., 2018).

While many consumer driven attitudes and behaviors can only be regulated by policy measures, some specific approaches inviting circular consumption patterns could be considered directly by the producers. They involve repairability, durability, upgradability, and recyclability inclusion into the product design to create longer lasting products:

- Design for standardization and compatibility mean manufacturing modules, parts and elements which can be used in different products and applications, enabling the repair of products and the replacement of faulty parts (e.g., in wood construction and modular furniture manufacturing).
- Design for ease of maintenance and repair to avoid functional obsolescence (implies that if products break down, they can be easily repaired. Repair and maintenance activities is provided by producers (e.g., in furniture manufacturing).
- Design for upgradability and adaptability means that products are developed to allow for future expansion, modification and updates to counter systemic obsolescence and be adapted to the changing needs of users. (e.g., in furniture manufacturing)
- Design for disassembly and reassembly serves to prevent systemic obsolescence. Products are designed in a way that allows for parts to be separated, disassembled, and reassembled, thereby facilitating remanufacturing (e.g., in furniture manufacturing) (den Hollander et al., 2017).
- Design for recycling and biodegradation implies smart material choices to ensure that material inputs are renewable, recyclable, safe and secure for humans and for natural environment. Pure materials are preferred whenever possible to facilitate sorting and biodegradation at the end of a product's life (e.g., in furniture manufacturing cellulose-based textiles and plastics).

Finally, the end of life is considered critically important stage of value chain from the perspective of CSCM. Strategies to recover the remaining value within a product to its maximum utility include repurposing, refurbishing, remanufacturing and recycling (Figure 4). Although, recirculation of used components and materials has significant economic and environmental performance implications (van Loon and Van Wassenhove, 2018), there is a lack of understanding of the true potentials of products' end of life management in many business sectors.

The evolving CSCM strategies offer different sectors the potential to transition towards circular economy and improve their sustainability performance. Consequently, they have been receiving growing interest from the industry, research and policy making parts. However, confusion on the terms related to supply chain circularity and sustainability still remain.

# Part 3
# Circularity in Forest-based Industries

# 3. Applying circularity concepts to forest-based industries

The basic reason for gradually moving towards circularity is linked to the increasing scarcity of natural resource and the ecological impact of human activities. This has led to the realization, across different sectors and disciplines, that a sustainable economic system is needed to replace linear production and consumption processes.

The key role of the forest sector in the transition to such a system is related to the fact that it provides wood, a biodegradable raw material and a strategic resource that can be used for creating reusable and recyclable materials. Wood-based products and production residues can be used, reused (in a cascading system), recycled and biodegraded. This material efficiency, well imbedded in the forest sector production processes, can now be used in other value chains. It can help transform strategic sectors, such as construction, textiles or packaging industries towards a more circular system with a reduced environmental footprint.

The scope of the present section is to analyze circularity approaches in the following forest-based industries:

- woodworking industry, focusing on cases of sawnwood processing, bioenergy production and wood in construction,
- furniture industry,
- paper and pulp industry,
- cellulose-based fibers,
- cellulose-based plastics.

A value chain analysis, covering these respective industries, will be adopted for this purpose.

## 3.1. Adopting a value chain analysis

For the needs of this section, the concept of a forest-based value chain (Box 4) will be used rather loosely as it is chiefly meant to frame a discussion on the prospects of a circular economy across different forest-based industries, or specific stages in their value chains. It is for this reason recognized that the value chain illustrations (e.g., Figure 10 and Figure 15) are generic for the given sectors. It is further recognized that there can be many variations of a given value chain. For instance, both pulp and oriented strand board (OSB) can be produced using pulp logs. Hence, regardless of the origin, the same raw material can be used for making pulp or OSB. This implies that there can be several variations of the same value chain.

Box 4. Forest-based value chains.

> The term "*value chain*" implies a series of manufacturing steps that link raw materials to final products through different sub-sectors of the forest-based sector. A value chain can range from the local to the global level, and the range of activities along the value chain may be implemented by different actors, such as harvesters, processors, traders, retailers and service providers. Each sub-sector (e.g., furniture and construction) covered by this study could, conceptually speaking, be described as a distinct value chain, however, processing steps in different product groups downstream often have common sources upstream. That means that many of the sub-sectors can be linked into the same value chain.

The value chain analysis (VCA) is intended to provide a map of forest-based industries against which it is possible to consider how each point in the value chain can address the concept of circularity (FAO, 2007, 2013). For this reason, it will be more of a qualitative analysis. More specifically, the VCA will be used to clarify how a circular economy can be adopted by focusing on a range of activities and transfers involved in the production, transport, distribution and use of particular forest-based products. The core purpose of the VCA is consequently to break up the chain of activities that run from the production of raw materials to the end of life into strategically relevant segments.

The forest-based value chains illustrations in this section are based on the Statistical Classification of Economic Activities in the European Community (NACE) Revision 2 codes (Directive, 1893/2006; EUROSTAT, 2008, 2017, 2019).[14] However, as the classification provided by NACE does not include all products which could be understood as forest-based products and production processes, additional product classifications, such as the FAO classification[15], were considered. The aim of the value chain graphs presented below is to demonstrate which kind of products are assigned to which defined product group and to show the degree of processing (primary, secondary and tertiary) in the respective value chain. Although forestry and forest-based industries are linked through their value chains, forestry was not included in this assessment. It was assumed, that a basic forest-based value chain starts with raw timber being transported to the relevant industry processing included in this study.

It should also be noted that the value chains introduced below have been adopted (with some modifications) from an assessment of the cumulative cost impact of specified EU legislation and policies on the EU forest-based industries (Rivera León et al., 2016). There are two main reasons for using these value chains. First and foremost, the value chains have been developed together with industry representatives from the respective sectors, such as the Confederation of European Paper Industries (CEPI) in the case of the paper and pulp value chain and the European Confederation of Woodworking Industries (CEI-BOIS) in the case of the woodworking chain Secondly, the value chains are generic enough to encompass a larger segment of the forest-based industries and they provide a useful overview of the sectors involved. In total, 12 representative organizations were involved in the development of these value chains illustrations, which implies that the value chains have been approved by relevant industry representatives (Rivera León et al., 2016).

Finally, in terms of design, the material flow is from left to right. However, some products consist of more than one preceding product, such as wood-based panels consisting of sawnwood, recovered wood and by-products. It should also be noted that the listing of products covered by each of the product groups are non-exhaustive. The value chains are mainly meant to showcase the complexity and variety of products within one product group and within the respective sectors. Moreover, the respective waste streams have not been explicitly indicated.



[14] The current NACE version is the European implementation of the UN classification International Standard Industrial Classification of all Economic Activities (ISIC).
[15] See http://www.fao.org/3/an647e/an647e00.pdf.

## 3.2. The woodworking value chain

Figure 10 illustrates the woodworking value chain. In this case, the woodworking sector is derived from NACE 16 and includes:[16]

- **Primary processing**: the production of sawnwood.
- **Secondary processing**: wood-based panels, solid wood products, wooden pallets and other wooden packaging and bioenergy products.
- **Tertiary processing**: builder's carpentry and joinery products and wooden flooring, (EUROSTAT, 2019).

In this illustration input materials within the woodworking value chain include hard wood and soft wood, industrial by-products (like bark, chips and dust) and used materials (recovered wood). Saw logs, which are the starting material for all woodworking industries, have not been included as it was considered part of forestry.[17] Some of the additional granularity that can be found in the FAO classification and definitions of forest products (e.g., residues of wood processing) are reflected in the processing steps (e.g., sawdust for energy) as compared to the NACE categories. Other raw materials, such as resins, coatings and impregnation chemicals, used in woodworking manufacturing have been left out to simplify the analysis.

Figure 10. Woodworking value chain.

<table>
<tr><th colspan="2">Primary processing</th></tr>
<tr><td>Hard wood</td><td rowspan="3">16.1 Sawnwood</td></tr>
<tr><td>Soft wood</td></tr>
<tr><td rowspan="2">Industrial wood</td></tr>
<tr><td rowspan="2">By-products (e.g., chips and bark)</td></tr>
<tr><td>Recovered wood</td></tr>
</table>

<table>
<tr><th colspan="3">Secondary processing</th></tr>
<tr><td rowspan="5">16.21 Wood-based Panels</td><td rowspan="3">Particle and fiber boards</td><td>Plywood</td></tr>
<tr><td>OSB</td></tr>
<tr><td>MDF</td></tr>
<tr><td rowspan="2">Veneer sheets</td><td>Hard & Softboard</td></tr>
<tr><td>Particleboards</td></tr>
<tr><td colspan="2" rowspan="3">Solid wood products (part of 16.21)</td><td>Glulam</td></tr>
<tr><td>CLT</td></tr>
<tr><td>Solid wood panels</td></tr>
<tr><td colspan="3">16.24 Wooden pallets & other wooden packaging</td></tr>
<tr><td colspan="2" rowspan="2">16.29 Bioenergy products</td><td>Wooden pellets</td></tr>
<tr><td>Briquettes</td></tr>
</table>

<table>
<tr><th colspan="3">Tertiary processing</th></tr>
<tr><td rowspan="7">16.23 Other builders' carpentry and joinery</td><td colspan="2">Windows & doors</td></tr>
<tr><td rowspan="5">Construction products</td><td>Scaffolding</td></tr>
<tr><td>Formwork</td></tr>
<tr><td>Frames</td></tr>
<tr><td>Beams, trusses</td></tr>
<tr><td>Outdoor products</td></tr>
<tr><td colspan="2">Prefabricated wooden buildings</td></tr>
<tr><td colspan="3">16.22 Parquet floors</td></tr>
</table>

*Source*: Adopted from Rivera León et al. (2016).

Based on the illustration of the value chain in Figure 10, the study will put a spot on the sawmilling industry (NACE 16.1), the bioenergy industry (NACE 16.29) and the use of wood in construction (NACE 16.23) as different levels of processing in the woodworking value chain. This will allow for

[16] NACE 16 is characterised as "the manufacture of wood products, such as lumber, plywood, veneers, wood containers, wood flooring, wood trusses, and prefabricated wood buildings. The production processes include sawing, planing, shaping, laminating, and assembling of wood products starting from logs that are cut into bolts, or lumber that may then be cut further, or shaped by lathes or other shaping tools. The lumber or other transformed wood shapes may also be subsequently planed or smoothed, and assembled into finished products, such as wood containers" (EUROSTAT (2017), p.131).

[17] Forestry, logging and related service activities is covered under NACE 2.01 and 2.02.

the analysis of opportunities and limitations related to the implementation of circular approaches across the value chain, from primary to tertiary processing.

### *3.2.1. The woodworking sector*

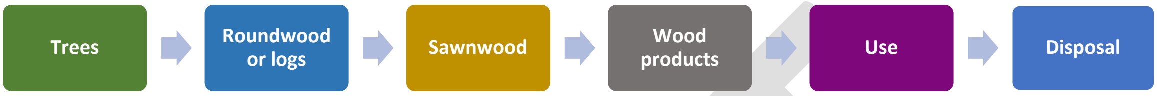
Taking a long-term perspective on wood as a raw material, it is arguably already used in a circular manner, as it can return as nutrients to the biosphere. Being bio-based and non-toxic, the forest sector follows a natural cycle even though the loop may stretch over many decades. This means that wood has a significant advantage over other materials that do not harmlessly biodegrade. However, in contrast, wood cannot be transformed or renewed (e.g., through chemical processes) in the same way as other materials, such as metals, in closed production loops. For instance, wood deteriorates over time and even paper fibers can only be reused a limited number of times. The circularity of wood should for this reason rather be seen through a perspective of cascading use of transformed wood products. This can refer to raw materials being transformed into sawnwood then boards and fiberboards followed by paper and finally wood energy.

It should be noted though, that applying cascading use principles does not meet all the criteria of circularity. For instance, if circular principles are followed to the letter, having wood recovery for energy as a final step in the material life cycle would not fulfil the criteria of being circular, principally, as it is not possible to recycle energy. It is for this reason commonly seen as leaving the loop. Even more, many conceptual ambiguities surrounding a circular economy, such as the lack of common definitions and criteria for circularity (Calisto Friant et al., 2020; Kirchherr et al., 2017; Korhonen et al., 2018b), further contribute to confusion in the woodworking sector. While these are issues that cannot be resolved by this study, a pragmatic approach will be taken when reviewing the woodworking value chain. The objective of the analysis will be to identify areas where the forest sector can become more circular. This will be done using the woodworking value chain (Figure 10) and the 9R approach as presented in the UNEP circularity concept. Bioenergy production, although can be the final stage of any woodworking value chain, will be considered separately because of its importance for the forest-based sectors (Section 3.2.4).

### 3.2.2. Sawnwood

Sawnwood[18] is a biodegradable material which disintegrates naturally, over time. It is also a renewable material as harvested trees can be replaced by planting new trees. The sawmilling sector operates in what is commonly described as the solid wood value chain (Figure 11).

Figure 11. Generic sawnwood value chain (without by-product streams).




*Source*: Own figure.

In the ECE region, sawnwood consumption amounted to approximately 250 million cubic meters (m3) in 2018, with consumption of sawnwood increasing 1.5 per cent that year as well (UNECE/FAO, 2019). To date, the construction sector is the most important consumer of sawnwood and other solid wood products (FOREST EUROPE, 2020). The sawnwood sector is a resource-based sector, therefore maximizing resource efficiency has been a key condition for its economic viability for a long time. Sawnwood, or associated side streams, are for this reason commonly used for a wide range of products like wood-based panels, solid wood products, construction products (such as beams windows and doors), wood chips and sawdust for bioenergy. For instance, wood waste obtained from timber in the production of sawn timber can be a source of raw material for the manufacture of either particle boards or for pulp production (Figure 10). The quantity of wood waste directed to side streams will depend on the type of wood being sawed and on the structure of the sawmills where such raw materials are being processed.

Although a circular material flow of sawnwood is not possible, mainly because of the material deterioration of wood, resource efficiency can be achieved by using sawnwood in one stage as long as possible before moving on to the next in a cascading mode (Box 2)., Theoretically, not contaminated waste wood could also be re-processed back into sawnwood., For example, depending on the wood quality, the recovery and utilization of post-consumer wood, such as discarded wood (e.g., untreated wood, not painted or glued wood and not impregnated wood) could be recovered for processing into sawnwood and then manufactured into particle boards in a cascading system. This would have an added benefit of reducing the use of fresh (or primary) wood. However, in practice, there are limitations to that. Most of the time, it is not pragmatic or economically viable. For instance, the damaged wood requires inspection and quality assessment to avoid possible contaminants and to ensure structural integrity of the sawnwood. Also, the dimensions of wood residues need to be standardized for the needs of reprocessing, likely generating additional waste and reducing value of sawnwood that would result from reprocessing. Hence the recovery of solid wood residues in sawmills is currently not a common practice.

Transitioning to circularity – or closing the loops – is not one single solution for the sawnwood sector but requires system innovation and coordination across the supply chain, covering from

[18] Sawnwood is wood that has been produced either by sawing lengthways or by a profile-chipping process and is generally greater than 6 millimeters (mm) thick (EUROSTAT).

primary to tertiary processing. There are in fact many steps that can be taken as related to the circular use of sawnwood, as a long-lived product, including the avoidance of waste generation. For instance, the potential for the material use of sawnwood residues demonstrates opportunities for improved system efficiency. Another opportunity for sawmills is to further reduce imbalances between material and energy uses of residues in the mills (e.g., it is a common practice that only waste wood that cannot be downcycled into paper and papers is incinerated for energy). This can include the application of intelligent wood cycles, whereby residues from the sawmill and recycled wood are more effectively utilized. “Intelligence” in wood cycles refers to an improved sorting process that may increase the amount waste wood that is suitable for cascading (Jarre et al., 2020). Another example could be finger-jointed sawnwood, whereby short pieces of sawnwood (trim-ends), which are often chipped for making pulp, are finger-jointed together to make marketable pieces of sawnwood.

There are also opportunities to think circular in the use of waste wood for bioenergy. In many cases there are for example integrated biomass energy plants, where waste products go directly to incineration for energy production. The remaining ashes could be used as fertilizer in agriculture and forestry. This is still not a standard practice (IEA, 2018; López et al., 2018).

It should be noted that this section presents only some examples of circular approaches which may be applied in woodworking industry, based on general circular concepts presented at the beginning of the study. Many others can be found when analyzing specific contexts and case studies of particular sawmills and value chains relating to them. However, such an analysis, which should also include an analysis of economic feasibility and sustainability of circular approaches, falls outside the scope of this study.

In general, improving the dissemination of knowledge on circularity among consumers and producers of sawnwood is key for further consideration of circular approached by the sector. That includes filling knowledge gaps on the practical realization of wood cascading upstream and downstream, including its economic viability and environmental externalities. In addition, an improved certification, to ensure sustainable sourcing of wood[19], is a prerequisite for a long-term sustainability of sawnwood value chains.

### *3.2.3. Wood in construction*

The construction industry is one of the most waste-heavy sectors, in fact, it is the highest producer of waste when compared with other economic activities, globally. For instance, in the EU, construction waste accounted for 36 per cent of the total waste generation[20] in 2018 (EUROSTAT, 2020). However, waste in construction has traditionally been considered as an inevitable by-product and has mainly been managed from a health and safety perspective, not necessarily with recycling in mind (Osmani and Villoria-Sáez, 2019). With regards to wood-waste, it is the second-largest component of construction waste (after concrete), representing 20 to 30 per cent of the overall waste generated globally. Estimates suggest that the global generation of wood waste from

[19] Circulating materials does not necessarily equate to greater sustainability. Increased circularity can in fact lead to a worse performance in terms of environmental sustainability (e.g., recycling plastics that contain hazardous additives can do more environmental harm than good).

[20] Mining and quarrying represent 26.2 per cent, manufacturing represent 10.6 per cent, waste and water services represent 9.9 per cent and households represent 8.2 per cent of the total waste in the EU (EUROSTAT, 2020).

construction amounts to 36.4 million tons (Mt) on an annual basis (29.7 Mt derived from demolition activities and 6.7 Mt), while only 10 to 15 per cent of the wood used in construction presently ends up being recycled, reused or upcycled.[21] This suggests that there is a potential for making in the construction sector more circular, including the use of waste wood as part of a broader systems loop (Dangel, 2017; Kaufmann and Nerdinger, 2012; Lignatec, 2015). For instance, reclaimed wood that has been used in construction can be upcycled[22] into flooring, cabinets, furniture or beams, where economically viable and without negative impact on environment and human health.

In order to facilitate that more reclaimed wood re-enters the supply chain, systemic developments are needed to enhance the possibilities for sorting, separating and recovering (e.g., efficient recycling/demolition is critical) to ensure that wood waste can be cycled back as efficiently as possible at the end-of-life. This would, amongst other things, require increased integration across the value chain (Figure 11), such as with deconstruction operators (from primary to tertiary processing). Moving away from the business-as-usual approach would require cross-cutting and networked systems with stronger collaboration between business ecosystems (e.g., municipalities, architects, designers, builders and end-users). There is also the issue of the organization and infrastructure of recovery. For example, if contaminated wood was to be recycled, metal would need to be removed by hand and if further milling was required, additional metal detection would need to be done before processing, to avoid damage to milling tools. This would also apply to the use of wood used as a concrete form to shape and hold concrete in place while it hardens. In both cases it is not easy to remove metal or concrete from the wood manually, without the risk of destroying saws. Also, it is certainly costly.

Another approach for the construction sector relates to design and detailing of mass timber buildings for greater durability, including steps to hold materials in place for longer, prolonging the lifespan of wood to reduce the demand for new materials. This can for example include gluing, dowelling or nailing major sections in a building as well as using preservatives or applying a surface coating. This would require that the entire wood life cycle (e.g., primary to tertiary processing) is taken into account when constructing new building, which would allow for more efficient usage of side products (e.g., recovered wood). However, while these actions may contribute to the prolonged use of wood in construction, on the other hand they may also affect the prospects to reuse and/or recycle the materials in question. For instance, treating the wood for durability makes reuse more difficult and may also contribute to increased pollution. Therefore, making a value chain more circular does not necessarily lead to increased sustainability. For this reason, all raw materials used for treatment of wood in construction should be renewable and wood itself originate from sustainably managed forests, while different techniques used to increase durability adapted to specific criteria for sustainability (e.g., infrastructure that allows for material separation and recycling).

The design aspect in construction also extends to business models that enhance the “designing for disassembly” to ensure that buildings can be dismantled for recovery of systems, components, and materials. This for example includes design for combined manufacture, assembly and disassembly (e.g., modular elements made of solid wood). Increasing the use of wood and other renewable materials can, in this context, help to reduce dependence on carbon-intensive materials such as

[21] See www.thebalancesmb.com/wood-recycling-construction-2877760.
[22] Upcycling implies transforming reusable materials (e.g., unsold goods and materials destined for landfills) into products or materials with higher added value.

cement and metals. Further to designing for reuse, there are also prospects for improving material efficiency and reducing waste at the design stage. Moreover, many processes (e.g., refurbishing, remanufacturing and recycling) can take place within the lifetime of a building (e.g., renovation by new owners), irrespective of the materials used. This adds another layer of complexity in defining typical processes applied in construction, which can range from the manufacturing, procurement, use, reuse, and final disposal of building materials. There are also other factors to consider, such as the need to improve awareness of people working in the construction sector as well as of end-users (e.g., customers) about the opportunities and limitations related to applying circular approaches.

The points noted above demonstrate that circular approaches relate to the recovery and reuse of wood used within the buildings (e.g., through enhancing recycling to ensure that waste is seen as a resource). From this perspective, circular construction approaches imply using and reusing construction materials in buildings and infrastructure to the highest extend possible to reduce the use virgin materials. Sustainable design is a key element to achieve that. It implies that durability and recyclability are incorporated in the development phase of wooden construction elements and buildings. From that perspective, the off-site wood construction technology, which involves a digitally precise design, fabrication and assembly of new building elements at a location different than the installation site, offers the most promising optimization of value chains with minimum waste.

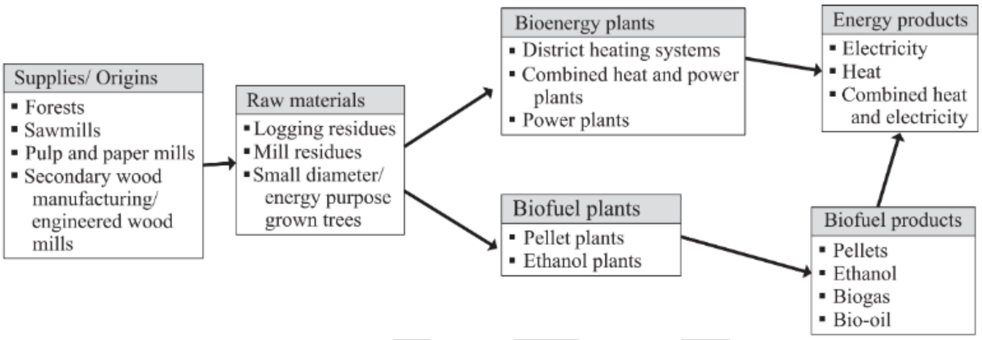
However, it should be recognized that the highest potential in increasing circularity in the sector likely lies in utilization of construction and demolition wood from the renovation and the decommissioning of already standing buildings. The degree to which a building can be reused, modified or upgraded at some point in time depends on how all materials can be either reused, recycled or upcycled at the end of their lifecycle. And while there are notable challenges related to that, there is also a significant business potential for wood in construction. For instance, markets for recycled wood include landscaping mulch, bedding material, boiler fuel, and fiber for composite board production. It can also be noted that recovered lumber can sell at a premium as compared to new material. However, to realize circular projects in construction, the sector needs to think beyond business-as-usual for the building. The success of a circular economy in construction depends the sector’s ability to identify and enable new markets and to explore new opportunities inside as well as outside of the current industry networks and associated value chains.

### *3.2.4. Bioenergy*

Bioenergy production is considered part of the cascading and resource efficient use of wood. (EC, 2018; Hetemäki et al., 2017). Forestry and woodworking industries create residues and side-stream raw materials, such as chips, sawdust and bark, which can be used to produce bioenergy or transformed into biofuels (Figure 12). Every tree stem produces different qualities of wood material that enters the bioenergy value chain. From the perspective of circularity and resource efficiency, the best-case scenario implies that wood stay as long as possible in one stage before cascading down (UBA, 2017). Wood recycling for energy can in this case be considered the final stage of wood cascading and it is not considered as a separate value chain. It is worth noting that based on the definition of circularity presented in this study, the incineration of wood (or biomass) is not part of the loops of the UNEP circularity concept, primarily, as energy is considered a leakage out of the system (Figure 6).

For this study, bioenergy products have been included as secondary processing in the woodworking value chain (Figure 10), however, it should be recognized that biofuels can come from various sources across the supply chain, including upstream and downstream stages (Figure 12). For instance, in the earlier section on sawnwood (see page **Error! Bookmark not defined.**), it was noted that a sawmill can have an integrated biomass powerplant that supplies energy for the sawmilling operation using waste residues from the milling process itself. From a circularity perspective, this is perhaps not an optimal use of the generated waste, however, from a sawmill perspective it means the valorization of what used to be a waste product and lower production costs. Even more, from a sustainability perspective, using the waste products locally (e.g., directly in the sawmill) may also imply a lower environmental impact (e.g., no transport or further processing). As in the preceding section, this demonstrates that circularity does not always equate to sustainability.

Figure 12. Supply chain for energy production.




*Source*: Shabani et al. (2013).

Circular economy objectives promote the reuse of waste streams as well as improved energy efficiency throughout the woodworking value chain. For instance, there are several international and national regulatory measures in place that encourage solid biomass extraction (including woody biomass) for bioenergy use as part of ongoing efforts to reduce fossil-based products. Renewable energy policies, which have been instrumental in advancing the bioenergy sector have also affected the woodworking value chains, such as increasing raw material costs (Münnich and Elofsson, 2017; Rivera León et al., 2016; Souza et al., 2017). These policy instruments have in fact significantly increased the demand for energy wood, drawing the supply of wood residues away from products with potentially higher added value.

This highlights the role of policy frameworks that support climate positive effects and, more importantly, ensure a hierarchy of wood uses, giving priority to long-life material uses. This implies the application of cascading use principles (to the possible extent) and more effective partitioning of waste streams back to other sectors, such as engineered wood, paper and pulp bioplastics, bio-textiles, and, lastly, to the bioenergy sector. The impact from increased competition also demonstrates how important it is to further diversify energy sources. and to explore how the available product mix can be expanded to ensure the sustainable sourcing of wood for energy production in the long term.

Although energy cannot be recycled, the examples above demonstrate that the bioenergy sector could find more resource-efficient combinations of biomass sources, including improving current conversion technologies. There are also prospects for improving quality standards and certification, for instance, as regards labelling of bioenergy products to ensure that end-users (e.g., consumers) are fully aware when making choices about bioenergy. This suggests that harmonized standards and regulations for labelling and monitoring procedures are needed.

The bioenergy is a sector that is considered to be carbon neutral and an alternative to fossil fuel use, therefore it can benefit from the transition towards a circular economy. However, sustainable bioenergy sourcing, without creating pressure on ecosystems and other woodworking value chains depends to a large extent on the sustainable management of forest resources and a coordinated planning of all production processes involving wood residues. There is for instance scope for sustainably growing biomass for energy on land, which is not used for other purposes; and for improving the utilization of residues from forestry and woodworking value chains. Finally, ash recycling can feature as part of the solution as well, allowing the nutrients to return to biosphere (IEA, 2018; López et al., 2018). This, however, is generally not seen as being in line with the circular economy principles.

## 3.3. The furniture manufacturing value chain

Figure 13 provides a representation of the furniture manufacturing value chain. This value chain has been defined using NACE 31 and it includes the manufacture of furniture and related products of any material except stone, concrete and ceramic (EUROSTAT, 2019).[23] It should be noted that the furniture sector is a very diverse industry that along with wood, uses a wide range of materials, as products move from the supply base to the manufacturers and eventually to the end-user (e.g., consumer). These materials can by themselves represent different product groups or value chains (e.g., metal and plastic). Furthermore, the sector is dominated by small and medium-sized enterprises (SMEs) and micro firms that may not fit the provided depiction (Morales-Rivas et al., 2020).

The furniture value chain is also characterized by a complex flow of different wood materials, which is what distinguishes wood furniture manufacturing from other wood product manufacturing. These materials do not represent separate product groups (Figure 13), but have been included in primary processing to provide a more complete picture of potential input resources for furniture production. While wood remains one of the main materials for manufacturing furniture, apart from the sawn and planed wood (NACE 16.1) and wood-based panels (NACE 16.21), also leather (NACE 15.11), fabrics (NACE 13.9), plastics (NACE 22.21) and metal (part of NACE section 25) were included. This means that although the depicted value chain is a simplified version, used for the needs of this study, the furniture industry is very diverse in terms of materials used and value chains involved. Its underlying complexity is also a reason for including it in this study. Given this heterogeneity, it is highly relevant to consider how circular approaches can be applied into its value chain.

[23] NACE 31 characterize processes used in the manufacture of furniture as "*standard methods of forming materials and assembling components, including cutting, molding and laminating*", also noting that the "*design of the article, for both aesthetic and functional qualities, is an important aspect of the production process*" (EUROSTAT, 2019, p.191).

Figure 13. Furniture manufacturing value chain.

| Primary processing | Secondary processing | |
|---|---|---|
| 16.1 Sawn & planed wood | 31.01 Contract Furniture | Office & shop furniture |
| 16.21 Wood-based panels | | Furniture for public facilities, companies, hotels |
| | 31.02 and 31.09 Domestic Furniture | Kitchen furniture |
| 15.11 Leather & 13.9 fabrics | | Dining room furniture |
| 22.21 Plastics & foam | | Bedroom furniture |
| 25 Metal | | Living room furniture |

*Source*: Adopted from Rivera León et al. (2016).

For this study, the relevant furniture products (seen as secondary processing by the sector) are defined as contract and domestic furniture. Contract furniture (NACE 31.02) refer to the kind of furniture that are purchased by public facilities or companies. It includes, amongst other, furniture for public facilities (e.g., schools, hospitals, theatres and churches), restaurants, hotels, companies, offices and shops. Domestic furniture (NACE 31.02 and 31.09) refers to all kinds of household furniture (e.g., kitchen, living room, dining room and bedding) produced for private households. This product group includes the manufacturing of sofas, sofa beds, sofa sets, garden chairs and seats, furniture for bedrooms, living rooms as well as the upholstery of chairs and seats and finishing such as spraying, painting and French polishing.

### *3.3.1. Wood in furniture sector*

As presented in the previous section, despite the variety of materials used for furniture manufacturing, the sector is accountable for a considerable consumption of wood. In the EU it is estimated that 30% of the materials that go into furniture production is wood. Also, more than two thirds of particleboard and about half of the medium density fiberboard (MDF) production is used in the furniture sector (EC, 2016). Consequently, the furniture manufacturing sector is one of the wood-based industries worth looking into for increased material efficiency and circularity.

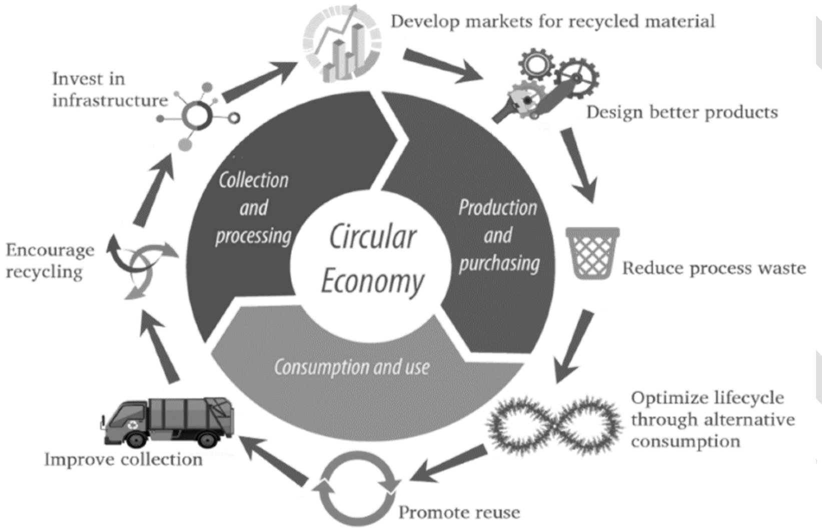
In general terms, circular systems are restorative by design. They aim to keep products and materials at their highest value, through repair, refurbishment, reuse, recycling, etc., over time. In the furniture sector, these restoring activities are relatively low. For instance, according to the European Federation of Furniture Manufacturers (UEA),[24] the total annual furniture waste equates to 10.78 million tonnes for the EU28 (EEB, 2017), with 80 to 90 per cent of all the furniture waste[25] being incinerated or sent to landfill and only 10 per cent being recycled. In the US, the Environmental Protection Agency (EPA) annual data on wood in municipal waste (including furniture and wood packaging, excluding yard trimmings and construction waste) showed that in 2018, more than 18.09 million tonnes of wood waste were produced in municipalities, out of which only 3.1 million tonnes (17 per cent) were recycled, 2.84 million tonnes (16 per cent) combusted while the majority, 12.15 million tonnes (67 per cent) ended up in the landfill (EPA, 2020).

Having this in mind, the furniture sector could benefit from efforts to improve circularity and resource efficiency. At the beginning of the value chain it relates to sustainable sourcing of raw material,

[24] See www.ueanet.com.
[25] Referring in this instance to the total municipal solid waste stream.

which either comes from the recycled wood – this should be increased, or from virgin wood – this should come from sustainably managed forests. The next step is the decision on if and how to use wood so that it can be kept in the loop for as long as possible – the product design (Figure 14). For instance, this can be done through product design, allowing for more efficient use of wood material thus reducing waste streams in the production process. It can also be done through planning for dismantling and recyclability, for instance by using ecological substitutes to chemically processed glues, varnish, or plastic coatings, thus avoiding contamination by non-recyclable and non-biodegradable materials. The latter approach would likely require adaptation of existing manufacturing processes. Another aspect is the furniture design that involves production of standardized modules, which enable customers to convert furniture items into alternative uses, to replace its specific parts or to add new elements in order to prolong their lifetime.

Figure 14. A circular economy model for the furniture sector.




*Source*: Barbaritano et al. (2019).

Further down the value chain, other circular approaches include increased reuse through repair, refurbishment and remanufacture services or recycling of discarded furniture through collection and sorting. However, it should be noted that both on the consumer and producer side, there is limited infrastructure for recycling, reuse, repair and remanufacturing, which undermines the potential for furniture being managed in accordance with the principles of a circular economy. In addition, the demand for second-hand furniture (reuse) is low, due to availability of low-cost products, which are easy to transport, assemble and dispose of. In a nutshell, there are weak market drivers for the collection, reuse and furniture takeback. In addition, transport and labor costs make repair and refurbishment costly, particularly where re-upholstery is required. There is also a cost increase related to preparing the furniture for reuse (EEB, 2017).

It should also be noted that the creation of new loops through recycling and recovery is complex due to the content of composite products, limiting the possibilities of further cascading use. Compared to the woodworking value chain, the furniture sector uses a much wider range of materials in production (e.g., sawnwood, wood-based panels, leather and fabrics, plastics and foam, and metal). This imposes significant limitations when it comes to recycling (e.g., recycled wood streams are often contaminated with hazardous substances such as glues, nails and varnish). That generates hazardous labor conditions and additional costs for recyclers.

Consequently, waste management infrastructure capacities have a major role to play when it comes to making the furniture sector more circular. For instance, there has been a trend to move away from solid wood and metal furniture (which are easier to recycle) to lower quality materials. This restricts the potential for reuse and highlights again the role of product design in defining the potential for recycling of materials, reusing of components, prolonging product durability, as well as possibilities for repair, reuse, and remanufacture. Design strategies (such as design for disassembly, design for modularity, design for recycling and material recovery, design for reuse and remanufacturing, design for maintainability, and design for end-of-life, need to consider complete life cycles of a furniture.

While ensuring the recycling and recovery of materials, the design strategies also need to take into consideration the needs of end-users or consumers of furniture. Most commonly, the producer responsibility ends when the furniture is sold. End-users are generally not given guidance on how to maintain and repair furniture (e.g., in order to extend the product lifespan), nor have they access to such services provided by the producer. Often, key parts ensuring functionality of the product are not made to last and spare parts are not available on the market. However, it is not all on the producers. There is still a prevailing linear trend: "take, make, use, dispose". Circular approaches in the furniture production should start with the 'Refuse' principle (i.e. decision not to buy non-recyclable materials), as part of the 9R approach (Figure 4). In many countries, the growth of the furniture industry relies on shortening the replacement cycles by stimulating consumers to buy new furniture before their existing one is used. Product marketing is prompting consumers to buy new furniture for design and fashion reasons. This is exemplified by the weak demand for second-hand furniture. As furniture purchases compete with other optional consumer spending, the low-cost product segments have developed to address the increasing demand driven by a raising interest in interior design (ITTO/ITC, 2005).l Also, the price difference between new furniture against the cost of second-life furniture is simply not significant to drive more sustainable purchasing behavior. This is coupled with poor awareness concerning the impact of increasing production and consumption of new furniture. Improvement in this area requires concerted action among different actors beyond the industry (e.g., market regulators).

Finally, the wide range of products that are considered to be furniture and the materials involved in their production (e.g., wood, plastics, textile, steel, glass, composites, foam) demonstrate that this is a highly complex value chain. Producers would for this reason need to take a systemic approach (or perspective) when considering circularity. For example, measures that support circularity would need to be adapted to the size and scale of the enterprises in question, from the large to the micro firms. Current sustainability challenges cannot be approached through single issue solutions, it is necessary to consider the furniture value chain in its entirety, starting from the upstream and the supply of raw materials up to the end-of life-of products. For instance, the furniture sector needs to consider the complex network of actors across the different supply chains involved in their production, ranging from raw material suppliers to customers and the post-consumer waste management sites. Partnerships and collaboration are thus key in finding solutions. There are also factors, such as education (e.g., awareness raising and training) and economical support (e.g., public incentives and technical assistance), which may allow producers to increase the sustainability and circularity of their products. Moreover, reducing the environmental impact of furniture production (e.g., using environmental management systems) and implementing innovation (e.g., using bio-based material streams and maximizing the value of waste) are also important within a circular context.

## 3.4. The pulp, paper, and cellulose manufacturing value chain

Figure 15 shows the pulp, paper and paperboard manufacturing value chain, including cellulose production as part of the value chain. The pulp, paper and paperboard manufacturing sector is derived from NACE 17 and includes different kinds of products made from pulp (EUROSTAT, 2019).[26] More specifically, pulp production includes pulp from several kinds of pulping processes (chemical: dissolving and non-dissolving; mechanical, semi-chemical and others). To produce pulp, paper and paperboard, other materials (e.g., chemicals) are also needed, but they do not represent a separate product category in this value chain. The paper and pulp industry is an interesting case example for this study due to the high-level of paper recycling, whereby recycled pulp derived from used paper is reused.

As illustrated in Figure 15, this section will cover three main product groups, the pulp and paper industry in general, covering the manufacture of pulp (NACE 17.11) and paper and paperboard (NACE 17.12), the production of cellulose-based fibers (also covered under NACE 17.12). The latter category will focus on specialty cellulose products (e.g., textiles) not fully covered in pulp and pulp-based manufacturing, and the production of cellulose-based plastics (NACE 20.16) and have been included as they are at the innovation forefront of the forest-based industries.



[26] NACE 17 characterizes pulp production as the separation of "*cellulose fibres from other matter in wood, or dissolving and de-inking of used paper, and mixing in small amounts of reagents to reinforce the binding of the fibres*" while the manufacture of paper is noted as involving the release of "*pulp onto a moving wire mesh so as to form a continuous sheet*" (EUROSTAT, 2019, p. 134).

Figure 15. Pulp, paper and paperboard manufacturing value chain.

**Primary processing**

- Inputs: Pulpwood; Other fibers than wood; Recovered paper; Industrial by-products
- 17.11 Manufacture of pulp (bleached - unbleached, hardwood - softwood pulp)
  - Mechanical pulp
  - Semi-chemical pulp
  - Chemical pulp
    - Sulfite pulp
    - Sulfate pulp
  - Recovered fiber pulp
  - By-products: wood chips, black liquor, tall oil, hemicelluloses.

**Secondary processing**

- 17.12 Manufacture of paper and paperboard (rolls and sheets of paper)
  - Graphic paper
    - Newsprint paper
    - Printing & writing paper (uncoated mechanical, coated mechanical, uncoated woodfree, coated woodfree)
  - Packaging paper & paperboard
    - Container board, carton board, wrapping paper, other paper & paperboard for packaging
  - Household & Sanitary Paper
  - Other paper & paperboard, incl. industrial & specialty paper
    - Cigarette and banknote paper, labels, etc.
  - Manufacture of cellulose wadding and webs of cellulose fibers
- 19.20 Biofuels for transport
- 20.16 Manufacture of plastics (e.g., cellulose and its chemical derivatives)

**Tertiary Processing**

- 17.2 Manufacture of articles of paper and paperboard
  - 17.23 Paper stationery
    - Notebook, envelopes
  - 17.21 Packaging (industrial and food & beverage packaging)
    - Sacks and bags of paper
    - Liquid packaging board
    - Carton and corrugated cases
  - 17.22 Household, sanitary & 13.95 non-woven products
    - Toilet paper, tissues, towels, napkins
    - Sanitary towels, absorbent hygiene products
    - Paper filter, textiles, medical applications.
    - Cellulose wadding products
  - 17.29 other articles of paper and paperboard

*Source*: Adopted from Rivera León et al. (2016).

It should further be noted that companies working with cellulose-based fibers and plastics differ significantly from company to company. Moreover, the number of companies operating in the market is low whilst their business focus is very individual. This means that cellulose-based fibers and plastics could be represented by their own respective value chains. However, in this case they have been integrated into the wider pulp, paper and paperboard manufacturing value chain. The reason for this integrative perspective being that the main component of pulp, paper and board is cellulose-based fibers while cellulose-based plastics are bioplastics manufactured using cellulose or derivatives of cellulose. In addition, when considering circular approaches, it makes sense to take a bird's eye perspective to understand the material flows and how they relate to one another.

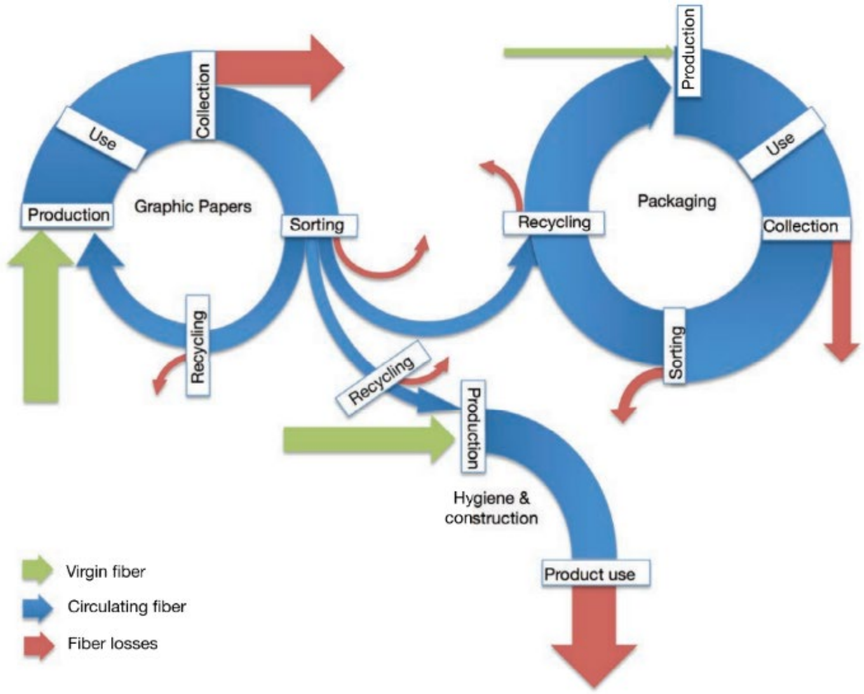
### *3.4.1. Pulp, paper and paperboard manufacturing*

Paper production requires significant amounts of natural resources, biomass in particular. The pulp and paper manufacturing value chain consequently has a significant environmental impact, both upstream (during raw material sourcing and production process) and downstream (when the paper and associated by-products are recycled). Consequently, pulp and paper manufacturing has a significant potential for implementing material efficiency and circular approaches. For example, according to the Confederation of European Paper Industries (CEPI),[27] the pulp and paper sector is particularly appropriate for circular approaches because it uses a sustainable, renewable and recyclable raw material as its primary resource. Also, paper recycling is already relatively well implemented thanks to existing automated processes and collection infrastructure. For instance, 72 per cent of all paper consumed in Europe was recycled in 2019,[28] while, at the global level, the recycling rate is around 54 per cent (Van Ewijk et al., 2018). In the US, in 2018, more than 67.39 million tonnes of paper and paperboard waste was produced in municipal waste, out of which 45.97 million tonnes (68 per cent) were recycled, 4.2 million tonnes (6 per cent) were incinerated, while 17.22 million tonnes (26 per cent) were landfilled (EPA, 2020).

Although relatively easy to recycle in its pure form, in practice, paper can only be recycled five to seven times (Figure 16). This is because fibers get lost or damaged during the recovery, collection and sorting process. For instance, from the global collection rate of 54 per cent it has been estimated that only 34 per cent reemerge as paper. This also means that an increase in paper recycling does not mean a proportionate decrease in virgin inputs (Van Ewijk et al., 2018). Moreover, it can be noted that for example the pulp and paper sector in the EU produces approximately 11 million tonnes of other waste on its own on an annual basis.[29] This suggests that, despite high recycling rates, engineering waste out of the system remains an important objective for the sector as a whole and an underlying driver for circular thinking in the sector.

[27] See www.cepi.org.
[28] See www.paperforrecycling.eu.
[29] It has been found that between 25 and 40 per cent of all municipal solid waste generated each year is paper-related.

Figure 16. Cellulose Fibers Life Cycle.




*Source*: WEF (2016).

It can be added that paper and paperboard are commonly printed on and coated by a variety of downstream actors that add chemicals (e.g., printing inks) which damage the fibers and limit the number of times a fiber can be recycled. This creates significant challenges when it comes to making the paper value chain circular, principally, as the many chemicals used cannot be completely or easily separated from the paper. Moreover, recycling processes have their limitations. For instance, increased variation in ink formulations and printing techniques are diversifying the number of material streams connected to the paper-based value chain, each requiring different recycling and deinking techniques (e.g., over 6,000 different chemicals are used in printing inks).

The complexity of the value chains makes a transition towards circularity more difficult. However, overall, it is important for the sector to reduce fiber losses and the amounts of virgin resources utilized in paper production. This can be done by making paper easier to recycle and by preserving the value of recycled fibers. The paper and pulp sector could partner with related actors (e.g., the ink, dyes and glue industries) to co-design additives that are easier to separate from paper. If possible, by-products from other industries could be inserted into the production process Improved coordination across the value chains (or sectors) may help ensure that recycling plants will be able to handle all new materials, including steps to improve relevant recycling infrastructures.

As with the preceding sections, the examples provided above demonstrate that circularity and sustainability start with the design. In case of the pulp and paper sector, the design should focus on recyclability. This may include rethinking the materials composition that paper is made out of, to influence the way it is physically structured, or how it reacts with the inks it comes into contact with. Other avenue for increased sustainability is the sustainable sourcing of raw material, not only from recycled paper but also from sustainably managed forests. Circularity approaches can also encompass steps to ensure improved traceability of existing and new materials (e.g., those used in packaging) and the standardization of new fiber-based materials, in the view of quality management for recycling.

The user also plays a central role in the circular story. In fact, including the end-user (e.g., consumer) as an actor in the material flow structure is vital for further increasing of recycling rates. For this reason, it is important to build awareness about recyclables to further increase recycling participation. However, policy measures that encourage recycling will succeed only if the markets for recycled products function well, the segregation and disposal of recycled material can be done in a cost-efficient manner. Moreover, the impact on the environment and the quality of the final product must be acceptable.

Another interesting potential for circularity lies in the use of pulp and paper side streams for bioenergy. Even though energy production is not considered circular as it does not fulfil end-of-waste criteria (e.g., waste ceases to be waste and obtains a status of a secondary raw material), the use of woody biomass by pulp and paper sector has the advantage of generating by-products that can be used for renewable energy production. For instance, a biogas plant can process the wastewater slurries from a paper mill and turn this into biogas for transportation, fertilizers or solid biofuel for a boiler plant. This is an industrial symbiosis[30] that valorizes waste from the paper manufacturing which, in turn, can contribute to reducing the reliance on fossil fuels (Lombardi and Laybourn, 2012). For example, black liquor has been an important biomass fuel[31] in many pulp mills, where it is used for chemical recovery and energy production. The recycling of ash from black liquor boilers can in turn be used in the production of a mineral fertilizer, potassium sulfate.

While the paper and pulp sector is moving toward circularity this transition has not necessarily been driven by the wish to integrate circularity into existing value chains but rather by efforts to improve profit margins and reduce costs due, in part, to increased global competition (Rivera León et al., 2016). As such, more can be done to further integrate circular thinking and perspectives into pulp and paper value chains, not only by increasing the number of recycled materials that go into production, but also by improving the recovery of pulp and paper production by-products and side streams for reuse. For instance, coupling increased recycling with improved recovery of materials and energy, when possible, can further reduce waste discharge. Waste generation and environmental pollution are two key areas where the sector can become more circular and sustainable. This includes efforts to reduce GHG emissions. Another area where action can be taken is related to material consumption and resource efficiency. For instance, water and energy are the two biggest resource inputs into the papermaking process, aside from wood pulp. Increased resource efficiency can include use of renewable energy and reusing water in multiple production cycles or even sourcing it from other industries.

[30] Industrial symbiosis is a form of bringing companies together in innovative collaborations, such as finding ways in which the waste or by-products of one become raw materials for another.
[31] The burning of black liquor (e.g., in a special recovery boiler) generates around 13 000 to 15 000 Kilojoule (kJ) per kg of black liquor.

### 3.4.2. Cellulose-based fibers

The global consumption of textiles is increasing rapidly. The average consumer buys 60 per cent more clothing than 15 years ago. Around 56 million tonnes of clothing are bought each year, worldwide, which is expected to rise to 93 million tonnes by 2030.[32] However, while consumption has increased, only 12 per cent of material used for clothing ends up being recycled, globally, with less than 1 per cent being recycled into new garments (CBI, 2020). Most of the fabric waste is incinerated or sent to landfills. This unsustainable trend is strengthened with increasingly shortened lifespans for clothing (due to the fast fashion phenomenon).[33]

This section will focus on the use of cellulose-based fibers as an alternative for synthetic fibers and cotton. These innovations have expanded the potential use of materials from forest-based industries, not only adding value to the forest sector but also addressing the demand for recyclable, responsible, and ecological fibers. Cellulose-based fibers may deliver environmental benefits compared to synthetic fibers in terms of biodegradability and to cotton in terms of land and water footprint. However, the conclusions about the environmental impact assessment among viscose, cotton and polyester depend on the emphasis put on different criteria in lifecycle analysis studies, which are often produced by the respective businesses themselves (Viitalia, 2016). For instance, the production of cellulose-based fibers, in particular viscose, requires a large amount of chemicals, of which a number cause concern. Without correct handling, they can cause significant health problems for factory workers through direct exposure, and when leaked into water, pollutants from the process present a high risk of acute aquatic toxicity, which can result in the death of aquatic organisms (EMF, 2017).

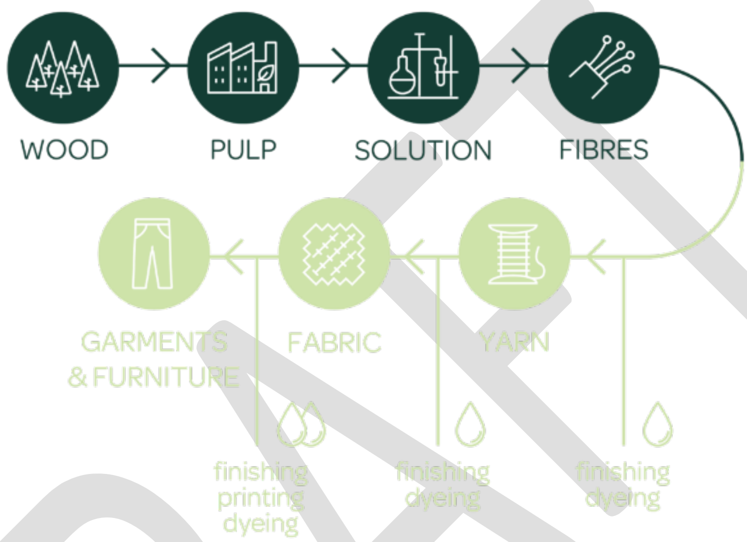
While in 2019, the cellulose-based fibers made only approximately 7 per cent of the global fibers market (Kallio, 2021), their global production has been growing steadily since 2000, at an average annual rate of 6 per cent. At the same time synthetic fibers (with 63 per cent share of the market) grew annually by 3 per cent between 2000 and 2010, and by 1,3 per cent between 2010 and 2018 (Fiber Year Consulting, 2020).[34] It is forecasted that by 2025, the average annual production growth of cellulosic fibers will be at 4.7 per cent while of synthetic fibers at 3.7 per cent. The annual growth of cotton use has been diminishing since 2000 and is expected to remain below 1 per cent by 2025 (Landsell-Hawkins, 2020).[35]

It is worth noting that in 2020 the cellulose-based fibers market dropped, after 11 years of growth, mainly due to the impact from the COVID-19 pandemics on the textile industry (excess inventory, low oil price lowering polyester price, less demand). However, it is estimated that the cellulose-based fibers consumption will continue to grow, particularly in niche markets, such as in fiber crafting[36], hygiene and medical products, where innovation in non-woven fibers has led to the development of functional characteristics of cellulose-based fibers, that combine those of polyester (e.g. cellular structure that prevents bacteria and viruses to survive) and those of cotton (e.g. breathability, biodegradability) (Author's notes, Second International Conference on Cellulose Fibers, 2021).

[32] Clothing, footwear and household textile represent 15 per cent of primary raw material use in the upstream supply chain of EU-28 household consumption (EEA, 2019).
[33] "Fast fashion" refers to a business model based on replicating catwalk trends and high fashion designs and mass-producing them at low cost.
[34] Presentation by Engelhardt, A. "Status and Outlook on Textile Fiber Markets, 2020" during the First International Conference on Cellulose Fibres, 2020
[35] Presentation by Landsell-Hawkins, O. "The Outlook for Dissolving Pulp Supply and Demand", during the First International Conference on Cellulose Fibres, 2020.
[36] Fiber crafts include knitting, crochets, sewing and weaving.

The textiles market is highly globalized and complex, dominated by millions of interconnected SMEs across the world, most of which are involved in primarily linear value chains. These value chains, from raw material extraction to production, transport, consumption and waste, are even more diverse than the furniture sector (Figure 13). The geographic extension and opaqueness of the sector make the “closing of the loop” impossible. However, other approaches may enhance the circularity of the value chains at their particular stages. For the needs of this study, a simplified version of cellulose based fibers value chain (Figure 17) has been chosen to demonstrate key stages of the fibers and textiles production process.

Figure 17. Simplified wood-to-textile value chain.




*Source*: Grete Project (see https://www.greteproject.eu/project/).

The production of cellulose-based fibers can support the woodworking sector by creating a demand for by-products (Jia et al., 2020; Kallio, 2021) and transforming side streams from pulp production to valuable materials and chemicals, thus contributing to resource efficiency and circularity of the value chains. On the other hand, the global dispersion of value chain actors limits the circularity. Dissolving pulp, the key raw material for cellulose based fibers, is mainly produced in China, East Asia and India, where also most global textile production takes place. Garments are then shipped to Europe and North America, where they are sold by retailers. Used clothes and fibers are mostly incinerated, donated to charities, sold at second-hand markets or recycled in a cascading way for other purposes at different geographical locations. ‘Closing of the loop’ with recovered materials is practically impossible.

Given the low rates of recovery and recycling of textile fibers, quoted at the beginning of this section, a system combining a reuse and cascading use of worn fabrics could be improved, wherever it is economically viable. The existing recovery technologies allow 50 per cent of the raw cellulose fibers to be replaced with alternative feedstocks, recovered from agriculture and municipal residues, recycled textiles and other sources (Author’s notes, First International Conference on Cellulose Fibres, 2020). However, at the commercial scale, the recovery of irregular streams with inconsistent quality may be economically and environmentally unsustainable

Therefore, more focus is needed on setting up recycling schemes and improving recycling technologies (e.g., on separating materials) to address the complex waste streams involved in textile production and move production towards the next generation fibers (e.g., from recycling).

Today most garments are produced from a mix of synthetic and natural fibers. This on the one hand entails improving sorting technologies and infrastructure, and on the other hand improving the recyclability of textiles (e.g., by ensuring that textiles are made of long-lasting fibers which can be recycled, or are biodegradable, and are free from hazardous substances). For instance, even content of elastane (elastic synthetic fibre), if higher than 7 per cent, prevents chemical recycling (Helena Claesson, Södra, 2020[37]). This relates back to the question of designing products that have a longer life cycle and that can be recycled. Also, in textile production value chains, the treatment and dyeing of textiles, in particular, cause significant freshwater pollution. This not only emphasizes the need for pollution prevention in textile production but also the importance of design strategies that can address the durability, reuse, repair and recyclability.

Another important aspect of addressing circularity and material efficiency in textile value chains relates to putting in place the third-party audits and traceability certification. From the industry perspective, traceability increases its ability to manage the supply chains more effectively, identify environmental impacts, and encourages sustainable production patterns. From the user perspective, increased traceability improves trust in the brand and potentially helps consumers become more aware of the environmental impact of the products they buy. Production and consumption are particularly interlinked in the textile industry. Production is prone to demand generated by fashion and the fast fashion trend has been shaping production and consumption patterns, fostering frequent purchase of products that only last one season and consequently lead to the concept of disposable clothing (ECE, 2020).

Therefore, an increased consumers awareness about material recycling and upcycling and their participation in reuse and recovery efforts is a cornerstone for reducing the amount of textile waste generated and thus potentially reducing the demand for raw materials. Second-hand clothes are often sorted and resold or redistributed by charities, while lower grade fabrics are used by other industries (e.g., for insulation material, mattress stuffing, wiping cloths and hygiene products). While still 73 per cent of all materials used for clothing end up in landfills or are incinerated (EMF, 2017), the second-hand clothes market is growing and is forecast to grow by 11 per cent per year through 2026[38]. However, the recyclability and biodegradability of cellulose-based fibers should not justify the overproduction. Thus, the primary sustainability imperative for the sector is to produce less and to recycle more.

Finally, the overall complexity of the textile sector underscores the importance of collaborative relationship building and interactions across supply chains Networks for waste management across the associated value chains are needed. Furthermore, improved cooperation across supply chains could contribute towards expanding the resource base for the production of cellulose fibers, an important point in the context of increasing competition over raw materials.

In conclusion, the choice of materials and the design influence the environmental impact of textiles and their end-of-life options (such as the potential for recycling). The application of circular approaches needs to be systematic and supported by cross-cutting policies, particularly with regards to efforts to improve recycling and reuse of materials, including upcycling (Kallio, 2021; Singh et al., 2019). The creation of sustainable material cycles for textiles would furthermore need to be supported by policy frameworks that emphasize sustainable safety requirements and waste reduction and treatment, as well as sustainable production and consumption patterns through the promotion of labelling, certification and harmonized product standards (EEA, 2019; Jia et al., 2020). It is equally important that the production of cellulose fibers does not equate to an

[37] Presentation by Helena Claesson from Södra during the First International Conference on Cellulose Fibres 2020.
[38] See www.futuremarketinsights.com.

unsustainable increase in the use of virgin raw materials and a negative impact on forest ecosystems. This emphasizes the need for sectoral integration with sustainable forest management and the increased production of cellulose fibers from recovered alternative feedstocks. For instance, the extended producer responsibility[39] is not widespread in the sector but could be useful in increasing the recovery rates of post-consumer streams. Finally, independent audits are needed to increase the credibility in sustainability and circularity of cellulose-based fibers value chains.

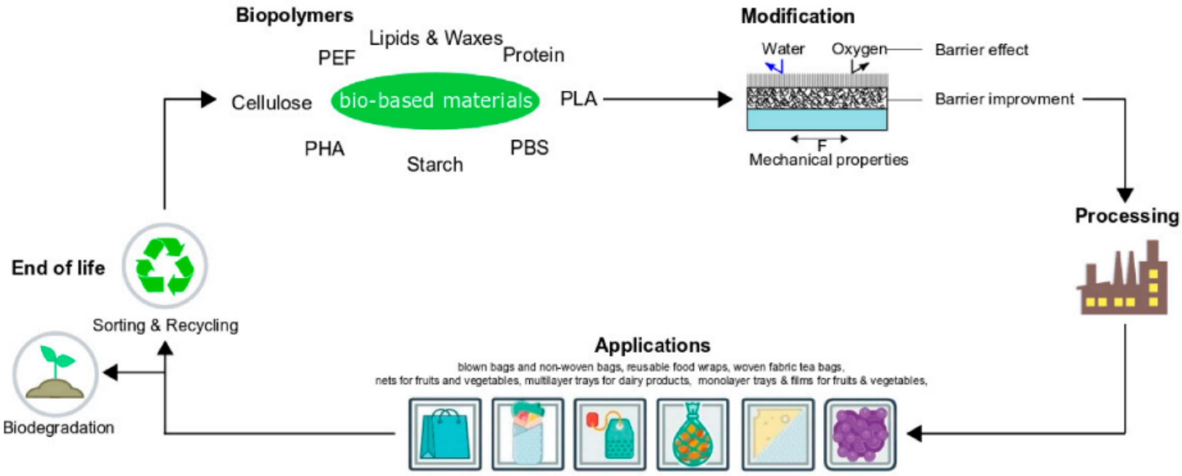
### *3.4.3. Cellulose-based plastics*

Plastic is a material utilized in nearly all aspects of modern life, mainly, due to the specific properties of petrochemical plastics,[40] such as low production costs, being light weight and transparent, its durability (use phase), as well as having a high stability with regards to water and organic solvents. Today, most plastics are consequently used for packaging (around 30 per cent, globally) as they are very functional as a packaging material. This is followed by the use of plastics in buildings and construction at around 17 per cent and transportation at 14 per cent (UNEP, 2018a). The global production of plastics has on average increased by approximately 9 per cent per year since 1950 (UNEP, 2018a), increasing nearly nine fold since the 1970s. Plastic production was approximately 360 million Mt in 2018 and plastic wastes is projected to exceed 340 million Mt by 2045, annually. However, less than 10 per cent of all plastic wastes are recycled, amongst other things, because there are high costs associated with recycling and it does not degrade easily (Reichert et al., 2020; Su et al., 2020). The plastics producers are for this reason likely to face increasing pressure to improve the recyclability and increase the recycled content within their value chains. This stresses the importance of developing sustainable and circular alternatives to plastics produced without using fossil raw materials.

Bio-based plastics provide such an alternative, particularly, considering that bioplastics are non-toxic, renewable and biodegradable. It should however be noted that bio-based plastics can be divided into three categories, namely, (1) bio-based and non-biodegradable, (2) bio-based and biodegradable, and (3) fossil-based and biodegradable (European Bioplastics, 2018). This section is primarily concerned with cellulose-based plastics, produced from wood pulp, but bio-based plastics can also be produced from other materials, such as food waste (Figure 16). However, while the global demand for bio-based plastics has increased, it still represents only a small niche market. For instance, in Europe, where they are quite highly promoted, only 1 per cent amongst the plastic produced annually is bio-based plastics (Bajpai, 2019). It should also be noted that cellulose-based plastics are only one type of bio-based plastics and on their own a highly innovative and heterogenous segment. The information about it is rarely made distinct, therefore, the analysis of the circularity of their value chains in this section will be based on bio-based plastics sector in general.

[39] Extended producer responsibility is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products.
[40] The most used plastic polymers are polypropylene (16 per cent), low density polyethylene and linear low-density polyethylene (12 per cent) and polyvinylchloride (11 per cent) (UNEP, 2018a).

Figure 18. Life cycle of bio-based material for packaging and textiles.




*Source*: Reichert et al. (2020)

Biodegradable and compostable bio-based plastics have been on the market for more than 25 years however, there is still confusion about what they are, which raw materials have been used for their production, to what extent they are bio-based, and how to recycle them. Cellulose-based plastics are bioplastics manufactured using cellulose or derivatives of cellulose. They are manufactured using softwood as the dominant raw material. However, as noted above, it is important to highlight that not all of them spontaneously decompose into the natural environment. The decomposition depends on the chemical process used during production. For instance, in most cases, biodegradable bioplastics will only break down in industrial composting facilities, with adapted temperature and atmosphere conditions. This means that the use of bioplastic, while better than petrochemical plastics, still requires improving waste management and recycling infrastructures.

Bio-based plastics types are very diversified, infrastructure for their collection non-existent or very fragmented. For instance, a variety of small-scale, local initiatives improving waste collection schemes have been introduced, however, they are rarely coordinated at the national or regional level and their economic viability have not been proven yet. Likewise, new sorting and reprocessing technologies have been developed, but they have not been implemented at a commercial scale yet. For instance, industrial composting infrastructure is scarce and requires investment This includes the modernization of waste disposal plants and using new technologies to improve separation and sorting of multi-materials.

From a user perspective, although certification and labelling schemes for bioplastics have emerged, they tend to focus on informing consumers on pragmatic features of the products, such as if the product is biodegradable or compostable, rather than the specification on their exact composition and the way they should be disposed of. This creates confusion about a possible reuse and recycling of bio-based materials. In this context, increasing the post-consumer value of bio-based plastics (considering their entire life cycle), which would allow the economic viability of keeping the recovered materials in the system, remains a challenge. This challenge highlights a need for further standardization and quality certification to ensure product quality, performance, recyclability and biodegradation.

# Part 4
# Challenges and opportunities of circular approaches

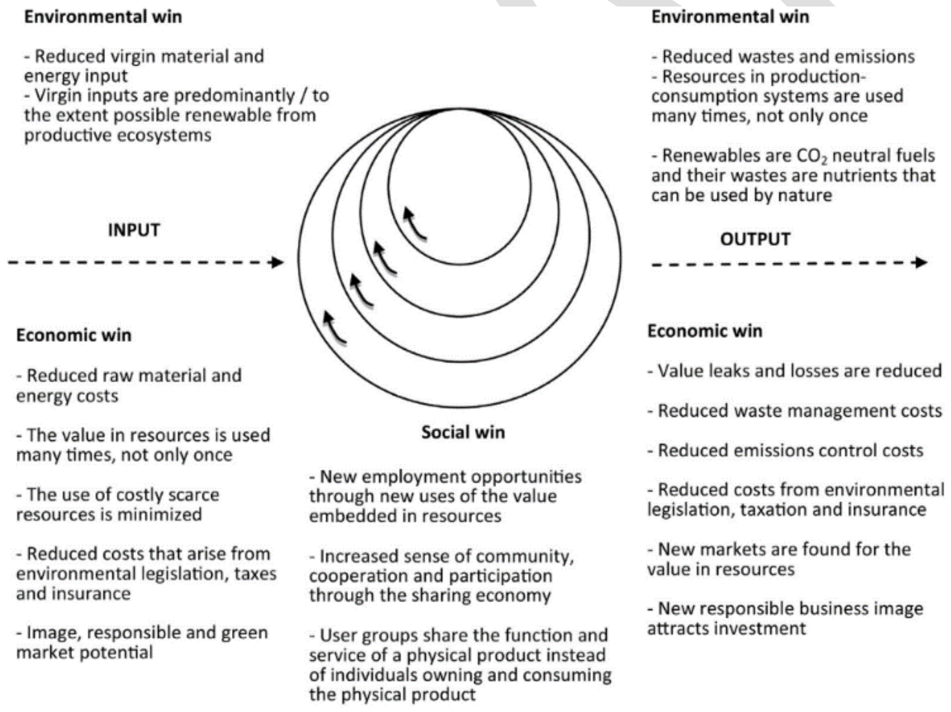
# 4. Understanding implications of circular approaches in forest-based industries

The basic premise for gradually moving towards circularity is linked to natural resource limits and the ecological impact of human activities. This has led to the realization, across different sectors and disciplines, that society needs a regenerative and restorative socio-economic system of production and consumption. In other words, industry needs to close the loop of linear processes.

The idea of a circular economy is a complex concept encompassing a range of materials, products and actors, with varying potential for circularity across different products and value chains. The transition to a circular economy is a multi-level organizational and governance challenge, from international to national level as well as private sector and individual citizens.

Consequently, circularity considerations should reflect both technical and biological resource cycles as well as the interplay between them, including moving, where possible, to a circular bioeconomy (Box 3). Furthermore, the interactions, synergies and potential trade-offs between a circular economy and related concepts such as sustainability and resource efficiency should be analyzed in a systemic approach. A successful transition to a circular economy means contributing to the three dimensions of sustainable development (economic, environmental and social) and adapting to the natural ecosystem cycles when using bio-based products in economic cycles (Figure 19).

Figure 19. Circular economy for sustainable development.




Source: Korhonen et al. (2018a).

Circularity is also a way of implementing the SDGs. As illustrated in Box 1, there is a strong relationship with SDG 6 (clean water), SDG 7 (affordable and clean energy), SDG 8 (work and economic growth), SDG 12 (responsible consumption and production) and SDG 15 (life on land) (Schroeder et al., 2019). However, while consideration of circularity can go beyond sustainable production and consumption, sustainable development does not necessarily contribute to circularity (and vice versa). In this study, circular approaches principally focus on resource cycles while the understanding of sustainability is related to three dimensions (the people, the economy, and the environment). Circularity and sustainability commonly go hand-in-hand, but not always. For example, in a specific sawmill, the use of residues to produce bioenergy on site (see page **Error! Bookmark not defined.**), may be considered sustainable, under some conditions, but it does not fulfill the criteria of circularity. In a circular model, these residues would be used for the production of wood-based panels first. However, this may incur increased emissions due to the transportation instead of using them on site to produce energy. Consequently, there are also reasonable concerns about the environmental impact of closing certain loops. Therefore, a circular economy model for the forest-based industries should account for sustainable development as well as for the natural limitations of wood (such as the natural degradation of wood over time) which prevent the sector from completely closing some of the loops.

## 4.1. Recognizing limitations to increased circularity

Forests and the forest sector can benefit from a transition to a circular and bio-based economy, as forest ecosystems are a source of renewable and biodegradable products which can substitute for finite and polluting materials; and they have a capacity to naturally restore the quality of their resources. Different parts of a tree can be used to manufacture various products, starting from the lowest to the highest quality grade. The European Confederation of Woodworking Industries (CEI-BOIS), the Confederation of European Paper Industries (CEPI), the Confederation of European Forest Owners (CEPF) and the European State Forest Association (EUSTAFOR) developed an illustrative overview of 99 benefits of a tree, which feed into various value chains in 14 different industries[41]. As demonstrated in the previous sections of this study, good practice in resource management in forest-based industries brings the forest sector closer to the principles of circularity. Nonetheless, challenges in overall circularity of forest-based value chains are present. They are mainly related to the limitations in sustainable sourcing of raw material and to unsustainable (linear) consumption of forest-based products.

While the transition towards a circular and bio-based economy is generating an increasing demand for forest-based products, the regenerative capacities of forest ecosystems have been decreasing, be it due to climate change, landscape degradation, soil erosion, forest fires or pests. Therefore, circular or not, the sustainability of forest-based value chains will always depend on the natural cycle of forests growth and renewal. Circularity and material efficiency may go only as far as the natural systems regeneration capacity allows. Consequently, sustainable forest practices are key in safeguarding ecosystem services and ensuring the provision of wood in a sustainable manner. They should be an integral part of the Circular Supply Chain Management (CSCM) (Section 2.5). Only strengthened coordination between the biological and the technical cycles along value chains will allow for their sustainability in the long term.

Various forest-based industries were described in the previous sections of this study. The examples cited attest that the adoption of circular approaches means reviewing all value chains stages involved in production cycles – from the design to the end of use of products (Tantau et al., 2018). And since a tree can be used in a number of different ways, the number of potential value chain connections and combinations creates a very complex industrial system. However, while the forest sector has the potential to play an important role in the circular economy, today the value

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[41] See www.cepf-eu.org/sites/default/files/document/What%20a%20tree%20can%20do%20-%20poster%20only.pdf

chains that make up the largest part of the forest-based industries still remain traditionally linear (Figure 20).

Figure 20. Example of a traditional forest-based value chain.


*Source*: Own figure.

In a traditional forest-based value chain once a tree has been harvested, the wood is transported to a pulp and paper mill or a sawmill, as part of the primary processing. There, it is transformed into products that can either be used directly (e.g., in construction) or transported for further (secondary or tertiary) processing to be turned into more complex products (e.g., furniture). The end life of the product is rarely the concern of the primary producers. It is too far downstream. The application of circularity, therefore, requires from producers to not only imagine end-of-use resource management options, but also and foremost, to create industrial symbioses with partners using side streams and by-products to reduce waste along the value chain. Good practice has already been in place, in particular at early stages of wood processing. Nevertheless, previous sections provide a number of examples of how the system can be optimized using strategies of slowing (extension of a product's lifetime), closing (recycling) and narrowing (using fewer resources per product) production loops.

As the demand for forest-based products has been growing, and pressures on ecosystems increasing, the recovery and use of waste streams creates a window of opportunity which needs to be examined with care. The resource-efficiency is relatively well established in forest-based industries, mainly due to economic reasons. On the other hand, the recovery of the end-of-life post-consumer waste streams is still limited. There are several reasons for that.

First, there is no standard classification of post-consumer wood at the international level. Some countries have developed their own classifications and apply them in trade with neighboring countries. However no internationally recognized standard, which would allow for identification, monitoring and trade of different post-consumer wood waste streams, exists. A potential classification at the international level could open new outlets for these residues – a positive development in the context of a circular economy.

Second, the number of collection and sorting facilities for post-consumer wood is limited. Paper recycling is an exception in this regard, as its recycling rates are high and the economic viability satisfactory in most areas. However, paper industry results cannot be simply replicated for the recycling of other wood-based residues. Primary, the sources of wood waste streams are various, contrary to paper which is mainly recovered within municipalities with easier-to-manage logistics. Also, sorting technologies are not widespread for most wood-based materials, contrary to sensor-based technologies for paper. That makes recycling dependent on manual sorting, a labor-intensive technique which incurs high processing costs, an inconsistent end-product quality and health risks for people (e.g., exposure to microorganisms and dust).

Third, post-consumer wood is a low value product, characterized by irregularity of streams in terms of quality and frequency. That leads to geographical limitations as regards the cost of transport and environmental sustainability of value chains.

In addition to the limitations related to recovery of exiting post-consumer wood streams, innovative cellulose-based materials, such as cellulose-based fibers and plastics also come with new challenges associated with their recovery. As mentioned in pervious sections of this study, these products are extremely diversified and their markets highly fragmented. Consequently, no standardized systems for the recovery of their waste streams exist. These new sectors are neither sufficiently structured yet in terms of quality standards nor organized in terms of industry representation to ensure the consistent approach to industrial cooperation and circularity of their business models. Information about sustainability of cellulose-based fibers and plastics is often confusing. Terms such as ‘recyclable’, ‘biodegradable’, ‘compostable’ are often used interchangeably, however they do not mean the same. Some of the products are biodegradable or compostable only in specific industrial conditions. That requires a development of a well-connected infrastructure for collection and sorting, which does not exist today.

All these challenges provide evidence that, in practice, not all forest-based value chains can be circular. In some cases, the focus on circularity may cause other externalities which do not guarantee sustainability in the long term (e.g., due to the impact of transport). Examples from previous sections repeatedly showcase that in existing business models the responsibility for production and waste creation are not interrelated, while in fact the elimination of externalities depends on a coordinated action at all stages of value chains including eco-design, the extended producer’s responsibility, investment in collection infrastructure, availability of technologies supporting sorting processes, the geographical proximity between production facilities and waste stream users, etc.

Finally, it is important to highlight that while the transition to a circular and sustainable economy can be enabled by policies, it will need to develop organically, based on profitability of individual companies and the consumer preferences. Ultimately, it will be the market forces, not policies, that will guide this process.

## 4.2. Supporting transition towards circularity

This study set out to explore what circularity concepts mean for forest-based products and value chains. In a circular economy, what is a product today can, in theory, become a raw material tomorrow. However, how can this be achieved for a material like wood, which deteriorates over time and cannot be reconstructed like glass and metals (e.g., through melting or smelting processes). The value chains analysis in Section 3 demonstrates that a circular economy approach, amongst other things, requires transformation across entire value chains. While it has only been possible to scratch the surface in this study, diving into the respective value chains has shown that circularity will require new business models, connections across sectors and companies, as well as the application of new technologies and management tools. It will also require an increased awareness about all existing approaches to make wood-based products more circular, as a circular economy is more than just waste recycling, it is a model that also redefines the processes of product design, manufacturing and consumption.

What the analysis has also demonstrated is that there are no precise answers or solutions to most of the questions surrounding circularity. Aside from the many different interpretations of a circular economy (Section 2), each value chain or sector presents its own set of limitations, challenges and opportunities. The differences in resource and energy use as well as waste management practices across woodworking, furniture and paper and pulp industries demonstrate that. There is furthermore a degree of value chains dependency that needs to be accounted for when thinking about possible solutions for closing the loop by specific industries. Having this in mind, while the analysis of the different value chains in previous section set out more details, this section will attempt to summarize some of the more general points of action that are equally applicable across the different forest-based value chains, regardless of the nature of the industry.

It is worthwhile noting that this study foresaw application of the three value retention loops from the UNEP circular economy model (Figure 6). These loops cover the entire life cycle of a product, from extraction through production to the end-of-life. However, the analysis has demonstrated that it is not easy to categorize all action points in the value chains according to these loops, in particular, as many are cross-cutting. For example, awareness-raising is an action that is equally applicable across all value chains and irrespective of taking place in the user-to-user, user-to-business, or business-to-business loop. For this reason, a number of generic action points have been listed in Box 5. While these points should not be seen as an exhaustive list, they demonstrate that there are many important issues that need to be addressed in a systemic way.

Box 5. Cross-cutting action points.

**Integration across value chains and supply chains**

Circularity needs to be reached through integration and cooperation across values chains (e.g., between producers and transport). That can improve performance and facilitate sustainability in supply chains. This implies the involvement and coordination of the different actors in the value chain, including producers and users (e.g., using multi-actor networks) to identify potential loops and/or side streams up and downstream (e.g., waste products that can be valorized) to maximize material use (e.g., sawdust used to produce energy in a mill can be cycled back as ash to the forest). Stronger collaboration between business ecosystems (e.g., municipalities, architects, designers, builders and end-users) is also needed.

**Awareness raising and education**

There is a need for increasing the general knowledge and awareness about circularity, both amongst producers and users. The dissemination of knowledge and measures on circularity to all stages of value chains up and downstream is necessary (e.g., on the practical realization of wood cascading). This can be done through training of personnel at the business level or public campaigns on sustainable wood labels or on bioplastics recycling options, for users.

**Circular policy frameworks**

Regulatory and legislative framework could address barriers for users and producers in implementing the reuse and recycling of wood-based products (e.g., regulating the market of reclaimed sawnwood). Policy measures have an important role to play in establishing a hierarchy of resource uses (e.g., giving priority to long-life material uses) and in addressing relevant trade-offs inherent in the application of circular thinking (e.g., promotion of biomass energy may not be compatible with circularity principles).

**Innovation and technological development**

Development of technological capacity to implement circularity is crucial. This is particularly important for the design of new products that can decouple production processes from fossil-based raw materials use and to enable businesses to “close the loop”. For example, innovative materials (e.g., bioplastics) allow for biodegradation while innovative chemical recycling processes, for recovery of textile fibers from mixed natural-synthetic feedstock (e.g. Södra).

**Certification, quality standards and labelling**

Certification, quality standards and labelling provide tools allowing users and businesses to make informed choices about sustainability. For instance, Chain of Custody certification[42], help to ensure that wood used for the products comes from sustainably managed forests. Similar labels could be introduced to ensure traceability of new cellulose-based materials, such as bioplastics, garments and footwear.[43] Other labels could inform the end-consumer about the options for disposal, thus facilitating collection and sorting for reprocessing (or composting) of waste streams according to relevant categories.

Apart from these cross-cutting action points, more specific circularity approached can be applied at different stages of value chains (Box 6). To illustrate the respective loops (business-to-business, user-to-business and user-to-user) the UNEP circular economy model (Figure 6) will be used loosely here to frame a list of suggestions for actions along different loops. It is recognized that the presentation of different loops here is a generic overview and combines examples coming from different sectors. Also, some approaches may apply to more than one loop. Again, it should be emphasized that it is not an exhaustive list, but an indication providing some insight into the types of actions that can be taken in order to support the forest-based industries in transition to a more circular model.

Box. 6 Value-chain-specific circularity approaches (based on Figure 6).

## User-to-user loop

**User-to-user loop** covers the stage of the value chain when a product provides its functions to the user (or subsequent users). In order to ensure that it is done in an optimal way. Different circularity approaches can be undertaken during the production process to allow for provision of product functionality with the highest material efficiency for as long as possible. (Guiding principles: **Reuse** – use the product in different applications or, where possible, turn the product into a service so that it can used by different users, and **Reduce** - use the least materials possible for its production). In this loop the following supporting actions can be identified:

**Re-designing systems and products**

The goal for businesses in a circular economy is to design out waste, pollution, negative environmental impacts, disposability, etc., and to ensure sustainability across the product life cycles. This will require the re-design of products and production systems. In forest-based industries, this transition means that wood and related side streams will need to be kept in the loop for as long as possible and cascaded down, as incineration is considered a leakage out of the system.

[42] See https://fsc.org/en/chain-of-custody-certification and www.pefc.org/for-business/supply-chain-companies.
[43] See https://unece.org/trade/traceability-sustainable-garment-and-footwear.

**Improving system effectiveness**

Businesses need to take a system approach to review barriers and challenges to circularity along their respective value and supply chains. For instance, production systems can be optimized to design out waste (e.g., the improvements that have been made to woodworking machines so that they generate less wood dust). Another example relates to service coordination. For instance, if businesses exchanged information about transport needs (e.g., through digitalization), transportation costs and emissions could be significantly reduced.

**Reducing environmental impact of production**

For resource dependent businesses, less is more, as raw materials should be used in an economical and sustainable manner. While the forest-based industries have become more material efficient, the reduction of the overall environmental impact of the production processes still remains a challenge. For example, aside from wood pulp, water and energy are the two biggest resource inputs into the papermaking process. In this case, increasing resource efficiency may include continued efforts to increase the use of renewable energy and reuse of water in multiple production cycles.

**Reducing competition over raw materials**

Increased demand for wood-based products has resulted in an amplified competition over raw materials, such as for instance between bioenergy and the wood panel industries. This has in turn resulted in higher feedstock prices, making some of the forest-based businesses less profitable. Synergies across different supply chains waste streams may be explored more thoroughly to improve the supply of secondary materials and reduce pressure on the use virgin raw materials and feedstock prices.

**Encouraging circular lifestyles**

Consumers and users may contribute significantly to the transition towards a circular economy. Therefore, understanding the factors influencing consumer choices (e.g., economic, social and psychological reasons which determine whether consumers engage in circular practices or not) is fundamental. Building on that understanding, the regulatory environment and awareness raising can support consumers in: choosing product-as-service models (e.g., renting rather than buying new furniture[44]); buying second-hand products (e.g., furniture); or sorting and recycling cellulose-based products (e.g., textiles, books, toys) thus allowing for their longer circulation in the loop.

### User-to-business loop

**User-to-business loop** refers to the stage of the value chain where users can interact with producers in order to update the functionality of the products with the aim to extending their lifespan (Guiding principles: **Repair** to amend the functionality of the product, **Refurbish** to upgrade the functionality of the product in line with latest technologies and design, **Remanufacture** – dismantle the existing product to use its parts in a new product with the same functions). In this loop the following supporting actions can be identified:

[44] See www.cleantech.com/the-circular-economy-meets-furniture-the-future-of-rentals-and-sharing.

**Extending producer responsibility**

Extended producer responsibility[45] is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products. It is a tool that has the potential to provide economic incentives for businesses to better design their products, ensuring that non-circular practices are penalized. Extended producer responsibility schemes could as such help drive product design towards repairability, refurbishment and reuse of wood-based products.

**Designing for circularity**

Circularity requires innovative design, a systemic perspective as well as new working methods. Design strategies, such as eco-design and smart design, are part of this bigger picture as they allow businesses to consider the complete life cycles of a wood-based products to extend the durability and lifespan of products. This can include strategies such as design for disassembly, repairability, modularity, design for remanufacturing and reuse.

**Making repair and refurbishment economically viable**

Incentives are needed to make repair and refurbishment viable. For instance, the demand driven by a raising interest in interior design has led to the development of low-cost furniture market segments which compete with repairing and refurbishment of existing products. The costs of transport and labor often make the repair and refurbishment overpriced vis-à-vis some new, low-cost product alternatives. The incentives could entail promotion of eco-design allowing for repairability and refurbishment, or increasing the warranty of products, thus producer responsibility for repair and refurbishment.

## Business-to-business loop

**Business-to-business loop** focuses on the stages of the value chain when specialized businesses treat products at the end of life in order to turn them into secondary materials for other businesses. (Guiding principles: **Repurpose** - dismantle products into parts in order to include them into new products with different functions, **Recycle** residues into secondary materials). In this loop the following supporting actions can be identified:

**Increasing the use of post-consumer waste streams**

The contribution of recycled materials to overall material supply stands out as part of the solution, addressing the increased competition over resources as well as efforts to minimize material consumption. While some of the forest-based industries have been very effective in addressing the after-consumption residues, such as the paper and pulp sector, others can still improve. For instance, given the low recycling rates of the cellulose-based fibers and plastics, their recovery on a commercial basis could be supported.

[45] See www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm.

**Expanding the available product mix**

The steady supply of forest-based biomass may be subject to pressures on ecosystems, competition for other uses, or seasonal inconsistencies (e.g., due to drought or limited logging in winter) affecting the supply stream. Consequently, there is much to gain from engaging with service providers (i.e. smaller companies whose business is to trade industry residues) in up and downstream value chains who can coordinate a sustainable and cost-effective extraction of secondary materials.

**Improving the infrastructure for collection and recycling of wood-based products**

One key barrier for extracting value from waste streams is a weak infrastructure for collection, sorting and recycling of wood-based products (whether a piece of furniture or bioplastic). This could be addressed through increasing the options for community collection and recovery by retailers (e.g., take-back and reverse-logistics strategies), through incentives for development of chemical recycling (e.g., of cellulose-based fibers and plastics) on a commercial basis, or through an improved coordination of waste streams management across value chains (mentioned above).

**Creating markets for waste streams**

Building the markets for secondary wood-based materials (e.g., residues from construction sector or recycled cellulose-fibers) depends to a large extent on the demand from relevant industries. Policy measures that encourage reuse will only meet with success if the markets for these secondary materials are functioning well. For instance, if the supply is irregular, the demand is difficult to build and prices difficult to predict.

**Building trust in secondary materials and products**

Moving away from the linear model will require the development of markets for secondary materials made from waste. Regulations, including on health and environmental safety, related to the use of wood-based residues would support business activities involved in recycling and development of markets for recycled products. For example, there is a degree of apprehension about using recycled carton for food-contact materials, because of contamination. Reliable quality labels and controls could be adopted to address these concerns.

The above action points demonstrate that circular economy strategies need to ensure that upstream decisions within the respective value chains are coordinated with downstream activities as well as with the users. The forest sector needs to connect better with producers, distributors, consumers and recyclers, and to link incentives across supply chains. Moreover, each action point has a potential to generate numerous benefits for the sector, such as reducing material cost, reducing price volatility, improving the security of supply, job creation, as well as reducing environmental pressures and health risks (e.g., from the decrease in the use of hazardous and toxic chemicals). Ideally, circular products based on renewable resources, will be easy to reuse or recycle, and create added value without having adverse effects on environment and population while maintaining a healthy profit for all supply chain actors.

# Part 5
# Conclusions

## 5. Conclusions

[This part will be completed after the discussion at the forty-second session of the Joint UNECE/FAO Working Party on Forest Statistics, Economics and Management (22 to 24 March 2021). It is expected that member States will inform the joint section about questions of their interest which may still be included in this study and will provide advice on the direction of the conclusions and recommendations which they would like to see resulting from this study in support to the further consideration of circularity concepts in forest-based industries].

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