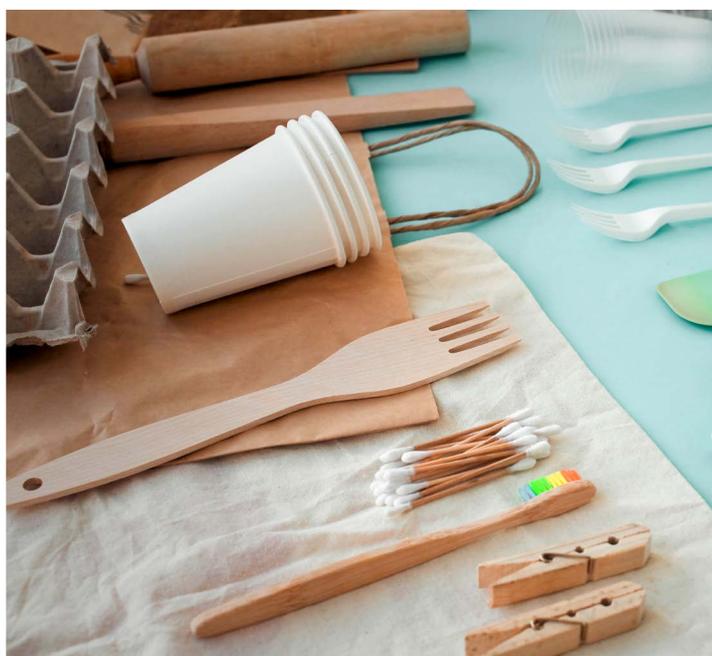
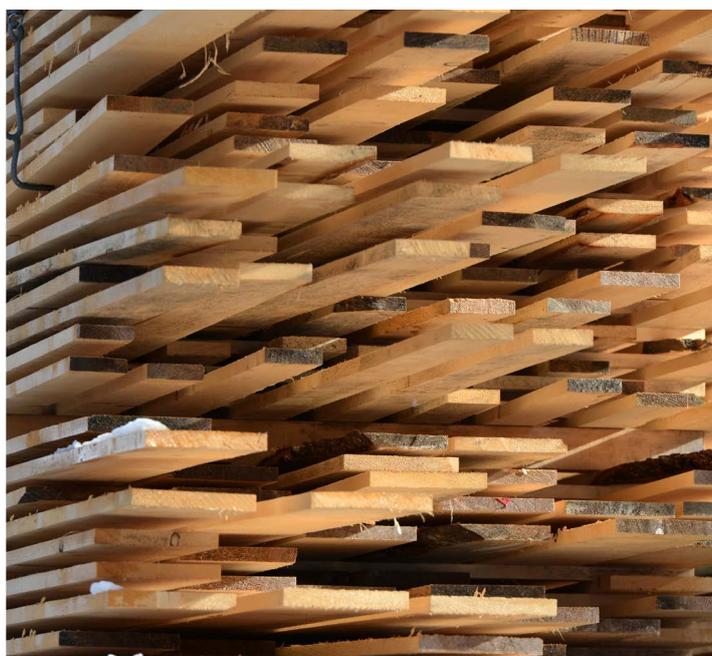




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Circularity concepts in forest-based industries



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ABSTRACT

The world's prevalent economic model, based on a 'take-make-use-dispose' approach, cannot maintain and raise human standards of living without causing environmental degradation and incurring economic risks. Decoupling economic activity from the increasing demand for natural resources could be done through circular, bio-based economy approaches leading to a regenerative growth model, allowing humankind to reduce its environmental footprint on the planet.

The forest sector, situated in both the biological and technical cycles of a circular economy, is well suited to embrace a circular, bio-based economic model. However, challenges in the overall circularity of forest-based value chains persist as a result of the sector's traditional means of operation.

To ensure the sustainability of the forest-based value chains, continuous consideration and coordination of circularity at all stages of the value chains are needed. A viable starting point for this is with the principles of sustainable forest management (SFM), following by the optimized cascading use of wood at every production stage and concluding with the recovery of post-consumer wood at the end of value chains.

This study analyses the existing and possible limitations to circular approaches in forest-based industries, namely the woodworking industry (focusing on sawn wood processing, bioenergy production and wood in construction), the furniture industry, the paper and pulp industry as well as industry using cellulose-based fibres and cellulose-based plastics.

The analysis provides evidence that not all circular approaches are sustainable under all circumstances. In some cases, the focus on circularity may cause environmental externalities, in other cases, it may not guarantee economic viability. While the transition to a circular, bio-based economy can be facilitated by a legislator, the process will need to develop organically, based on the location of industries, proximity to available (waste) resources and consumer preferences.

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FOREWORD

The year 2020 gave birth to a new reality that most of the world had not previously imagined and that most societies were ill-prepared for. Covid-19 held a magnifying glass to the globe's economic, social and environmental fabric and revealed its fragility, caused at least in part by harmful economic practices impacting human health, biodiversity loss and driving climate change. These damaging patterns of economic activity, such as the unsustainable use of natural resources, were sobering indicators of human society's unsatisfactory progress towards achieving global sustainability.

While economic and social recovery from the COVID-19 crisis is possible, for such a recovery to be durable and resilient, returning to 'business as usual' is not a viable option. Continuing to see human health and activity in isolation from nature, ecosystems and animal health is fraught with danger. Enduring environmental crises are causing, and will continue to cause, social and economic damage more profound than that incurred by COVID-19. To avoid this, planning for the world's economic recovery needs to be done using a sustainable model that allows us to "build back better".

The COVID-19 crisis, while traumatizing and tragic for so many, is also an opportunity that we should not miss. The recovery policies being realized should aim to trigger investment and behavioural changes that will reduce the likelihood and severity of future health, economic and environmental shocks while increasing society's resilience to them when they do occur. Central to this approach is a focus on human well-being and reconnection with the broad interplay of natural processes at work around the globe.

More specifically and in the context of this study, forest-derived biomass has for centuries been an important raw material for the global economy. Being both widely available and renewable serves to heighten its importance, however, both of these positives will remain only if forests are sustainably managed. Woodworking industries have made progress in this regard by being genuinely committed to sustainable forest management, and not only because their industry depends on this natural resource. Today, forest sector activities rely on large volume flows of wood as a commodity, with the sector's innovation efforts focusing on raw material productivity and optimization of production processes. From both the economic and environmental points of view, these strategies have been successful and align well with the principles of a circular bioeconomy.

Nevertheless, in the context of the "green recovery", the forest sector stands on the cusp of a new opportunity – one that would allow an enhanced role for wood manufacturing and create new jobs in many economies. Being a strategic provider of a key resource to many forest-based industries, the forest sector can play a central role in the successful implementation of many post-COVID recovery policies focusing on a circular bioeconomy.

With this publication we want to contribute to a better understanding of what circularity means for forest-based industries, what its limitations are and what is needed to make circularity sustainable and economically viable in these industries in the long term.



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The editorial work was done by Ian Silver, Alicja Kacprzak, Matthew Fonseca and Stephen Hatem.

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
DFD	Design for Dismantling
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
MDF	Medium-density fibreboard
mm	Millimetres
Mt	Million tonnes
NACE	Statistical Classification of Economic Activities in the European Community
NWFP	Non-wood Forest Products
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
SCM	Supply Chain Management
SDG	Sustainable Development Goals
SFM	Sustainable Forest Management
SME	Small and medium-sized enterprise
TCO	Total Cost of Ownership
UEA	European Federation of Furniture Manufacturers
VCA	Value Chain Analysis
WWF	World Wildlife Fund

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Section 1
**SETTING THE STAGE
FOR A CIRCULAR
FOREST SECTOR**



1.1 Introduction

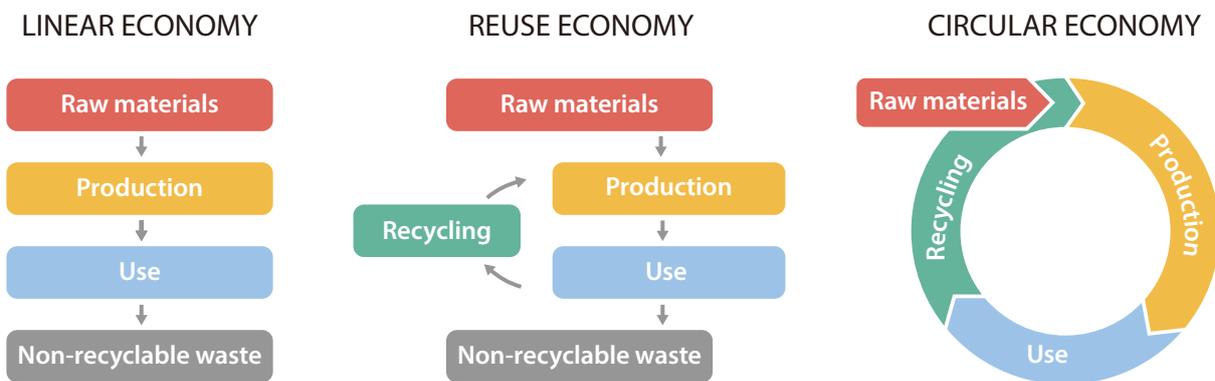
In the face of pressing socio-economic and environmental challenges and ever-increasing use of natural resources, the concept of a circular economy has emerged as a promising paradigm aimed at minimizing waste and making the most of natural resources. It has been attracting significant public and private interests which is, amongst other things, reflected in policy instruments and strategies, research as well as private sector commitments to circularity. Reference to circularity principles can also be found in the Sustainable Development Goals (SDGs), in particular Goal 12¹ 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, a public-private collaboration platform to accelerate the transition to a circular economy, launched by the World Economic Forum, World Resources Institute, Ellen MacArthur Foundation, United Nations Environment Programme, and over 40 other organizations. However, while the potential for a circular economy is recognized in both policy and science, there is no commonly accepted definition of what a circular economy is (Kirchherr *et al.*, 2017). Despite that, as illustrated by definitions below, core tenets of circularity are somewhat clear. Also, while it is important to recognize that circularity is not interchangeable with sustainability and bioeconomy and

there could be instances when bioeconomy cannot be circular and vice versa, there are more commonalities than differences among all these concepts.

In general terms, a circular economy concept is commonly characterized as an approach that can reduce resources consumption by slowing, closing or narrowing natural resource loops (Geissdoerfer *et al.*, 2017). Providing more detail than this framework description, the Ellen MacArthur Foundation has defined a circular economy as an “*industrial economy that is restorative and regenerative by intention and design*” (EMF, 2012, 2015) and an approach for “*gradually decoupling economic activity from the consumption of finite resources*”³. The concept put forward by the Ellen MacArthur Foundation relies on three principles, namely, to design out waste and pollution; keep products and materials in use; and regenerate natural systems. Another definition has been put forward by the European Commission (EC). It defines 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 minimized*” (EC, 2020a). Despite these somewhat different perspectives, it can be noted that a circular economy builds on the responsible and cyclical use of natural resources (e.g., closed-loop systems) and minimizing the creation of waste and pollution (CGRI, 2019).

FIGURE 1.

The linear, reuse and circular economy.



Source: UNECE/FAO, adapted from <https://www.government.nl/topics/circular-economy>.

The prospects for circularity and a circular economy reside in the fact that prevailing linear economic models (e.g., take-make-use-dispose) depend upon an unsustainable use of limited natural resources that are extracted, processed into goods and, at the-end-of-life, commonly

disposed of as waste (Figure 1). While it is undeniable that the linear economy has delivered high standards of living and tremendous wealth in some parts of the world, this has been achieved by paying high socio-economic and environmental costs. The unsustainability of the linear

1 www.un.org/sustainabledevelopment/sustainable-consumption-production/

2 <https://pacecircular.org/>

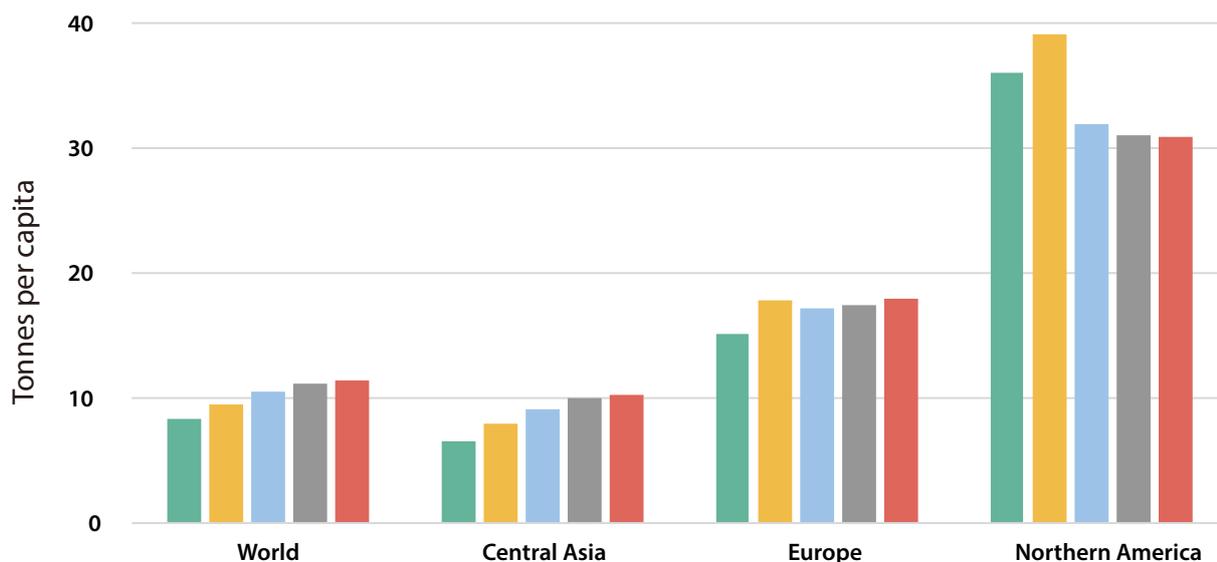
3 <https://www.ellenmacarthurfoundation.org/circular-economy/concept>

approach is arguably best seen in the light of the fact that the global use of materials⁴ has almost tripled since 1970 and it is accelerating. For the UNECE region, material production has increased from around 13 billion tonnes in 1970 to approximately 20 billion tonnes from 1998 onwards (ECE, 2019). It can be noted that the average material

footprint⁵ per capita generated by the UNECE region has been at about 25 tonnes, annually since 2010, although 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).

FIGURE 2.

Material footprint in tonnes per capita, 2000, 2005, 2010, 2015 and 2017.



Source: UNECE (2019).

In addition, the current rate of natural resource use means that 1.75 Earths are needed to sustain global demand for natural resources.⁶ Moreover, it can be noted that 62 per cent of global greenhouse gas (GHG) 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 the resultant products (CGRI, 2020). This implies that the linear economy model fosters a scale of economic activity that is not sustainable.

Economic models, based on this linear process suggest growing extraction rates of raw materials (Figure 3) and raw material use contributes significantly to climate change, while the extraction and production of materials have negative effects on land use and ecosystems. It contributes to eutrophication, acidification as well as affects freshwater quality and terrestrial toxicity.

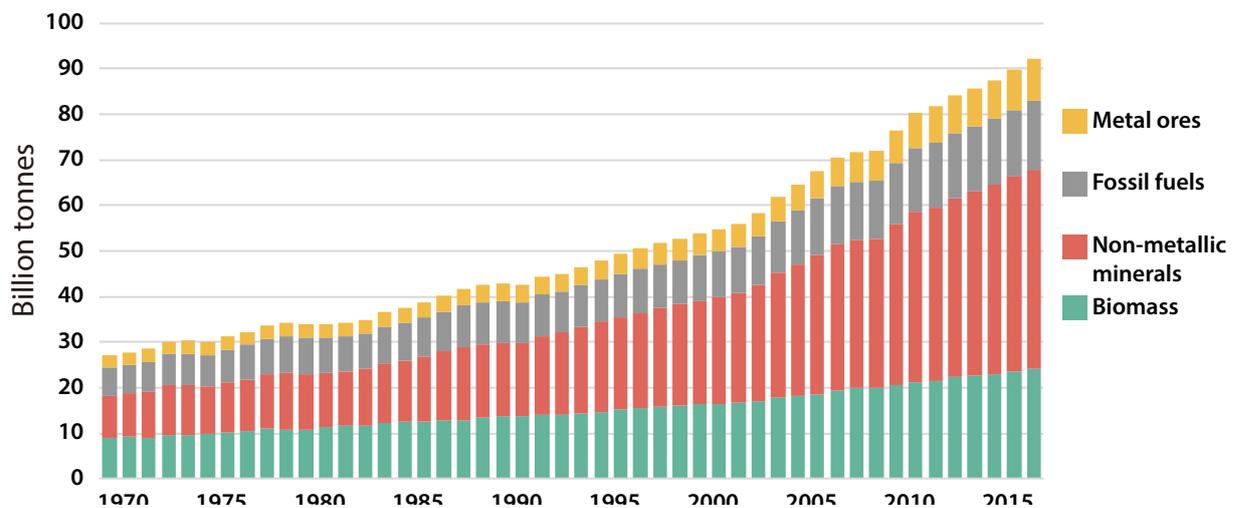
⁴ Wood is a material, while forest is a resource.

⁵ The material footprint in this case related to the use of raw materials by the global economy (Wiedmann et al., 2015).

⁶ www.overshootday.org.

FIGURE 3.

Projected global material extraction, 2015 to 2060.



Source: UNEP (2019).

1.2 Background and objectives

The circular model is often seen as a promising framework to address pressing challenges, such as climate change, pollution and resource efficiency. However, given the many definitions and applications associated with circularity and, more broadly, a circular economy (Kirchherr *et al.*, 2017; Korhonen *et al.*, 2018b; Reike *et al.*, 2018), it is relevant to clarify some of the conceptual ambiguities underlying circularity concepts.

Consequently, this study will first detail some of the concepts most often used to describe circularity before clarifying what circularity means in this study.

Forests have the potential to play an important role in the development of a circular economy, primarily because they provide a strategic natural resource that can be used for creating reusable and recyclable materials. Moreover, wood can sequester carbon and it is both renewable and biodegradable, meaning that when it cannot be reused or recycled, it can be returned to the biosphere in the form of nutrients. For these reasons, forest-based industries can offer solutions to global socio-economic and environmental challenges through their role in a circular economy. As such, it is important to explore what circularity means for forest-based industries as well as how it may affect the use of forest resources, including what constitutes good practices and any possible limitations that exist.

Consequently, second, the study will examine how circularity principles can be applied across different value chains in forest-based industries.

The reason for taking a value chain approach was based on the fact that opportunities for closing the loop of products and raw materials circles are interlinked with the structure of their respective value chains. The prospects for a circular economy in the forest sector will depend upon how the sector is structured. It is therefore important to analyse the extent to which different sub-sectors could become circular and how significantly the material value and physical properties influence the potential for circularity.

Third, the study will consider the implications of circular approaches on forest health and the sustainability of wood provision, especially the balance between the use of forest resources and other ecosystem services, including climate change adaptation and mitigation.

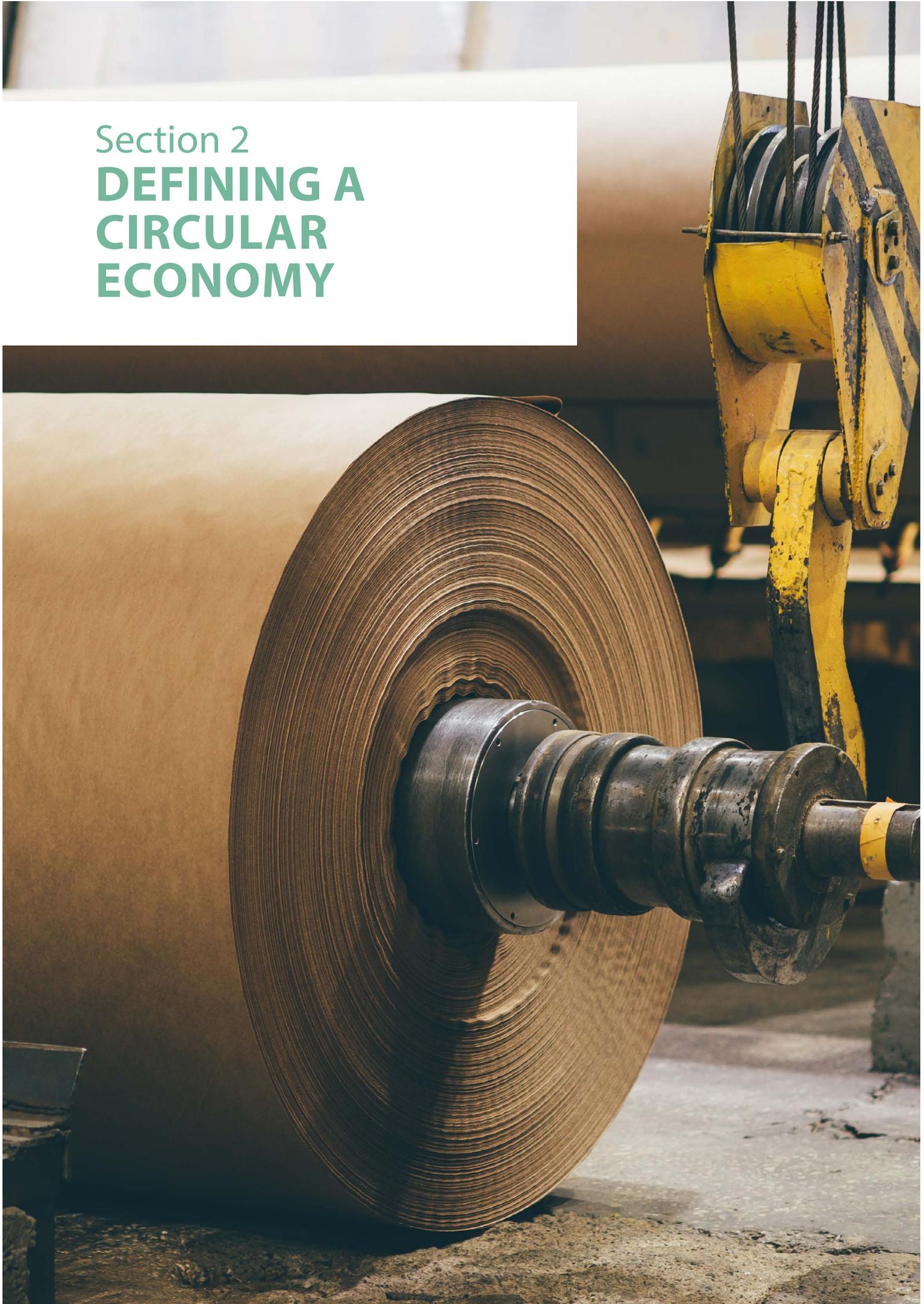
It is important to note at this point that circularity does not always equate to sustainability, nor does it indicate economic viability. Furthermore, a circular system that emphasizes the continuous reuse of materials may generate more emissions (e.g., increased transport) when compared to other approaches (e.g., cascading use). Although the consideration of all these aspects falls outside the scope of this study, an effort has been made to recognize that successful implementation of a circular system is related to its economic feasibility, practicality as well as its impact on the environment and public health.

1.3 Structure of the study

- Section 1 sets out the background and objectives of the study and provides an initial introduction to what a circular economy means.
- Section 2 describes different circular economy models. Given the many existing definitions of circularity, it proposes a conceptual understanding of a circular model for forest-based industries.
- Section 3 outlines examples of forest-based industries values chains and considers how circularity could be implemented across them. It also describes the implications for various sectors should they become more circular.
- Section 4 considers possible challenges and opportunities related to the implementation of circular approaches in forest-based industries and these approaches link to sustainable management of forests, in particular, in the context of climate change mitigation. It also summarizes some of the key insights from the preceding sections.
- Section 5 presents the study's conclusions and recommendations.



Section 2
**DEFINING A
CIRCULAR
ECONOMY**



2.1 Origins of circularity

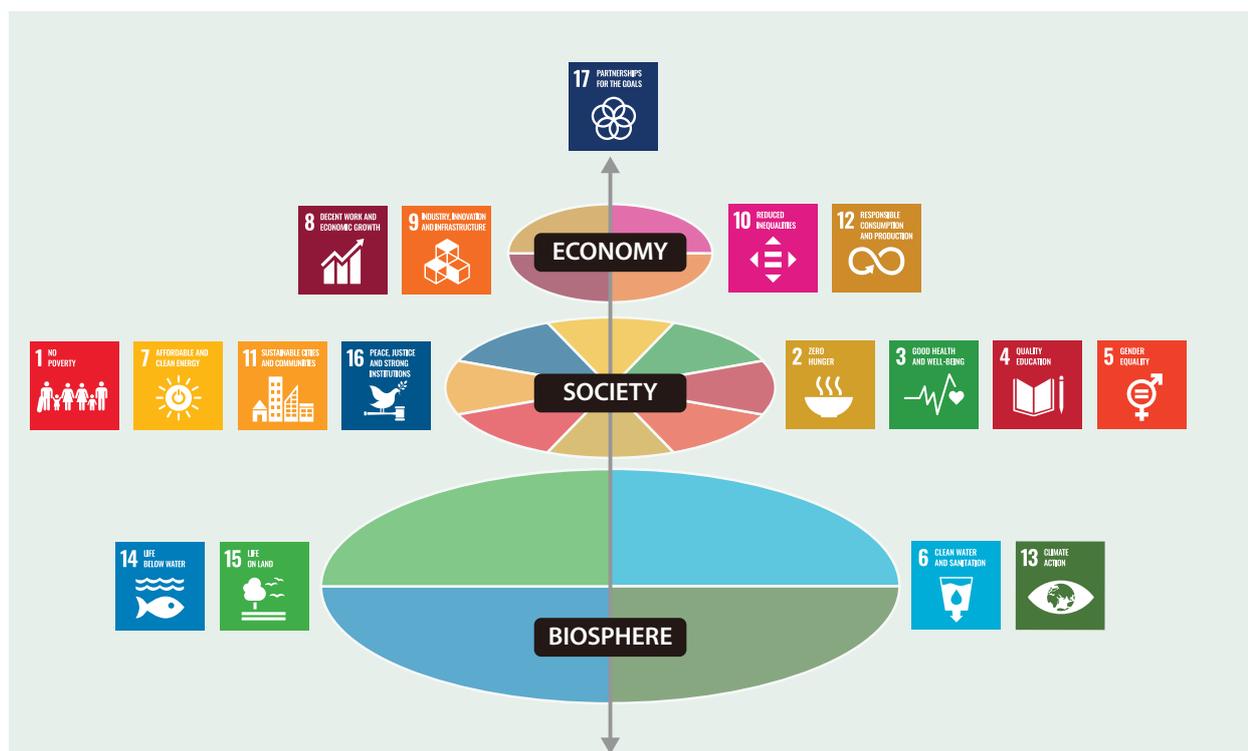
The circular model is both older and more diverse than is commonly perceived. Circularity can be seen as a continuation of ideas that started with the onset of modern industrial practices, which despite being dominated by linear production models, did involve early attempts to repurpose objects and materials. The initial ideas surrounding the reuse of materials came from the intention to optimize the use of resources and to improve economic efficiency (Reuse Economy in Figure 1).

The modern-day concepts behind a circular economy are 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 with providing the first reference to a circular system, Boulding (1966) introduced the concept of a closed system from a material use perspective. He 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), “Overshoot” (Catton, 1980), “Cradle-to-Cradle” (Braungart and McDonough, 2002)⁷ and the “Performance Economy” (Stahel and Clift, 2016) all provided further substance for the circular model to develop as a concept. Formally, a circular economy was introduced in the “Economics of Natural Resources and the Environment” by Pearce and Turner (1990) where they employed the

notion that everything eventually becomes an input to everything else to develop their “circular economy” model. This can be seen as the metaphorical birth of the circular economy concept.

At its beginning, circularity was primarily concerned with waste management and recycling different waste streams (Reike *et al.*, 2018). These efforts focused on technological innovations and finding ways to turn waste into a valuable input for other supply chains. In contrast, practices of reusing or remanufacturing materials and systematically reducing material consumption were rare (Ghisellini *et al.*, 2016; Ritzén and Sandström, 2017). However, in the last 20 years, circularity has moved beyond its focus on “waste reduction” and “increased recycling” towards a more comprehensive socio-economic approach. It builds on the adoption of a systems perspective with regards to natural resource use, emphasizing that the implementation of a circular economy entails a major transformation of existing production and consumption patterns. These advances in understanding are also being embedded in policy developments which, for example, take more account of the objectives of the Rio Declaration (UN, 1992) and the 2030 Agenda for Sustainable Development (UN, 2015). It can be noted that, while the 2030 Agenda does not explicitly address circularity (Box 1), it does highlight the importance of a transition to circularity to achieve the SDGs (Schroeder *et al.*, 2019).

⁷ www.c2ccertified.org/about/about.

Box 1. Circularity and the Sustainable Development Goals.

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

Circularity does not imply sustainability per se, it has to be made sustainable. 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). Nevertheless, there are important interlinkages between the circular model and the SDGs, especially given that circular economy practices can contribute (both directly and indirectly) towards achieving a sizeable number of the SDG targets.

A 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 of them. 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) as well as those promoting economic growth and jobs (SDG 8), eliminating poverty (SDG 1), ending hunger and sustainable food production (SDG 2). In summary, the implementation of a circular economy is seen as an important prerequisite for achieving a number of SDGs.

Apart from UN work, circular economy has also been in the focus of other international organizations, such as the Organisation for Economic Co-operation and Development (OECD) and the EU. For instance, the EU has been active in promoting a circular economy. Its conceptual work has highlighted the importance of circularity in policymaking and influenced the work of the United Nations Environment Programme (UNEP, 2018b). The idea of transitioning to a circular economy has been articulated in the EU’s action plan for a circular economy as a part of its strategy for industry in Europe as well as in the European Green Deal

(EC, 2015, 2019, 2020a, 2020b). In so doing, the EU has ensured that circularity will stay on its political agenda for the foreseeable future.

The discourse on circularity has increasingly been followed by the private sector (CGRI, 2020) as well as civil society. For example, the World Economic Forum and the World Business Council for Sustainable Development have become notable advocates of the social, economic and environmental benefits of circular business models and policies. Another prominent voice promoting the circular

model is the Ellen MacArthur Foundation,⁸ an NGO formed in 2010 to accelerate the transition to a circular economy (EMF, 2012, 2015).

2.2 What is a circular economy?

The preceding section demonstrates that circularity has been influenced by several concepts and ideas over time and that it remains an ambiguous concept with a diverse range of approaches being taken by various actors. This ambiguity was highlighted by a systematic analysis conducted in 2017 that identified 114 different circular economy definitions (Kirchherr *et al.*, 2017). Additionally, with regard to diverse approaches, there is one school of thought that wants to operationalize circularity within the boundaries of the existing economic system (Fullerton, 2015; Rifkin, 2011) while another seeks the transformation of the socio-economic order (Latouche, 2009; Trainer and Alexander, 2019). While 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 two perspectives reveal that a circular economy concept is still fluid, and the wide range of definitions makes it difficult to measure whether an industry is circular or not.

Notwithstanding the varied approaches to circularity, most definitions of a circular economy focus on material use and system change:

- 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 components) 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 thinking⁹ (Korhonen *et al.*, 2018b).

The 3R-approach may seemingly mirror a reuse economy (Figure 1) to some degree, however, in a closed-loop system, it is not only important that materials are recycled properly but that products and raw materials retain sufficient quality for reuse. The number and sequence of these Rs have consequently evolved and a more comprehensive 9R-approach has been developed. This may be seen as a combination of the 3R- and system-thinking approaches by widening the focus to include both material use and system change (Potting *et al.*, 2017). The 9Rs include: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover (Figure 4).

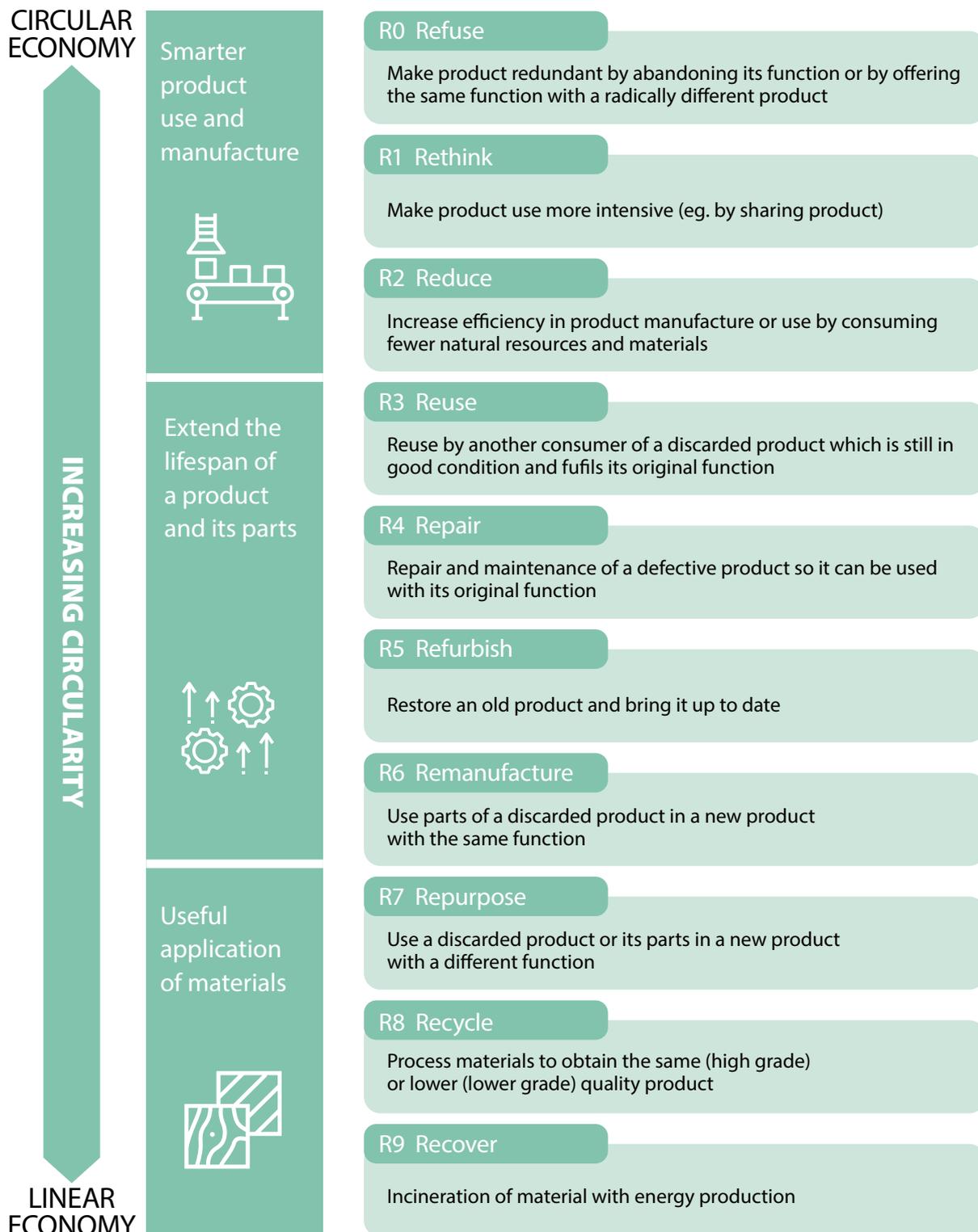
In this study, the analysis of circularity will focus on the material flow across forest-based value chains. The 9R approach will be used for the value chain analysis (VCA) and will capture a complete picture of the life cycle of a product. The analysis of circularity concepts will be based on existing wood-based materials produced by forest-based industries, such as those involved in woodworking, paper and pulp manufacture as well as their actual value chains. Since the circular model has been created primarily by the business community, the focus of this study has been made on analysing circularity in forest-based industries rather than in forests and forestry operations.

⁸ The Ellen MacArthur Foundation develops and promotes the idea of a circular economy. Its aim is to educate society on the merits and possibilities of building circularity into all economic activity (www.ellenmacarthurfoundation.org).

⁹ 'System thinking' is an approach to help understand complexity and identify system leverage points and is often recognised as being critical to delivering a circular economy. (<https://www.wrforum.org/world-resources-forum-2019/scientific-sessions/ss-3-circular-economy/systems-thinking-for-a-circular-economy/>)

FIGURE 4.

Circularity and the 9Rs.



Source: UNECE/FAO, adapted from Ellen MacArthur Foundation (<https://www.ellenmacarthurfoundation.org>).

Another important factor when considering circularity in forest-based industries is the recognition that there are limitations to recyclability of certain materials. For example, wood fibres used for paper production deteriorate over time and cannot be recycled more than five to seven times.¹⁰

Bioenergy production is another critical topic in this context since it is not possible to recycle energy (e.g., heat) and, as such, there is commonly no consideration of energy cycles in circular systems. In fact, most circular approaches (or definitions) do not consider energy production from biomass¹¹ as being circular. This is based on the reasoning that once biomass is used for energy it cannot be cycled back unless the entire biosphere carbon cycle is considered. Consequently, questions remain as to whether energy production can be considered as a part of a circular approach.

For forest-based industries, it is more common to consider the cascading use of wood-based materials, e.g., using by-products such as black liquor for the co-production of heat and power by the paper and pulp industry,¹² rather than a circular use of wood-based materials for energy production. While it is beyond the scope of this study to answer whether circular models, in general, should consider the entire biosphere carbon cycle as a part of their design, it is recognized that it is a highly relevant question for circular models in the forest sector. Not only because the sector relies on bioenergy production but also because the characteristics of wood as a material make it

more suited to a cascading approach with bioenergy at the end of the cycle.

Although there is no commonly agreed definition of a circular economy, there are a few which are used more than others. For example, the definition put forward by the Ellen MacArthur Foundation describes a circular economy both in terms of material use and from a systems perspective (Figure 5). The focus is on the design of materials, products and systems (EMF, 2012, 2015), drawing on cradle-to-cradle¹³ principles and system thinking (Braungart and McDonough, 2002). The basic premise is that a product's circularity is considered at every stage of its lifecycle, from conceptualization, to design and development and then through to use, disposal and reuse (Su *et al.*, 2013). This forms the basis for the 9R-approach, in a closed loop, where the overall goal is to minimize the resources and energy put into the system and turning what was once considered waste into inputs. The Ellen MacArthur Foundation model distinguishes between technical (blue) and biological (green) cycles (Figure 5). This interpretation of circularity involves materials of biological origin, such as biomass products, that can return to the biosphere as feedstock as well as technical materials, such as plastics and metals which cannot biodegrade but can nevertheless circulate in closed loops. A further advantage foreseen by this model is that emissions associated with resource extraction and waste management decrease in line with the reduction in resource extraction.

¹⁰ <https://www.worldatlas.com/articles/how-many-times-can-paper-be-recycled.html>.

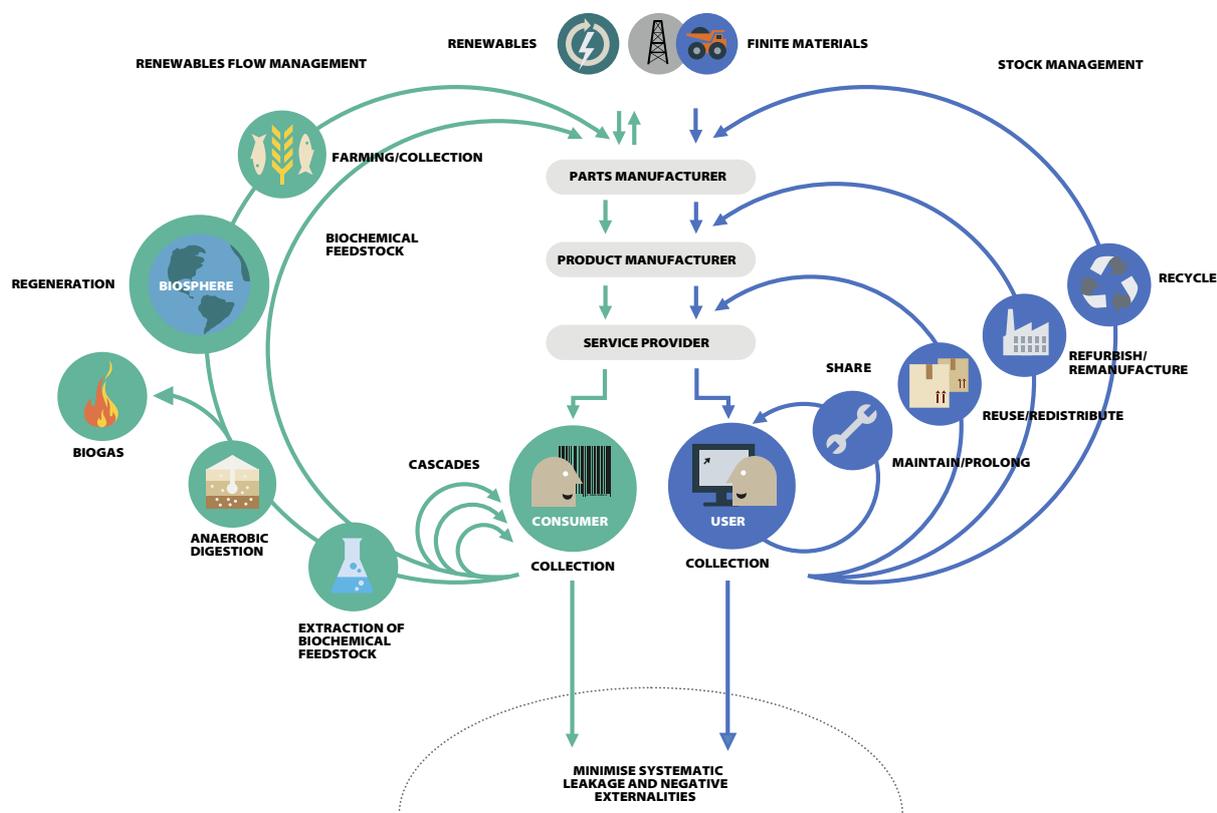
¹¹ FAO defines biomass as organic material (both above- and below-ground) that can be either living or dead, (such as trees, crops, roots) (FAO, 2009). In contrast, the European Commission defines biomass as "the biodegradable fraction of products, waste and residues from biological origin from agriculture (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).

¹² 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-based fibres. It is the black liquor that can be burned for heat and/or power.

¹³ Cradle-to-cradle are design principles for products and processes in a circular economy that work like in natural systems (<https://www.treehugger.com/what-is-cradle-to-cradle-5191335>). Materials are viewed as nutrients circulating in industrial metabolism processes.

FIGURE 5.

Biological and technical cycle in a circular economy model by the Ellen McArthur Foundation.



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

The European Environment Agency (EEA) stated that circularity as a concept 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). It can however be noted that the approach to a circular economy at the EU level focuses primarily on achieving circularity through resource efficiency and technological change. Most EU measures and targets are geared towards the recycling of different types of waste (Friant et al., 2020). For example, while the EU has passed a number of repair and eco-design regulations for some products, including extended producer responsibility and harmonized standards, there are no set targets on repair and reuse activities in the broader economy. This same approach can be seen in the Union’s measures designed to raise awareness and reduce consumption.

To the extent possible in this study, the understanding of circularity will be based on the concept put forward by Potting et al. (2017) and employed by UNEP (Figure 6)¹⁴. In this model, a circular economy is characterized as three

value retention loops that cover the life cycle of a product and/or material from extraction to production and end-of-life, these are:

- **The user-to-user loop**, that covers the stage of the value chain when a product provides its functions to the user (or subsequent users). In order to ensure that this is done optimally, different circularity approaches can be undertaken during the production process to allow for the provision of product functionality with the highest material efficiency and for products that can be used for as long as possible. (Guiding principles: **Reuse** – use a product in different applications or, where possible, turn the product into a service as well as **Reduce** - minimize the materials used in its production). This can mean, for example, reusing furniture by subsequent users before recycling.
- The user-to-business loop, which refers to the stage of the value chain where end-users can interact with producers to update the functionality of the products, for example, to extend their lifespan. (Guiding principles: **Repair** – to sustain the functionality of the

¹⁴ <https://buildingcircularity.org/>.

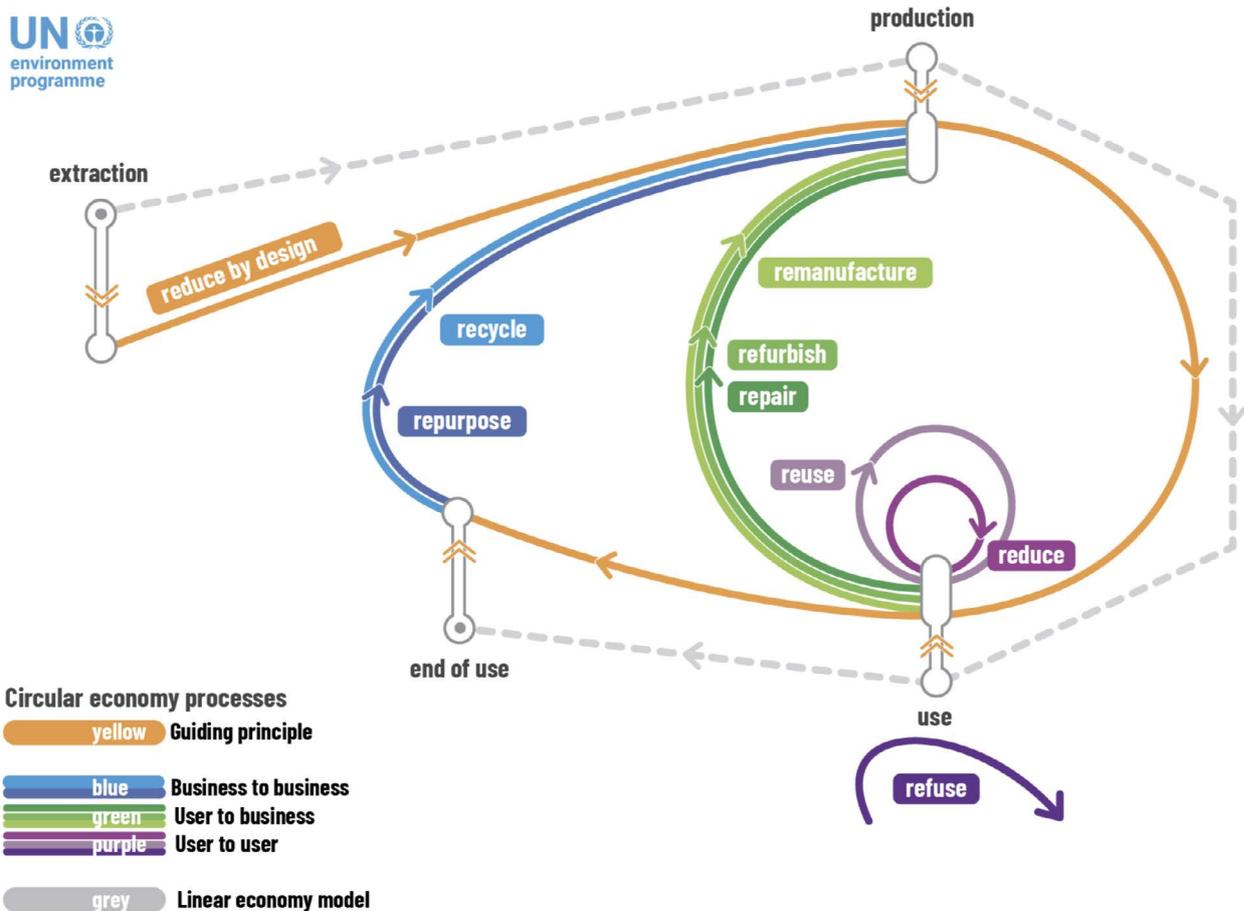
product, **Refurbish** – to upgrade the functionality of the product in line with latest technologies and design as well as **Remanufacture** – to dismantle the existing product to use its parts in new products with the same functions). This can mean, for example, repair services provided by furniture producers to extend their products’ lifespan.

- **The business-to-business loop**, which focuses on the stages of the value chain when specialized businesses treat products at their end-of-life stage to turn them into secondary materials for other businesses. (Guiding principles: **Repurpose** - to dismantle products into components useful in new products with different functions as well as **Recycle** – to recycle residues into secondary materials). Recycling in this context can mean, for example, using paper to produce pulp for new paper or recycling clothing to make insulation materials or fibres for new textiles.

UNEP’s circularity concept uses the 9R-approach (Figure 6) when considering how to make an economy more circular (Potting *et al.*, 2017). More specifically, circularity in this model can be achieved within the three loops (user-to-user, user-to-business, and business-to-business). In this model, reduction in the quantity of materials used in production is primarily achieved 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 user-to-user loop, it is possible to further encourage reducing and re-using while the user-to-business loop focuses on repairing, refurbishing and remanufacturing (Potting *et al.*, 2017) and the business-to-business loop focusing on repurposing and recycling. It should also be noted that dead-end pathways are not represented in this model. This includes activities such as the production of energy from waste as it is only consumed once and not returned to the system.

FIGURE 6.

A circular economy model used by UNEP.



Source: <https://buildingcircularity.org>.

2.3 A bioeconomy, a circular bioeconomy and the cascading use of wood

Having characterized what a circular economy entails in the context of this study (Figure 6), it is also important to consider some of the similar concepts that are frequently used in connection with circularity. This section will briefly introduce how a bioeconomy concept and cascading use relates to the circular model to better define the role of bio-based materials – in this case, wood – in a circular system.

Wood has several inherent characteristics which make it more difficult to recycle over time (e.g., wood decays) but it is renewable and biodegradable. As such, it can be returned to the biosphere (e.g., in the form of nutrients) and this means that, when compared to other materials such as metals, wood cycles in the economy differently.

2.3.1 A bioeconomy

A bioeconomy refers to the production and consumption of biomass-based goods, services and energy. It encompasses sectors such as for instance forestry, pulp and paper production, agriculture, fisheries and food industry. It also covers parts of the chemical, biotechnological and energy industries as well as the manufacturing of bio-based textiles (Hetemäki, 2014; 2017; Winkel, 2017; Wolfslehner *et al.*, 2016). The vision for a bioeconomy entails a system where materials, chemicals and energy are based on renewable biological resources that allow economies to move away from fossil-based inputs. A bioeconomy is, as such, not about being circular but about breaking the dependence on non-renewable resources.

The base resource of a bioeconomy is biomass and, when looking at the biomass supply in forests, it is apparent that apart from providing wood, forests are responsible for a wide range of ecosystem services which can be divided into supporting, provisioning, regulating and cultural ecosystem services (de Groot *et al.*, 2002; MEA, 2003, 2005)¹⁵. Consequently, sustainable management of forests in a bioeconomy necessitates the balancing of a steady supply of biomass along with other forest ecosystem services (Box 2). Major risks caused by maximizing the utilization of forest biomass include overexploiting soils, compromising climate change mitigation potential and reducing biodiversity. For example, extracting stumps and other logging residues from forests can lead to reduced carbon storage capacities in soils while the quality of the biomass supply will suffer if resilient ecosystems are not maintained. In addition, societies gain non-material benefits from forests which range from recreation, tourism, health and wellbeing

¹⁵ See <http://www.fao.org/ecosystem-services-biodiversity/background/en/>.

¹⁶ Formerly the Ministerial Conference on the Protection of Forests in Europe (MCPFE).

¹⁷ Annex 1 of Resolution L2 (<https://foresteurope.org/sfm-criteria-indicators2/>).

¹⁸ Helsinki Resolution H1 (https://www.bmel.de/SharedDocs/Downloads/DE/_Wald/ForestEuropeResolution.pdf?__blob=publicationFile&v=3).

benefits through to aesthetic experiences, spiritual enrichment and cognitive development (MEA, 2003, 2005).

On the other hand, livelihoods of many rural communities depend directly on biomass harvesting through the creation of employment opportunities and benefits to rural economies, providing incentives preventing land use change through valuation of forest products such as timber and non-wood forest products (NWFPs). This diversity of uses may create potential conflicts between biomass harvesting and other forest ecosystem services and, as such, need to be taken into account to ensure sustainable management of forests (Aggestam *et al.*, 2020). The basic premise for a bioeconomy is the focus on using renewable biological resources sustainably to produce food, feed as well as bio-based industrial goods and services, including energy.

Box 2. Sustainable forest management (SFM).

While the original principle of sustained yield and sustainability in forestry has a relatively long history in Europe, a recognized definition of sustainable forest management (SFM) was only developed in 1993 through the Forest Europe¹⁶ process, a definition which has subsequently also been adopted by FAO (Linser *et al.*, 2018; Rametsteiner and Mayer, 2004). This definition was followed in 1998 by a European set of criteria and indicators for SFM, also adopted through the Forest Europe process (Linser *et al.*, 2018).¹⁷ SFM was defined in the Forest Europe General Guidelines for the Sustainable Management of Forests in Europe¹⁸ as the “*stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*” (para. D). This means that SFM can be described as the pursuit of balance between meeting the increasing demands for forest products and services with the preservation of forest health and biodiversity.

In contrast to the needed raw materials in a fossil-based economy, the renewable raw materials powering a bioeconomy can be sourced indefinitely, if produced sustainably. Moreover, often, bio-based versions of existing fossil-based products, for example, some bioplastics, detergents, solvents and lubricants are biodegradable. The

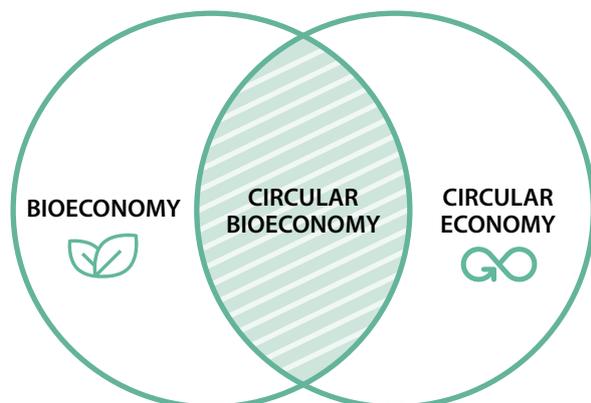
final point of note is that there are conceptual ambiguities when it comes to a bioeconomy. For example, the terms “bioeconomy” and “bio-based economy” are often used interchangeably, however, there is a difference between the meaning of these two terms. The bio-based economy concerns primarily the production of non-food goods while bioeconomy is a broader term that covers the production and use of food and feed as well as the bio-based economy (Staffas *et al.*, 2013). Such ambiguities show that not only the term circular economy is subject to varied conceptual definitions.

2.3.2 A circular bioeconomy

A circular economy refers to a wide range of materials and processes, both in the technical and biological cycle of the economy (Figure 5). However, as noted above, a bioeconomy is not identical to a biological cycle in a circular economy. Resources from a bioeconomy may feed into both cycles. As an example, wood may enter the technical cycle when it is combined with technical materials in the construction of buildings or manufacture of furniture. Hence, an overlap exists between a circular economy and a bioeconomy. A circular economy is aimed at sustainable and resource-efficient processes, and a bioeconomy offers a possibility to substitute fossil-based non-renewable and non-biodegradable materials with renewable and biodegradable ones. The synergy of these two concepts is expressed in the term “circular bioeconomy”, which can be defined as the sum of all activities that transform biomass for use in different product streams such as materials, chemicals, biofuels, and food (Figure 7) (Hetemäki, 2014; Newton, 2017; Stegmann *et al.*, 2020; Winkel, 2017).

FIGURE 7.

A circular bioeconomy.



Source: UNECE/FAO, adapted from Newton (2017).

Box 3. Describing a circular bioeconomy.

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

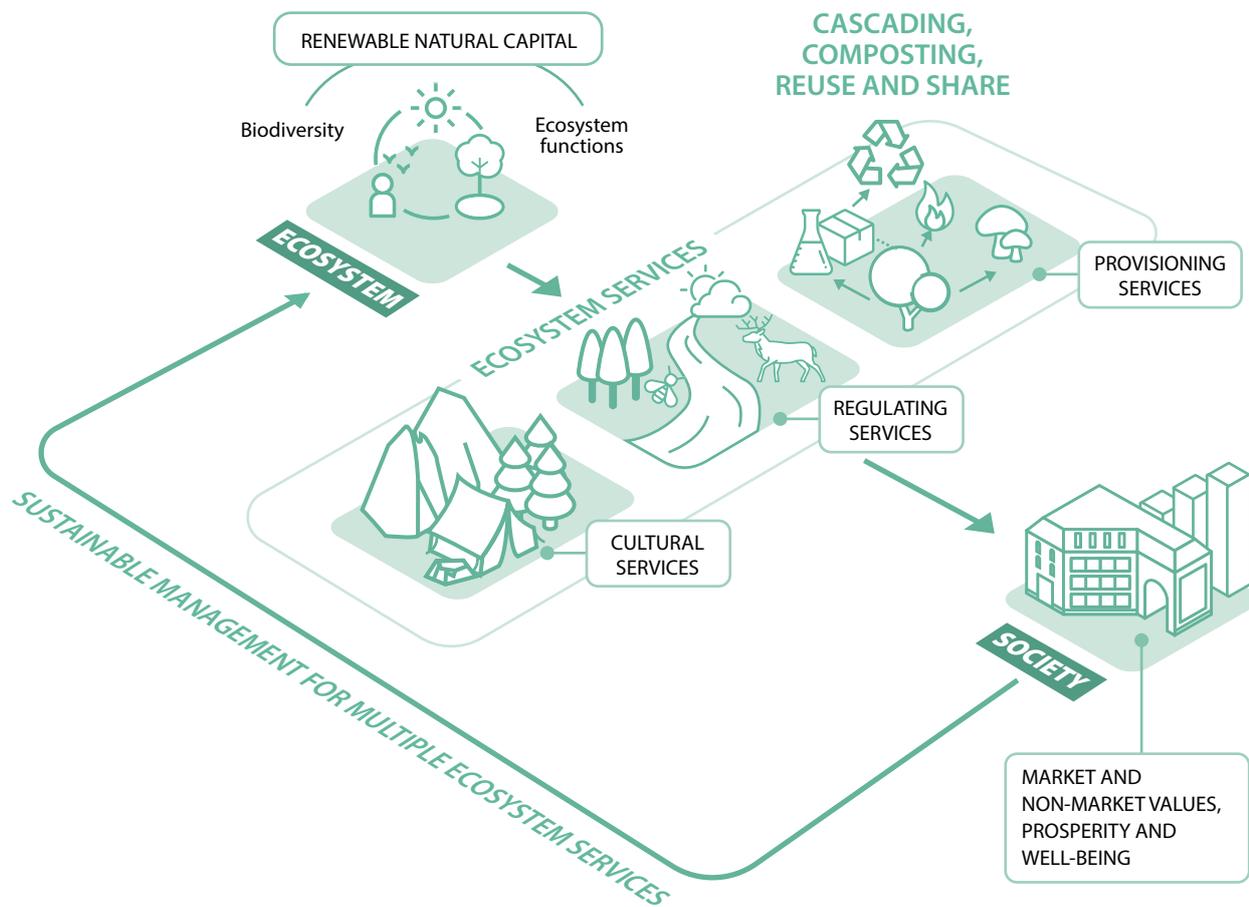
- Use of organic side and waste streams from agriculture, forestry, fishery, aquaculture, food and feed to applications such as aquaculture feed.
- Biodegradable products being returned to the organic and nutrient cycles.
- Successful cascading of paper, other wood products and natural fibre textiles.
- 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 illustrates how healthy and resilient ecosystems provide ecosystem services which, benefit society by generating value as well as creating prosperity and well-being. Among these ecosystem services is the provision of the biomass that feeds into bio-based value chains that employ the principles of a circular economy. The resulting bioproducts, bioenergy and food are essential in sustaining society.

The combination of a bioeconomy and a circular economy can be a beneficial pairing that provides useful synergies, however, there are inherent differences between circularity and a bioeconomy that need to be kept in mind. Certain elements of a bioeconomy go beyond the objectives of a circular economy, including the replacement of non-biodegradable technical materials by biological ones which reintegrate into the biosphere. For example, the majority of bio-based products in a circular economy enter the technical cycle and only a small portion enters the biological cycle (Carus and Dammer, 2018).

FIGURE 8.

Ecosystem services in a circular bioeconomy.



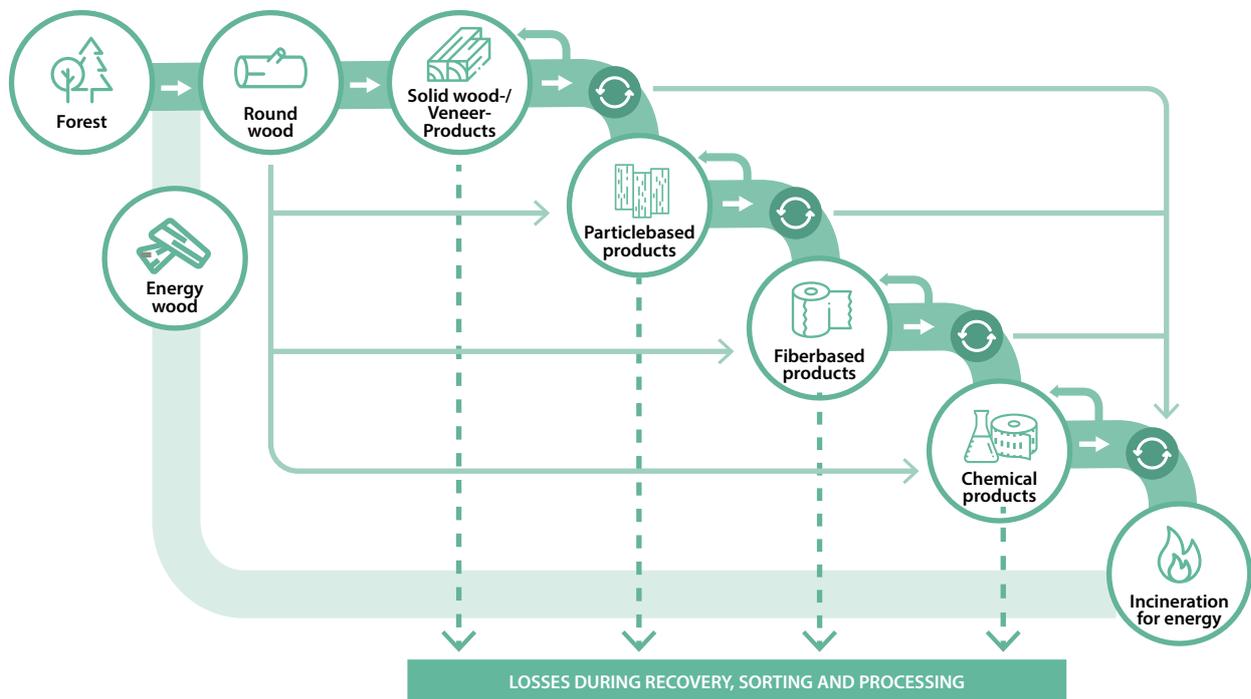
Source: UNECE/FAO

2.3.3 Cascading use of wood

When discussing the role of wood in a circular economy, it is important to acknowledge that recycling it faces inherent limitations when compared to technical materials. While some metals and glass can be recovered and transformed into similar quality materials, once wood is transformed, it cannot be reprocessed to form the same quality as the original (wood fibres used for paper production being exception to that). Therefore, wood requires an approach that maintains its structural integrity in as many applications as possible for as long as possible before it is shredded or incinerated. This approach is the principle of cascading use, where the use of a given piece of wood may span several reuse, recovery and/or recycling loops, with the products it is incorporated into being used for as long, as often and as efficiently as possible. Although the principle of cascading

use is usually applied to the biological cycles of a circular economy, its application to technical cycles is also feasible (Lokesh *et al.*, 2018; Mair and Stern, 2017).

The cascading use concept was first formulated and described by Sirkin and ten Houten (1994) in the context of sustainable resource management and has received much attention as a part of bioeconomy and circular economy policies (EC, 2016; Mair and Stern, 2017; Risse *et al.*, 2017). Vis M., U. Mantau, B. Allen *et al.* defined cascading use as the "efficient utilization of resources by using residues and recycled materials for material use to extend total biomass availability within a given system" (Vis M. *et al.*, 2016). Following this definition, cascading use applies principles of a hierarchical utilization of resources where high-quality raw material is used for high-value products with lower-value products employing degraded forms of the raw materials as they are repeatedly processed over their lifespans (Figure 9).

FIGURE 9.
The cascading use of wood.


Source: UNECE/FAO, adapted from Höglmeier *et al.*, 2015.

In forest-based industries, the implementation of cascading use often faces technical, market and governance barriers. First, from a technical perspective, wood typically suffers from both a loss of quality at each transformation step and is prone to the accumulation of contaminants when recycled due to past applications of preservatives, paints and glues. Consequently, the detection and sorting of wood waste in mixed fractions at a reasonable cost remains challenging. Notwithstanding the issues raised above, the recycling success story of paper needs to be mentioned here as an example defying these limitations.

Second, market barriers for wood and its derivatives are often related to poor coordination among users of such multifunctional materials. Hence, improved cooperation and a better understanding of the needs of the actors involved in later-stage processes of value chains are key to effectively implementing the cascading use principle. Furthermore, the fact that the costs of collecting, sorting and cleaning used wood make its price comparable to that of virgin wood makes cascading use less attractive from an economic standpoint. Therefore, building the necessary infrastructure to connect different sectors is vital to improving material efficiency, economic viability and thus successful cascading systems without relying on state funding.

Third, in terms of governance barriers, the lack of both an international classification for post-consumer wood and a policy framework dedicated to material reuse further hinders cascading use from reaching its full potential (Vis M. *et al.*, 2016). As is the case with other circular approaches, the economic viability and environmental externalities need to be considered and embedded in related policies and market regulations to rationalize the cascading use principle for large-scale and widespread use.

2.4 Circular business models

The transition towards a circular economy entails the systemic transformation of several domains. This includes the transformation of the existing system of production and consumption which implies, among others, redefining the relationship between consumers and products. Taking into consideration constraints in resource availability and their impact on production and consumption of new goods, circular model promotes, where relevant, access to goods through leasing, renting and sharing rather than buying and owning them.

In line with this paradigm, new business models have been proposed whereby service providers retain ownership of products, giving access to them before the materials are recycled at the end of the products' lifecycle. These approaches involve greater levels of collaboration among

supply chain actors, from suppliers and manufacturers to distributors, consumers and recyclers than those in place in linear models.

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

- **Circular Supply Model:** This business model emphasizes renewable, bio-based and recycled materials replacing traditional inputs. Through cradle-to-cradle product design, material loops are closed, nutrients are cycled and waste is designed out to the greatest extent possible. This model is built upon marketing sustainable products, targeted at environmentally conscious consumers and is especially relevant to companies that rely on scarce resource inputs as well as to those that have major negative environmental impacts related to their raw material sourcing. Most forest-based industries should aspire to apply this model.
- **Resource Recovery Model:** This business model focuses on producing secondary raw materials from waste streams. Waste is collected, sorted into its constituent materials and then transformed back into raw materials, thereby creating closed material loops. Variants include recycling, upcycling and industrial symbiosis where the waste of one firm is used as an input by another. This model is based on the valorization of materials contained in waste streams and is particularly relevant for companies that generate large quantities of by-products during manufacturing processes as well as those with access to products at their end-of-life. In the forest sector, sawmills, for example, generate wood chips and sawdust which are used for pulp and paper production, fibreboard manufacturing and energy use.
- **Product Life Extension Model:** This model seeks to extend product life as well as retain products and embedded materials for as long as possible, thereby slowing the cycle of material loops. Model variants include the classic long-life model, where products are designed for longevity, direct reuse, maintenance, repair, refurbishment and remanufacturing. This model is particularly suitable for capital-intensive business-to-business segments of an economy, such as those involving industrial machinery, as well as high-value consumer products such as luxury watches and cars.
- **Sharing Model:** This model is designed to increase 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 being 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 apartment or car-sharing services.

- **Product Service System Model:** This model combines a physical product with a service component, thereby also narrowing resource loops. Consumers purchase the service which a product provides, however, ownership is retained by 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 Ownership¹⁹ (TCO) and substantial requirements for product maintenance and repair.

In summary, circular business models focus on product design, production processes and extended product use which aim to minimize resource consumption and to keep the highest possible quality and value products in use 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 are extracted and changed into a product before being distributed and used until, finally, they are disposed of. In these value chains, value is generated by selling products, encouraging the use of relatively short lifespan products to continuously create demand through their replacement.

In the context of ever-increasing resource scarcity, pollution, as well as the related environmental and economic risks described at the beginning of this study, circular value chains (Figure 10) are being increasingly recognized as a better alternative to the linear model (take-make-use-dispose). However, for most supply chains, the impetus to embrace circularity is still heavily reliant on government policies as these force businesses to adopt more circular practices by regulating activities such as what products can be sent to landfills, what products should be recycled and what methods are required for supply chains to limit their

¹⁹ 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.

environmental impact. While some circular approaches across value chains, such as recycling, redistribution and sharing, are already functioning with the support of specific policy measures, circularity in value chains is not yet managed in a systematic and coordinated manner.

The concept of Supply Chain Management (SCM) is the management of the flow of goods and services that includes all processes that transform raw materials

into final products²⁰. It has emerged in reaction to the increased importance of value chains in many business models and the need to align all the actors in a given sector to optimize economic performance. Building on SCM, the Circular Supply Chain Management (CSCM) integrates the philosophy of a circular economy into supply chain management, offering a new perspective on the sustainability of value chains.

FIGURE 10.

A circular value chain example.



Source: UNECE/FAO, adapted from the General Journal of Europe (www.journalgeneraldeleurope.org).

It needs to be recognized that even closed-loop supply chains still generate substantial amounts of waste as it is rarely feasible to reuse and recycle all the material present within a given supply chain. In this regard, CSCM has added value as it comprises recovering value from waste by collaborating with other value chains within the same industrial sector (open loop, same sector) or with different industrial sectors (open loop, cross-sectors) (Weetman, 2016). Within the forest sector, wood and its various residues can be used in several different ways. Many value chains overlap, creating a complex web of dependencies (an industrial ecosystem) with numerous industrial symbioses. Having this in mind, value chains stretching across different forest-based industries and different service providers can promote sectoral collaboration and support industrial clusters that share a mutual interest in resource efficiency where benefits can be gained.

CSCM further aims to minimize waste production across different industrial sectors through system-wide approaches. This allows the recovery of value from what was traditionally classed as waste (Scheel and Vasquez, 2013; Scheel and Vazquez, 2012). For example, wood buildings can be deconstructed and the wood (that is not contaminated) can be reused for other purposes while some other wood residues can be recycled into mulch for landscaping. Similarly, a manufacturer can 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 in the production of biodiesel (Genovese *et al.*, 2017). Other biomass waste can also be minimized at its source and that which remains can be used to produce methane as a renewable energy source, with the remaining organic

20 www.investopedia.com/terms/s/scm.asp

matter used as a fertilizer in agriculture and horticulture (Farooque *et al.*, 2019).

When examining individual value chains, the transition towards a circular economy almost invariably requires a profound transformation of practices related to product and service design, production, consumption, waste management, reuse and recycling (Hobson, 2015; Mendoza *et al.*, 2017). Product design has a crucial role in material circulation. For example, circular design strategies 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 extending product life and closed-loop systems (Bakker *et al.*, 2014; den Hollander *et al.*, 2017; Moreno *et al.*, 2016; Sumter *et al.*, 2018). It can, for example, be mentioned that Bocken *et al.* (2016) introduced CSCM strategies of slowing, closing, and narrowing resource loops:

- **Slowing resource loops** entails product-life extension through the design of long-life products (e.g., service loops to extend a product's life), for example through repair and refurbishment, the utilization period of products is extended and/or intensified, resulting in a slowdown of resource use as products need replacing less often.
- **Closing resource loops** means reducing material loss post-use and feeding it back into 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) can be used as a guiding principle for eco-design. The directive details a priority order for managing waste, such as moving from waste prevention to waste reuse, recycling and recovery and when these are no longer feasible, disposal. Another strategy, the Design for Dismantling (DFD) which originated in CSCM, has already been adopted by many sectors, partially as a result of technological advancements that offer cost savings and partially due to extended product responsibility regulations. The DFD adds value to products not only at their end-of-life stage but also during the usage, lifetime and maintenance stages of a product's lifecycle (Sabaghi *et al.*, 2016) allowing for easier repair or replacement of faulty parts.

Circular practices seek to minimize the use of non-renewable, environmentally harmful materials and often involve both manufacturing and services (Ghisellini *et al.*, 2016). Many industries also recognize that adopting circular production practices not only offers long-term cost savings but also improves their brand image, regulatory compliance

and investor interest (Dubey *et al.*, 2015). Moving down the value chain to the production stage (or primary processing), a circular economy requires raw materials to be either technically restorative or biologically regenerative to minimize negative impacts on the environment (Genovese *et al.*, 2017). This brings into focus the role of sustainable management of natural resources, sustainable procurement and consumption for reducing raw material utilization and improving resource efficiency through recovery and lower waste generation. Reducing the resource inputs in production processes has been essential for manufacturing industries not only to maintain their competitiveness but also due to the imperative of mitigating the environmental and climate risks that threaten the stability of both business and society.

Another important aspect of CSCM is the reduction of environmental impacts of various logistics and distribution strategies that it promotes, including reducing the energy requirements of logistics-related activities, reducing waste as well as the treatment of residual waste in transport, warehousing and inventory management from suppliers to consumers (Sbihi and Eglese, 2007). CSCM places a particular focus on secondary markets by employing processes of extracting value from products at their end-of-life in a closed-loop recovery system by integrating reverse logistics. This entails recovering goods from what, under the linear model, would be their final destination (consumers) to extract further value from them, with disposal being the last resort. This includes returning goods purchased via e-commerce and traditional retail, as well as, components for refurbishing and remanufacturing of products that may be resold or disposed of.

Further up the value chain, there is the consumption stage. Awareness campaigns and sustainability education play a crucial role in changing consumer attitudes and choices. However, there is still an overarching need for a variety of policy instruments to increase the awareness of circular consumption, especially given that cultural differences play a significant role in framing consumer attitude towards circularity and the environment in general (Gaur *et al.*, 2019; Lakatos *et al.*, 2018).

While many consumers' core attitudes and behaviour can only be regulated by policy, some encouragement to adopt circular consumption patterns could nevertheless be facilitated by producers. This involves the inclusion of repairability, durability, upgradability and recyclability as core aspects in product design to keep products, circulating in the economy for longer. Some specifics here involve:

- Design for standardization and compatibility, which entails manufacturing modules, parts and elements that can be used in different products and applications, enabling the repair of products and the

replacement of faulty parts (e.g., wood construction and modular wooden furniture could be used in different applications).

- Design for ease of maintenance and repair to avoid functional obsolescence. This means that if products break down, they can be easily repaired at home or with repair and maintenance activities being provided by producers (e.g., broken or used parts of furniture could be detached to be repaired or replaced).
- Design for upgradability and adaptability means that products are manufactured in a way that readily allows for future expansion, modification and updates to counter systemic obsolescence, permitting such products to adapt to the changing needs of end-users. (e.g., IT and electronics).
- 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., furniture would include standard parts such as joints and hinges which could be readily replaced if broken or recovered for new furniture when a product reaches its end of life) (den Hollander *et al.*, 2017).
- Design for recycling and biodegradation requires smart material choices to ensure that material inputs are

renewable, recyclable, safe and secure for humans and the natural environment. Materials of a single type, as opposed to mixes such as painted wood or plastic-coated paper, 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 of a product is considered critically important in a circular economy. In line with the 9Rs, a given product in its end-of-life form may become defunct, however, strategies to repurpose, refurbish, remanufacture and recycle that product entirely or in part will result in new value creation. However, while the circulation of used components and materials has significant economic and environmental benefits, there remains a lack of understanding concerning the potential of managing the end-of-life of products for many business sectors (van Loon and Van Wassenhove, 2018).

CSCM strategies provide different sectors a workable framework to transition towards a circular economy and to improve their sustainability performance. As such, they have been receiving growing interest from various industries, researchers and policymakers alike, although it should be noted that, as with the circular model in general, confusion remains with regards to the terms related to supply chain circularity and sustainability.

Section 3
**CIRCULARITY IN
FOREST-BASED
INDUSTRIES**



3.1 Applying circularity concepts to forest-based industries

The main arguments for a transition towards circular value chains are linked to the increasing scarcity of natural resources and the ecological impact of human activities. This has led to the realization, across different sectors and disciplines, that employing circular models in the world's economies is needed to replace linear production and consumption practices. The key role for the forest sector in the transition to such a system is related to wood being a biodegradable raw material and a strategic natural resource that can be used for creating reusable and recyclable materials. Further, it is not a finite, energy or carbon-intensive raw material when compared to materials such as aluminium, steel, glass and petroleum products. 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 sectors production processes, can be extended to other value chains as well. Forest-based industries can thus help transform several strategic sectors, such as construction, textiles and packaging industries towards more circular systems, each with a reduced environmental footprint.

The scope of the present section is to analyse the circular approaches across different value chains in the forest sector. A value chain analysis will be adopted for this purpose covering the following:

- **Woodworking industry** (focusing on sawn wood processing, bioenergy production and wood in construction) in Section 3.2
- **Furniture industry** (focusing on wood use) in Section 3.3
- **Paper and pulp industry** in Section 3.4
- **Cellulose-based fibres** in Section 3.4.2
- **Cellulose-based plastics** in Section 3.4.3.

3.2 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 intended to frame a discussion on either the prospects of a circular economy across different forest-based industries or specific stages in their value chains. The value chain illustrations applied are generic for the given sectors and in reality they can have many variations. For example, both pulp and oriented strand board (OSB) can be produced using pulp logs, meaning that regardless of the origin, the same raw material can be used for making pulp and OSB.

Consequently, there can be several value chains resulting from one raw material.

Box 4. Forest-based value chains.

The term "value chain" entails a series of manufacturing steps that link raw materials to final products through different sub-sectors of an industrial or economic sector. A value chain can vary in scale from being local to global and the range of activities along the value chain may be implemented by different actors, such as resource extractors, processors, traders, retailers and service providers. Each sub-sector (e.g., furniture manufacturing or construction) covered by this study could 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 to the same value chain.

The VCA is intended to provide a map of forest-based industries against which it is possible to consider how each point in a given value chain can apply a circular model (FAO, 2007, 2013). It will, for this reason, be oriented more toward qualitative analysis and, more specifically, the VCA will be used to clarify how forest-based industries can adopt circularity principles by focusing on a range of activities and transfers involving the production, transport, distribution and use of particular forest-based products. The main purpose of the VCA is therefore to divide the chain of activities that run from the production of raw materials to the end-of-life into strategically relevant segments.

The value chain 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).²¹ 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 those used by the FAO²², were considered. The value chain graphs presented demonstrate which kind of products are assigned to which defined product group and show the degree of processing (primary, secondary and tertiary) in their respective value chains.

Although forestry is undoubtedly a part of all forest-based industries, the analysis in this section of the study adopted value chain models (with some modifications) from an assessment of the EU forest-based industries (Rivera León *et al.*, 2016). There are two main reasons for

²¹ The current NACE version is the European implementation of the UN classification International Standard Industrial Classification of all Economic Activities (ISIC).

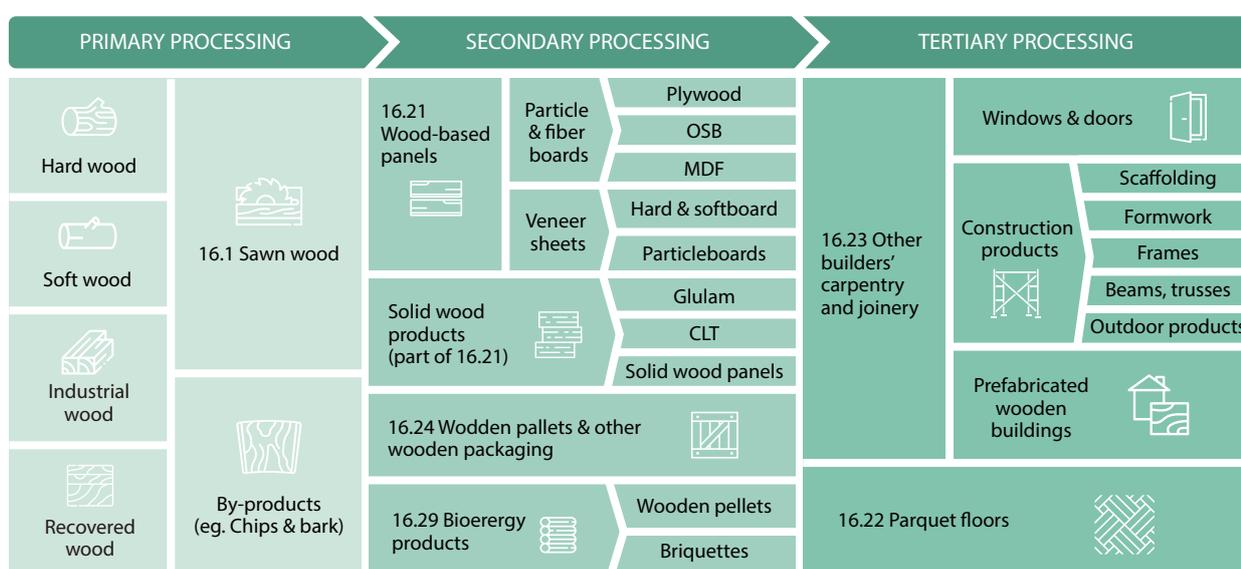
²² <https://www.fao.org/3/ap410m/ap410m.pdf>

using these value chains: First, the value chains have been developed together with industry representatives from relevant sectors. In total, 12 representative organizations²³ were involved in the development of these value chain illustrations (Rivera León *et al.*, 2016). Secondly, the value chains are meant to be generic and provide an overview of industrial processes in the sectors involved, as seen by their actors. To ensure a proper attention is given to the role of forests and forestry in forest-based industries, distinct consideration to the concept of natural forest cycles and sustainable forest management is given in Section 4.

Finally, in terms of the 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 sawn wood²⁴, recovered wood and by-products. It should also be noted that the listing of products covered by each of the product groups is non-exhaustive. The value chains are meant to showcase the complexity and variety of products within one product group and within different sectors. The waste streams have not been explicitly indicated.

FIGURE 11.

A woodworking value chain.



Source: UNECE/FAO, adapted from Rivera León *et al.* (2016).

3.3 The woodworking value chain

Figure 11 illustrates the woodworking value chain. The woodworking sector is derived from NACE 16²⁵ (Eurostat, 2019) and includes:

- **Primary processing** resulting in the production of sawn wood.

- **Secondary processing** involving wood-based panels, solid-wood products, wooden pallets and other wooden packaging and bioenergy products.
- **Tertiary processing** to manufacture builder's carpentry and joinery products and wooden flooring.

In this illustration, input materials within the woodworking value chain include hard and soft wood, industrial by-

²³ Alliance for Beverage Cartons and the Environment (ACE); European Biomass Association (AEBIOM); The European Confederation of woodworking industries (CEI-Bois); Confederation of European Paper Industries (CEPI); International Confederation of Paper and Board Converters in Europe (CITPA); European Furniture Industries' Confederation (EFIC); European Organisation of the Sawmill Industry (EOS); European Panel Federation (EPF); European Federation of Wooden Pallet and Packaging Manufacturers (FEFPEB); International confederation for printing and allied Industries (INTERGRAF); and European Furniture Manufacturer's Federation (UEA).

²⁴ Sawn wood is wood that has been produced either by sawing lengthways or by a profile-chipping process and is generally greater than 6 millimetres (mm) thick (Eurostat).

²⁵ NACE 16 is characterized 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).

products (such as bark, wood chips and sawdust) as well as used materials (post-consumer recovered wood). Saw logs, which are the starting material for all woodworking industries, have not been included as they are considered a part of forestry.²⁶ 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) and provide more detail than the NACE categories. Other raw materials, such as the resins, coatings and impregnation chemicals used in woodworking manufacturing, have been omitted to make the value chain simpler for this study.

Based on the illustration of the value chain in Figure 11, the study will focus on the sawmilling (NACE 16.1) and bioenergy (NACE 16.29) industries as well as the use of wood in construction (NACE 16.23) as the different levels of processing in the woodworking value chain. This will allow for the analysis of opportunities and limitations related to the implementation of circular approaches across the value chain, from primary to tertiary processing.

3.3.1 The woodworking sector

Taking a long-term perspective on wood as a raw material, it is arguably already used circularly, primarily because it can return as nutrients to the biosphere. Being bio-based and non-toxic in its natural state, wood follows a natural carbon cycle even though the loop may stretch over many decades. This means that it has a significant advantage over other materials that do not harmlessly biodegrade. In contrast, however, 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. The circularity of wood should, for this reason, rather be seen as a process of the cascading use of transformed wood products.

As has been previously noted, applying cascading use principles to wood does not meet all the criteria of circularity. For example, if circular principles are strictly

adhered to, using recovered wood to produce energy does not fulfil the criteria of being circular simply because energy is not possible to recycle (even if ash could be applied to forests, having a regenerative benefit). Energy is, for this reason, commonly seen as leaving the loop and is thus not included in the circular model used in this study.

Furthermore, the conceptual ambiguities surrounding a circular economy noted previously, such as the lack of common definitions and criteria for circularity, further contribute to confusion in the woodworking sector (Calisto Friant *et al.*, 2020; Kirchherr *et al.*, 2017; Korhonen *et al.*, 2018b). While these conceptual ambiguities cannot be resolved by this study, a pragmatic approach will be taken when reviewing the woodworking value chain. The main objective of the analysis will be to identify and consider areas where the forest sector can become more circular. This will be done using the 9R approach, as presented in UNEP's circularity model (Figure 6) and the woodworking value chain (Figure 11). Even though bioenergy is not part of the circular model presented in this study, it is nevertheless recognized as being of fundamental importance for the forest sector as well as a renewable energy source in view of the implementation of the SDG7 and its contribution to the bioeconomy. Therefore bioenergy production will accordingly be considered separately in Section 3.2.4.

3.3.2 Sawn wood

Sawn wood is a biodegradable material that disintegrates naturally over time, that originates from both a source (forests) and material (saw logs) that is renewable as harvested trees can be replaced by planting new trees. In the UNECE region in 2018, sawn wood consumption increased 1.5 per cent over the previous year and amounted to approximately 250 million cubic metres (m³) (UNECE/FAO, 2019). To date, the construction sector has been the primary consumer of sawn wood and other solid-wood products (Forest Europe, 2020).

FIGURE 12.

A generic sawn wood value chain (without by-product streams).



Source: UNECE/FAO.

²⁶ Forestry, logging and related service activities is covered under NACE 2.01 and 2.02.

The sawn wood sector operates in what is commonly described as the solid-wood value chain (Figure 12). It is a product in a resource-based sector where maximizing resource efficiency has been a key condition for economic viability for a long time.²⁷ Sawn wood is for this reason commonly used for a wide range of products in areas such as construction for beams, windows and doors as well as a number of associated side streams such as wood chips and sawdust, which can be used for the production of wood-based panels or bioenergy. The quantity of wood co-products directed to side streams will depend upon the type of wood being sawn and on the specifics of the sawmills where such raw materials are being processed.

Although a truly circular material flow of sawn wood is not possible given wood's propensity to deteriorate over time, a high degree of resource efficiency can be achieved by using sawn wood in one stage for as long as possible before it passes into the next stage in a cascading use model. However, doing so can be challenging as the implementation of cascading use in forest-based industries faces technical, market and governance barriers (Section 2.3.3) and, as it is the case for many areas attempting to embrace circularity, the viability and environmental externalities need to be considered before applying a cascading use model at each level (Figure 9).

Uncontaminated wood in used products could also be re-processed back into sawn wood. For example, post-consumer wood, such as that present in defunct and discarded products could be recovered (depending on the wood's quality, e.g., wood not treated with paint, glue or impregnating agents) for re-processing into sawn wood and then manufactured into particle board in a cascading system. This would have the added benefit of reducing the use of fresh (or primary) wood, however, there are limitations to such processes in practice as most of the time they are neither pragmatic nor economically viable. For example, post-consumer wood requires physical inspection and quality assessment to avoid possible contaminants entering re-use processes and to ensure the structural integrity of the sawn wood. Hence, the recovery of solid-wood residues in sawmills is currently not common practice.

Despite the limitations imposed by wood as a material, many steps can be taken regarding a circular use of sawn wood given its potential longevity as a product and biodegradability. Transitioning to circularity – or closing the loop – is not a panacea for the sawn wood sector, it requires system innovation and coordination across the entire supply chain (primary to tertiary processing). For example, the potential for the material use of sawn

wood residues demonstrates opportunities for improved system efficiency. Another opportunity for sawmills is to further reduce the imbalances between their material and energy uses of residues (e.g., it is common practice that only waste wood that cannot be downcycled into paper 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. The "intelligent" component in such wood cycles refers to improved sorting processes that increase the volume of waste wood that is made available for cascading use (Jarre *et al.*, 2020). Another example is finger-jointed sawn wood, whereby short pieces of sawn wood (trim-ends), which are often chipped to make pulp, are instead finger-jointed together to make marketable pieces of sawn wood.

There are also opportunities to use waste wood for bioenergy. For example, many sawmills have integrated biomass energy plants where waste products are incinerated for energy production. While it can be argued that a waste stream can be more effectively used in a cascading use, taking the entire biosphere carbon cycle into account may be decisive in determining the degree to which circularity principles should be applied rather than direct incineration. The case in point here would be to ensure that the carbon impact of incineration is lower than the transport and transformation of residues into other products as well as the resultant ash is used as fertilizer in agriculture and forestry, something which is still not standard practice in the woodworking sector (IEA, 2018; López *et al.*, 2018). Where it is, ash undergoes rigorous analysis to limit the spread of toxic substances. Consequently, both the economic and environmental viability of each of the alternative options should be taken into account.

Another area of opportunity relates to the dissemination of knowledge on circularity among consumers and producers of sawn wood, a key factor for further developments regarding circular approaches by the sector. This dissemination process includes filling knowledge gaps on the practical realization of wood cascading upstream and downstream, including its economic viability and environmental externalities. In addition, improved certification to ensure sustainable sourcing of wood²⁸ is a prerequisite for the long-term sustainability of sawn wood value chains (e.g., Chain of Custody certification).

This section has presented a limited number of examples that may be applied by woodworking industries, many others can be found when analysing specific contexts and case studies involving particular sawmills and the

²⁷ It is mainly sawn wood producers that have been able to purchase the raw material cost effectively, quickly react to market conditions, and managed to efficiently market their co-products that have been able to survive price competition in the past years.

²⁸ 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).

value chains relating to them. However, undertaking such specific analyses, which would also require analysis of the economic feasibility and sustainability of each of these circular approaches to particular circumstances, falls outside the scope of this study.

3.3.3 Wood in construction

The construction industry is one of the most significant producers of waste in any given economy. In fact, construction is responsible for more waste globally than any other single area of economic activity. For example, in the EU, construction waste accounted for 36 per cent of the total waste generation²⁹ in 2018 (Eurostat, 2020). However, waste in construction has traditionally been considered as an inevitable by-product that is usually managed from a health and safety perspective rather than with recycling in mind (Osmani and Villoria-Sáez, 2019). According to a study in the United Kingdom of Great Britain and Northern Ireland, about 10 to 15 per cent of the wood used in new construction ends up in recycling. This statistic is a concern to policymakers, who observe that the recycling rate for C&D derived wood is considerably lower than for other C&D materials such as concrete (82 per cent) and structural steel (98 per cent).³⁰ This suggests that there is considerable work to be done to make the construction sector more circular, including the use of waste wood as a part of a broader system loop (Dangel, 2017; Kaufmann and Nerdinger, 2012; Lignatec, 2015). For example, post-consumer wood from construction can be upcycled³¹ into flooring, cabinets, furniture and beams where such is economically viable and without negative impacts on the environment or human health.

To facilitate more post-construction wood re-entering the supply chain, systemic developments are needed to enhance sorting, separation and recovery options through, for example, more efficient recycling during demolition so that wood waste can be cycled back at the end-of-life stage to other industrial processes. This would require increased integration across the value chain (Figure 12) involving actors such as demolition operators and stretching from primary to tertiary processing. Moving away from the business-as-usual approach would furthermore require cross-cutting and networked systems with stronger collaboration between business ecosystems (e.g., municipalities, architects, designers, builders and inhabitants). There are also issues concerning the organization of and infrastructure involved in recovery processes. For example, if contaminated wood is to be

recycled, materials such as metal will need to be manually removed and if further milling is required, additional metal detection safeguards will need to be in place to avoid damage to milling tools. This also applies to wood used as a concrete form to shape and hold concrete in place while it hardens. In both of these cases, the risks to saws and the labor-intensive nature of the tasks mean it is not easy to cycle back construction waste wood in an economically viable manner.

Another approach to improve the circularity of the construction sector relates to the design and detailing of mass timber buildings for greater durability, including measures to hold materials in place for longer, prolong the lifespan of wood to reduce the demand for new materials and standardize modular wood construction elements that could be re-used and recycled more easily. This can, for example, include glueing, dowelling or nailing major sections in a building as well as using preservatives or applying a surface coating. This requires that the wood's entire life cycle (from primary to tertiary processing) is taken into account when constructing new buildings to 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, they may also affect the prospects for reuse of recycled materials. For example, treating the wood for durability makes reuse more difficult and may also contribute to increased pollution. This highlights a key concern regarding circularity, namely, that making a value chain more circular does not always lead to increased sustainability and can sometimes have detrimental environmental impacts. In this example, the substances used for treatment of wood-based components need to be drawn from renewable sources and the wood itself should originate from sustainably managed forests. Moreover, the different techniques used to increase durability should be adapted to specific criteria for sustainability (e.g., infrastructure that allows for material separation and recycling) to avoid negative externalities.

The design aspect in construction also extends to business models that enhance the “*designing for disassembly*” concept to ensure that buildings can be dismantled in a manner that optimizes the recovery of systems, components and materials. This includes designing 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 reduce dependence on carbon-intensive materials such as cement and metals. Furthermore, designing for reuse

²⁹ 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).

³⁰ www.thebalancesmb.com/wood-recycling-construction-2877760.

³¹ Upcycling implies transforming reusable materials (e.g., unsold goods and materials destined for landfills) into products or materials with higher added value.

enhances the prospects for improving material efficiency and reducing waste at the design stage. Another concern that relates to circularity in construction is the lifespan of a building in which many processes, such as refurbishing, remanufacturing and recycling, can take place.

The points noted above suggest that circular construction primarily relates to the recovery and reuse of wood used in buildings during construction, renovation and demolition (e.g., through enhanced recycling to ensure that waste is seen as a resource). From this perspective, circular construction has a focus on using and reusing construction materials in buildings and infrastructure to the greatest extent possible to reduce the use of new materials. Sustainable design is a key element to achieve that as durability and recyclability are incorporated in the development phase of wooden construction elements and buildings. One example of this is off-site wood construction technology, which involves a digitally precise design, fabrication and assembly of new building elements away from the construction site. This is an appealing option in construction as it provides optimization to value chains by minimizing waste.

There are also other factors to consider, such as the need to improve the awareness of people working in the construction sector as well as of end-users (e.g., consumers) about the opportunities and limitations related to applying circular approaches. However, it should be recognized that the highest potential for increasing circularity in the construction sector resides in the utilization of construction and demolition wood from the renovation and the decommissioning of already standing buildings, because they constitute the majority of the real estate stocks. There are less buildings being built than renovated and most of the time it is more economically viable and less environmentally harmful to undertake a renovation of an existing building than to construct a comparable one in a new location.

The degree to which a building can be reused, modified or upgraded in a sustainable manner during its lifespan depends on how all the materials used in its construction can be either reused, recycled or upcycled at the end of their lifecycle. Certainly, there are notable challenges related to that, however, there is also some business potential for wood waste from construction. For example, markets for recycled wood include landscaping mulch, plant-bedding material, boiler fuel and fibre for composite board

production. It can also be noted that recovered lumber can sell at a premium when compared to new material for construction of traditional high-end houses, in particular in some touristically attractive areas. Nevertheless, to realize circular projects in construction, the key actors in the sector need to think beyond business-as-usual. The success of a circular economy in construction depends on the sector's ability to identify and tap into new markets while exploring new opportunities both inside as well as outside the sector's networks and value chains.

3.3.4 Bioenergy

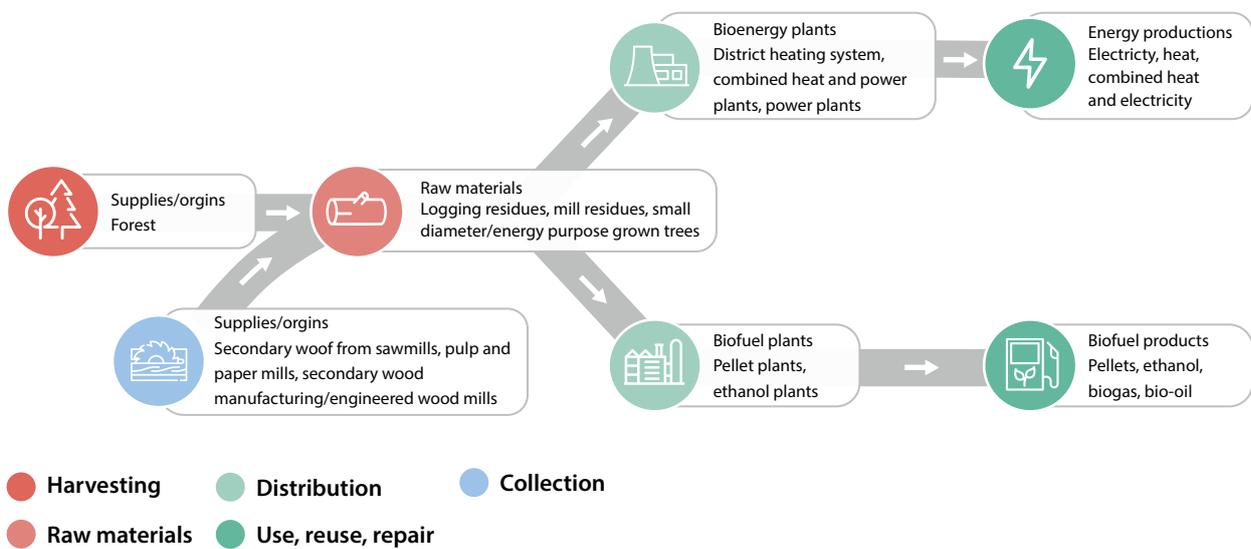
Every tree trunk produces wood materials with different qualities that can enter the bioenergy value chain. On the other hand, bioenergy production is considered to be a part of the cascading and resource-efficient use of wood. (EC, 2018; Hetemäki *et al.*, 2017). Forestry and woodworking industries create residues and side-stream raw materials, such as wood chips, sawdust and bark, which can be used to produce bioenergy or be transformed into biofuels. In this scenario, recycling wood for energy can be considered the final stage of wood's cascading use and is not considered as a separate value chain.

From the perspective of circularity and resource efficiency, the best-case scenario entails that wood stays as long as possible in one stage of its lifecycle before cascading down to another use (UBA, 2017). The resource-efficient use of wood for bioenergy in a circular bioeconomy occurs when wood residues are derived from the industrial processing of wood coming from sustainably managed forests and when no other use of woody biomass is economically viable or environmentally beneficial compared to producing bioenergy.

As noted previously, this study does not address whether or not bioenergy production can be considered as a part of circular processes, although based on the circular model adopted in this study, the incineration of wood (or biomass) is treated as a leakage from the system and is thus not a part of its various loops. Having said that, it would be negligent to ignore the significant relevance of bioenergy production as an inherent aspect of the woodworking value chain. This is particularly relevant given that wood cannot be cycled in perpetuity, meaning that cascading use principles have to be applied and, being bio-based, bioenergy can feature as a part of the biosphere carbon cycle.

FIGURE 13.

The supply chain for energy production.



Source: UNECE/FAO, adapted from Shabani *et al.* (2013).

While bioenergy products have been included as secondary processing in the woodworking value chain one has to keep in mind that biofuels can come from various sources across the supply chain, including upstream and downstream stages. In the UNECE region, wood energy comes primarily from wood processing residues.³² For example, in the preceding section on sawn wood (Section 3.2.2), it was noted that a sawmill can have an integrated biomass powerplant that supplies energy for its milling operations using waste residues from the milling process itself. From a circularity perspective, this is arguably a sub-optimal use of the generated waste, however, from the sawmill's perspective, it means the valorization of what used to be a waste product that lowers production costs. Furthermore, from a sustainability perspective, using the waste products locally (e.g., directly in the sawmill) may also lower the environmental impact (e.g., no transport or further processing related emissions). This demonstrates once again that circularity does not necessarily equate to sustainability nor is it always environmentally friendly.

Another area of concern for the woodworking sector relates to the increased competition for raw materials generated by the growing demand for energy wood. For example, several international and national regulatory measures across the UNECE region encourage solid biomass use (including woody biomass) for bioenergy use as a part of ongoing efforts to reduce dependence on fossil-based products. However, renewable energy policies, which have been instrumental in advancing the bioenergy sector, have also affected woodworking value chains by increasing raw

material costs (Münnich and Eloffsson, 2017; Rivera León *et al.*, 2016; Souza *et al.*, 2017). These policy instruments have significantly increased the demand for energy wood, drawing the supply of wood residues away from products with potentially longer chains of cascading use. While this may be seen as a positive development in some regards (e.g., increasing profitability), it also provides incentives that may limit the prospects of making some woodworking value chains more circular.

This latter point highlights the key role of policy frameworks that need to balance encouraging positive impacts on the climate while also ensuring a hierarchy of wood uses, giving priority to long-life material uses. This involves the application of cascading use principles (to the greatest extent possible) and more effective partitioning of waste streams back to other sectors, such as mass timber, paper and pulp, bioplastics, biotextiles, and then at the very end of the chain, to the bioenergy sector. The impact from increased competition over raw materials 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.

Even though energy cannot be recycled, the bioenergy sector is generally considered to be neutral in the biosphere carbon cycle and offers a viable alternative to fossil fuel use. The examples provided above demonstrate that the bioenergy sector could find more resource-efficient biomass sources, including by improving existing biomass conversion

³² <https://unece.org/circular-economy/press/products-and-residues-form-increasing-part-wood-energy-consumed-unece-region>.

technologies. Additionally, there are prospects for improving quality standards and certification in areas such as the labelling of bioenergy products to ensure that end-users (e.g., consumers) are better informed before making choices about bioenergy. This requires better harmonized standards and regulations for labelling and monitoring of production procedures. Moreover, sustainable bioenergy sourcing should not put pressure on ecosystems and other woodworking value chains. How successfully this can be done depends on the sustainable management of forest resources and coordinated planning of all production processes involving wood residues. There are also other opportunities to improve the utilization of residues from forestry (such as leaving some residues in place for the ecosystem's benefit) and woodworking value chains (such as the production of wood-based panels). Finally, as noted previously, ash recycling can feature as a part of the circularity process allowing the nutrients to return to

the biosphere (IEA, 2018; López *et al.*, 2018) in line with the biosphere carbon cycle .

3.4 The furniture manufacturing value chain

Figure 14 provides a basic 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).³³ It should be noted that the furniture sector is a very diverse one that, in addition to wood, uses a wide range of input materials as products move from the supply base to the manufacturers and eventually to the end-user (e.g., consumer). A variety of these materials can also be present, either alone or in combination with other materials, in different product groups and value chains (e.g., metal and plastic).

FIGURE 14

The furniture manufacturing value chain.



Source: UNECE/FAO, adapted from Rivera León *et al.* (2016).

The furniture value chain is characterized by a complex flow of different materials, which is what distinguishes it from other value chains of wood product manufacturing. 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. The five main categories of listed materials do not result in separate product groups per se but have been itemized in

primary processing to provide a more complete picture of the various input resources common to furniture production. This means that the depicted value chain is a simplified version of reality useful in serving the needs of this study and that the furniture sector is much more diverse in terms of materials used and the value chains involved. Its underlying complexity is also a key reason for including the furniture sector in this study. Given this heterogeneity, coupled with the sector's size, it is highly relevant to consider how furniture manufacturing could better embrace circularity.

³³ 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).

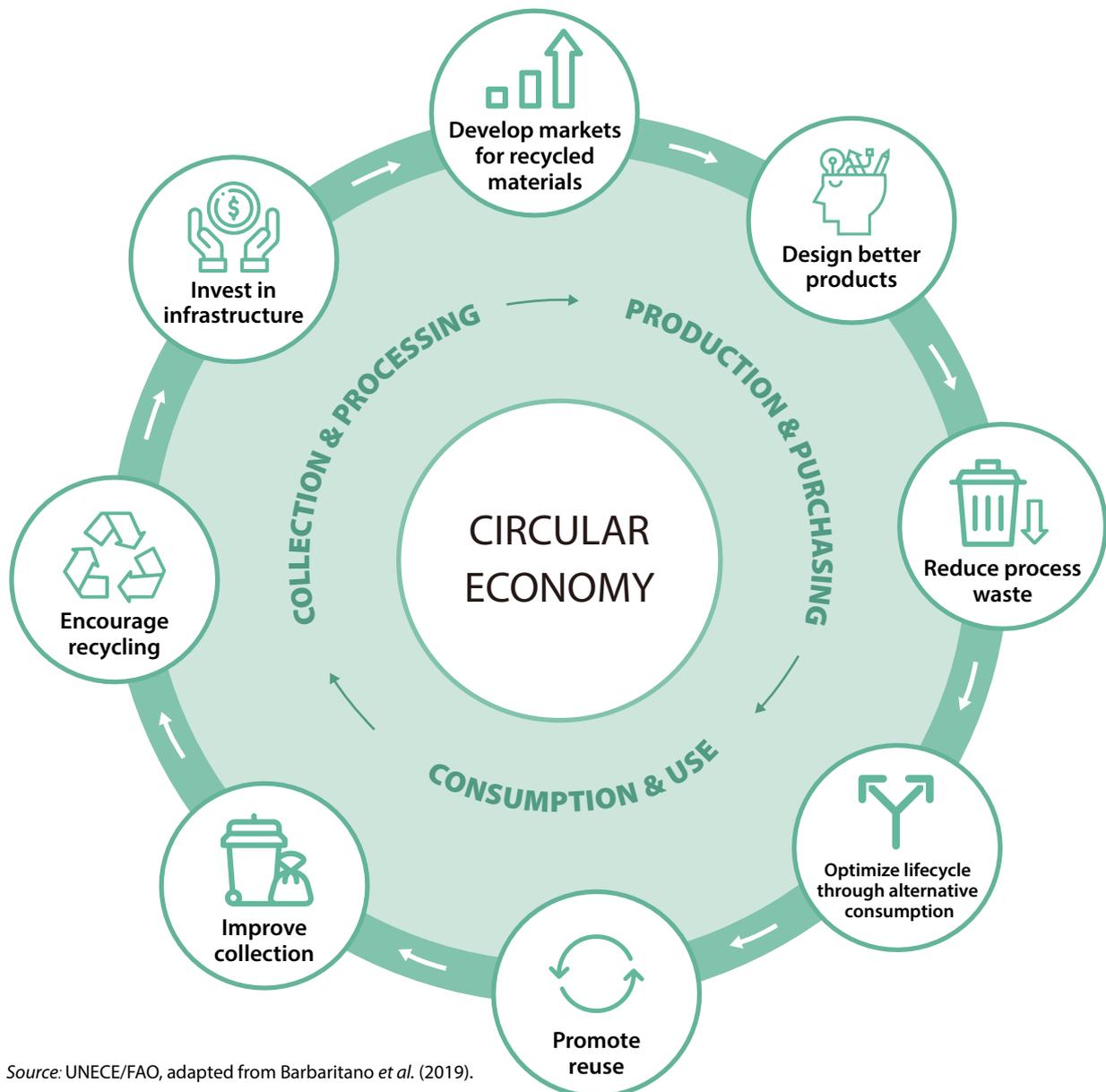
The relevant furniture products (secondary processing) in this section are divided into contract and domestic furniture, where contract furniture (NACE 31.02) refers to that which is purchased for public facilities such as schools and hospitals or by companies such as theatres and restaurants. Domestic 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 but is not limited to the manufacturing of sofas, sofa beds, sofa sets, garden chairs and seats as well as bedroom furniture but also includes the upholstery of seats and finishing processes such as sealing, painting and French polishing.

3.4.1 Wood in the furniture sector

Despite the variety of materials used for manufacturing furniture, the sector accounts for a significant portion of the economy's wood consumption. In the EU, it is estimated that 30 per cent of the materials used in manufacturing furniture is wood with more than two-thirds of particle board and about half of all medium-density fibreboard (MDF) produced within the Union used by the sector (EC, 2016). Consequently, furniture manufacturing is a heavily wood-based economic activity worth looking into for increased material efficiency and circularity.

FIGURE 15.

A circular economy model for the furniture sector.



Source: UNECE/FAO, adapted from Barbaritano *et al.* (2019).

Circular systems are restorative by design as they aim to maintain the condition and value of products and materials for as long as possible through repair, refurbishment, reuse and recycling. In the furniture sector, these restorative activities are infrequent and not widespread. For example, according to the European Federation of Furniture Manufacturers (UEA),³⁴ total annual furniture waste equates to 10.78 Mt for the EU28 (EEB, 2017), with 80 to 90 per cent of all furniture waste³⁵ being incinerated or sent to landfill and only 10 per cent being recycled. In the United States of America, the Environmental Protection Agency's (EPA) annual data for 2018 on wood in municipal waste (including furniture and wood packaging but excluding yard trimmings and construction waste) revealed that more than 18.09 Mt of wood waste were produced in municipalities, of which only 3.1 Mt (17 per cent) was recycled, 2.84 Mt (16 per cent) was incinerated while the majority, some 12.15 Mt (67 per cent), ended up in landfill (EPA, 2020).

The benefits to the furniture sector arising from efforts to improve circularity and resource efficiency are closely tied to sustainable sourcing of raw material at the beginning of the value chain. Such sourcing would ideally focus on either employing recycled wood, an area that could be increased or from virgin wood obtained from sustainably managed forests. The next step is to decide how the wood can be kept in the loop for as long as possible using tools such as product design which would allow for the production of standardized modules that enable consumers to use furniture for different functions, to replace specific worn parts or add new elements to prolong its lifespan. Other tools could include manufacturing with dismantling and recyclability in mind and using non-toxic bio-based substitutes rather than fossil-fuel based glues, varnishes and plastic coatings to avoid contamination by non-recyclable and non-biodegradable materials. Although the latter aspect would likely require adjustments to existing manufacturing processes as well as recycling infrastructure.

Other circular approaches of value to the furniture sector include increasing product reuse by providing repair, refurbishment and remanufacturing services as well as the recycling of discarded furniture through the collection, sorting and dismantling further down the value chain. However, there is limited infrastructure for recycling, reuse, repair and remanufacturing, both on the consumer and producer side. This deficiency undermines the efforts and opportunities to manage the furniture sector in accordance with the principles of a circular economy. In addition, the demand for second-hand furniture (reuse) is low due to the availability and affordability of new low-cost products

which are easy to transport, assemble and dispose of. There is also a cost increase related to preparing the furniture for reuse (EEB, 2017). Consequently, there are inherent structural weaknesses in the furniture market that actively counter circularity principles and will need addressing to ensure the economic viability of circularity in this context

The creation of new loops involving recycling and recovery is particularly complex in connection with furniture due to the material composition of products that may limit the possibilities of further use. Compared to the woodworking value chain, the furniture sector uses a much wider range of materials in production. 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) and can create hazardous working 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 example, there has been a trend away from using solid wood and metal in furniture (which are easier to recycle) toward using lower-quality materials. This restricts the potential of both the final product and its constituent materials to be cycled and again highlights the important role of product design for disassembly, modularity, recycling and material recovery, reuse and remanufacturing, maintainability as well as for end-of-life which means designers need to consider the complete life cycles of 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. Most commonly, the responsibility of producers ends when the furniture is sold. End-users are generally not given guidance on how to maintain and repair furniture (e.g., to extend the product's lifespan) nor do they have access to such services from the producer or sales agent. For example, key components ensuring the functionality of the product are often not made to last and spare parts are not available on the market or only available for a limited time. Indeed, in many countries, the growth of the furniture industry relies heavily on shortening the replacement cycles by stimulating consumers to buy new furniture before their existing pieces are no longer functional or by manufacturing products with short lifespans. Product marketing encourages consumers to buy new furniture to have the latest design and fashion, further exasperating weak demand for second-hand furniture. As manufacturers within the furniture sector have competed over consumers, low-cost product segments have developed as a means to

³⁴ www.ueanet.com.

³⁵ Referring, in this instance, to the total municipal solid waste stream.

both accentuate and address the increased demand driven by raising interest in 'interior design' (ITTO/ITC, 2005).

It can also be noted that the price difference between new furniture against the cost of second-hand furniture is simply insufficient to encourage more sustainable purchasing behaviour. This is coupled with poor consumer awareness concerning the broader impact of the ever-increasing production and consumption of new furniture. However, this situation is not attributable to the producers as the prevailing linear economic model (take-make-use-dispose) still dominates consumer culture. Improvement in this area requires concerted action among different actors beyond the industry (e.g., market regulators) and efforts to raise awareness both amongst end-users and producers. The later point could include promoting the 'Refuse' principle as a part of the 9R approach.

Given the wide range of products and materials involved in furniture production, producers and other furniture industry actors need to take a systemic approach and adopt measures that are tailored to the specificities, size and scale of different production facilities. In other words, existing sustainability challenges in the furniture sector cannot be addressed by a one-size-fits-all solution, it requires a consideration of the furniture value chain in its entirety, starting from the upstream and supply of raw materials through to the end-of-life stage of products. For example, the furniture sector needs to consider the

complex network of actors operating across the different supply chains involved in their production, ranging from raw material suppliers to consumers and post-consumer waste management sites. Partnerships and collaboration are thus key in finding solutions. There are also other factors, such training, providing economic support 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 the implementation of technical innovations (e.g., using bio-based material streams and maximizing the value of waste) are also important in a circular context.

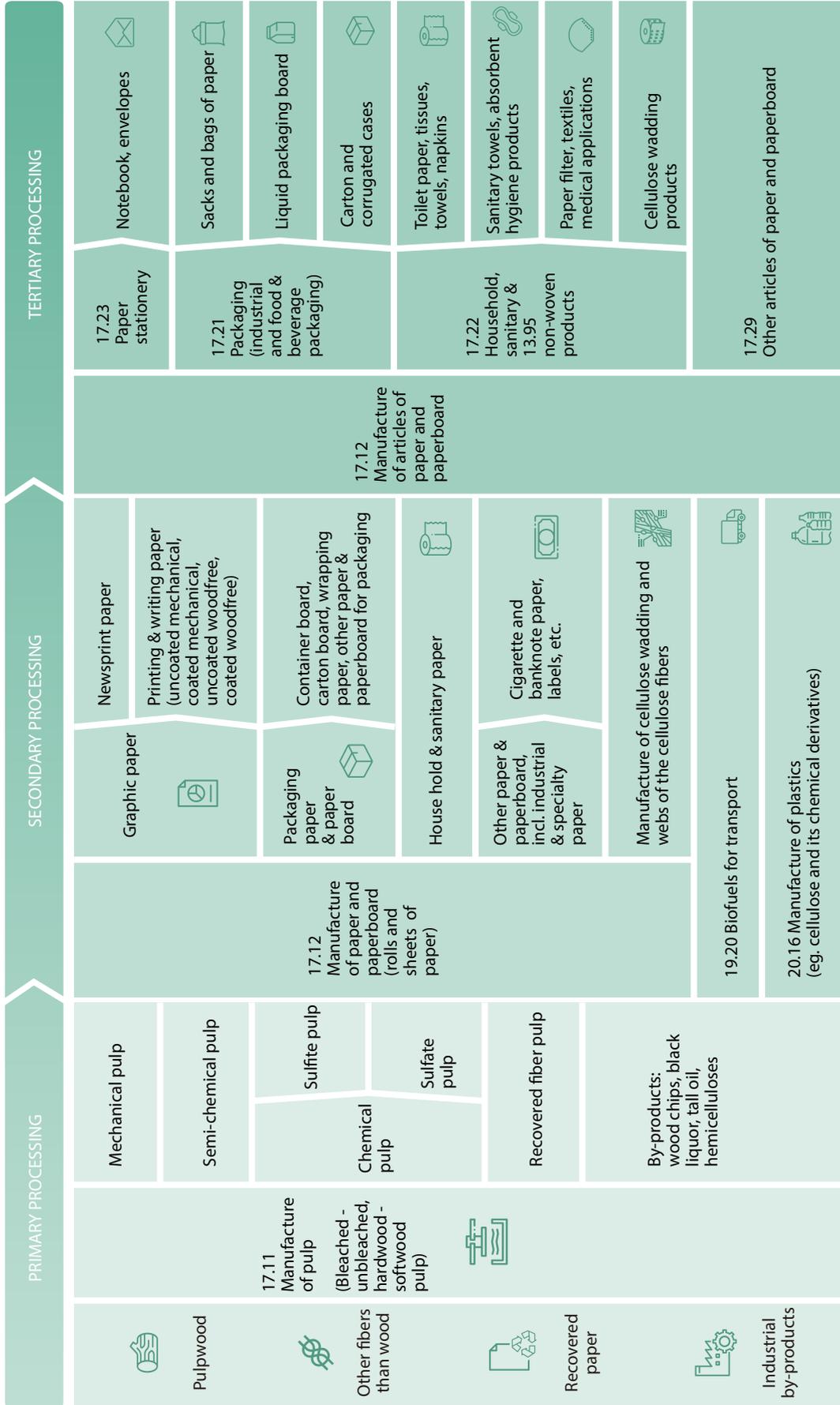
3.5 The pulp, paper and cellulose manufacturing value chain

Figure 16 shows the pulp, paper and paperboard manufacturing sector's value chain, including cellulose production. This sector is derived from NACE 17 and includes different types of products made from pulp (Eurostat, 2019)³⁶ and, more specifically, includes pulp production 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 needed but they do not represent a separate product category in this value chain.

³⁶ 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 16.

The pulp, paper and paperboard manufacturing value chain.



Source: UNECE/FAO, adapted from Rivera León et al. (2016).

This section will cover three main value chains, the pulp and paper industry in general, including the manufacture of pulp (NACE 17.11), paper and paperboard (NACE 17.12), as well as the production of cellulose-based fibres (also covered under NACE 17.12). The latter category will focus on speciality products such as cellulose-based plastics and textiles not fully covered in pulp and pulp-based manufacturing (NACE 20.16).

Cellulose-based plastics and textiles have been included in the study as they show an innovative application of cellulose-based fibres and that their importance is growing given the general sustainability trend in most economic sectors. It should however be noted that the companies working with cellulose-based fibres are significantly diverse, their business and market focus is very specific (e.g. production of chemical filters, non-woven fibres for hygiene etc.) and they also use cellulose from other plants such as cotton, hemp, and linen. This means that cellulose-based fibres can be found in a wide range of different value chains. In this study they have nevertheless been integrated into the wider pulp, paper and paperboard manufacturing value chain to show the material flows in this sector and how they relate to one another, even though for the production of bioplastics and textiles cellulose-based fibres may undergo different preparation than for the production of pulp and paper.

3.5.1 *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 the production process) and downstream (when the paper and associated by-products are recycled).

This also means that pulp and paper manufacturing would benefit by implementing processes that lead to greater material efficiency and circular flows of resources. For example, according to the Confederation of European Paper Industries (CEPI),³⁷ the pulp and paper sector is particularly well-suited to circular approaches because it uses a sustainable, renewable and recyclable raw material as its primary resource. Additionally, paper recycling is already relatively well advanced when compared to other products thanks to existing collection infrastructure, automated sorting processes, allowing for its economic feasibility. For example, 72 per cent of all paper consumed in Europe was recycled in 2019,³⁸ compared to the global average of approximately 54 per cent (Van Ewijk *et al.*, 2018). In the United States of America, more than 67.39 Mt of paper and paperboard waste was produced in municipal waste, of which 45.97 Mt (68 per cent) was recycled, 4.2 Mt (6 per cent) was incinerated, while 17.22 Mt (26 per cent) was sent to landfill in 2018 (EPA, 2020).

Although relatively easy to recycle in its pure form, paper can only be recycled five to seven times in practice (Figure 17). This is because its constituent fibres are lost or damaged during the recovery, collection and sorting process. For example, it has been estimated that only 38 per cent of fibre material input into paper production comes from the recycling with the rest being virgin fibrous harvest. (Van Ewijk *et al.*, 2018). Moreover, the pulp and paper sector in the EU alone produces approximately 11 Mt of assorted waste each year.³⁹ This indicates that despite relatively high paper recycling rates, engineering waste out of the paper production and recycling processes remains an important objective for the sector as a whole and an underlying driver for circular thinking.

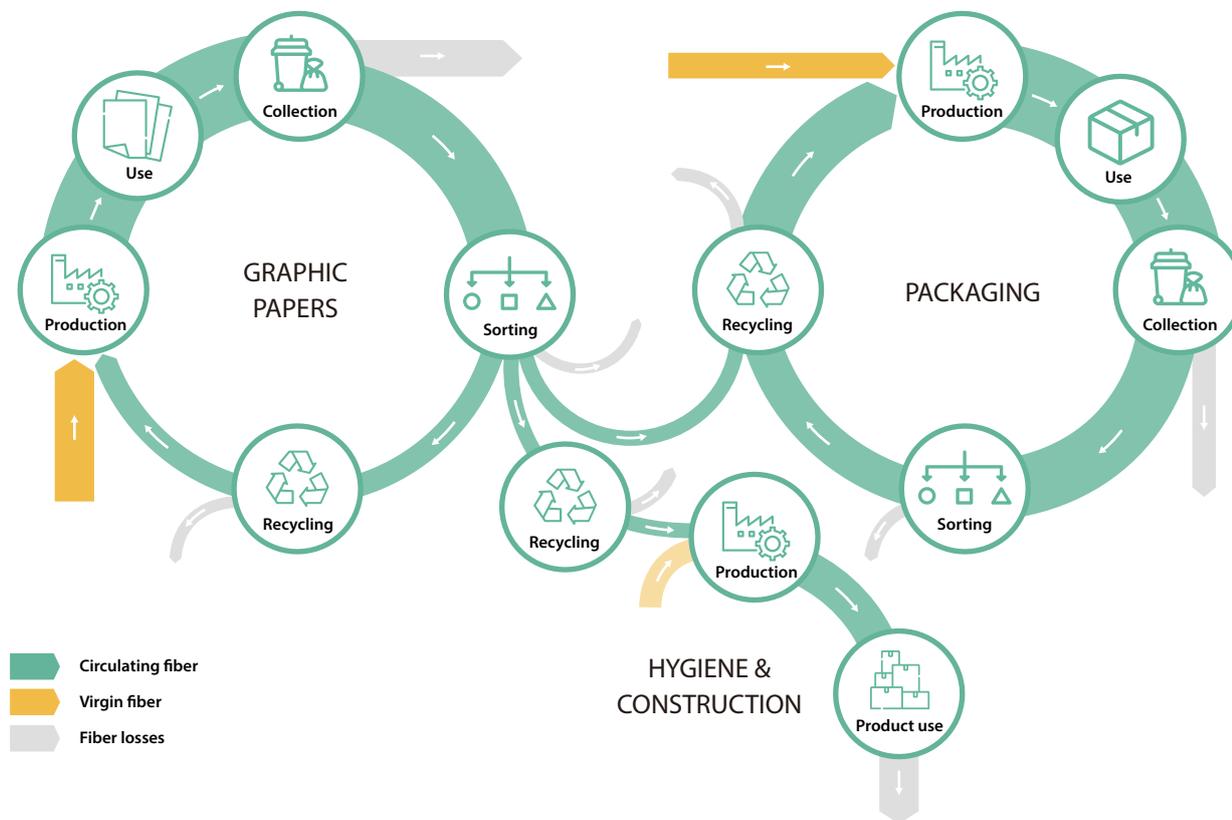
³⁷ www.cepi.org.

³⁸ www.paperforrecycling.eu.

³⁹ It has been found that between 25 and 40 per cent of all municipal solid waste generated each year is paper-related.

FIGURE 17.

The cellulose-based fibres life cycle.



Source: UNECE/FAO, adapted from 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 fibres and further limit the number of times a product can be recycled. This creates significant challenges when it comes to making the pulp and paper value chain circular, as these chemicals and coatings cannot be completely or easily separated from the paper. Furthermore, recycling processes have their limitations as, for example, the increased variation in ink composition and printing techniques are proliferating the number of material streams connected to the paper-based value chain, each requiring different recycling and de-inking techniques (e.g., over 6,000 different chemicals are used in printing inks).

While the complexity of the value chain makes a transition towards circularity more difficult, it is nevertheless important for the sector to reduce fibre loss and the amount of virgin resources utilized in paper production. This will invariably require all paper and pulp sector actors (e.g., ink, dye and glue manufacturers) to partner with paper recyclers in co-design of inks and coatings that are easier to separate from paper. Improved coordination across value

chains can help recycling plants to efficiently process paper waste and materials integrated into it.

As with the preceding sections, the examples provided above demonstrate that circularity and sustainability start with design and, in the case of the pulp and paper sector, the design should focus on recyclability. This may include rethinking the material composition of paper to influence the products' physical structures and how these react with applied inks and coatings. Another avenue for increased sustainability involves the sourcing of raw material, this concerns not only maximizing inputs from recycled paper but also ensuring that the virgin fibres used come from sustainably managed forests. Circular approaches in this sector can also encompass informing end-users about the origin of recycled paper (e.g., those used in food packaging or hygiene products) to reassure consumers about safety and sustainability of choices related to recycled paper and cellulose products.

The end-user also plays an important role in the circular production and consumption of paper. When seen as a whole, end-users (e.g., consumers) are an important actor in the material flow structure that is vital in increasing recycling rates. It is for this reason important to continue

building public awareness about recyclables to further increase participation in recycling efforts. However, policy measures that encourage recycling will only succeed if the markets for recycled products function well and if the separation and disposal of recycled material can be done in a cost-efficient manner. The impact on the environment and the quality of the final product must be acceptable to make pursuing such a course viable.

Another area with potential for circularity lies in the use of pulp and paper side streams for bioenergy. Setting aside whether energy production can be considered as circular (e.g., it does not fulfil end-of-waste criteria), the use of woody biomass by the pulp and paper sector results in the generation of by-products that can be used for renewable energy production. For example, a biogas plant can process the wastewater slurries from a paper mill and turn this into biogas for vehicles, fertilizers or solid biofuel for a boiler plant. This is an industrial symbiosis⁴⁰ that valorizes waste from paper manufacturing and this can, in turn, contribute to reducing several other sectors' reliance on fossil fuels (Lombardi and Laybourn, 2012). For example, black liquor has been employed as an important biomass fuel⁴¹ in many pulp mills where it is used for both chemical recovery and energy production while the recycling of ash from black liquor boilers can be used to produce a mineral fertilizer (potassium sulfate), allowing it to be returned to the biosphere.

It is important to mention that the paper and pulp sector is relatively advanced in terms of having circular value chains when compared to the other sectors dealt with in this study. Circular thinking can be further integrated into pulp and paper value chains, not only by increasing the quantity of recycled materials fed back into production but also by improving the recovery of pulp and paper production by-products and side streams for reuse. For example, coupling increased paper recycling with improved materials and energy efficiency, when possible, during the production and recovery processes, can further reduce waste discharge. Despite the significant work that the industry has done over the years to increase the recycling rates and reduce greenhouse gas (GHG) emissions, waste generation and environmental pollution still remain important areas of focus in transition to a circular model. This includes efforts to further reduce GHG emissions. Another area where action can be taken relates to material consumption and resource efficiency. For example, water and energy are the two biggest resource inputs in the papermaking process after wood pulp. Consequently, increasing resource

efficiency in the sector can include the use of renewable energy and reusing water in multiple production cycles or, where possible, sourcing it from other industries. For instance, improved technology and innovation allow water to be reused 10 times or more throughout the pulp and paper mill process before it is discharged (AF&PA, 2020).

3.5.2 Cellulose-based fibres

The global consumption of textiles is increasing rapidly. Globally, consumers buy on average 60 per cent more clothing than 15 years ago. Around 56 Mt of clothing are bought worldwide each year, a figure which is expected to rise to 93 Mt by 2030.⁴² However, while global consumption has increased markedly, only 12 per cent of the materials used in clothing ends up being recycled, with less than 1 per cent being recycled into new garments (CBI, 2020). Most textile waste ends up being incinerated or sent to landfills, an unsustainable trend that is further exacerbated by the increasingly short lifespan of clothing, largely due to the fast-fashion phenomenon.⁴³ Having this background in mind, this section will focus on the use of cellulose-based fibres as an alternative for synthetic fibres and cotton.

Recent innovations in the use of cellulose-based fibres have expanded the potential use of materials from the forest-based industries, not only adding value to the forest sector but also addressing the demand for recyclable, responsible, and ecological fibres. Cellulose-based fibres can have some environmental benefits as compared to synthetic fibres, which are not biodegradable, and cotton, which has significant land and water footprints. In this regard, it should also be noted that the outcomes of environmental impact assessments concerning viscose, cotton and polyester can depend upon the emphasis put on different criteria in lifecycle analysis studies, which are often determined by the involved businesses which commission such assessments (Viitalia, 2016). For example, the production of cellulose-based fibres, in particular viscose, requires large quantities of chemicals, a number of which are a source of concern. These concerns centre on the significant health problems for factory workers when directly exposed and, if the chemicals or process pollutants leak into bodies of water, the high risk of acute aquatic toxicity lethal to aquatic organisms (EMF, 2017). The point in making these observations is to highlight that the environmental benefits from cellulose-based fibres come with costs and risks and their actual sustainability, may warrant further investigation.

⁴⁰ Industrial symbiosis is a process that brings companies together in innovative collaborations to explore ways in which, for example, the waste or by-products of one can become raw materials for another.

⁴¹ The burning of black liquor (e.g., in a special recovery boiler) generates around 13 000 to 15 000 Kilojoules (kJ) per kg of black liquor.

⁴² 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).

⁴³ "Fast fashion" refers to a business model based on replicating catwalk trends and high fashion designs and mass-producing them at low cost (<https://thevou.com/fashion/fast-fashion/>).

While the verdict may still be out on the sustainability of cellulose-based fibres, it can be noted that they made up only approximately 7 per cent of the global fibre market in 2019 (Kallio, 2021). However, their global production has been growing at an average annual rate of 6 per cent since 2000 while synthetic fibres – which account for 63 per cent of the market – grew 3 per cent per annum between 2000-2010 and by 1.3 per cent per annum between 2010-2018 (Fiber Year Consulting presentation, First International Conference on Cellulose Fibres, 2020).⁴⁴ Forecasts until 2025 show that average annual growth in the production of cellulose-based fibres will be 4.7 per cent while that of synthetic fibres will be 3.7 per cent. The annual growth rate in cotton use has been diminishing since 2000 and is expected to remain below 1 per cent until 2025 (Landsell-Hawkins presentation, First International Conference on Cellulose Fibres, 2020).⁴⁵

It is however still unclear how the COVID-19 pandemic will affect these forecasts. For example, in 2020 the market for cellulose-based fibres decreased, after 11 years of growth, mainly due to excess inventory, the low oil price and less demand during the pandemic. However, estimates suggest

that cellulose-based fibre consumption will return to growth, particularly in niche markets such as fibre crafting⁴⁶ as well as hygiene and medical products, where innovation in non-woven fibres has led to the development of cellulose-based fibres with functional characteristics that combine that of polyester (e.g., a cellular structure that inhibits bacteria and viruses ability to survive) and that of cotton (e.g., breathability and biodegradability) (UNECE/FAO notes from the Second International Conference on Cellulose Fibres, 2021).

The textile sector is highly globalized, complex, and dominated by millions of interconnected SMEs across the world, most of which are involved in primarily linear value chains. These value chains, ranging from raw material extraction to production, transport, consumption and waste management, are even more diverse than the furniture sector. Moreover, the geographic extension and opaqueness of the sector make “closing the loop” virtually impossible. However, some approaches may enhance the circularity of the value chains at particular stages. For the needs of this study, a simplified version of a cellulose-based fibre value chain has been included to depict key stages of the fibres and textiles production process (Figure 18).

FIGURE 18.

A simplified cellulose-based fibre value chain.



Source: UNECE/FAO, adapted from Grete Project (<https://www.greteproject.eu/project/>).

⁴⁴ Presentation by Engelhardt, A. “Status and Outlook on Textile Fiber Markets, 2020” during the First International Conference on Cellulose Fibres, 2020

⁴⁵ Presentation by Landsell-Hawkins, O. “The Outlook for Dissolving Pulp Supply and Demand”, during the First International Conference on Cellulose Fibres, 2020.

⁴⁶ Fibre crafts include knitting, crochets, sewing and weaving.

From a circular perspective, the production of cellulose-based fibres can support the woodworking sector by creating a demand for by-products (Jia *et al.*, 2020; Kallio, 2021). This means transforming side streams from pulp production to valuable materials and chemicals, thus contributing to the resource efficiency and circularity of the value chains. However, the global distribution of value chain actors limits the prospects for circularity as, for example, dissolving pulp, the key raw material for cellulose-based fibres is primarily undertaken in China, East Asia and India, where most global textile production also takes place. Garments are then shipped to Europe and North America where they are sold by retailers. In these markets, the majority of used clothes and fibres are normally incinerated with lesser quantities being donated to charities, sold in the second-hand market or recycled in a cascading way for other purposes at different geographical locations. Labour and shipment costs related to collection in Europe and North America make “closing the loop” with recovered materials unlikely, as using the virgin fibres produced in China, India and East Asia remains a more profitable option.

Given the low rates of recovery and recycling of textile fibres, as outlined at the onset of this section, it is clear that the textile industry could benefit from an improved system that combines reuse and a cascading use of worn fabrics wherever this is economically viable. For example, existing recovery technologies allow for 50 per cent of the raw cellulose-based fibres to be replaced with alternative feedstocks, which can be recovered from agriculture and municipal residues, recycled textiles and other sources (UNECE/FAO notes from the First International Conference on Cellulose Fibres, 2020). Having these material flows in mind, it is further clear that more focus is needed on establishing recycling schemes and improving recycling technologies (e.g., for separating textile types). This is a prerequisite to address the complex waste streams involved in textile production and produce the next generation of fibres. Having said this, the recovery of irregular material streams with inconsistent quality may ultimately be economically and environmentally unsustainable at a commercial scale. Also, the recyclability and biodegradability of cellulose-based fibres should not justify overproduction as the primary sustainability imperative for the sector remains to produce less and recycle more.

Most garments are produced from a mix of synthetic and natural fibres. As such, improving capacities to recycle these mixed fibres is essential and would, on the one hand, entail improving both sorting technologies and infrastructure, and on the other hand, entails improving the recyclability of textiles by ensuring they are made of long-lasting fibres

that can be recycled, are biodegradable and free from hazardous substances. An illustration of this concern relates to the use of elastane (elastic synthetic fibre) in fabrics. If fabric has more than 7 per cent elastane it is no longer possible to engage in chemical recycling (Helena Claesson, Södra presentation, the First International Conference on Cellulose Fibres, 2020).⁴⁷ The most pragmatic and feasible solution to this issue relates to product design, ensuring that the sector uses textiles with a longer life cycle that can be recycled. There is also the sector’s extensive use of hazardous chemicals to consider, especially in the treatment and dyeing of textiles that can cause significant freshwater pollution. While this alone is cause for concern, eliminating these treatments and dyes during the recycling process often involves the use of equally or more hazardous chemicals. This not only emphasizes the need for pollution prevention in textile production but also the importance of design strategies that can address durability, reuse, repair and recyclability issues.

Another important aspect for textile value chains relates to third-party audits and traceability certification. Improved traceability would increase the sector’s capacity to manage its supply chains more effectively, identify its environmental impacts and encourage sustainable production patterns. From an end-user perspective, increased traceability improves trust in the brand and helps consumers become more aware of the environmental impact of the products they buy. Production and consumption are particularly interlinked in the textile industry. Garment production is subject to rapid changes in demand, largely determined by the fast fashion trends which have been shaping production and consumption patterns for the last three decades. Consequently, fashion changes seasonally, and fosters the purchase of products that are only demanded for one season, leading to a consumption culture that sees clothing as disposable (ECE, 2020). This highlights that increased consumers awareness about material recycling and upcycling and the importance of their participation in reuse and recovery efforts is a cornerstone for reducing the amount of textile waste generated. Second-hand clothes are often sorted and resold or redistributed by charities, while lower grade fabrics are used by other industries (e.g., as insulation material, mattress stuffing, wiping cloths and hygiene products). While the cascading use of textiles via the second-hand clothes market is growing and is forecast to continue growing by 11 per cent per annum until 2026,⁴⁸ 73 per cent of all the material used for clothing still ends up in landfills or is incinerated (EMF, 2017).

Finally, the overall complexity of the textile sector underscores the importance of collaborative relationship

⁴⁷ Presentation by Helena Claesson from Södra during the First International Conference on Cellulose Fibres 2020.

⁴⁸ www.futuremarketinsights.com.

building and interactions across supply chains. Improved cooperation across supply chains would contribute towards expanding the resource base for the production of cellulose-based fibres, which is an important point in the context of the ever-increasing competition over raw materials.

In summary, the choice of materials and product design are the key factors influencing the environmental impact of textiles and their end-of-life options (especially their 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 the reuse of materials, including upcycling (Kallio, 2021; Singh *et al.*, 2019). Furthermore, the creation of sustainable material cycles for textiles would need to be supported by policy frameworks that include sustainable safety requirements as well as mandating waste reduction and treatment along with sustainable production and consumption patterns via labelling, certification and harmonized product standards (EEA, 2019; Jia *et al.*, 2020). It is equally important that the production of cellulose-based fibres does not result in an unsustainable increase in the use of virgin raw materials and a negative impact on forest ecosystems. This highlights the need for shifting the production of cellulose-based fibres to alternative (recycled) feedstocks. Increased producer responsibility,⁴⁹ which is not widespread in the sector but could in this context be useful in increasing the recovery rates of post-consumer materials. Finally, independent audits are needed to increase the credibility of sustainability and circularity in connection with cellulose-based fibre value chains, to standardize the principles, practices and key characteristics relating to voluntary environmental labelling and industry self-declaration claims.

3.5.3 Cellulose-based plastics

Plastic is one of the most ubiquitous materials utilized in modern life, primarily due to the specific properties of petrochemical plastics,⁵⁰ such as low production costs, being light weight, variable transparency, durability (use phase) and resilience when exposed to various man-made and natural elements. The single largest use of plastic is packaging (around 30 per cent of global plastic production

per annum) as it is very functional as a packaging material. This is followed by its use in construction and transportation, which account for approximately 17 per cent and 14 per cent respectively (UNEP, 2018a). Global production of various plastics has increased, on average, approximately 9 per cent per annum since 1950 (UNEP, 2018a), increasing nearly ninefold since the 1970s. Plastic production was approximately 360 Mt in 2018 with less than 10 per cent of all plastic waste being recycled because, amongst other things, of the high costs associated with recycling and it being difficult to degrade (Reichert *et al.*, 2020; Su *et al.*, 2020). This has led to projections that plastic waste will exceed 340 Mt annually by 2045, adding to the pressure on plastics producers to improve the recyclability of plastics and increase the recycled inputs within their value chains. This highlights the importance of developing sustainable and circular alternatives to fossil-based plastics that are less environmentally harmful and can be produced using renewable materials.

Bio-based plastics (or simply bioplastics) provide such an alternative, particularly given that bioplastics can be non-toxic, renewable and biodegradable. However, the variety in bioplastics means they can be divided into three categories, namely, plastics that are (1) bio-based and non-biodegradable, (2) bio-based and biodegradable, and finally, (3) fossil-based and biodegradable (European Bioplastics, 2018). This section of the study is primarily concerned with cellulose-based plastics produced from wood pulp, although cellulose-based plastics can also be produced from a variety of other materials, such as food waste (Figure 19).

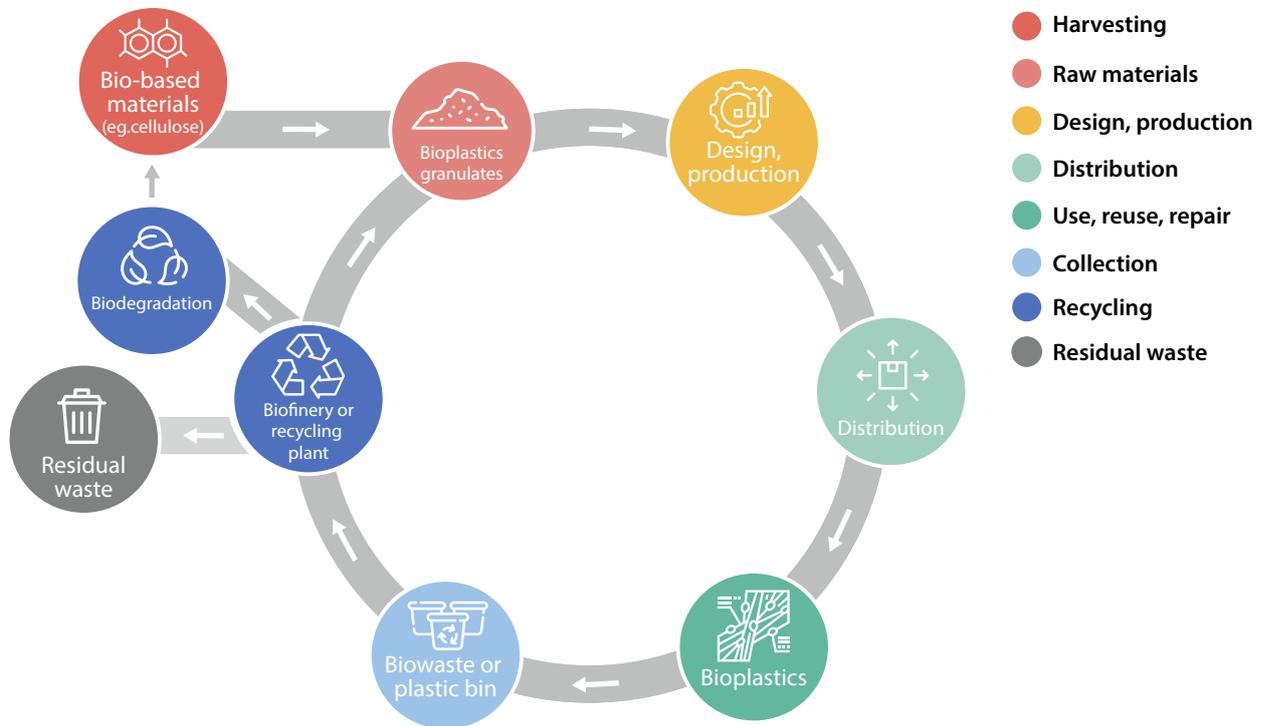
It can be noted that while the global demand for bioplastics has increased, it still only represents a small niche market. For example, in Europe, where bioplastics are actively promoted, only 1 per cent of the plastic produced annually is bio-based (Bajpai, 2019) of which cellulose-based plastics are only one type that forms a highly innovative and heterogeneous segment of the bioplastics sector. Moreover, information about cellulose-based plastics is rarely distinguished from bioplastics in general, therefore the analysis of the value chains in this section will be based on the bioplastics sector in general.

⁴⁹ 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.

⁵⁰ 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 19.

The life cycle of bio-based material for packaging and textiles.



Source: UNECE/FAO, adapted from Reichert *et al.* (2020).

Even though biodegradable and compostable bioplastics have been on the market for more than 25 years, there is still confusion about what they are, which raw materials are used for their production, to what extent they are bio-based and how to recycle them. Cellulose-based plastics are a particular type of bioplastic that is manufactured using cellulose or derivatives of cellulose. They are manufactured using softwood as the dominant raw material, however, can also be obtained from agricultural residues (corn stover, sugarcane bagasse, spent sugar beet pulp and sweet sorghum, etc.). As noted above, not all of bioplastics are biodegradable in the natural environment as their susceptibility to decomposition depends on the chemical process used during production. For example, biodegradable bioplastics will, in most cases, only break down in industrial composting facilities, with particular temperature and atmospheric conditions. This means that the use of bioplastics, while better than fossil-based plastics, still requires a coordinated waste management and a well-developed recycling infrastructure.

Bioplastic types are very diversified and the infrastructure for their collection is either non-existent or very fragmented. For example, a variety of small-scale, local initiatives to improve bioplastic waste collection have been introduced,

however, they are rarely coordinated at the national or regional level and the economic viability of such pilot project has not yet been proven. Similarly, new sorting and reprocessing technologies have been developed that can break down bioplastic into its chemical building blocks before recombining them into new products, although these have not yet been implemented on a commercial scale.⁵¹ Regarding recovery infrastructure, industrial composting infrastructure is still underdeveloped and requires further investment in new technologies to improve the separation and sorting of different types of plastics.

Increased consumer awareness is also a key concern for the bioplastics sector. For example, although certification and labelling schemes for bioplastics have emerged, they tend to focus on informing consumers about whether the product is biodegradable or compostable without specifying chemical composition and means of disposal. This creates confusion about the possible reuses and recycling options of such bio-based materials which, in turn, makes it more difficult to increase the post-consumer value of bioplastics. This challenge highlights the need for further standardization and quality certification to ensure product quality, use, recyclability and biodegradation.

⁵¹ <https://resource.co/article/scientists-discover-new-bioplastics-recycling-method>

A stack of plywood sheets is shown, with a white text box overlaid on the top left. The text box contains the following text:

Section 4
**CHALLENGES AND
OPPORTUNITIES
OF CIRCULAR
APPROACHES**

4.1 Understanding implications of circular approaches on forests and forest-based industries

The basic premise for moving towards circularity in the forest sector is linked to natural resource constraints and the ecological impact of human activities on forests and ecosystems. However, a circular economy model for the forest sector entails complex concepts that encompass many materials, products and industries across the forest-based value chains, all of which have varying potential for circularity. As indicated throughout the preceding sections, the transition to a circular economy is a multi-

level organizational and governance challenge that extends from the international to the national level, from industries to individual production facilities, all the way down to individual consumers.

Moreover, this transition needs to account for both technical and biological resource cycles as well as the interplay between them, including moving, where possible, to a circular bioeconomy. The interactions, synergies and potential trade-offs between a circular economy and its related concepts, such as sustainability and resource efficiency, are best understood when analysed using a systemic approach to address the relevant trade-offs (Box 5).

Box 5. Trade-offs between a circular economy and sustainability.

The circular model can contribute to environmental sustainability, however, trade-offs may occur between some closed-loop production systems and the environment. Some of these trade-offs and challenges are outlined below:

- **Impact assessments** usually estimate the environmental success of circular practices by using GHG emissions as the key indicator. This is, however, insufficient as many aspects related to environmental sustainability cannot be captured by a single indicator. Examples include circular practices impacts on ecosystem resilience and biodiversity as well as their effects on air, water and soil quality (Sehnm *et al.*, 2019). Another example is the fact that the amount and quality of water used in circular processes are rarely considered in modelling and case studies (Sehnm *et al.*, 2019). Consequently, there may be trade-offs between water use and material efficiency that are not revealed. This would suggest that more integrative impact-based indicators are needed to complement those focusing on material consumption and GHG emissions. Including these types of indicators in assessments may also reveal synergies and trade-offs between different environmental objectives (Haupt and Hellweg, 2019).
- Another phenomenon relates to **rebound effects**, where technological developments lead to higher, instead of lower, resource consumption. For example, Figge and Thorpe (2019) argued that introducing incentives for recycling may, in fact, lead to less reuse due to behavioural mechanisms while some studies have shown that increased energy efficiency in machinery can result in an overall increase in emissions. Shifts to greener consumption patterns can also result in the need for new infrastructure and increased transportation, both of which can have detrimental effects on the environment.
- From a resource perspective, the **optimal recycling** rate is material-dependent and often well below 100 per cent. For example, when identifying the optimal recycling rate, the resources lost in extraction and disposal must be weighed against those needed for recovery and recycling processes. Material recycling may consume a lot of energy, water, and/or chemicals, making energy production or disposal the preferred options (Maletz *et al.*, 2018). This is of particular relevance for multi-stage cascading use, where material quality decreases in the later stages while the inputs required for their further recycling increase. Another challenge is posed by the risk of transferring hazardous substances into secondary materials and products in the recycling process such as the cascading use of wood. For example, an accumulation or concentration of toxic substances may pose a risk to the natural environment and human health when the recycled materials are exposed to the environment at the use or disposal stage.

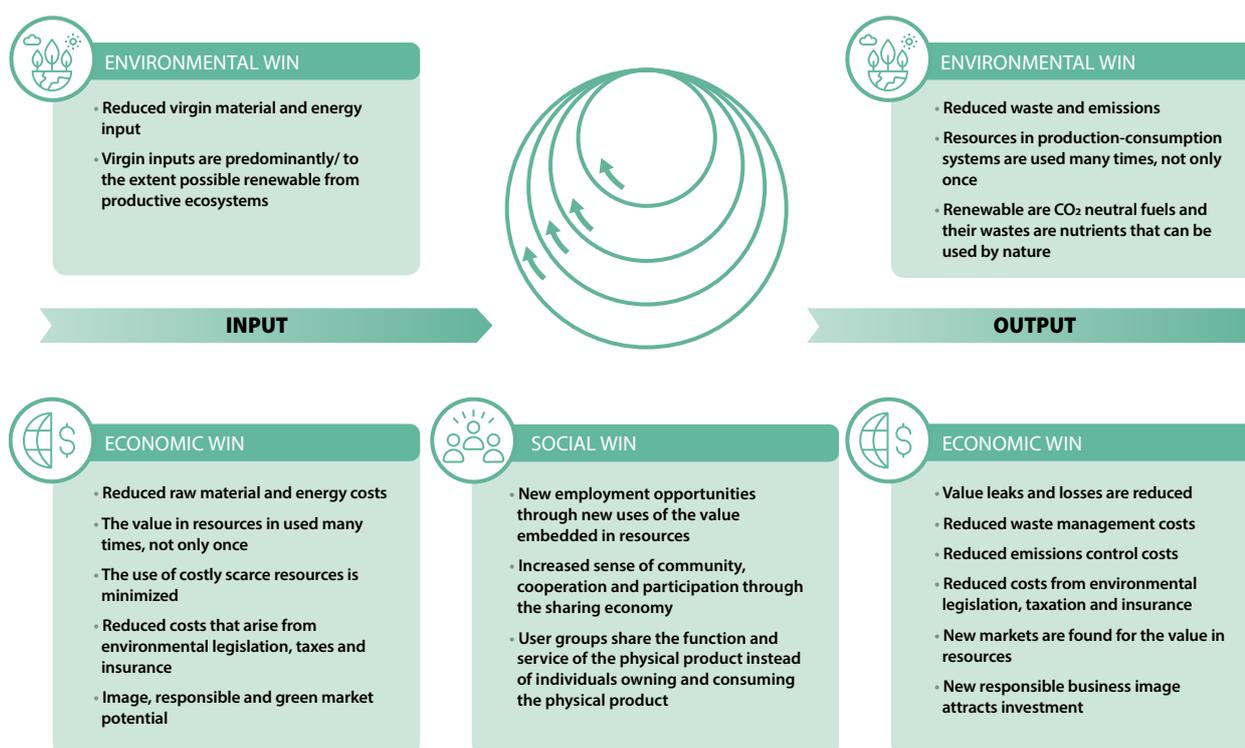
These few examples demonstrate that the provision, use and recycling of raw materials in a circular economy are not always compatible with sustainability principles and that steps have to be taken to ensure that biological cycles of a circular economy do not detrimentally impact ecosystem services, such as food production, biodiversity, climate change mitigation or hazard control (Hetemäki *et al.*, 2017).

While it is clear that circular business models can deliver more resilient value chains, reduce resource use and increase profits, it is also important to note that a transition to a circular economy should contribute to all three dimensions of sustainable development (economic,

environmental and social) and that the necessary steps are taken to respect natural ecosystems' regeneration cycles when using bio-based products in economic cycles (Figure 20).

FIGURE 20.

A circular economy for sustainable development.



Source: UNECE/FAO, adapted from Korhonen *et al.* (2018a).

Circularity is also a way of implementing the SDGs. Box 1 at the beginning of this study illustrates, that there is a strong relationship between the circular model and 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), i.e. all the SDGs that deal with natural resource use.

While circularity can contribute to sustainable production and consumption, sustainable development does not always contribute to circularity (and vice versa). In this study, circular approaches principally focus on resource cycles, while the principles of sustainability take a more holistic view of natural resource use, accounting for socio-economic and environmental impacts which are beyond the scope of this study. This is why circularity and sustainability commonly go hand-in-hand but can diverge in places and under certain circumstances. For example, under some conditions, the use of residues to produce bioenergy on-site in a sawmill may be considered sustainable even

though it may not fulfil the criteria of circularity. It relates to the environmental impacts associated with circularity. Residues could be used to produce other products (e.g., wood-based panels), however this could imply increased emissions due to transport of the residues instead of using them on site to produce energy. There are consequently reasonable concerns about the environmental impacts of closing certain loops in forest-based industries. The sector will need to account for sustainability criteria as well as the natural limitations on the use of wood in its attempts to close some of the loops.

4.2 Balancing the provision of wood with other forest ecosystem services

The preceding sections reviewed forest-based value chains involved in each production cycle – from product design to end-of-life. They did not include natural forest ecosystems regeneration cycles and sourcing wood from forests as raw material. While the focus in this study has been on

forest-based industries, it needs to be mentioned that sustainable forest management and forestry operations are undoubtedly the first stage of any process entailing the transformation of wood. Having said that, it needs to be clarified that the generic value chains developed by 12 representative organizations involved with forest-based industries from various sectors (Rivera León *et al.*, 2016) were adopted for analysis in this study with the aim to set boundaries to the scope (Section 3.1).

From an industry perspective, the key role of forestry in a circular economy is that it provides the timber and raw materials that can be used to create wood-based products. It was, however, recognized by the authors of this study that forests have a key role to play in a circular economy, not only do they provide the strategic raw material upon which many economic sectors rely but because they are of overwhelming importance for a bioeconomy. It is for this reason important to consider the effect that a circular economy in forest-based industries has on forest health, the balance between the use of forest resources and other ecosystem services, including climate change, adaptation and mitigation. This is particularly true given that forests, if managed in a sustainable manner, can provide renewable resources and ecosystem services *ad infinitum*. Furthermore, forests play a key role in the biosphere carbon cycle, being both a source of energy and carbon storage, making forests an important asset in combating climate change, especially if bioenergy is to be included as a part of a circular model.

Forestry, as the underlying foundation of forest-based industries, relies on wood as a natural resource and on natural forest regeneration cycles. Using these resources beyond sustainable limits undermines the future of all the interconnected sectors further downstream in the value chain, including the benefits they generate for society (e.g., substantial quantities of carbon are stored in wood products for long periods). Forest management patterns also have flow-on effects for the provision of non-wood forest products (NWFPs), as well as for various forest ecosystem services other than timber. As hinted at above, even if forest biomass resources are renewable, they are not unlimited and therefore sustainable forest management is essential to ensure long-term viability and that regenerative and circular feedstock systems (circular forestry) are in place. This means that when forests are managed sustainably, their capacity to regenerate is not overwhelmed by the demands placed upon them thus, in the context of a circular economy. Consequently SFM is key to the long-term flow of forest raw materials.

Aside from highlighting the key role of forests for many sectors and at many levels, from a supply-side perspective, forest-based industries have an important role to play in making products that can be easily reused and recycled

as well as taking steps to maximize the retention of value throughout these products life cycle. This is crucial to reduce the demand for virgin feedstock and to ensure overall forest health as well as maintaining the provision of all ecosystem services. In this context, it is also relevant for forest-based industries to look beyond measures that focus on increased material efficiencies and to consider what impacts their activities have on forest ecosystems, be it further up- or downstream along the value chain. This is a powerful way of not only reducing resource use, but also contributing to reducing overall pressure on natural ecosystems. Producers should also be encouraged to apply chain-of-custody certification related to materials and products from sustainably managed forests in later stages of the value chain.

Another important reason for considering the role of forestry in a circular economy relates to the conceptual ambiguities associated with circularity (Section 2.3). More specifically, it is an open question whether energy production and the biosphere carbon cycle should be considered as a part of a circular model (which often depends upon the time scales applied) or whether the circularity concept should only be applied to materials that can be recycled over time in closed-loop systems. While forests clearly have an important role in preventing GHG emissions (carbon sequestration) and in moving away from fossil-based materials (energy substitution), they do not produce a material that can be circular in the short term. The biosphere carbon cycle is a process that takes decades but even then, appropriate forest management is necessary to ensure that forests continue to act as carbon sinks. The latter point regarding forest management is so crucial that it is worth emphasizing again, as any circular model that promotes the cascading use of wood and bioenergy production has to consider sustainable forest management as a part of the picture.

A circular economy offers a conceptual framework for using forests (or renewable natural capital) to transform and manage industrial systems, allowing industries to move away from linear processes and fossil-based materials and contribute to climate change mitigation. It is, however, less clear whether a circular model can adequately balance the provision of wood with other forest ecosystem services or whether the use of circularity can be used as a form of greenwashing. It is further unclear whether circular economy principles can be applied effectively given wood's specific characteristics, as a biodegradable and renewable raw material and whether the biosphere carbon cycle and bioenergy production should be considered as a part of a circular economy. These are particularly valid concerns given that originally, circular models were developed primarily as frameworks for industries to reduce non-renewable materials use (or improve economic efficiencies).

While these concerns cannot be fully answered by this study, it would however be important for the forest sector as a whole to explicitly address these issues in further analytical work, taking into consideration the specific context of the sector.

4.3 Recognizing limitations to increased circularity

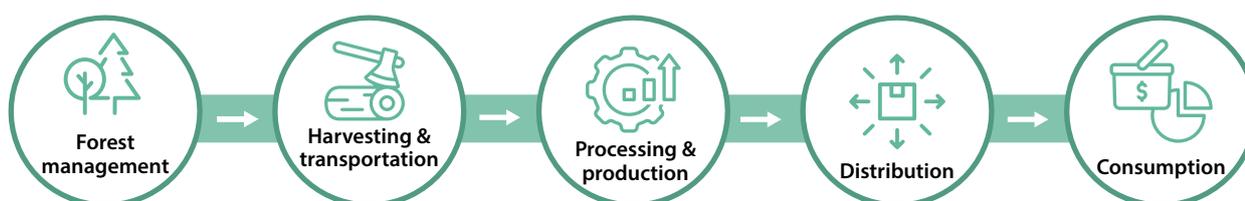
One core argument for implementing a circular model for the forest sector is that forest ecosystems are a source of renewable and biodegradable products that can substitute finite and polluting materials. If sustainably managed, forests can also naturally restore the quality of their own ecosystems. Furthermore, wood is an incredibly versatile material as different parts and types of trees are used to manufacture a vast array of products and materials as diverse as base lumber through to highly advanced nanocellulose fibres. 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) have developed an illustrative overview of 99 benefits of trees that feed into the value chains of 14 different industries,⁵² ranging from heat and energy production, perfume and textile manufacturing through to furniture and construction materials. There are however some limitations to increasing the use of wood

as substitute to non-renewable materials. They relate to limitations in sustainable sourcing of raw material and the unsustainable (linear) consumption of forest-based products, limiting the options of replacing virgin materials by using recovered materials.

While the continued transition towards a circular and bio-based economy is generating ever-increasing demand for forest-based products, the regenerative capacities of forest ecosystems have been decreasing for reasons that include climate change, landscape degradation, soil erosion, forest fires and pests to name but a few. The sustainability of forest-based value chains, whether they are circular or not, will therefore depend upon the natural regeneration cycles of forests and the rate at which they can be renewed. Circularity and material efficiency can only go as far as the natural systems regenerative capacity allows, meaning that SFM is key in safeguarding ecosystem services and ensuring the long-term provision of wood sustainably. Thus, it should be an integral part of CSCM (Section 2.5). As demonstrated in the previous sections, good practice in resource management can contribute to the forest sector's shift towards a more systemic embrace of the principles of circularity. Also, the coordination between the biological and the technical cycles along the respective value chains need to be further strengthened to allow for SFM in the long term.

FIGURE 21.

A traditional forest-based value chain.



Source: UNECE/FAO.

Various forest-based industries have been detailed in this study (Section 3), with the examples cited attesting to the fact that the adoption of circular approaches entails reviewing all stages of value chains involved in forest-based industries (Tantau *et al.*, 2018). Since a tree can be used in several different ways, the number of potential value chain variations and combinations create a very complex industrial ecosystem where a variety of circular approaches can be applied. However, although cascading use is largely applied, the value chains that make up most of the forest-based industries remain traditionally linear (Figure 20).

In a traditional forest-based value chain, as a part of primary processing, wood is transported to a pulp and paper mill or a sawmill once a tree has been harvested. In the mill, the wood is transformed into different products that can either be used directly, such as in construction, or transported for further (secondary or tertiary) processing where it can be turned into more complex products, such as furniture. In these linear value chains, the end-of-life stage of wood-based products is rarely considered by primary producers as it is generally seen as being too far downstream and the waste streams created as having very limited monetary value. The application of circular approaches would therefore require producers to not only

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

develop and employ end-of-life resource management options but also to enter into industrial symbioses with partners using side streams and by-products to reduce waste along the entire value chain. While there are some good practices in place already, in particular, at the early stages of wood processing, untapped potential remains for forest-based industries to slow (extend a product's lifetime), close (increase recycling) and narrow (use fewer resources per product) their production loops.

With growing demand for forest-based products and ever-increasing pressure on ecosystems, the recovery and use of waste streams represent areas of opportunity that are merit further examination. While resource efficiency is relatively well established in forest-based industries, primarily for economic reasons, the recovery of materials from end-of-life and post-consumer waste streams remains limited for two key reasons.

The first reason in this regard concerns the lack of an international classification post-consumer wood. Some countries have developed their own classifications and apply them in trade with neighbouring countries, however, having an internationally recognized classification would allow for the comprehensive identification, monitoring and trade of different post-consumer wood waste streams. Furthermore, such an international classification could open new markets to absorb these residues – which would be a positive development in the context of a circular economy.

The second reason contributing to forest-based industries recovering limited material from end-of-life and post-consumer waste streams is the scarcity of collection and sorting facilities for post-consumer wood. Paper recycling is an exception in this regard as its recycling rates and economic viability are satisfactory in most areas. However, the approach applied by the paper and pulp industry cannot be replicated for the recycling of other wood-based residues. The primary reason for this is that the sources of wood waste streams are varied, contrary to paper, which is largely recovered at the municipal level with easy-to-manage logistics. A further complication for recovering used wood arises in that sorting technologies are not well-developed for most wood-based materials, contrary to the sensor-based technologies which work well for paper. This makes recycling dependent on manual sorting, a labour-intensive process that incurs high costs, results in inconsistent end-product quality and can incur health risks for the personnel involved (e.g., exposure to microorganisms, chemicals and dust). Post-consumer wood's irregular supply streams as well as its varied quality compound its characteristics as a low-value product which, when combined with concerns regarding the cost of transport and the environmental sustainability

of reintroducing it to various value chains, do not make it a competitive product in many commercial operations.

Looking beyond the limitations associated with the recovery of exiting post-consumer wood streams, innovative cellulose-based materials, such as cellulose-based fibres and bioplastics, also face challenges associated with their recovery. As mentioned in previous sections, these products are extremely diversified, their markets are highly fragmented (Section 3.4.2 and 3.4.3) and, as is the case with post-consumer wood, no standardized system for the recovery of their waste streams exist. These sectors are still new and, as such, are neither sufficiently structured in terms of quality standards nor are they organized in terms of industry representation that can ensure a consistent approach to industrial cooperation. Furthermore, the information that is available on the sustainability of cellulose-based fibres and bioplastics is often confusing. Terms such as 'recyclable', 'biodegradable', 'compostable' are often used interchangeably, however, they refer to markedly different processes. As previously noted, some of these products are only biodegradable or compostable in specific industrial conditions. This requires the development of well-connected infrastructure for the collection and sorting of cellulose-based fibre and bioplastic waste.

All the challenges highlighted above illustrate that not all forest-based value chains can employ circular concepts in practice. Furthermore, for some forest-based value chains or portions thereof, embracing circularity may cause negative externalities such as increased emissions due transport. Examples from previous sections also showcase that in existing business models, responsibility for production and waste creation are not interrelated, while the elimination of externalities depends on coordinated action among relevant actors at all stages of value chains. This can include eco-design, extending the producer's responsibility, investment in collection infrastructure, the availability of technologies supporting sorting processes, the geographical proximity between production facilities and waste stream users, etc.

4.4 Supporting a transition towards circularity

This study set out to examine what circularity means for the forest sector, what the potential for implementing circular economy principles in forest-based industries is and what is needed to make circularity sustainable and economically viable in the sector in the long term. This was, in part, driven by definitional ambiguities and conceptual uncertainties associated with circularity as a concept, such as the relationship between circularity and sustainability (Haupt and Hellweg, 2019; Schroeder

et al., 2019). One of the study's key goals was to consider what the advance of a circular economy means for wood, a raw material that deteriorates over time and cannot be reformed like glass and metals. Even though the analysis has been limited to a consideration of the material flows, the value chain analysis in Section 3 demonstrates that a circular economy approach in the forest sector requires a transformational process to be undertaken involving entire value chains. A more detailed analysis of the various value chains considered there has shown that circularity requires new business models, new connections between sectors and companies as well as the application of new technologies and management tools. All of this will need to be supported by increased awareness of policy makers, producers and consumers about existing approaches that can make wood-based products more circular, as a circular economy entails more than just recycling waste, it is a model that redefines, in a systemic way, the processes of product design, manufacturing and consumption (Box 6).

What this study's analysis has also demonstrated is that there is no panacea or clearly defined set of solutions to address most of the open issues surrounding circularity. Aside from the many different interpretations of a circular economy (Section 2), each value and supply chain has a unique set of limitations, challenges and opportunities. The stark differences in resource and energy use, as well

as waste management practices across woodworking, furniture and paper and pulp industries, demonstrate that. Furthermore, there is a degree of value chains' dependency that needs to be accounted for when considering possible solutions to "close the loop" for different industries. Having this challenge in mind, the following section will attempt to summarize some of the general points of action that are applicable to the various value chains, regardless of how the given industry is structured.

It is also worthwhile noting that from the outset this study foresaw the application of three value retention loops that were characterized in UNEP's circular economy model (Figure 6). These loops cover the entire life cycle of a product, from extraction to production and then through to the end-of-life (Potting *et al.*, 2017; UNEP, 2018b). However, one lesson learned from the analysis conducted in this study is that it is not easy to categorize all action points according to these loops, particularly as many are cross-cutting. For example, raising awareness is an action that is applicable across all value chains, irrespective of whether it takes place in the user-to-user, user-to-business or business-to-business loop. It is for this reason that a number of generic action points have been listed in Box 6 below. These points should not be seen as an exhaustive list but as demonstrative that many important cross-cutting issues need to be addressed systemically.

Box 6. Cross-cutting action points supporting a transition towards circularity.

- **Integration across value chains and supply chains**

Circularity needs to be attained through integration and cooperation across value and supply chains actors. This can improve performance and facilitate sustainability. This approach will help identify potential loops and/or side streams in both up and downstream processes (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 among business ecosystem actors is also needed to share skills, expertise, and knowledge related to different circularity aspects across businesses.

- **Raising awareness and education**

General knowledge and awareness of circularity need to be increased both amongst producers and end-users. The dissemination of knowledge on different circularity aspects needs to be shared across value chains, both up and downstream (e.g., on the practical realization of wood cascading). This can, for example, be achieved through the increased training of business personnel at or through public information campaigns on topics such as sustainable wood labels or bioplastic recycling options.

- **Circular policy frameworks**

Regulatory and legislative frameworks should address barriers for end-users and producers in implementing the reuse and recycling of wood-based products (e.g., regulating the market of reclaimed sawn wood). 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 the principles of a circular economy).

- **Innovation and technological development**

Improving existing and developing new technologies to better implement circularity is crucial. This can, for instance, contribute to improved sorting of used wood and the removal of toxic substances from value chains, as well as create opportunities to address existing technology and processes limitations. Innovation must also extend into the design of new products that can decouple production processes from fossil-based raw materials use and enable businesses to “close the loop”. For example, innovative materials (e.g., bioplastics) allow for biodegradation while innovative chemical recycling processes, for the recovery of textile fibres from mixed natural-synthetic feedstock.

- **Certification, quality standards and labelling**

Certification, quality standards and labelling provide tools that allow end-users and businesses to make informed choices about sustainability. For example, Chain-of-Custody certification⁵³ helps to ensure that the wood used in a given process or product comes from sustainably managed forests. Similar labels could be introduced to ensure the traceability of new cellulose-based materials, such as bioplastics, garments and footwear.⁵⁴ Other labels could inform the end-user about the options for disposal, thus facilitating increased collection and sorting for reprocessing (or composting) of waste.

More specific action points can be individually applicable to different value chains cited in Section 3 of this study. In this regard, the respective loops in UNEP’s circular economy model will be used loosely here to outline the potential action points within the various loops (user-to-user, user-to-business and business-to-business loops) and several of the action points may apply to more than one loop.

Furthermore, as the different loops employed are generic in nature, the suggestions provided combine examples from various sectors. The action points listed below are not exhaustive and they are meant to highlight some of possible actions which can be undertaken to support the transition to a circular model.

⁵³ <https://fsc.org/en/chain-of-custody-certification> and www.pefc.org/for-business/supply-chain-companies.

⁵⁴ <https://unece.org/trade/traceability-sustainable-garment-and-footwear>.

Box 7. User-to-user action points supporting a transition towards circularity.

The **user-to-user loop** covers the stage of the value chain when a product provides its functions to the end-user. Different circularity approaches can be undertaken during the production process to allow for the provision of product functionality with the highest possible material input efficiency and that result in products that can stay in the loop for as long as possible.

Guiding principles: Reuse – use a product in different applications or, where possible, turn the product into a service so that it can be used by different users; Reduce - use the least materials possible in its initial production (Figure 6).

The following action points can be identified:

- **Re-designing systems and products**

A primary goal for businesses in a circular economy is to design out negative production externalities (e.g., waste and air pollution), improve disposability and ensure the sustainability of a given product across its life cycle. This will require the re-design of products and production systems that are based on a linear economic model. In forest-based industries, this transition means that wood and its related side streams will need to be kept in the loop for as long as possible by employing a process of cascading use.

- **Improving system effectiveness**

Businesses need to take a systemic approach to address barriers and challenges to circularity along their respective value and supply chains. For example, production systems can be optimized to design out waste (e.g., improvements to woodworking machines so that they generate less wood dust). Another example in this area would be service coordination where, for example, businesses exchange information online about their transport needs to reduce transportation costs and emissions).

- **Reducing the environmental impact of production**

For resource-dependent businesses, less is more, as circularity implies that raw materials are used economically and sustainably. While forest-based industries have become more material-efficient, the overall environmental impact of their production processes remains a challenge. For example, aside from wood pulp, water and energy are the two important resource inputs into the papermaking process. Given that these are indispensable inputs, increasing resource efficiency may include continued efforts to increase the use of renewable energy and the reuse of water in multiple production cycles.

- **Reducing competition over raw materials**

Increased demand for wood-based products has resulted in amplified competition over the limited supply of raw materials, as typified by the tension between the bioenergy and wood panel industries. This has resulted in higher feedstock prices, making some forest-based businesses less profitable. The competitive pressure between different sectors, such as these two, may be at least partially relieved by exploring synergies across different supply chains to improve the supply of secondary materials and reduce the use of virgin raw materials and, in turn, feedstock prices.

- **Encouraging a circular lifestyle**

Consumers can contribute significantly towards a circular economy. Therefore, understanding the factors influencing consumer choices (e.g., socio-economic reasons and values rationale) which determine whether consumers engage in circular practices or not is fundamental in making such practices viable. Building on that understanding, the regulatory environment and raising consumer awareness is key in promoting product-as-service models (e.g., renting rather than buying new furniture⁵⁵); buying second-hand products (e.g., clothing); or sorting and recycling cellulose-based products (e.g., textiles, books, toys), thus allowing these products and materials to circulate for longer in their respective loops.

55 www.cleantech.com/the-circular-economy-meets-furniture-the-future-of-rentals-and-sharing.

Box 8. User-to-business action points supporting a transition towards circularity.

The user-to-business loop refers to the stage of the value chain where end-users can interact with producers to update the functionality of the products, for example, to extend their lifespan.

Guiding principles: Repair – to restore the functionality of a product; Refurbish – to upgrade the functionality of a product in line with the latest technologies and designs; Remanufacture – to dismantle the existing product to use its components in new products (Figure 6).

In this loop the following supporting actions can be identified:

- **Extending producer responsibility**

Extended producer responsibility⁵⁶ is a policy approach under which producers are assigned responsibility to either financially and/or physically make provision for the treatment or disposal of post-consumer products. This policy tool has the potential to provide economic incentives for businesses to design better products (from a circular perspective) and ensure that non-circular practices are penalized. In some forest-based industries, extended producer responsibility schemes could help drive product design towards reparability, refurbishment and reuse of wood-based products.

- **Designing for circularity**

Circularity requires innovative design based on a systemic perspective and new working methods. Design strategies, such as eco-design and smart design, are a part of this bigger picture as they provide products and components with functionalities that allow them to extend their durability and lifespan. Such strategies allow for greater disassembly, reparability and modularity while helping to facilitate remanufacturing and reuse.

- **Making repair and refurbishment economically viable**

Incentives are needed to support sustainable consumption patterns and to make repair and refurbishment not only viable but preferable to buying new. For example, rising interest in interior design has led to the development of the low-cost furniture market which has, in turn, resulted in a reduced consumer interest in repairing and refurbishing existing products. Also, transport and labour costs often make the repairing and refurbishing existing pieces unattractive vis-à-vis the price of a new, low-cost replacement. Increasing incentives to produce good quality, durable furniture or repair and refurbish existing pieces could entail the promotion of eco-design or increasing the warranty of products, thus increasing producer responsibility for repair and refurbishment.

Box 9. Business-to-business action points supporting a transition towards circularity.

The **business-to-business loop** focuses on the stages of the value chain when specialized businesses treat products at their end-of-life to turn them into secondary materials for other businesses.

Guiding principles: Repurpose – to dismantle products into components and materials to incorporate them into new products with different functions; Recycle – to transform material residues to secondary materials (Figure 6).

In this loop the following supporting actions can be identified:

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

The contribution of recycled materials in the overall supply of material stands out as part of the solution in addressing issues associated with increased competition over resources and efforts to minimize virgin material consumption. While some forest-based industries have been effective in addressing their post-consumption residues, especially the pulp and paper sector, other industries still have considerable ground to cover to become more circular. For example, given the low recycling rates of cellulose-based fibres and bioplastics, their recovery on a commercial basis could be supported.

⁵⁶ www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm.

- **Expanding the available product mix**

The steady supply of forest-based biomass is subject to the various pressures placed on ecosystems, competition for other uses and seasonal inconsistencies (e.g., drought or limited logging in winter), all of which affect the supply stream. There is, consequently, much to gain from engaging with service providers (e.g., smaller companies that trade in industry residues) that can coordinate the sustainable and cost-effective extraction of secondary materials.

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

Underdeveloped infrastructure for the collection, sorting and recycling of wood-based products (whether that involves furniture or bioplastics) is a key barrier to extracting value from waste streams. This could be addressed to some degree by increasing the options for collection at the municipal level and recovery by retailers (e.g., take-back and reverse-logistics strategies), through incentives for the development of chemical recycling (e.g., cellulose-based fibres and bioplastics) on a commercial basis or through the improved coordination of waste streams management across value chains (as mentioned above).

- **Creating markets for waste streams**

Building the markets for wood-based secondary materials (e.g., residues from the construction sector or recycled cellulose-fibres) 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 functional. That requires addressing irregular supply issues which undermine demand growth and result in difficult to predict price fluctuations.

- **Building trust in secondary materials and products**

Moving away from the linear model will require the development of markets for secondary materials coming from recycling and repurposing. Regulations on health, environmental safety and so forth, related to the use of wood-based residues, will need to support business activities involved in recycling and the development of markets for recycled products. For example, there is a degree of apprehension about using recycled cartons for food-contact materials (because of the perceived risk of contamination). Reliable quality labels and controls will need to be adopted to address these concerns.

The action points listed above demonstrate that circular strategies need to ensure that upstream decisions within the various value chains are coordinated with downstream activities as well as with the end-users. The forest sector needs to become more interconnected with producers, distributors, consumers and recyclers while simultaneously linking incentives across supply chains. Moreover, each action point has the potential to generate numerous benefits for the sector, such as reducing material cost and

price volatility, improving supply security and job creation as well as reducing environmental pressures and health risks (e.g., from the decreased use of hazardous and toxic chemicals). Ideally, circular products based on renewable resources will be easy to reuse and recycle, create added value without having adverse effects on the environment and human health while maintaining the economic viability of all supply chain actors.



Section 5 **CONCLUSIONS AND RECOMMENDATIONS**



5.1 Conclusions and Recommendations

In the face of pressing environmental challenges coupled with the extreme levels of demand for natural resources, the concept of a circular economy has been recognized as a promising paradigm to deliver sustainability. It is gaining appeal among policymakers and private sector actors alike with numerous policy instruments, business strategies and research seeing circularity practices as a way to reduce humankind's use of natural resources and slow the environmental pollution and generation of waste.

These efforts are gaining ground because the linear economy model, based on a "take-make-use-dispose" approach to resources management, cannot be sustained and is leading to increasingly dire environmental and economic consequences. A progressive transition to a sustainable economic system, based on the coherent management of natural resources and sustainable production and consumption patterns is needed to increase both the longevity and resilience of the global economy to meet the variety of economic, ecological and societal challenges. The transition to a circular, bio-based economy will also require breaking the silos of sectors, analysing the way they interact through value chains and linking this with the objectives of sustainability and a low-carbon economy.

Wood as a key renewable resource can be used for creating biodegradable and recyclable materials. Production residues can be reused in cascading systems that result in minimum waste. When discussing the role of wood in a circular economy, it is important to acknowledge that its recycling faces inherent limitations compared to technical materials, such as glass and some metals which, after being melted down, can be recovered in a quality similar to original. In contrast, once wood is transformed, its fibres cannot be reprocessed to form material possessing the quality of the original (paper being an exception to this rule).

In addition, all forest-based products are bio-based and are therefore both renewable and can naturally decompose if properly designed. Wood has great enduring value as a renewable material as almost all its production side-streams can become raw materials for other streams, even the smallest off-cuts. This material efficiency, recognized and employed in forest-based industries for centuries, certainly fulfils the criteria of circularity and will contribute significantly to the circularity of value and supply chains using it.

As demonstrated in previous sections, the circular efficiency of different forest-based industries may concentrate on different aspects and at different stages of value chains. However, the design for the end-of-life valorization, which aims to reduce the amount of post-consumer wood waste,

is likely the single most important factor for all industries in the sector to successfully embrace circularity. In addition, and in the context of increasing demand for forest-based products, coordination between the biological cycle of forests and the technical cycle of forest-based industries will need to be strengthened to maximize circularity along the various value chains. For example, if a tree is left at a harvesting site, it does not directly serve the economy but does serve the ecosystem.

Given the foregoing, the most important objectives of this study were to analyse what circularity means for the forest sector, what its limitations are and what is needed to make circularity sustainable and economically viable in the sector in the long term. The study was designed to be a starting point, preparing the ground for a more detailed review of circular approaches in each forest-based industry.

Based on the key findings of the study (Section 4.3.), further targeted analytical work is recommended and detailed as follows:

5.2 Knowledge building for informed policymaking

- Based on this pilot study, undertaking a series of focused studies on circular models and their practical application by specific forest-based industries (those covered by the study, but also e.g. packaging or NWFPs) could prove beneficial. Such studies could include a more detailed examination of how circularity concepts are being applied by specific forest-based industries, case studies that examine real-world impacts as well as a consideration of both existing and foreseeable obstacles coupled with the lessons learned thus far.
- A definition of a circular economy in the forest sector should be developed for possible adoption by the UNECE Committee on Forests and the Forest Industry and the FAO European Forestry Commission to provide member States with an agreed understanding of the concept.
- Guidelines on good practice for the implementation of the principles of a circular economy, tailored to forest-based industries in the UNECE region should be developed. Such good practice would preferably be based on case study analyses of the value chains mentioned above and would also include information on how different forest-based industries can collaborate in a single industrial ecosystem to avoid silo approaches and further enhance a circular use of natural resources.
- A strategy for implementation of the principles of a circular economy in forest-based industries that considers the specificity of individual industries and wood-based products should be developed

5.3 Tools for data collection

- There is no internationally recognized classification of post-consumer wood. Definitions used by Eurostat do not correspond with those of the World Customs Organization. In addition, the annually issued Joint UNECE/FAO/ITTO/Eurostat Forest Sector Questionnaire (JFSQ) has its own definitions, used also in FAOSTAT. The Joint UNECE/FAO Forestry and Timber Section should continue exploring the possibility of developing a detailed classification focused on post-consumer wood involving all the relevant organizations in the UNECE region. Such a classification would serve as a tool to support data collection and facilitate the trade of wood waste.
- Currently, key data is not collected by member States but calculated based on material inputs and outputs in production chains, meaning the data used is actually estimations that require resource-intensive and complex processes to refine. Capacity building in data collection for a circular economy in the forest sector would be both expedient and provide a more accurate view of the sector.
- There is still significant variation in national capacities to report on forests and forest sector-related data within the UNECE region. While some countries have developed advanced reporting systems, others still struggle to generate even basic information. As such, intensive capacity-building work is required to reduce these discrepancies.

5.4 Soliciting input from member States

- An assessment of UNECE member States' priorities and needs to transition to a circular economy would be very useful – a survey to identify additional activities and policy tools, with a particular focus on renewable materials, should be undertaken.

Efforts towards a transition to a circular bio-based economy for forest-based industries should focus on using holistic approaches which extend beyond specific circular bio-based products. They should include natural forest regeneration cycles, the biosphere carbon cycle, renewable energy use as well as the design of circular business models, supported by the design of circular services. Therefore, the analysis undertaken by this study can be extended by further in-depth work on specific aspects of circularity relevant for each forest-based industry. Joint UNECE/FAO Forestry and Timber Section invite forest sector experts, academics and other stakeholders to engage in discussion and further work on the topic of circularity in the forest sector to build a knowledge-based foundation for policy development in this area.

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Circularity concepts in forest-based industries

The world's prevalent economic model, based on a 'take-make-use-dispose' approach, cannot maintain and raise human standards of living without causing environmental degradation and incurring economic risks. Decoupling economic activity from the increasing demand for natural resources could be done through circular, bio-based economy approaches leading to a regenerative growth model, allowing humankind to reduce its environmental footprint on the planet.

The forest sector, situated in both the biological and technical cycles of a circular economy, is well suited to embrace a circular, bio-based economic model. However, challenges in the overall circularity of forest-based value chains persist as a result of the sector's traditional means of operation.

To ensure the sustainability of the forest-based value chains, continuous consideration and coordination of circularity at all stages of the value chains are needed. A viable starting point for this is with the principles of sustainable forest management (SFM), following by the optimized cascading use of wood at every production stage and concluding with the recovery of post-consumer wood at the end of value chains.

This study analyses the existing and possible limitations to circular approaches in forest-based industries, namely the woodworking industry (focusing on sawn wood processing, bioenergy production and wood in construction), the furniture industry, the paper and pulp industry as well as industry using cellulose-based fibres and cellulose-based plastics.

The analysis provides evidence that not all circular approaches are sustainable under all circumstances. In some cases, the focus on circularity may cause environmental externalities, in other cases, it may not guarantee economic viability. While the transition to a circular, bio-based economy can be facilitated by a legislator, the process will need to develop organically, based on the location of industries, proximity to available (waste) resources and consumer preferences.

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