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Circularity concepts in the pulp and paper industry

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Circularity concepts in the pulp and paper industry

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Abstract

The circularity of paper and paperboard value chains is implemented principally thanks to the link between the design and production on the one hand and the use and end-of-life management on the other. As paper products become more complex and have to fulfil more functions, it is important that designers and producers of paper-based products are aware of the paper recycling process and contribute to high rates of and high-quality recovered paper allowing paper products to stay in the material loop. Various initiatives have been put in place in the pulp and paper value chain to ensure this objective and increase the circularity of paper-based products. However, the high rate of recycling is an achievement distinct from the pulp and paper industry among forest-based industries.

The study describes the complexity of the pulp and paper industry with its different stages of raw material use, pulp and papermaking production processes and, finally, the trend to create higher-value products from side stream utilization. The study also gives the general industry context by describing an overall trend from a resource-intensive industry to one that has reduced its resource consumption, including through increased recycling rates over the last few years and the attention given to the optimization of water use and energy consumption.

The design for the end-of-life valorization is equally important for all industries in the forest sector to successfully embrace circularity. However, in the pulp and paper industry, this important aspect of circularity has been realized as the high level of recycling is a prominent industry-wide feature. For this reason, this study places a particular focus on circular design and its interlinkages with the high level of paper recycling.

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Glossary

Blue Angel - is an ecolabel of the German Federal Government which sets stringent standards for environmentally friendly products and services.

Bring banks - are unstaffed collection points for recyclable materials like glass bottles, drinks cans and food cans.

Cellulose fibres - are made from trees, mostly grown in sustainably managed forests, from sawmills' residues and from paper for recycling.

Circular economy - A circular economy is one in which materials and products are kept in circulation for as long possible. Such an economy uses a systems-focused approach and involves industrial processes and economic activities that are restorative or regenerative by design, enables resources used in such processes and activities to maintain their highest value for as long as possible, and aims for the elimination of waste through the superior design of materials, products, and systems (including business models).

Circularity - Refers to use of materials and products in alignment with the principles of a circular economy.

Crystallinity of cellulose - is an inherent property that governs its mechanical properties, affinity for water, and accessibility to chemical reagents.

EU Ecolabel or EU Flower - is a voluntary ecolabel scheme established in 1992 by the European Union.

GHG emission intensity - is determined by adding Scope 1 and Scope 2 emissions and expressing this figure as metric tonnes of carbon dioxide equivalent per metric tonne of production. Scope 1 emissions are direct GHG emissions that occur from sources that are controlled or owned by an organization. Scope 2 emissions are indirect GHG emissions associated with the purchase of electricity, steam, heat or cooling.

Integrated paper mill - indicates that a paper mill is located at the same site as a pulp mill, Most pulp is used onsite in integrated pulp and paper mills where it is transformed into paper and paperboard. In integrated mills, residues from pulp production (e.g. bark) can be used for onsite energy generation or can be refined (e.g. lignin) into value-added products.

Life cycle assessment (LCA) - is an environmental accounting and management approach that systematically considers all aspects of resource use and environmental releases associated with a product or industrial system from defined beginning and ending points. Assessment through an entire life cycle considers environmental impacts resulting from procurement of raw materials and the production and distribution of energy, transportation, manufacturing, assembly, and use through the end of useful life of a product.

The Net Zero Emissions by 2050 Scenario - is a normative IEA scenario that shows a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050, with advanced economies reaching net zero emissions ahead of others. This scenario also meets key energy-related SDGs, in particular, by achieving universal energy access by 2030 and major improvements in air quality. It is consistent with limiting the global temperature rise to 1.5 °C with no or limited temperature overshoot (with a 50 percent probability), in line with reductions assessed in the Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report.

Paper for recycling (PfR) or recovered paper - both terms can be used as synonyms for this raw material. Until the end of the 20th century, the term 'waste paper' was also used. While the term 'paper for recycling' (PfR) stems from the European Union's standard "Paper and board - European list of standard grades of paper and board for recycling" (CEN, 2014), the term 'recovered paper' is used in North America and in the global trade (e.g. by FAO and the World Trade Organisation). The evolution of the term from 'waste paper' to 'recovered paper' and to 'paper for recycling' illustrates the increasing level of circular thinking in the sector.

Paper mill – is a factory devoted to making paper from wood pulp and other ingredients. Paper mills can be integrated or non-integrated.

Primary energy - energy in the form that it is first accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy. For example, coal can be converted to synthetic gas, which can be converted to electricity; in this case coal is primary energy, synthetic gas is secondary energy, and electricity is tertiary energy.

Pulp - is an intermediary product in the paper production process obtained from virgin biomass coming from forests and other sources. It can also be produced from recovered paper (recycled pulp) or from non-wood cellulose fibres. Pulp can be manufactured using mechanical, semi-chemical or fully chemical methods.

Pulp mill – is a manufacturing facility that convert wood chips or other plant-fibre sources into thick fibreboards which can be used by a paper mill for further processing.

Selective collection - means the gathering of specific types of paper for recycling from industrial and commercial outlets as well as from households and offices, this is done separately from non-paper material and from other paper material.

Tensile strength of cellulose - is the breaking strength of a specimen under exertion of a force capable of breaking many threads simultaneously, at a constant rate of extension/ load.

Useful life - refers to the amount of time an asset is expected to be functional and fit-for-purpose. With regard to the life of building, useful life can be defined by the number of years before a building deteriorates to the point that it is no longer safe or desirable to continue using, the point at which it no longer meets existing code requirements and would be too costly to bring up to code, the point in time at which other uses for the building site are more financially viable than keeping the existing building in place, and so on.

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Executive Summary

If managed sustainably, forests continue to grow and fulfil an extensive range of economic, environmental, and social functions. Like other wood products, pulp and paper production is part of the cascading use of wood, which aims at extracting the highest value from wood at every step of the manufacturing process. Pulp producers do not often source wood directly from forests but from the by-products of sawmills and, in this way, keep them in a material loop. In pulp mills, new innovative products are extracted as side-streams of pulp production, offering renewable alternatives to fossil-based products.

The circularity of paper and paperboard value chains is implemented principally thanks to the link between the design and production on the one hand and the use and end-of-life management on the other. As paper products become more complex and have to fulfil more functions, it is important that designers and producers of paper-based products are aware of the paper recycling process and contribute to high rates of and high-quality recovered paper allowing paper products to stay in the material loop. Various initiatives have been put in place in the pulp and paper value chain to ensure this objective and increase the circularity of paper-based products. However, the high rate of recycling is an achievement distinct from the pulp and paper industry among forest-based industries.

The environmental benefits of increased paper recycling are not only in the diversion of paper waste from disposal. They also broaden the raw material base for fibre-based products that can substitute fossil-based products in the circular economy.

Circularity in the pulp and paper industry also involves closed water cycles and the use of processing residues, such as fibre-containing sludges from other industrial sectors, such as the chemical industry and the construction sector. During the pulp and paper production process, significant efficiencies have been achieved in the use of energy, water and overall material use as well as finding uses for waste and residues.

Circularity approaches vary in different parts of the forest-based sector, this is also a case within the pulp and paper industry. Different paper mills have different circularity approaches depending on their feedstocks (e.g. paper for recycling, sawmill residues) energy sources and so forth. Therefore, there is not a one-size-fits-all circularity solution for the industry. Life Cycle Assessment (LCA) methodologies contribute to analysing the environmental benefits and impacts of how fibre flows throughout the value chains. However, LCAs have their limitations as well given the difficulty of modelling market dynamics and the use of simplified assumptions that impact analysis results. Therefore, circularity approaches should be evaluated case by case, taking into consideration environmental, economic and social impacts.

Besides other factors, a successful transition towards a circular economy depends also on supporting policies. For example, policies for waste management and landfill avoidance are already in place in many countries. Product-related policies have the potential to further support a transition, including by promoting science-based tools to enable comparisons between the environmental footprints of different products and allowing consumers to make informed purchasing choices.

Examinations of the different aspects of circularity and sustainability of the pulp and paper industry in this study have led to the following conclusions:

- The pulp and paper industry is a complex industry with many different processes and a growing trend to of refining bio-based feedstock into more value-added products

- The changing industry context impacts the structure of the sector. It includes decreasing use of newsprint and graphic papers and increased use of packaging papers. Also, material efficiency has grown in the past decades.
- Further growth in packaging papers production will depend on the uptake of reusable packaging.
- Paper recycling rates will keep increasing, however, a continuous inflow of virgin fibres will be needed.
- Pulp mills also implement circularity approaches through the development of innovative products in biorefineries.
- Circular design is key for both high recycling rates and high quality of products made from recovered paper.
- Standardization is a compelling enabler for the circularity of paper and paperboard.
- Paper recycling is a business case.
- The environmental performance of paper and paperboard made from virgin fibres and from recovered paper can be compared only case-by-case.
- Recycling paper and paperboard extends the raw material base substituting fossil-based products.
- Policy has a key role in creating an enabling environment for circularity in the pulp and paper industry.

Building on these conclusions, the following actions have been identified as key in supporting a successful transition to a circular economy in the pulp and paper industry:

- Support for sustainable forest management should continue. While recycling rates are high and can be further increased in many areas, a steady inflow of virgin fibre will be needed, and it must be sourced from sustainably managed forests;

- The use of recycled fibres should be promoted to widen the sustainable raw material base for renewable products substituting fossil-based ones. However, promotion campaigns on paper recycling should avoid associating the use of virgin fibres with misleading information on deforestation, which is driven by factors outside the forest sector, including agricultural expansion and poverty;

- Waste streams including valuable raw materials such as paper and paperboard should be, as much as possible, diverted from landfills and other disposal options to keep materials circulating and creating added value in the economy;

- Paper and paperboard should be collected separately from residual waste and other recyclables. There should be consistent waste collection programmes at least at national levels, although ideally this should be done in larger economic areas to enable the value of secondary raw materials to be maintained;

- Sorting instructions for the end consumer of pulp and paper products should be included on the products and also elsewhere, along with the legally required information concerning the origin;

- Waste management policies, including on collection and sorting, should be linked to the product design and production policies to allow for closed material loops in which products are designed in full knowledge of the recycling processes that keep them in use;

- Product support policies (e.g., green procurement) should be further developed to take into account the recyclability of products and the renewability of their raw materials to favour nature-based material over fossil fuel-based ones;
- Innovation and access to research and development funding should be encouraged to facilitate product and energy efficiency innovations. This would support the continued development of mills into biorefineries, that can produce more value-added products from side-streams and other waste;
- Pulp and paper sector should be encouraged to use their potential to become more energy self-sufficient by producing renewable energy onsite using e.g., waste and residues for bioenergy in line with the cascading use of biomass. For the remaining energy needs, access to affordable clean energy is crucial to increase the synergy between increasing circularity and efforts to mitigate climate change;
- Science-based environmental footprint information needs to be publicly available to make sure that claims on products are reliable and comparable for consumers;
- Cooperation among different actors across value chains and the establishment of industrial ecosystems should be promoted to facilitate exchange along supply chains and make them more circular, i.e. turn the linear supply chains into supply circles;
- Various value chains should be analysed by industrial associations and policy makers to identify their potential for increased circularity while keeping in mind all associated environmental impacts and sustainability aspects.

CHAPTER 1 Setting the stage for circularity in the pulp and paper industry

1.1. Understanding circularity and sustainability

Many of the global priorities embedded in the 2030 Agenda for Sustainable Development[1] and the Sustainable Development Goals (SDGs) relate to forests, forestry, forest-based industries and bioenergy. For example, SDG 15 Life on Land directly refers to the need for the sustainable use of ecosystems, sustainable management of forests and reversing land degradation as well as biodiversity loss. Similarly, SDG 13, which is dedicated to Climate Action, cannot be achieved without resilient forests and responsible forestry practices, while SDG 6 mentions the need for the protection and restoration of water-related ecosystems, including forests, wetlands, rivers and lakes.

Existing linear production and consumption patterns, based on 'make, use, dispose' models are not sustainable and saw many economic sectors and industries, including those using forest-based products, such as construction, furniture manufacturing and the pulp and paper industry, significantly contribute to pollution and waste generation. In addressing this, SDG 12 calls for responsible production and consumption and refers to circularity principles as well as the sustainable use of natural resources. It points out the need to increase resource efficiency, promote sustainable lifestyles, and decouple economic growth from environmental degradation in the long-term.

Achieving many of these objectives in the context of the increasing use of forest resources and growing environmental challenges, linked with greenhouse gas (GHG) emissions and waste generation, requires an application of production and consumption models based on a sustainable use of natural resources and the regeneration of biological systems (UNECE/FAO 2023).

Although the term 'circular economy' does not appear in the 2030 Agenda for Sustainable Development, circular economy practices can contribute to achieving a number of SDGs. A study by Schroeder, Anggraeni and Weber in 2019 noted that strong relationships exist between a circular economy and SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 12 (Responsible Production and Consumption) and SDG 15 (Life on Land) (UNECE/FAO 2022).

A transition towards a sustainable and circular bioeconomy at the global level is often perceived as a way to achieve an economic model that can increase sustainability in its environmental, economic and social dimensions while simultaneously reducing the global economy's dependence on non-renewable resources in the long term (UNECE/FAO, 2023).

In particular, the circular economy model coexists in the policy space and in research with a number of similar concepts that were developed earlier or simultaneously. The origins of circularity itself are older and more diverse than is commonly perceived, being rooted in ecological and environmental economics as well as industrial ecology (UNECE/FAO, 2022). Similar concepts regularly referenced today, such as a circular economy, green economy, bioeconomy and sustainable economy differ, but are consistent with each other since they all aim to synchronize the optimization of ecological economic and social objectives at different levels (Durocher, 2021),[2] similar to the 2030 Agenda for Sustainable Development.

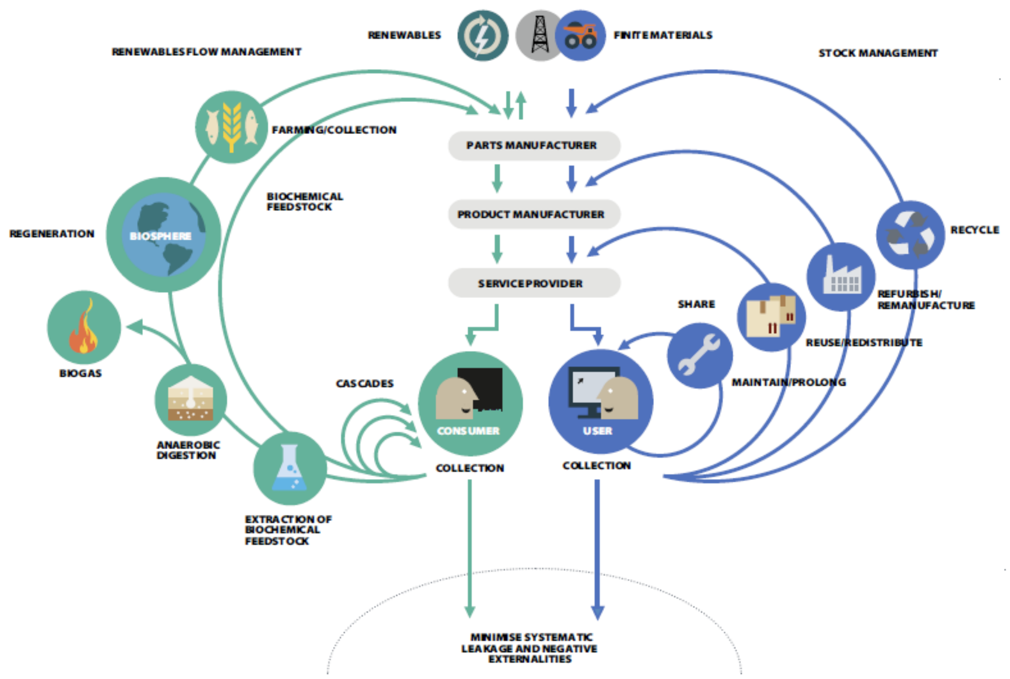
[1] https://www.un.org/sustainabledevelopment/development-agenda/
[2] Claude Durocher, 2021. State of the Global Forest Bioeconomy.

For the needs of this study, the concept of a circular economy based on the model of the Ellen MacArthur Foundation (Figure 1) is used as presented in UNECE/FAO (2022).

The Ellen MacArthur Foundation model distinguishes between technical (blue) and biological (green) cycles. This interpretation of circularity involves, on the one hand, materials of biological origin that can return to the biosphere in the form of nutrients and, on the other hand, technical materials that cannot biodegrade but can circulate in closed loops thanks to circular practices.

Figure 1 Biological and technical cycle in a circular economy model by Ellen McArthur Foundation.

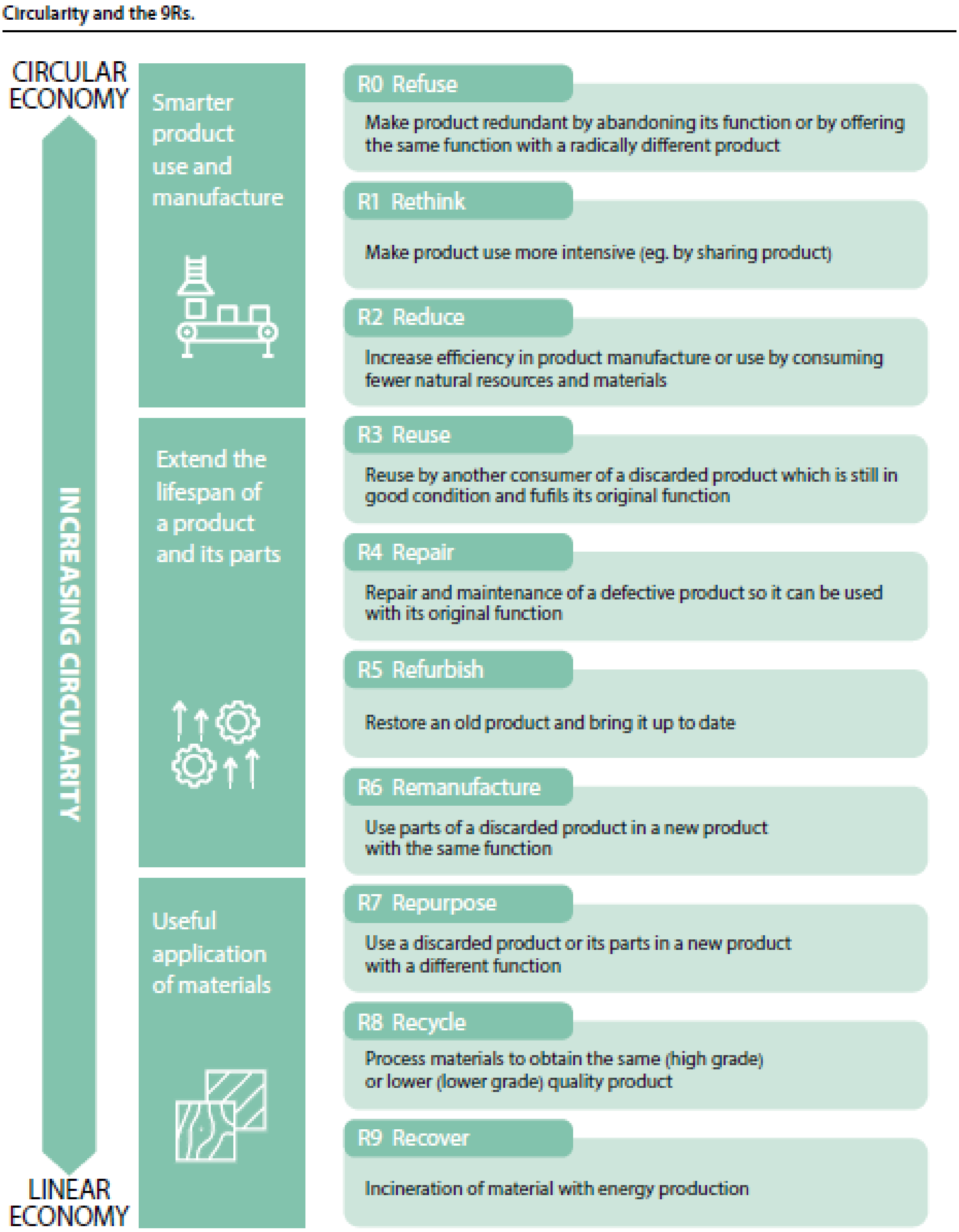
Biological and technical cycle in a circular economy model by the Ellen McArthur Foundation.



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

In this study, the circularity and sustainability principles and approaches are understood by the application of the 9R approach (Figure 2). This is applied to the different stages of the pulp and paper manufacturing value chains, as presented in UNECE/FAO (2022), with the recognition that the focus is on analysing industry practice without a consideration of forests and forest operations. This latter consideration is provided by a separate UNECE/FAO study "General conditions for a transition to a sustainable and circular bioeconomy in forest-based industries" in the same series.

Figure 2 Circularity and the 9R



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

While the 9R model will be the basis for the consideration of circularity and sustainability presented in this study, it is understood that many of these R-approaches should be applied differently than in the case of technical materials such as glass or aluminium. This is because wood, as a biological raw material, can be transformed in a cascading way to feed back into the biological cycle of wood growth before being used by the technical cycle again. That is contrary to technical materials which, once they enter the technical cycle, can only be recycled and transformed into materials similar to their origin without leaving the technical cycle.

1.2. Circularity and sustainability in the pulp and paper industry

A circular economy is based on three core principles: reducing waste by design, retaining materials in circulation and restoring the systems from which resources are extracted. In that sense, the pulp and paper industry appears to be the embodiment of circular economy principles, maximizing the reuse of resources by making the best possible use of side streams.

First, the 'Reuse and Recycle' is the principle that goes hand in hand with the existing practice in the industry, reducing the use of virgin resources and raw materials by utilizing waste streams. Secondly, circular economy reduces waste generation, avoiding the environmental damage caused by landfilling. Thirdly, it reduces GHG emissions and saves money, especially when considering the costs of landfilling, the loss of reusable materials, the livelihoods that could have been supported and the environment costs when waste degrades.

The circularity of paper and paperboard products has also a wider benefit for the entire forest sector and many forest-based industries as it broadens the availability of renewable raw materials for all forest-based products. When less virgin material is used for pulp production, it can be directed to other applications. Paper recycling also strengthens the cascading use of wood across different value chains in forest-based industries which has an impact on the entire forest sector. That benefit becomes evident when taking into consideration the definition of the cascading use of wood as specified by Vis, Mantau and Allen in their study on the optimized cascading use of wood: The "efficient utilization of resources by using residues and recycled materials for material use to extend total biomass availability within a given system" (Vis, 2016).

1.3. Background and objectives of the study

This study aims to provide a comprehensive overview of how circularity concepts and sustainability practices, based on models presented in the previous section, can be applied in the pulp and paper industry. Work on this study results from a mandate given by the Committee on Forests and the Forest Industry (COFFI) of the United Nations Economic Commission for Europe and the European Forestry Commission (EFC) of the Food and Agriculture Organization of the United Nations. During their Joint Session in November 2021, COFFI and the EFC requested the UNECE and FAO to "(a) prepare a series of studies further reviewing the application of circular models in specific forest-based industries, including through the identification of case studies and best practice, and (b) to take into consideration the whole forest-based value chain and bring attention to the circular nature of wood as a renewable resource and the role of sustainable forest management".[3]

The focus of the above-mentioned studies was identified through consultations with the UNECE/FAO Team of Specialists on Sustainable Forest Products and the FAO Advisory Committee on Sustainable Forest-Based Industries between February and August 2023. This consultative process was supported by the Joint UNECE/FAO Working Party on Forests Management, Economics and Statistics during its session in June 2023. The series includes the following studies:

- General conditions for a transition to a sustainable and circular bioeconomy in forest-based industries;

[3] (ECE/TIM/2021/2 FO:EFC/2021/2)
See also E/ECE/1494 B(69) Circular Economy and the Sustainable Use of Natural Resources; and E/ECE/1503 C (70) Promotion of Circular Economy and the Sustainable Use of Natural Resources.

- Circularity concepts in the wood construction sector, as an example of long-lived products value chain; and
- Circularity concepts in the pulp and paper industry, as an example of a group of commodities with short life spans.

This study, as part of the series, analyses circularity and sustainability approaches in the pulp and paper industry, and related industry practices and value chains. It has a limited focus on forests as the starting point for pulp and paper value chains and the sustainable provisioning of biomass directly from forests as the first study, the 'General conditions for a transition to a sustainable and circular bioeconomy in forest-based industries', deals with these aspects. However, this study highlights the use of recovered materials as a priority feedstock for pulp mills in line with material efficiency and circularity rules. It also recognizes that when wood is sourced from forests, it is only a sustainable process if those forests are managed in line with SFM principles.

The entire series builds on the previous UNECE/FAO study 'Circularity concepts in forest-based industries' (2022) and aims to present more detailed insights into the circularity issues in forest-based value chains. The series contributes to the research and guidance for policymaking activities of the UNECE/FAO Integrated Programme of Work 2022-2025, implemented by the UNECE/FAO Forestry and Timber Section in Geneva.

1.4. Scope and limitations

The UNECE/FAO study 'Circularity concepts in forest-based industries' showed that forest-based industries apply circularity in different ways and at different stages of their value chains. However, the design for the end-of-life valorization is equally important for all industries in the forest sector to successfully embrace circularity. In the pulp and paper industry, this important aspect of circularity has been realized as the high level of recycling is a prominent industry-wide feature. For this reason, this study places a particular focus on circular design and its interlinkages with the high level of paper recycling.

Before more closely examining these interlinkages, the study describes the complexity of the pulp and paper industry with its different stages of raw material use, pulp and papermaking production processes and, finally, the trend to create higher-value products from side stream utilization. The study also gives the general industry context by describing an overall trend from a resource-intensive industry to one that has reduced its resource consumption, including through increased recycling rates over the last few years and the attention given to the optimization of water use and energy consumption.

This approach has been chosen to show that circularity aspects need to be considered in all stages of the pulp and paper industry value chains. They are all examined in the study, albeit some in less detail than others. This, at times basic examination, has been applied as an in-depth description of all circularity aspects throughout the pulp and papermaking process, including considerations of all supporting chemicals, side streams, water and energy supply would require separate publications beyond the scope of the study. For this reason, the focus has been placed on the circularity of the raw materials in pulp and paper production while other accompanying materials and resources, including water and energy, are mentioned with less detail.

The present analysis of circular approaches is complemented by an analysis of the environmental benefits and drawbacks of paper production and recycling, as well as the role of policy in achieving the still untapped potential for increased circularity in the sector. This study also includes good practice examples to complement its analysis before presenting its conclusions and recommendations.

As the overall purpose of this study is to present theoretical concepts related to a circular economy and how they apply to the pulp and paper industry, the general industry context has been included in the study only to provide a background for these considerations. The industry policy and economic analysis has been focused on the evolution of production and consumption as well as resource efficiency trends. Consequently, a detailed overview of the latest developments in the industry, itself still undergoing a major transition, falls outside the scope of this study. An analysis of this transition in all its complexity merits a separate consideration, which could be provided by a subsequent study.

1.5. Methods and data sources

The evidence and information sourced in this study come mainly from desk research, a review of the scientific literature and the subject-matter knowledge of the authors. Additional information has been provided from industry documentation and interaction with industry experts, government information sources as well as documented case studies and examples of good practice.

1.6. Structure of the study

Chapter 1 sets out the context and the objectives of the study. It defines a circular economy as referenced in this study and how it applies to the forest sector and how it is linked to pulp and paper industry practice.

Chapter 2 explains the complexity of pulp and papermaking processes. It maps out different stages of the raw material transformation and describes the auxiliary products, as well as the side streams and the innovative products, used in different applications. It highlights weaknesses in circularity and sustainability that subsequent chapters will consider in the context of the more efficient use of all resources involved in the production, recovery and recycling of paper and paperboard products.

Chapter 3 reiterates the evolution of the pulp and paper industry, its production and consumption patterns, ongoing trends and the industry's outlook. The chapter also highlights the industry's efficiency gains in its use of raw materials and other resources as well as its reduction of environmental and climate impacts.

Chapter 4 explains the role of circular design and focuses on the recycling of paper products as the most prominent circularity feature in the pulp and paper industry. The chapter outlines the typical paper recycling processes and explains how paper products can be designed and produced with recyclability considerations in mind. The analysis also includes a consideration of the environmental benefits and drawbacks of paper recycling as well as the role of policy in further improving circularity and providing support for consumers' choices.

Chapter 5 provides case studies of good practice in the implementation of circularity and sustainability principles in the pulp and paper industry.

Chapter 6 provides conclusions and recommendations.

Chapter 2 Pulp and paper manufacturing process, products, and their characteristics

Pulp and paper production is a complex industrial process that requires significant amounts of natural resources, chemicals, water and energy. Besides cellulose biomass, it involves a variety of chemical substances, such as those used for coating and printing on paper and paperboard, bleaching agents and other chemicals injected into the pulp to aid the recycling process. Consequently, pulp and paper manufacturing, as well as the associated recycling processes, have significant environmental (e.g. water and land use) and climate impacts.

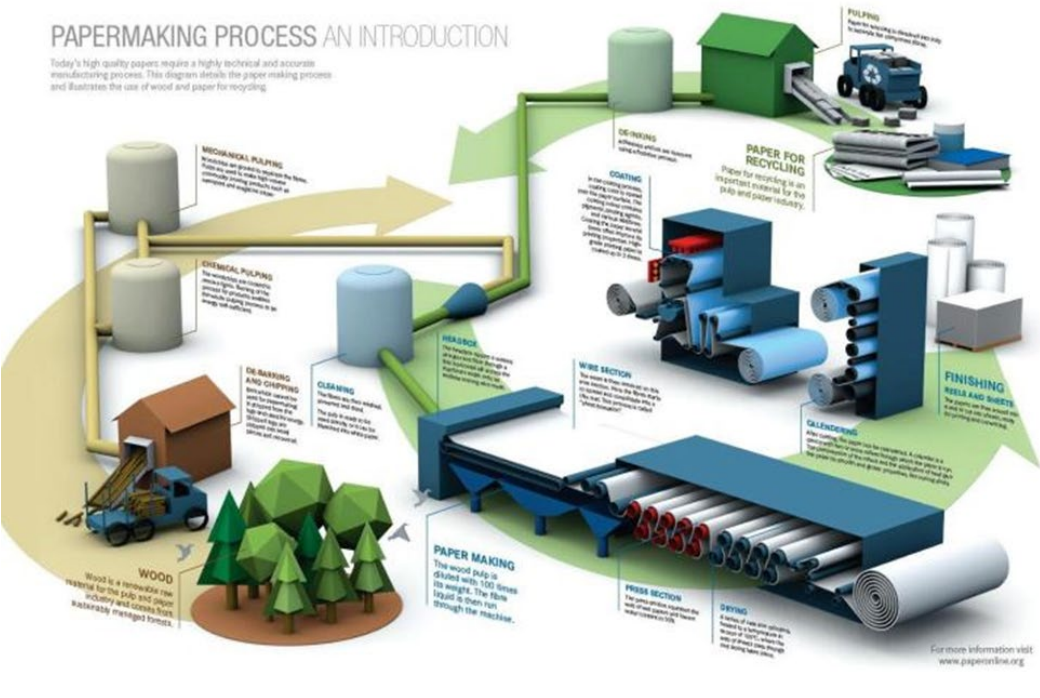
These impacts would be significantly reduced by implementing processes that lead to greater material efficiency and a circular flow of resources (UNECE/FAO, 2022). Consequently, this chapter outlines different materials and substances involved in the pulp and paper production to provide foundation for an analysis of sustainable and circular approaches which can be applied to either optimize their use or to replace them with more sustainable alternatives. To a certain degree such analysis is undertaken in the following chapters. In many cases the analysis requires technical knowledge which falls out of the scope of this study. Nonetheless information provided aims to inspire further research by industry professionals.

In general, the pulp and papermaking process turns cellulose fibres from forest-sourced wood or residues coming from sawmills into paper of different qualities and different purposes for the needs of industry and retail consumers. The pulp can also be made from paper for recycling (also called recovered paper) or other fibre sources, such as bamboo, cork, cotton, hemp, mulberry, jute and kozo (legionpaper.com, last accessed 27 April 2023).

The pulp and paper manufacturing process involves a sequence of physical and chemical transformations of raw material that starts with the creation and (optional) bleaching of a pulp mixture made from raw material. This is typically followed by the cleaning and pressing of a fibre slurry on a thin mesh screen to enhance the material's density before being dried, formed as fresh paper sheets and treated to provide suitable properties for different paper uses (Figure 3). This complex process differs between mills, depending on the raw material and desired end products, but can be generically illustrated in four major processing steps:

1. Preparation of raw material (debarking and chipping));
2. Pulping (chemical or mechanical);
3. Bleaching; and
4. Paper production (cleaning, paper-sheet formation and drying, finishing).

Figure 3 The papermaking process



Source: Cepi

2.1. Preparation of raw material

Wood received at a pulp mill can come in different forms depending on the requirements of the pulping process and the origin of the raw material. The raw material may be received in the form of short logs of round-wood with the bark still attached or as wood chips that may have been produced by a sawmill from debarked round wood elsewhere. If round wood is received, it is first debarked, usually by tumbling in large steel drums before the debarked wood logs are chipped in a chipper. Wood chips are then screened for size, cleaned and temporarily stored for further processing.

Besides using trees for paper production, paper mills may also use manufacturing leftovers from sawmills whose outputs are used in construction, furniture and other products. A significant part of the wood delivered to pulp and paper mills originates from sawmills and is already delivered in the form of wood chips. The share of wood chips from sawmills in the virgin fibre input of the European pulp and paper industry was 24.6 percent in 2021 (Cepi, Key statistics , 2022).

2.1.1. Cellulose fibres

Recovered paper is the largest single source of cellulose fibres for pulp and paper production at the global level. It is also called paper for recycling (PfR). Both terms can be used as synonyms for this raw material. Until the end of the 20th century, the term 'waste paper' was also used. While the term 'paper for recycling' (PfR) stems from the European Union's standard "Paper and board - European list of standard grades of paper and board for recycling" (CEN, 2014), the term 'recovered paper' is used in North America and in the global trade (e.g. by FAO and the World Trade Organisation). The evolution of the term from 'waste paper' to 'recovered paper' and to 'paper for recycling' illustrates the increasing level of circular thinking in the sector.

Recycling is an aspect of circularity most associated with the pulp and paper industry by the public. This is due to high recycling rates as well as the direct involvement of consumers in paper collection.

In the United States of America, 94 percent of the population has access to paper collection. (AF&PA, 2021). In 2021, approximately 80 percent of all pulp and paper mills in the United States used at least some paper for recycling (American Forest and Paper, 2023).

However, the recycling process involves losses at different stages of the cycle, starting from paper that cannot or is not collected, losses during sorting and the recycling process itself. For this reason, the pulp and paper industry needs fresh fibres from forests to keep the renewable cycle going. Therefore, only SFM and the responsible harvesting of wood will ensure the long-term growth of forests and circularity in the sector.

While the best quality roundwood is, in most cases, used by sawmills for construction and furniture, the upper parts of trees and their branches are used to produce pulp and paper, in the panel industry or to produce bioenergy.. In order to ascertain that fresh fibres originate from sustainably managed forests, the pulp and paper industry is increasingly using third-party forest certification systems, such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC), to demonstrate the sustainable origin of the wood.

Wood has a high fibre yield and mixing different wood fibres gives paper products properties that are required for different end applications, such as strength (e.g. in packaging), softness (e.g. in tissue) or flexibility (e.g. in printing). Different wood species used in the pulp and paper industry provide fibres with specific characteristics, for example, hardwoods that have short fibres are incorporated into papers to improve printability. The overall formation of paper is improved with the inclusion of shorter and narrower fibres. Birch, beech, poplar and aspen are the mostly commonly used hardwoods in the production of wood pulp for papermaking.

Eucalyptus can either be considered as having hardwood characteristics, or as a stand-alone wood type. Softwoods are predominantly used for their long fibres which increase the tear-strength of paper and can improve runnability on printing and converting machinery. Softwood fibres are typically long, strong and entangle well, creating higher bulk and air-permeable papers. Spruce, Pine and Fir are typical softwood species used for papermaking (nisshametallizing.com, last accessed on 27 April 2023)

2.1.2. Non-wood cellulose fibres

The first paper was produced about 2000 years ago from a cellulose-containing puree made from plants. Precursor products, like papyrus and parchment, made from animal skin are not considered true paper. For centuries paper and paperboard were made from various raw materials that contain cellulose, such as cotton and straw, however, it was not until the late 19th century when a chemical process was developed that could isolate cellulose from wood, making wood a relative newcomer as a raw material.

Historically, the choice of raw material used for papermaking depended on its availability and price. For example, until the 1970s, straw was the main raw material to produce paper and paperboard. However, innovations in crop breeding techniques aimed at facilitating kernel harvest also led to lower stems yields in wheat crops and consequently a significantly lower availability of straw. At the same time, wastepaper collection systems were being set up in many countries extended the resource base to recovered paper.

Today, the pulp and paper industry is turning towards non-wood cellulose fibres again, albeit for different reasons. The finitude of oil and natural gas resources and the need to reduce CO_2 emissions contributing to climate change have led to an increased interest in renewable raw materials to substitute for fossil-based materials and reduce the impact on the natural environment. Furthermore, the ongoing transition towards a sustainable and circular bioeconomy creates a growing demand for wood from a number of industries beyond the forest sector, in particular the chemical industry, that provides materials to a variety of value chains. That has impacted pulp and paper industry activities as it has sparked an evaluation of the utility and better management options for side streams coming from wood processing for paper production and broadened the industry's interest in non-wood cellulose fibres.

For example, since the 2010s in many European Union (EU) countries, there has been a growing interest in making paper from straw, textile waste, flax, hemp, sugar cane bagasse, meadow grass, miscanthus, sugar beet pulp and silphia. These materials are now used in a wide range of paper products, such as tissues and hygiene paper, graphic and packaging paper as well as special paper with technical or security applications, e.g. cigarette paper and banknotes respectively. However, in the overall raw material mix, the volumes of non-wood fibres are still at a low level compared to wood-based cellulose fibres.

Box 1 Classification of non-wood cellulose fibres

1. **Dedicated feedstocks for non-wood fibres** (technical fibres). These are crops that are specifically grown for papermaking, either on marginal land or on regular arable land, when high-quality fibres are desired. These include hemp, flax, meadow grass, miscanthus and silphia.
2. **Residues, by-products and co-flows** Straw, textile waste, sugar cane bagasse, sugar beet fibres and flax are generated in large volumes which, as by-products, do not require their own cultivation areas. That has a positive effect on the climate balance and can be relatively easily integrated into pulp and paper processes in certain proportions. In general, residues from crops have lower papermaking properties than wood or dedicated crops (i.e. result in paper with lower strength). From the above list, only sugar cane bagasse (Figure 4) has already been used for decades as a proper replacement for wood fibres, albeit only in countries where sugar cane is produced (Nova-Institute, 2022).

Non-wood-based cellulose fibres are used alone only in some specific cases, for example, in the production of banknotes from cotton. Most of the time they are mixed with wood-cellulose fibres to achieve the desired specific properties of the final product. Additionally, their limited use is linked with their limited availability, when compared to wood-cellulose fibres.

While the use of non-wood cellulose fibres for papermaking contributes to circularity by giving a use to residues, it is important that they do not negatively impact the quality and recyclability of paper products. The fibres can be considered recyclable if they have been prepared for papermaking, however, more research and testing are needed to support the design for circularity of such fibres.

Figure 4 Non-Wood Cellulose Fibers for papermaking

Source: Essity

2.2. Separation of fibres (Pulping)

The pulping of wood chips refers to the process by which wood chips are degraded into fibres by the removal of lignin, a substance that holds the cellulose fibres together, from the cellulose and hemicelluloses. The type of pulping and the amount of bleaching used depend on the nature of the feedstock and the desired qualities of the end product. (Reese, 1999). Several pulping technologies may be distinguished in which the raw material is treated either chemically or mechanically or by combining these two treatments.

The term pulp is collectively used for a variety of chemical, semichemical, chemi-mechanical (thermomechanical) and mechanical pulps, achieved through different transformation processes. Although pulps are mainly used for papermaking, some pulps (e.g. dissolving pulps) can also be processed into cellulose derivatives (cellulose esters and ethers) and regenerated celluloses, for the production of materials such as viscose or rayon (Raimo Alén, 2019) that are used in the textile industry.

Box 2 Pulp can categories with specific characteristics and application

1. **Mechanical wood pulp**. This is a high-yield pulp (95 to 99 percent) obtained by grinding or milling coniferous or non-coniferous pulpwood or wood chips from sawmills into short fibres. This pulp is mainly used for products that need high stiffness, such as newsprint or folding boxboard used for food packaging).

2. **Semi-chemical wood pulp**. Also called chemo-mechanical wood pulp, is produced by a combination of a chemical pre-treatment, followed by a mechanical treatment like grinding of milling. This pulp still had a relatively high yield (80 to 95 percent).

3. **Chemical wood pulp**. This is obtained by subjecting wood, wood chips or other wood residues to a series of chemical treatments in which the lignin is dissolved. As a result, different products are obtained, including sulphate (kraft) wood pulp, soda wood pulp and sulphite wood pulp (Cepi, Pulp and Paper Industry - Definitions and Concepts, 2021). Kraft wood pulp is the most used type because it is strong and durable. It is used in a wide range of paper and paperboard products, especially packaging, but also in printing, writing and tissue papers. Soda wood pulp has high brightness and is used in products such as high-quality writing paper while sulphite wood pulp is used mainly for fine paper products like books and magazines. The yield of the chemical pulping process is typically 45 to 65 percent.

4. **Dissolving pulp**. This can be obtained from wood and non-wood cellulose fibres, including coniferous or non-coniferous wood, rags, cotton linters and so forth. This type of pulp is highly bleached (using sulphate, soda or sulphite) and is characterized by a special quality of having a high alpha (or even pure) cellulose content (usually 90 percent or more). This pulp is readily adaptable for uses other than papermaking as it also has lower viscosity levels compared to pulps for papermaking, which makes the production of viscose fibres and lyocell fibres efficient and effective. Viscose and lyocell fibres are used for textile and non-woven applications in the textile industry. Other fields of application include cellulose-based plastics, lacquers and explosives to mention but a few. (Cepi, Pulp and Paper Industry - Definitions and Concepts, 2021).

2.2.1. Chemical pulping

Chemical pulping consists of cooking wood chips with specific chemicals in an aqueous solution at an elevated temperature under pressure. The chemicals used in chemical pulping can be either alkaline (kraft process) or acidic (sulfite process) (Reese, 1999)). Building on that, four processes are principally used in chemical pulping: kraft, sulfite, neutral sulfite semichemical (NSSC), and soda process. The choice of pulping process is determined by the desired product, by the wood species available and by economic considerations. Of these four processes, the first three cause the highest air pollution. (EPA, 2022).

The alkaline (kraft process) has become the chemical pulping method of choice because of its advantages in chemical recovery and pulp strength. However, the formation of organic sulfides in the kraft process has caused environmental concern due to their escape as malodorous gases (Reese, 1999).

Sulfite pulps resulting from acidic processes typically have less strength than kraft pulps in papermaking applications and recovery. Furthermore, the regeneration of chemicals in the waste liquors from sulfite pulping is more difficult than from kraft liquors, therefore sulfite pulping processes have been extensively evaluated in laboratory and pilot tests but have found only limited commercial application. In principle, sulfite pulping may offer possibilities for alternative chemical recovery processes with lower capital costs and by-product recovery, however, very high rates of recovery must be achieved to attain economic and environmental gains (Hintz, Sunday and Lawal, 2018)

Neutral sulphite semi-chemical pulping is yet another chemical pulping process where a cooking liquor is used under high temperature and pressure to chemically dissolve the lignin that binds the cellulose fibres. The main cooking agent, sodium sulphite (acidic) is combined with sodium bicarbonate (alkaline) to maintain a neutral solution. The pulping process is completed by mechanical means with the resultant NSSC pulps used in corrugating media as well as in certain writing and printing papers (European Union, 2000).

Soda pulping, invented in England by Burgess and Watts in 1851, uses sodium hydroxide (caustic soda) as the cooking chemical. Many of the early soda mills converted to the kraft process once it was discovered. The soda process has a limited use only for easily pulped materials, such as straws and some hardwoods, (Bajpai, 2018)because compared to kraft pulps, soda pulps contain a more condensed structure which is less reactive toward bleaching chemicals. This low reactivity lowers the brightness of bleached soda pulps in comparison to kraft pulps.

2.2.2. Mechanical pulping

Mechanical pulping is the original way of pulping that has been largely replaced by chemical pulping, however, it is still used for lower-grade papers such as newsprint and is the only process used for recycled paper (Casey, 1983a). Mechanical pulping relies on mechanical actions to separate and develop wood fibres rather than using chemical means. Electricity is the main source of energy for generating the mechanical forces necessary to produce mechanical pulp (Pratima Bajpai, 2016).

Mechanical pulps are produced by using only mechanical attrition to lignocellulosic materials, consequently, no chemicals (other than water or steam) are used. Often light-coloured, non-resinous softwoods are used as the fibre source for their production as only some hardwoods are suitable for this process. Lignin is retained in the pulp and, therefore, high yields of pulp from wood are obtained. Besides this high yield, mechanical pulps are characterized by high bulk, high stiffness and low production cost. However, they have low strength because the lignin interferes with bonding between fibres when paper is made and the lignin also causes the pulp to turn yellow with exposure to air and light.

Mechanical pulps occupy an important position in the paper industry as they have low production costs, simple production processes, strong ink absorption, high opacity yielding soft and smooth paper as well as being suitable for producing printing paper. However, the strength of the paper is low because it is made from short fibres and has a high content of non-cellulose components. Consequently, the paper produced by mechanical pulping can easily become yellow, brittle and, therefore, cannot be preserved for a long time (paperpulping.com, last accessed 26 April 2023). As such, the use of mechanical pulps is confined mainly to non-durable papers such as newsprint and catalogue paper. Mechanical pulps constitute 20 to 25 percent of global pulp production, however, this figure is increasing due to the high yields of the process and increasing competition for fibre resources. (Bajpai, 2018).

Mechanical pulps are usually divided into white mechanical pulps and brown mechanical pulps. White mechanical pulps are mainly used to produce newsprint but can also be used in other pulps for copy writing paper and printing paper. Brown mechanical pulps are usually used in the production of packaging paper and paperboard, especially industrial paperboard (paperpulping.com, last accessed 26 April 2023).

Box 3 The mechanical pulping techniques

- **Stone groundwood pulp** (SGW) is produced by pressing wood onto a rotating grinding stone. The grinding grits on the stone's surface penetrate the surface of the wood and separate the fibres by a combination of compression, heating and shear.
- **Pressurized groundwood pulp** (PGW) is produced similarly to SGW but where the grinding is performed in a pressurized chamber with steam. This makes the process more efficient and reduces the energy consumption.
- **Refiner mechanical pulp** (RMP) is produced by feeding wood chips into the centre of a disk refiner that consists of two grooved discs. Either one disc rotates and the other is stationary or both rotate in opposite directions. The wood chips are forced toward the periphery by the centrifugal force and are crushed into pulp between the discs.
- **Thermomechanical pulp** (TMP) is produced similarly to RMP but in an atmosphere with elevated pressure.
- **Chemi-mechanical pulp** (CMP) is produced with refiners where wood chips are impregnated by soaking in chemicals before refining. This softens the wood by dissolving some of the lignin, although consequently the yield drops below 90 percent.
- **Chemi-thermomechanical pulp** (CTMP) is produced similarly to CMP but the refining is done under elevated pressures and less chemicals are used.
- **Bleached chemi-thermomechanical pulp** (BCTMP) is CTMP that has undergone a bleaching step in its production (Walker, 2006).

Mechanical pulping processes are electricity intensive. The energy consumption in mechanical pulping is dependent on the pulping process, the properties of the raw material (wood species) and, to a large extent, the quality requirements (freeness) of the pulp that is set by the desired end products.

2.3. Bleaching

After the pulping process, the cellulosic pulp obtained has a brown colour due to dissolved lignin being still soaked in the cellulose. Lignin remains a major constituent of pulp even after digestion by chemical pulping, therefore, the removal of lignin by bleaching is regarded as a continuation of the pulping process. Any lignin that remains in a pulp will continue to darken with age and impact the end product (e.g. will cause the yellowing, darkening and embrittlement of newspaper exposed to sunlight).

Besides lignin, raw pulp also contains a significant amount of other discolouration. Thus, it is often subjected to a bleaching process to produce the light-coloured or white paper preferred for many products, such as printing, tissue and sanitary paper. Brightness may be achieved by either lignin removal (delignification) or lignin decolonization (removal of microorganisms degrading lignin).

Bleaching that removes lignin gives more brightness to the pulp than is possible with lignin decolonization and also leads to more durable and stable paper. In addition to the removal and decolonization of lignin, bleaching serves to clean the pulp of dirt and foreign matter that escaped the digestion process (US congress, Office of Technology Assessment, 1989).

The fibres are delignified by solubilizing lignin from the cellulose through chlorination and oxidation. The chemical substances used include chlorine dioxide, chlorine gas, sodium hypochlorite, hydrogen peroxide and oxygen. These bleaching agents are responsible for the harmful substances generated in paper manufacturing due to the formation of toxic organic chloride compounds (Sharma et al., 2020).

The bleaching process of chemical pulp is a multistage sequential procedure carried out with two or more chemicals to achieve high pulp brightness. In the bleaching process, substances such as phenol, resins and lignin which are present in wood react with chlorine and chlorine-based compounds and are transformed into highly toxic pollutants. For decades, chlorine and hypochlorite have been used for chemical pulp bleaching because they are less expensive and produce very bright pulp, however, many modifications to the process have been carried out because of pressures on the environment and stricter environmental norms (Sharma et al., 2020). Further reductions of effluent volumes and pollutants through modifications in the bleaching process are a must to deal with the environmental externalities and at the same time fulfil the needs of the industry for very bright and strong pulp.

2.4. Papermaking

Bleached or unbleached pulp is refined to cut the fibres and roughen their surface as they enter the paper machine. Water is added to the pulp slurry to make a thin mixture normally containing less than 1 percent fibre. The diluted fibre slurry is then cleaned in and screened before being fed into the press section at the wet end of the paper-forming machine. Here, the wet fibre mesh passes between large rollers loaded under high pressure to squeeze out as much water as possible. The diluted fibre slurry passes through a head-box that distributes the slurry uniformly over the width of the paper sheet to be formed (pulpandpaper-technology.com, last accessed 27 April 2023). Wet-end operations remove water from the slurry and form a sheet, which is then moved to the dry end of the paper-forming machine to dry, coat, smooth and wind the sheet around a large reel before it is transformed into a variety of final products, as detailed in the following section.

Paper and paperboard products include several categories of finished products with different qualities and applications. Compared to paper, paperboard is a heavier paper product commonly made in several plies into a multi-ply construction.

Definitions of the term paperboard vary. According to the International Standardization Organization (ISO), a paper product with a grammage exceeding 200 g/m^2 is paperboard, however, the definition used by the Confederation of European Paper Industries[4] (Cepi) reads that "paper is usually called board when it is heavier than 220 g/m^2", while in the market, products are labelled as multi-ply paperboard with weights starting at 160 g/m^2. Two clear features distinguish paperboard from paper. Paperboard contains a greater proportion of long fibres than paper and it usually does not contain fillers (Iggesund.com, last accessed 28 April 2023), namely water-insoluble particulate substances ranging in size from about 0.1 to 10 µm that are added to cellulosic-fibre slurries before the formation

[4] Confederation of European Paper Industries is an industry association composed of representatives of national paper associations from Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland.

of paper (Hubbe and Gill, 2016). The advantages of the multi-ply construction of paperboard lie in the ability to optimize fibre characteristics in the different plies to reach certain functionalities.

Paper and paperboard products can be divided into the following groups of products (adapted from UNECE/FAO, 2021):

1. Graphic papers
    a. Newsprint
    b. Printing and writing papers
        i. Coated mechanical papers
        ii. Uncoated mechanical papers
        iii. Coated woodfree papers (freesheet)
        iv. Uncoated woodfree papers (freesheet)
2. Packaging papers
    a. Case materials (container board)
    b. Folding boxboard (carton paperboard)
    c. Wrapping papers
    d. Other paperboard for packaging
3. Household and sanitary paper
4. Specialty paper and paperboard

2.4.1. Graphic papers

Digitization has impacted the printing industries and consequently the graphic papers markets in a significant way. Information gained through digital media is immediate, more competitive and certainly affects the usage and manufacturing of paper producers where a major part of their business is printing-paper products. However, graphic papers (also known as communication papers) continue to be widely used for communication purposes. This group of products includes two main paper-grade types: printing/writing papers and newsprint. Printing and writing papers are broadly segmented into four major grades: coated woodfree (freesheet), uncoated woodfree (freesheet), coated mechanical and uncoated mechanical papers.

Printing and writing papers are used for magazines, catalogues, books, commercial printing, business forms, stationery, copying and digital printing. Newsprint is a low-cost non-archival paper consisting mainly of wood pulp and most used to print newspapers and similar short-lived publications and advertizing material. It is usually made by a mechanical milling process that excludes the chemical processes that are often used to remove lignin from pulp. Newsprint paper is used for the printing of newspapers, flyers, and other printed material intended for mass distribution (researchandmarkets.com, last accessed 28 April 2023).

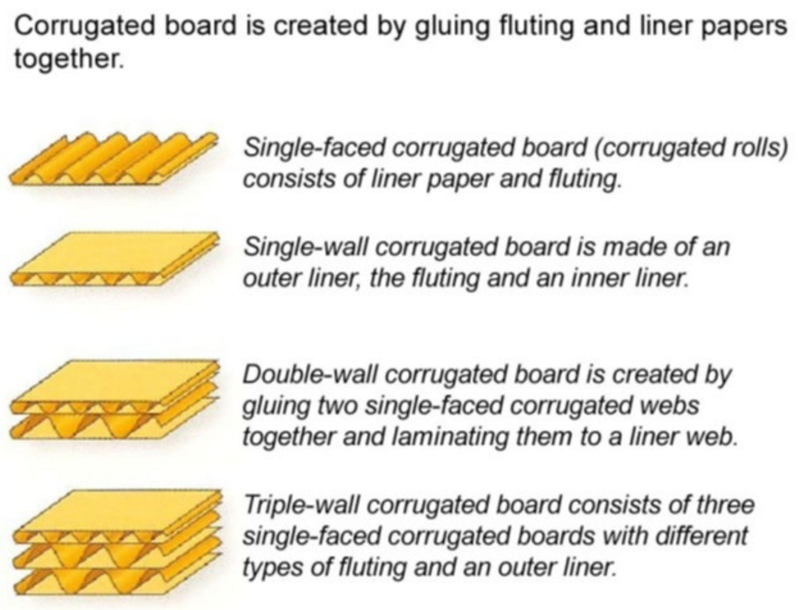
Newsprint has a high utilization rate of paper for recycling whereas other graphic papers are mainly made from virgin pulp. However, both newsprint and other graphic papers enjoy high recycling rates and become a valuable source of raw material used again in newsprint, household, and sanitary papers as well as other paper and paperboard grades. This contributes to circularity and material efficiency.

2.4.2. Packaging papers

Packaging papers have experienced a revival of demand since services like e-commerce integrated sustainability requirements into their business models and turned to paper manufacturers to provide different grades of packaging papers, with mutual business growth benefits for both. Since most online stores sell and deliver all kinds of products, they require a high variety of quality packaging to ensure safe delivery. The preference for paper grade depends on the class of packaging needed for the product being sold.

Packaging papers are used in different categories of paper-based packaging. These include corrugated boxes, folding cartons, paper bags and sacks as well as moulded fibre packaging. The cardboard boxes are one of the most used packaging materials and a core product in packaging manufacturing. They can be seen all throughout the supply chain. They are typically printed and branded with different colours and wording. Cardboard is formed from dried pulp and corrugated cardboard includes two pieces of paper or cardboard, called liners, and a portion of fluted cardboard, which sits in between the liners. Fluting helps to give the cardboard further strength and a higher level of protection against damage (Figure 5).

Figure 5 Corrugated cardboard



Source: https://thecpi.org.uk/library/PDF/Public/Publications/Fact%20Sheets/Case%20for%20Corrugated.pdf Picture to be updated.

Corrugated boxes are mainly used for transport packaging which requires strong and lightweight materials. This is achieved by combining three layers of paper: Two layers of kraft paper (mainly virgin-fibre based) or a test liner (recycled-fibre based) with a central corrugating fluting paper (generally from recycled fibre). Kraft paper (called also kraft liner) is made with at least 80% virgin kraft fiber content. Its advantage is that it is made from pure wood pulp, and the cellulose fiber structure is tightly intertwined, so the paper has a good bearing capacity, good tensile strength, and is difficult to tear. These properties make the paper ideal for the packaging with complex structures and requirements for strength and bearing capacity. Kraft paper is also a special paper suitable for high humidity environments. The term test liner is used to refer to paperboard that is like kraft paper but is manufactured from 100% recycled fiber, with colorants that provide consistent colour quality. The addition of powdered paste helps to increase strength while strengthening the surface of the paper, optimizing the printing ability of the paper. However, because it contains many recycled fiber components, the bearing capacity, as well as the printing results on test liner, are lower than that of the kraft liner (tlppackaging.com accesses 28.08.2023).

The quality of the box being made will depend on the level of fluting required. Increasing the fluting leads to higher use of material and therefore increased strength, therefore it is used for high-quality boxes. For cheaper boxes, less fluting can be used which can help to create space-saving, a reduced amount of material used and can lower the carbon emissions.

Corrugated packaging has several advantages including elevated protection for the product, flexibility, and different treatments based on the need. The fluting within the material allows for high durability and strength, to ensure that package arrives safely. Combining structural soundness of the fluting with the cushioning qualities of a linerboard, corrugated packaging can be designed to fit specific protection needs. Protecting against shocks and bumps, it is extremely useful for the packaging of fragile objects.

Corrugated packaging is cost-effective, as its shipping costs are lower due to the lightweight material and higher fill density. It is also sustainable and renewable. Corrugated fiberboard is the most recycled packaging material and is continuously being recycled. Recycling corrugated materials helps reduce the amount of waste disposed of and allows for a constant cycle of reusable material. Most of corrugated material is made up of 70% to 100% of recycled material, further reducing the cost and environmental impact of producing corrugated fiberboard. Another benefit of corrugated packaging is its ability to be reused. Many case styles are designed to be collapsible and used repeatedly. Consumers use this material through its entire life cycle, from moving and shipping packages to using old packaging pieces as floor protectors (bpkc.com accessed 28.08.2023). Folding cartons are made from solid paperboard (virgin- or recycled-fibre based) and are typically used by retailers for packing items sent to end consumers, this includes products such as food, beverages, cosmetics and pharmaceuticals.

When a luxury item is being packed and delivered, a higher grade of packaging paper is used whereas small or non-luxury products employ lower-grade papers. Usually, for more robust boxes, glue and stitching are used to fold sections together and keep the box secure (ribble-pack.co.uk, accessed 28.08.2023)

Another broad category of packaging papers is paper bags and sacks which are used for heavy materials, such as cement, although they are also used in the retail and gastronomy sectors.

Finally, moulded fibre packaging is used to protect delicate items. Egg cartons and beverage cupholders (Figure 6) are classic applications, however, they are increasingly used as trays or for protecting items during transport.

Figure 6 Beverage cupholder

Photo to be updated

The food industry has specific requirements for paper and paperboards. To meet these requirements, paper is treated for improved wet strength, grease resistance and/or to provide barriers against oxygen, moisture and mineral oils as well as to protect food against aroma loss. When used as primary packaging (that is, in direct contact with food), paper is treated, coated, laminated or impregnated with materials such as resins, lacquers or even waxes to improve its functional and protective properties. These treatments are commonly used for corrugated boxes, milk cartons, folding cartons, certain paper bags and sacks as well as for wrapping paper. Tissue paper as well as paper plates and cups are other everyday examples of paper products that are in contact with food.

Box 4 Papers in the food packaging industry

- **Parchment/baking paper**. This is made from an acid-treated pulp where the acid modifies the cellulose to make it smoother and impervious to water and oil which provides some wet strength. These papers, used to pack fats such as butter and lard, are not a good barrier to air or moisture and are not heat sealable.
- **Greaseproof paper**. This is used to wrap snack foods, cookies, candy bars and other oily foods, a use that is being replaced by plastic films.
- **Kraft paper**. This is available in several forms: natural brown, unbleached, heavy-duty and bleached white. Natural kraft is the strongest of all paper types and is commonly used for bags and wrapping. It is also used to pack flour, sugar, dried fruits and vegetables.
- **Corrugated board (or corrugated** fibreboard) resistantt to impact abrasion and crushing damage makes it widely used for shipping bulk food and case packing of retail food products (pgpaper.com, last accessed 28 April 2023).
- **Moulded paper**. This is made from a pulp slurry which is pressed and formed into various shaped packaging trays and containers. Its most well-known applications are egg cartons, cup carriers and protective filling material substituting for polystyrene foam.

There are many more examples of packaging papers, however, their detailed descriptions is out of the scope of this study.

Most of them have a high utilization rate of paper for recycling and, at the end of their useful life, are readily recyclable. And while research shows that paper can be recycled up to seven times, and corrugated box fibres up to ten times, a recent study from Graz University of Technology in Austria found that fibre-based packaging material can be recycled at least 25 times without losing mechanical or structural integrity. While this new research suggests that paper and board fibres are even more durable than previously thought, we know that we still have work to do to try to better understand how many times paper fibres can be recycled in Canadian recycling systems.

2.4.3. Household and sanitary papers

Household and sanitary papers cover a wide range of products used in households as well as commercial and industrial premises. They include toilet paper, paper towels, napkins, some disposable diapers and sanitary pads, facial tissues and several other personal care products. The paper used for the manufacture of these products is processed in a way that makes the final products soft, absorbent and strong at the same time.

Operators in this part of the pulp and paper industry predominantly make soft papers used for tissue grades although some mills also produce more specialized products, such as cellulose wadding and wet wipes. In these production processes, papermaking machines manufacture tissue parent reels, which are large rolls that can weigh up to several tonnes. These are then transformed in the tissue-converting process into finished products, such as rolls of bathroom tissue or kitchen paper towels, as well as folded products like facial tissue, handkerchiefs and napkins.

The transformation process is done through advanced high-speed machines that carry out the complex winding, cutting, slitting, printing and embossing steps while retaining the papers' functional properties such as softness, strength and absorbency. The final products are wrapped and packaged into the format needed for stocking in a supermarket or other distribution centre before going to the final consumer (tissueeasy.com, last accessed 29 April 2023). Some companies specialize in converting and, as such, do not always make their own paper, but rather purchase parent reels on the international market.

Cellulose fibres used for making household and sanitary products are made either from paper for recycling or from virgin pulp. When paper for recycling is used, mills often have deinking facilities to remove printing inks from fibres on site. For virgin pulps, the importance of both strength and softness in the finished products is critical, therefore, the fibres used are often a blend of long and coarse fibres for strength while short and even fibres provide softness. The pulp is then bleached to obtain white-paper grades (paper.org.uk, last accessed 29 April 2023).

The demand for hygiene products continues to increase and manufacturers make products for various market segments, from branded premium products focused on intrinsic qualities to generic grades focused on price. Consumers are used to using white tissues, however, there are campaigns to raise awareness of the environmental benefits of the lower levels of brightness of recycled tissue products and encourage customers to buy such recycled products.

When it comes to the end of life, most sanitary papers are not collected for recycling due to their specific uses, however, they can be collected with biowaste and composted or, in the case of toilet paper, they become part of municipal wastewater sludges that can be used for biogas production. Since the early 2020s, there have also been projects to collect paper towels selectively to recycle them. Paper towels for drying hands in washrooms in airports, larger office buildings and the like are collected through specific containers placed in washrooms and reserved exclusively for paper towels. Paper towels are kept separate from other waste streams during logistics and are then recycled in paper mills to produce new tissue papers (Essity, 2023).

2.4.4. Specialty papers and paperboard

Speciality papers and paperboard refer to a broad range of paper and paperboard products developed for specific purposes and applications. They include a great variety of products which find their applications in:

- The food and beverage industry
- The fast-moving consumer goods (FMCG) industry
- The cultural sector
- Pharmaceuticals
- Consumer Electronics
- Digital industry
- Garments (itcportal.com, last accessed 29 April 2023)

Some examples of speciality papers and paperboard include teabag filter paper, air-filter bag paper, plug-rap paper, meat-casing paper, insulation paper, lint-free paper, wiper paper, rayon-coated paper, gold threads base paper, adhesive paper base, special tape paper base, wrapping paper for drying agents, stencil paper, tracing paper, long-term preserving paper, surgical tape base paper, oiled paper, hair setting paper, facial tissue and permeable kitchen-wastepaper bags (nipponpapergroup.com, last accessed 29 April 2023).

2.4.5. Innovative products

Besides the production of traditional paper products, pulp and paper mills are involved in the development of innovative products made from production side-streams by using biorefineries.

Biorefineries are processing facilities that convert biomass into value-added products such as biofuels, biochemicals, bioenergy and biopower as well as other biomaterials. Various types of biorefineries have been presented in the literature. They can be defined based on the type of feedstock they use, such as wood-based biorefineries, or the technologies used for the generation of feedstock, typically these are defined as first-generation biorefineries (energy crops, edible oil seeds, food crops, animal fats, etc.), second-generation (lignocellulosic biomass) through to third (algae) or fourth generation biorefinery genomically synthesized microorganisms). To further enhance the efficiency of biorefineries, integrated biorefinery projects, with various biomass conversion technologies and multiple feedstocks have been developed (Denny, 2017).

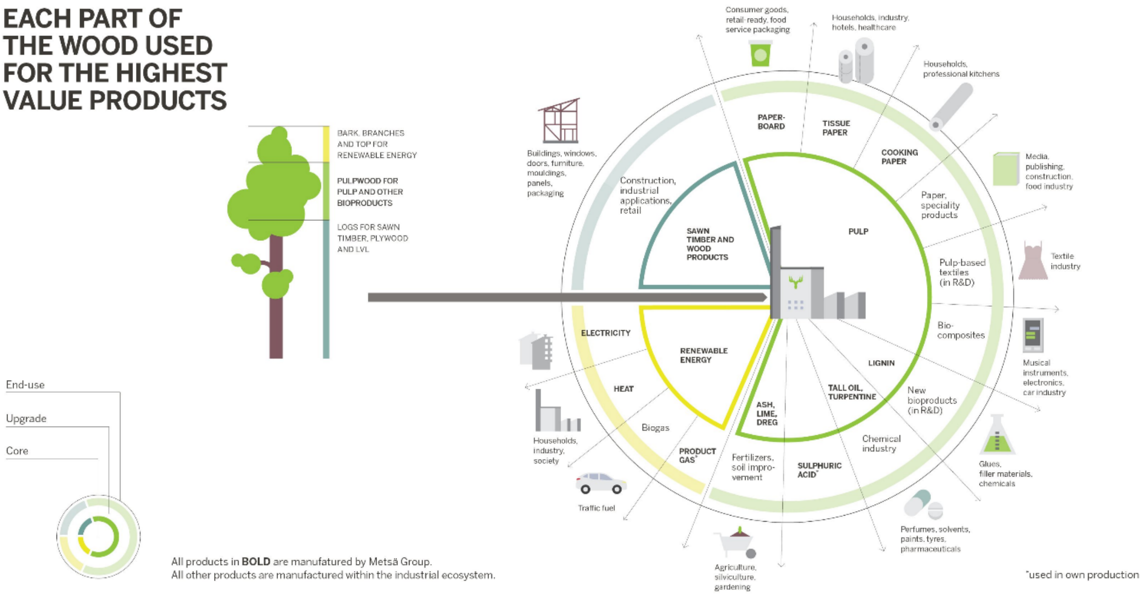
In the pulp and paper industry, biorefineries built on mills' side streams can be divided into three types, namely those:

- based on chemical pulping
- based on papermaking
- based on other processes

A study (Partnering, 2021) has shown that there were 167 biorefineries in Europe, of which 139 were active in 2021 and 28 in the planning phase, with 84 percent of them being of the first type (based on chemical pulping). These emerging biobased products have been estimated to have an annual turnover of almost EUR 3 billion, this equates to approximately 3 percent of the European pulp and paper industry's turnover.

Biobased products are classified as materials, chemicals, fuels, food and feed, pharmaceuticals and cosmetics (Figure 7).

Figure 7 Innovative cellulose-based products



Source: Metsä Group

Innovative cellulose-based products manufactured in biorefineries contribute to the increased sustainability and circularity of the pulp and paper industry because they increase material efficiency by creating value-added products from secondary raw materials, in particular, side streams. Often, they create sustainable alternatives for fossil-based products with a lower environmental footprint.

2.4.5.1. Nanocellulose

Nanocellulose materials are biobased nanomaterials that originate from plant-based materials (https://forestbiofacts.com/, n.d.). Biobased micro-and nanomaterials were invented decades ago, however, their production and use became feasible only with technological breakthroughs made at the beginning of the 21st century. Biobased nanomaterials are used in a range of paper and paperboard products as they add strength or flexibility to them along with some unusual features not commonly found in classic paper products, for example, by making paper transparent. Imparting these features opens new applications for nanocellulose outside of the pulp and paper industry, such as in optical and electronic structures, where they can substitute for fossil-based components. Several companies in the pulp and paper industry are already active in this field.

Box 5 The Paperchain Project - valorization of pulp and paper waste streams

Paperchain is a project financed under Horizon 2020 that examined the potential for valorizing waste streams of five different pulp and paper mills (sulfate, sulfite, mechanical pulp and integrated mills) in Sweden, Spain, Portugal and Slovenia. Mills in these countries all have different types and quantities of waste streams, the most common of which are waste streams from boilers (e.g. ash and slag), bark and wood residues, fibre-containing sludge, green liquor sludge and bio sludge.

Results showed that all five of the case-study pulp mills already had, at least to some extent, valorization processes for waste streams (e.g. in the construction sector).

The project also showed in its five cased studies that there is potential to expand waste-stream valorization beyond existing solutions (Processum, 2017):

- Valorization of the paper industry's causticizing residuals (i.e. lime mud, slaker grits and green liquor dregs) as secondary raw materials for concrete and asphalt manufacturing.
- Valorization of the ash produced in the energy recovery from the paper waste produced by recycling pulp mills as an alternative binder for soil stabilization works in road projects.
- Valorization of deinking paper sludge and wastepaper ash produced by recycling pulp mills for the rehabilitation and slope stabilization of landslides in railway lines.
- Valorization of fibre-sludge waste generated by the pulp industry as secondary raw materials to produce ethanol derivatives for the chemical industry (i.e. paints).
- Valorization of green liquor dregs produced by the pulp industry as reactive sealing layers for acid rock drainage mitigation in mine waste deposits (Paperchain, 2023)

Nanocellulose prepared from wood cellulose has unique and promising properties, such as high crystallinity, viscosity, elasticity and tensile strength which originate from the properties of natural wood cellulose microfibrils (Mohammed Nasir, 2017). Nanocellulose is gaining importance in the development and applications of biodegradable polymer materials and composites due to its biocompatibility, biodegradability and sustainability. In addition to having high mechanical strength and high surface area, nanocellulose structures can be modified, tailored, or combined with different materials to obtain nanocellulose-based biofilms with customized properties (Jayasankar, Janeni, Nadeesh and Adassooriya, 2021).

Nanocellulose is gaining prominence in the rapidly developing range of sustainable materials, nanocomposites, medical and life sciences devices, cosmetics, foods, and packaging as well as in the fields of biomedical engineering, material science and pharmaceuticals. The growing interest in nanocellulose materials is a result of several factors, such as their abundance, good mechanical properties, high aspect ratio, biocompatibility and the fact they are renewable materials (Ilyas, Norizan, Mohd and Nurazzi, 2022).

Nanocellulose also has many uses in electrochemical applications as membranes in energy storage devices such as lithium-ion batteries and solar cells in addition to its uses in anti-corrosion additives in paint coatings and as modified electrodes for electrochemical sensing of biological compounds. Some researchers are using nanocellulose as the substrate in flexible electronics[5] (Figure 8) and these nanocellulose-based electronics are becoming more environmentally friendly, durable and lighter than their traditional counterparts.

Figure 8 Flexible cellulose electronics

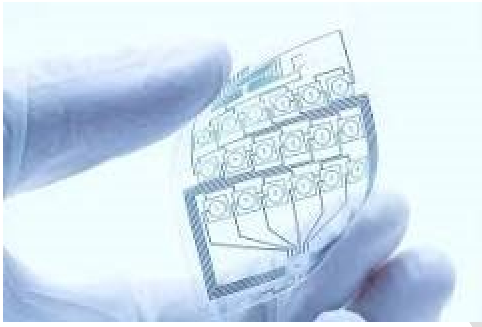


Photo to be updated

The superior properties of nanocellulose, such as good light transmittance, thermal stability and smoothness, are very promising for developing natural-based electronic applications. Besides the foregoing, the use of nanocellulose for electronic-material purposes are expected to provide high performance in terms of physical, mechanical, thermal, and electrical properties and increased durability (Atiqah and Asrofi, 2022).

2.5. Auxiliary products and side streams

Inputs to pulp and paper manufacturing processes include fibrous and non-fibrous raw materials from wood and non-wood virgin sources as well as from recycled fibres in the form of paper for recycling and other secondary fibres from, for example, textile waste. Some chemicals stay in products (coating chemicals and some functional chemicals), while process chemicals, synthetic strength agents and crosslinkers are not retained in products.

2.5.1. Chemicals

The pulp and paper industry continues to be one of the largest users of chemical additives. Even with the increasing usage of electronic media that contributes to decreasing paper use, speciality chemical consumption in the industry is still considerable. As detailed previously, various chemicals are involved in different stages of paper production processes.

Different chemicals are used in the pulp and papermaking process and can be divided into three main areas (Figure 9).

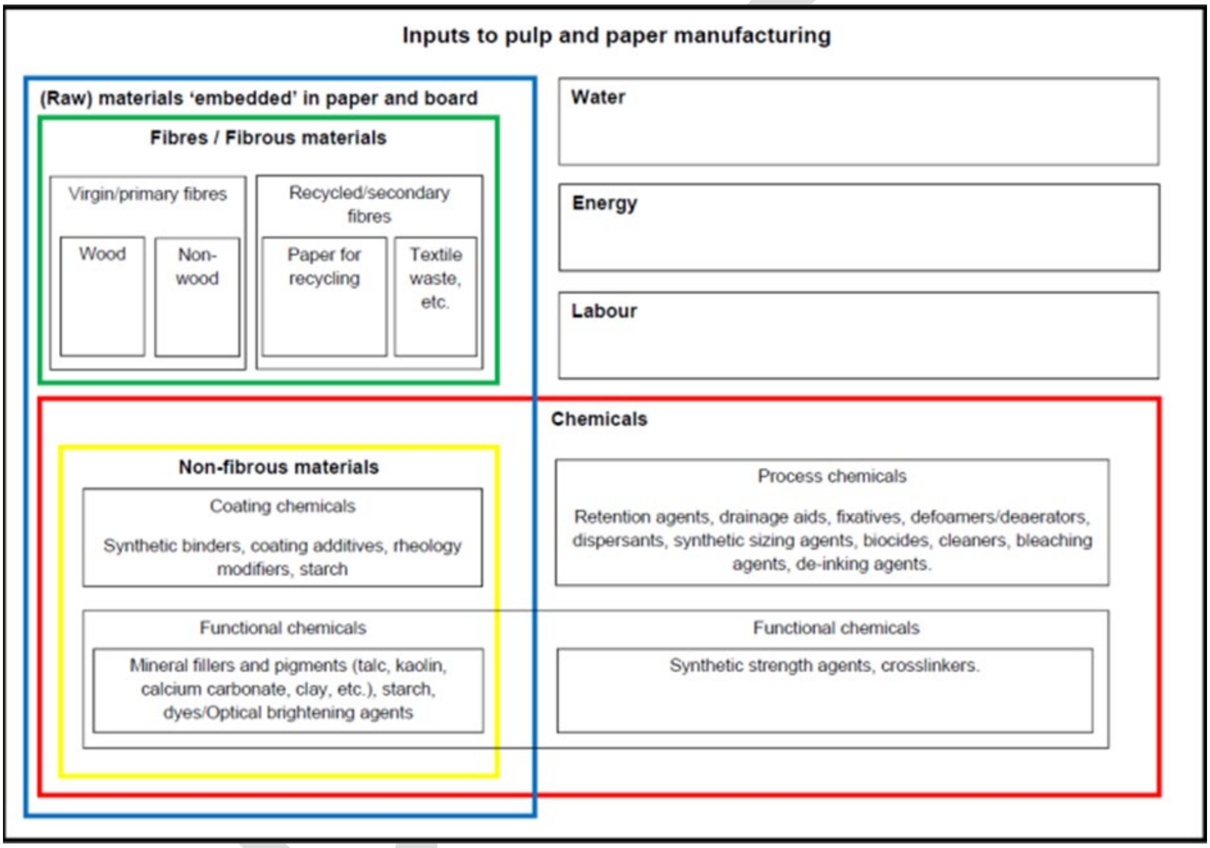
- process chemicals

[5] Flexible electronics is a class of electronic devices built on conformable or stretchable substrates, usually plastic, but also metal foil, paper and flex glass.

- functional chemicals
- coating chemicals

These chemicals have different functions and impacts on the sustainability of paper products. They can reduce the base weight of a given product as there is less need for fibres or they optimize the composition and prevent fibre loss. They also contribute to energy savings as they help to evacuate the water more quickly in the papermaking process. Process chemicals optimize costs and increase machine efficiency, functional chemicals attribute specific properties to paper and coating chemicals improve the appearance and performance of printed paper and paperboard. (Cepi, Pulp and Paper Industry - Definitions and Concepts, 2021)

Figure 9 Inputs to pulp and paper manufacturing



Source: Cepi

Chemical additives used in papermaking fall into three groups, general (commodity) and two classes of specialty chemicals, namely process and functional. Process chemicals are used to optimize the production process by increasing machine speed, runnability, provide deposit control and reduce steam consumption. Retention aids, fixative agents, biocides and defoamers (antifoam additives) are some typical examples of process chemicals.

Functional chemicals directly affect paper quality and paper properties, such as colour, water repellence, strength, printability and so forth. Typical examples of such functional chemicals are dyes, coating binders as well as strength and sizing additives. The boundary between process and functional chemicals is not very definite as process chemicals may either significantly influence the performance of functional chemicals and/or affect paper sheet properties directly. Some 90 percent of all chemicals used in papermaking are functional additives with the remaining 10 percent being process chemicals where retention aids (including fixatives, coagulants, flocculants and microparticles) represent the biggest proportion and most important part (Bajpai, 2016a)

The use of enzymes in pulp and paper production (e.g. cellulase, xylanase, lipase, esterase, amylase, pectinase, catalase, laccase and peroxidase) contributes to enhanced productivity, reduced environmental damage and lower energy requirements.

The development of new chemicals and technologies in the manufacturing of speciality papers, coupled with the growing demand for recycled paper, is expected to open new opportunities for growth in the chemical additives market. Technology innovation, focusing on sustainable processes to minimize environmental impacts, is expected to be a crucial factor in this market development. Functional chemicals are expected to experience high growth over the next few years with process chemicals expected to follow suit, albeit with lower growth rates (Pratima Bajpai, 2016a)

A typical chemical pulp mill uses several hundred tonnes of chemicals per day. They contribute to improved environmental and economic efficiency and it is desirable for such pulp mills to recover and recycle these chemicals.

2.5.2. Non-fibrous materials

Besides cellulose fibres, non-fibrous raw materials are used in the paper manufacturing process. The increase in the use of non-fibrous raw materials has allowed for a more efficient use of fibres and improved the functionalities of finished paper products. For example, in the case of publication papers, the use of clay fills in the gaps between the fibres gives the paper a smooth surface to print or write on and makes it less transparent, which are important features for papers used for printing newspapers and magazines. Other examples of non-fibrous raw materials are calcium carbonate, a mineral applied to paper to increase its whiteness and brightness, and starch, which is made from potatoes, corn or wheat and acts as a binder between fibres, holding them together.

Box 6 Circular starch

When potatoes are processed into chips and crisps, starch is released into the process water. Novidon, a producer of sustainably grown, native and modified potato starch for industrial applications, uses starch recovery machines to reclaim the starch. This 'side stream starch' is refined into both technical and food grade starch for applications, including in the pulp and paper industry which uses this circular starch for the production of containerboard (Novidon, 2023)

2.5.3. Hemicellulose

Hemicellulose is one of key tree cell components next to cellulose and lignin. It is a crucial strength-enhancing component in papermaking fibres.

Only in some applications where pure cellulose is needed (e.g. dissolving pulp for textile applications) is hemicellulose removed. The removed hemicellulose-based components can be converted into a variety of chemicals and fuels that are then used in different industries (Figure 10) For example, furfural is an organic hemicellulose compound, a colourless or brown liquid used to synthesize a wide range of industrial chemicals, including solvents, resins, plastics and so forth.

Figure 10 Different applications of hemicellulose-based components

Source: Cepi

2.5.4. Black Liquor

A typical chemical pulp mill uses several hundred tonnes of inorganic chemicals per day, which are needed for separating lignin from cellulose fibres. The resulting mixture of inorganic cooking chemicals and lignin is called black liquor, the waste from the kraft pulping process after pulping is completed. It comprises an aqueous solution of lignin residues, hemicellulose and the inorganic chemicals used in the process and contains 15 percent solids of which, 10 percent are inorganic and 5 percent are organic (Speight, 2019).

For both environmental and economic reasons, it is desirable for pulp mills to recover and recycle the inorganic chemicals in the black liquor. These chemicals are recovered in a recovery boiler where all the organic components in the black liquor are incinerated while the inorganic components are recovered. As black liquor has a high organic content, in a concentrated form (more than 60 percent of dry matter), it has similar calorific properties to heavy oil. If the water content in black liquor is above 80 percent it has a negative net heating value, which means that all the heat from the combustion of organics in black liquor would be spent evaporating the water it contains (Vakkilainen, 2017).

A mill that produces bleached kraft pulp generates 1.7 to 1.8 tonnes of black liquor (dry matter) per tonne of pulp. Since it is available within pulp mills, it can be conveniently processed into a biomass fuel without additional transportation costs and is utilized to meet the pulp mills' energy demands, which contributes to the mills' economic and material efficiency (Bioenergy, 2007). Black liquor gasification is another technique that has the potential to achieve higher overall energy efficiency than conventional recovery boilers while generating an energy-rich syngas. Syngas can be burned to produce electricity or converted through catalysis into chemicals or fuels such as methanol or biodiesel, all of which also increase circularity and material efficiency.

2.5.5. Tall oil

Tall oil, also called liquid rosin, is a viscous yellow-black odorous liquid obtained as a by-product of the kraft pulping process and is derived mainly from coniferous trees. Crude tall oil can be refined to different fractions like fatty acids, rosins and sterols. These intermediates can be used in a wide variety of applications and products across various industrial and consumer markets. For example, once refined, they can be used to make coatings, sizing for paper, paint, varnish, linoleum, drying oils, emulsions, lubricants and soaps. In addition, tall oil can also be refined into biofuels, thus contributing to a reduction in the use of fossil-based fuels.

Tall oil is a versatile secondary raw material that maximizes the life cycle of wood-based raw materials by providing an alternative to petroleum and vegetable-based oils or by adding value to products such as detergents, soaps, adhesives, lubricants, paints and coatings. In addition, it is a sustainable secondary raw material that is non-land-based and non-food competing biobased feedstock.

2.5.6. Water

The pulp and paper industry consumes fresh water in large quantities and discharges high amounts of wastewater into the environment (Ashrafi et al., 2015, Gavrilescu et al., 2008). Water is used in both the pulping and papermaking process for washing and transportation as well as for heat transfer and energy generation in the form of steam. During the pulping process, wood chips are boiled in a watery-chemical solution and turned into a pulpy soup, however, it is the bleaching process that is the most water-intensive part as a water and bleach mixture turns the naturally brown pulp into a bright-white substance. A pulp mill can use more than 50 million cubic meters of water per year, although most of it returns to its source after use, having been treated and made cleaner than when it was taken. Approximately 5 percent of the water returns to the environment in the form of evaporation (Oliveira, 2017).

Wastewater from a pulp mill contains a lot of organic material (tannins and lignin) from trees as well as chemical contaminants, such as chlorinated organic material from the bleaching process and other persistent organic pollutants (POPs). If properly treated, effluent may be considered safe to discharge into water catchment areas. Mills that discharge untreated or poorly treated effluent can pollute waterways with chemical contaminants and high nutrients from decomposing organic material that will quickly deteriorate water quality (niva.co.nz, last accessed 2 May 2023.)

Box 7 Waste-water treatment technologies for water reuse in pulp and paper mills

Waste-water treatment technologies for water reuse in pulp and paper mills:

- **Filtration technologies** using media and/or membrane filtration to remove particulate solids from waste streams.
- **Biological treatments** use a variety of technologies to break down and/or remove biodegradable solids.
- **Ion exchange and reversed osmosis**, including a variety of resin-based technologies, to selectively remove dissolved ionic contaminants.
- **Distillation**, a heat-driven separation process used to separate liquid components from a mixture, often deployed for the recovery of industrial solvents (samcotech.com, last accessed 2 May 2023).

The amount of water consumption per tonne of air-dry pulp is an important performance indicator for pulp mills. Therefore, pulp mills are becoming more aware of their impact on the environment and reacting to improve their processes to reduce water waste. Important developments have been made to reuse more of the water in the production process that have employed, for example, closed circuits, re-circulations and new bleaching techniques to contribute to decreased water consumption. Some pulp mills reuse water throughout the various stages of the papermaking process, sometimes returning up to 90 percent to the water system once they have finished with it (Sharma et al., 2020).

Besides developments in water treatment technologies, much research is focused specifically on the pulp bleaching process to reduce the toxic compounds and wastewater volumes it creates (Tripathi et al., 2018a, Kaur et al., 2018, McDonough, 1998).

2.5.7. Energy

From an energy consumption perspective, manufacturing one tonne of paper products requires on average about 11.5 GJ of primary energy, which is comparable to that of other energy-intensive products, such as steel or cement (Suhr et al., 2015). However, despite its high energy consumption, the pulp and paper industry is less CO_2-intensive than steel, aluminium and cement (Bernstein et al. 2007). This is due to the widespread utilization of biomass as a primary energy source, which is considered carbon neutral by the Intergovernmental Panel on Climate Change (IPCC).

Overall, about 93 percent of the total energy consumption by the European pulp and paper industry is used to generate heat, mainly for the creation of pressurized steam, and about 7 percent is used to generate electricity. (Moya and Pavel, 2018) Thermal energy in the form of steam is used to heat various products (e.g. water, pulp fibres, air, chemicals, cooking liquor, etc.) and to trigger the evaporation of water from spent liquors and in the dryer section of a paper machine. Thermal energy is also used for the dispersion of fibres derived from recycling paper and the drying of coated paper, among various other uses. In mechanical pulping, electricity is mainly used for the separation of wood fibres and in paper machines to press and dry coatings. Kraft pulping produces more electricity than it consumes. Among these various uses, the area with the greatest potential for efficiency improvements is the drying process as this currently accounts for about 70 percent of energy use (IEA, 2022).

Thermal energy consumption varies greatly between different technologies and products, the process used, fibre quality and the grade of paper needed to be produced. Among paper products, packaging and fine paper are the most thermal energy intensive. On average, the energy consumption per tonne of packaging paper, coated fine paper and uncoated fine paper is 17 GJ/t, 14.6 GJ/t and 12.6 GJ/t, respectively (Moya and Pavel, 2018). Although the average electricity consumption range for different pulp and paper products is much narrower in comparison to the thermal energy, for the same product the consumption of electrical power varies broadly between different mills.

The pulp and paper industry can play an important role in decarbonization by largely adopting new energy-efficient technologies and by making more efficient use of bioenergy sources available on site. Little progress has been made in this area as the share of energy provided by fossil fuels has remained at about 30 percent since 2018 (IEA, 2022). The modernization of old mills, fuel switching to carbon-neutral/renewable energy as well as improving productivity and the quality of products are the most promising options for reducing energy consumption and CO_2 emissions. Apart from the direct CO_2 emissions generated at pulp and paper mills, additional emissions are associated with the off-site production of energy (i.e. steam and electricity) that is purchased and transferred to these mills.

Consequently, bioenergy, which is already a major source of energy for the sector due to the use of pulp by-products such as black liquor, will be particularly important in fossil fuel replacement. For example, a study comparing different scenarios for using one cubic meter of spruce in Austria showed that the black liquor generated as a residue in pulp-making was sufficient to cover the heat and electricity needs of the papermaking process (Lettner, 2017). Therefore, the pulp and paper industry should increasingly recover and use its by-products to reduce the proportion of fossil fuel it uses. Furthermore, pursuing the use of other renewable energy sources is also important, particularly for recycled production, for which natural gas is used when biomass by-products are not readily available.

These other energy-source options include producing heat from renewables such as heat pumps, solar thermal energy and biogas, depending on the resources available.

Chapter 3 Pulp and paper industry context

Paper and paperboard products are part of people's everyday lives and lifestyles. They are used from morning to night and they provide various indispensable products for all. Coffee drinkers use them as filters for their morning coffee. While rushing to work, many people take a book to read on the train or bus and, on less busy mornings, they may read a newspaper. In offices, while most of the work has become more digital, paper is widely used for taking notes and printing documents. Lunch often comes in a paper box and the after-work groceries and shopping are packed in a paper bag. At their homes, people receive mail in paper envelopes and cardboard boxes are frequently left on the doorstep to protect online-shopping deliveries.

Paper and paperboard are also increasingly present in diverse industrial applications in many sectors, such as filters or filling material in packaging. Although they are often not visible to the end consumer, paper-based products are often mixed with other materials, for example, in the production of banknotes and some furniture components. Paper and paperboard are, in fact, essential components of most industrial products' supply chains. They are crucial elements of logistics as they protect goods during transport and handling until they reach the next transformation stage or the retailer where they are unpacked for displayed on shelves.

At the same time, the global pulp and paper industry has been transforming itself in such a way that pulp production is increasingly moving from the northern to the southern hemisphere – especially Brazil, Chile and Uruguay, while paper production is shifting from Europe and the Americas to Southeast Asia – particularly China. In the pulp segment, fast-growing eucalyptus trees and lower labour costs have driven the growth in production capacity in South America which dwarfs all other countries combined. In the paper sector, numerous closures or conversions of newsprint as well as printing and writing paper machines to paperboard, especially in Europe, North America and Japan, have occurred at an alarming rate. However, investment into papermaking and integrated pulping capacity in countries like China and others in Southeast Asia has been significant with more constantly being planned and built as the region's economy grows quickly. This transformation of the industry at the global scale has and will continue to affect communities and economic development in the affected countries in the regions for decades to come.

As such, this chapter will focus on the evolution of production, consumption and resource efficiency trends around the globe. A detailed overview of the latest developments in the industry which is undergoing a major transition, falls outside the scope of this study. Rather, the general overview of the industry context provided here aims to serve as background for the analysis of circularity and sustainability of the pulp and paper industry presented in chapter four of this study.

3.1. Evolution of production and consumption trends

3.1.1. Production

Over the last 30 years, the world has seen a significant shift in fibre supply from the northern to the southern hemisphere. In the early to mid-1990s, major investments into world-class chemical pulp mills saw them being built in countries such as Brazil, Chile, Indonesia and, more recently, Uruguay. Meanwhile, numerous old pulp mills have closed in Europe and North America due to high operating costs and, at times, difficulties associated with government policies that limited their access to fibres.

During the 1990s, Indonesia's chemical pulp market capacity expanded by over 6 million tonnes. In Brazil, the expansion of capacity in the same period resulted in it exceeding 24 million tonnes, a developmental process that was often aided by the Brazilian Development Bank (BNDES) which provided preferential loans to companies. In Chile, expansion has totalled slightly less than 4 million tonnes, while in Uruguay this figure is 4.9 million tonnes (M. Valois, VVM, 2023).

The main reason for this massive expansion of pulp-market capacity in these countries has been their fast-growing tree species, which grow much faster than those in northern-hemisphere countries, where pulp and paper production has been concentrated for the decades leading up to the 1990s. As an example, eucalyptus trees can grow to maturity in five to six years when managed in a plantation-based ecosystem, compared to the 20, 30 or more years most other trees take to mature, depending on the type. This provides a significant competitive advantage and, consequently, the chemical pulp market expansions have concentrated on the South American and Asian continents.

In addition, the size of most new pulp mills has grown along with the capacity of their pulp lines. While most new pulp mills built in the 1990s and 2000s had a one- or two-million-tonne production capacity, or slightly more, modern pulp mills built in the 2020s are designed to have at least three-, four- or five-million-tonne capacities, with each line's capacity exceeding two million tonnes. Having such production capacity concentrated in one line provides cost advantages and strategic opportunities, however, this can also exacerbate supply-demand imbalances in the global market.

Competing producers find it necessary to counter the aggressive entry of so much pulp into the market by lowering prices, while buyers see the opportunity to obtain fibres at a lower price. High-cost mills that are unable to compete in such a low-price environment find themselves having to move into value-added specialties, take downtime until prices recover or close permanently.

In China, where the demand for imported fibre has grown from a few hundred thousand tonnes of chemical pulp in the early 1990s to over 30 million tonnes (including dissolving and fluff pulps) in 2022, many large conglomerates that produce paper, packaging papers and tissue are in the process of building integrated pulping facilities. This phenomenon is being repeated in several countries to limit exposure to volatile and uncontrollable global pulp prices.

This will likely impact global sales to these countries, including China, as the demand for imported pulp is expected to slow down. Furthermore, in 2021, the Chinese government banned the import of recovered papers and, consequently, Chinese paper mills opted to secure an alternative supply of recovered fibres by importing recycled brown pulp. This resulted in a reconfiguring of the flow of global recovered papers (, M. Valois, VVM, 2023).

In 2022, the share of employment in the pulp and paper sectors was between 0.2% and 0.7% (Eurostat, U.S. Bureau of Labor Statistics). The total number of jobs in the sector went down in the 2000s before stabilizing and even recovering in some countries thanks to the adaptation to a context of decreased demand for graphic paper, and increased demand for packaging and cardboard.

The sector offers highly technical jobs and generates activity in downstream and upstream sectors such as those producing, supplying, and maintaining machinery.

Most of the jobs in waste management are in countries where the paper is used and often the material is provided to near-by paper industries. The Paper Scrap Recycling Industry employs a relevant number of people. For example, in 2018, in the United States, 40 thousand people worked directly in this sector, the equivalent of 11% of the pulp and paper industries or one third of the forestry and logging activities (ISRI, 2019).

From an employment perspective, increasing circularity in the pulp and paper sector will rely on upscaling the collection, sorting and recycling facilities, leading to more jobs in these sectors, further development of research capacity to design products easier to recycle, innovative products from paper for recycling as well as new recycling processes.

3.1.2. Consumption

Overall changes in consumer habits over the last few decades have impacted the paper and paperboard sector's trends. For example, the production of graphic paper declined due to reduced consumption because of increased electronic communication. (UNECE/FAO, 2021)

While the consumption of publication papers grew steadily in Europe and North America during the 1980s and 1990s, at the beginning of the following decade, this trend was reversed in North America. Globally, a downward consumption pattern began to show in the mid-1990s, when declining newsprint consumption resulted in 32 million tonnes of global capacity being either closed or converted to printing and writing papers or packaging grades. As for printing and writing paper machines, over 73 million tonnes of global capacity were permanently shuttered with many machines converted to packaging grades where demand was growing.

In the 2000s, reading habits also changed as consumers increasingly used electronic media. In Europe, a reversal of this trend was observed several years later, namely in the second half of the 2000s, and it accelerated with the financial and economic crisis of 2008. Generally, the quicker information became outdated the more likely consumers were to use electronic media to source it. Accordingly, the first sector to be affected by this development was newsprint, followed by other printing and writing papers.

In the 2010s, the downward trend in the use of print paper continued. In the United States, the production of paper for newspapers dropped to less than 33 percent of its peak in the early 2000s. One prominent example among many was "Newsweek" Magazine which, having been in continuous print since 1933, was discontinued on 31 December 2012.

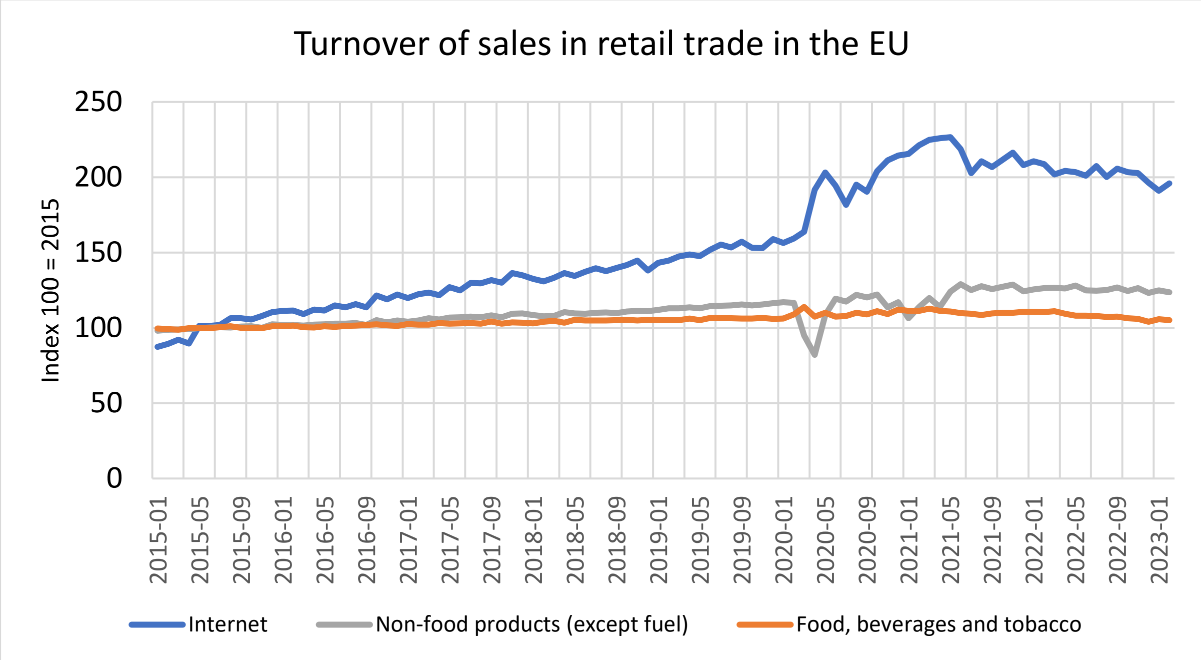
While newsprint as well as printing and writing paper machines have been shuttered or converted in Europe, North America and elsewhere, China remained one of the few major countries where paper capacity in these segments kept growing as its economy experienced continuous growth. Since the 2010s, over 190 million tonnes of paper capacity have been built or announced to support the production of pulp, newsprint, printing and writing papers, packaging and sanitary papers.

In contrast to the decline in graphic papers-consumption trends, growth continued in the consumption of sanitary and household papers, certain paperboard products, speciality papers and pulps, including fluff and dissolving pulp (UNECE/FAO, 2021). The production and consumption of packaging papers have been growing since the beginning of the 2000s with the increased use of online shopping being attributed as one of several reasons that led to this trend. In this context, optimized logistics and transport, especially over longer distances, require increased protective packaging and this has been accompanied by GDP growth in many parts of the world, leading to more consumption and hence a greater need for packaging.

A further contributor to the increase in the use of packaging paper has been innovation in digital printing technology. While the primary function of the packaging is the protection of goods, advances in digital printing allow all kinds of packaging, including corrugated board to function as a carrier of messages (i.e. advertizing functions). All of these factors have led to an increased use of paper packaging, especially case materials that are used to produce corrugated boxes.

Figure 11compares the development of turnover in retail and e-commerce. While retail trade slightly increased from 2015 to 2022 both for food and non-food products, sales in e-commerce doubled in the European Union between 2015 and 2020. This development accelerated during 2020-2021 due to COVID-19-related lockdowns in many countries but has been flat since the pandemic's end.

Figure 11 Turnover of sales in retail trade in the EU



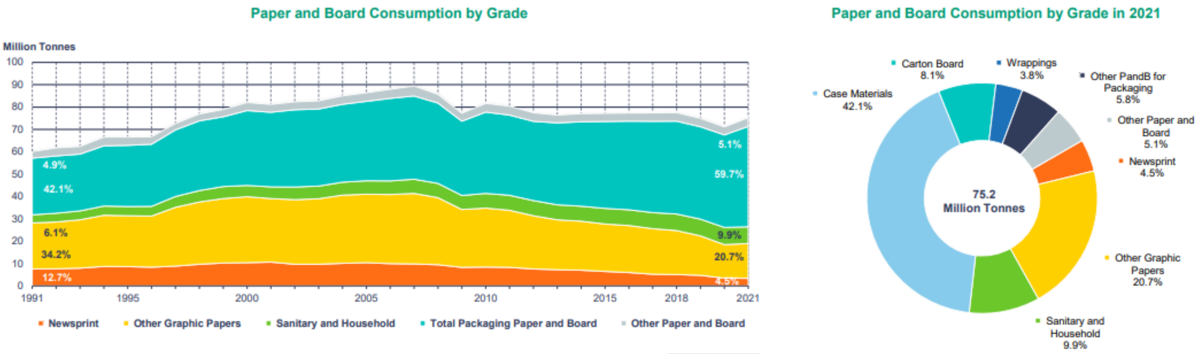
Source: Eurostat, 2023

In parallel, sustainability efforts have also contributed to a strong trend in substituting plastic with paper, in particular for packaging. According to the European Commission, in 2015, as much as 59 percent of plastic waste generation in the European Union came from packaging while demand for recycled plastics accounted for only around 6 percent of plastics demand. This was related to low commodity prices and uncertain market outlets for recycled plastics (European Commission, 2018). Sustainability and circularity concerns related to plastics' reuse, combined with the low economic viability of plastic recovery, created opportunities for other materials, such as paper and glass. Use of these latter two materials expanded in the packaging sector thanks to advantages related to their higher recycling rates and physical properties that allow, for example, their contact with food.

Additionally, paper has been successfully used as a replacement for plastics in a wide range of short-lived applications beyond packaging, including single-use straws, cutlery and plates. These types of items became a major source of plastic leakage into the environment and have caused harm to ecosystems, damaged economic activities such as fishing and tourism as well as negatively affected human health through their uncontrolled re-entry into the food chain. Considering these events, particularly affecting the pollution of oceans, numerous brand owners and retailers made commitments to significantly reduce or stop the use of single-use plastic items and to replace them with sustainable alternatives, including materials made of wood-cellulose fibres. To a large extent, these voluntary commitments have been driven by shifting consumer preferences to avoid plastic in packaging and other short-lived applications.

The overall trends in the consumption of paper and paperboard by grade between 1991 and 2021 have been captured by Confederation of the European Paper Industries (Cepi) statistics for their member countries (Figure 12) In 1991, newsprint represented 12.7 percent of total paper and paperboard consumption, by 2021 this figure had dropped almost threefold to 4.5 percent. In contrast, during the same period, case materials experienced growth from 42.1 percent of total consumption to 59.7 percent.

Figure 12 Paper and Paperboard Consumption by Grade based on data provided by Cepi



Source: Cepi

Behind packaging as well as printing and writing papers, tissue papers are the third biggest segment in paper and paperboard production. In the European Union, they represent just under 10 percent of paper production. The consumption trends for tissue papers correlate with the general economic development and their production has been growing globally at low but constant rates, typically 4 to 6 percent in developed economies and 8 to 10 percent in developing countries, such as China and Indonesia (M. Valois, VVM, 2023).

Although the recovery of used paper and paper products in industries and service sectors is already high, major progress could be made on the recovery and recycling of household paper and paper products. This progress will rely on informing the public about the importance of paper recycling for the environment.

Waste collection rates are often impacted by the confusion about the rules on how to dispose of various paper products, which vary among municipalities and countries. Consequently, clear and consistent guidance is needed on how to sort scrap paper. Also, since the lack of availability or difficulty to access recycling facilities is a major issue in several areas, there is a need to develop the waste collection infrastructures in local communities. These changes will encourage better sorting, recovery, and recycling of household scrap paper (Nicolas Robert, 2023)

3.2. Resource efficiency trends

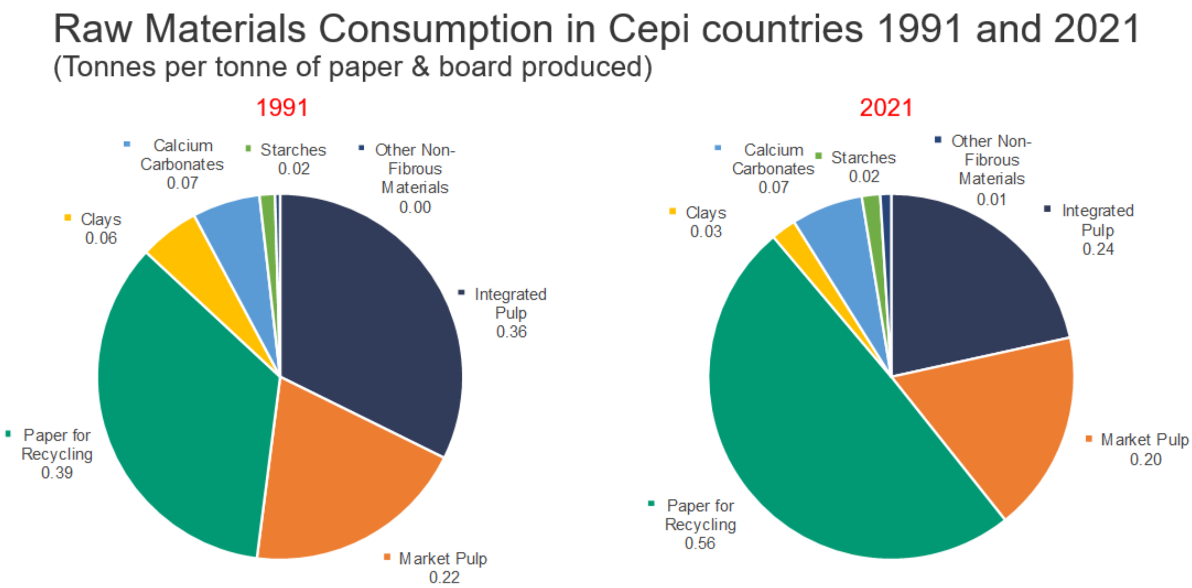
Important indicators demonstrating increased circularity and sustainability in the pulp and paper industry are its use of raw materials, increased recycling, the use of energy and water as well as the overall material use and the use of waste and residues.

3.2.1. Use of raw materials and recycling

The strong growth of the pulp and paper industry and, related to it, an increasing demand for raw materials over the last few decades, has led to a more efficient use of available resources. The pulp and paper industry has always used paper for recycling to produce new paper, however, this practice has seen a strong increase since the beginning of the 1990s. Consequently, the industry succeeded in stabilizing its wood consumption while increasing the overall production of paper and paperboard. This material efficiency has been facilitated by strong investments in new paper mills able to use paper for recycling to produce paper for the printing or packaging industries. Companies traditionally active in northern Europe have invested in new recycling mills in the agglomerations of central and southern

Europe. For example, data provided by Cepi shows that back in 1991, paper for recycling represented 39 percent of raw materials consumption, by 2021 this figure stood at 56 percent. While integrated pulp (pulp from wood fibres that is produced for use as raw material in the production of paper at the same mill), accounted for 36 percent of total raw materials consumption in 1991, it represented only 24 percent 30 years later. Market pulp (pulp from wood fibres that paper mills buy from pulp mills) remained stable over that period as did non-fibrous materials (Figure 13).

Figure 13 Raw materials consumption in 1991 and 2021 based on data provided by Cepi



Source: Cepi

3.2.2. Energy use

Pulp and papermaking are energy-intensive processes. Energy is used at the different stages of the process, starting with the transforming of wood and wood chips into pulp through to the various mechanical and chemical processes. Furthermore, when a pulp is transformed into paper in the paper machine, the wet pulp is distributed onto a moving screen from which water is progressively removed through different processes in heated cylinders. That requires high amounts of energy for electricity and heat. It has therefore for a long time been important to generate energy more efficiently (through the wide application of combined heat and power production), to reduce overall energy consumption by, for example, installing state-of-the-art equipment, and to reduce CO_2 emissions related to energy generation. Energy efficiency and switching to fuels with lower CO_2 emissions are crucial for pulp and paper mills to reduce GHG reductions and remain competitive in the context of increasing energy costs. Next to raw materials, energy is one of the most important cost factors in papermaking. It ranks second in the cost structure of the European pulp and paper industry, and the pulp and paper industry is the fourth largest industrial consumer of energy in the European Union. (Moya, 2018)

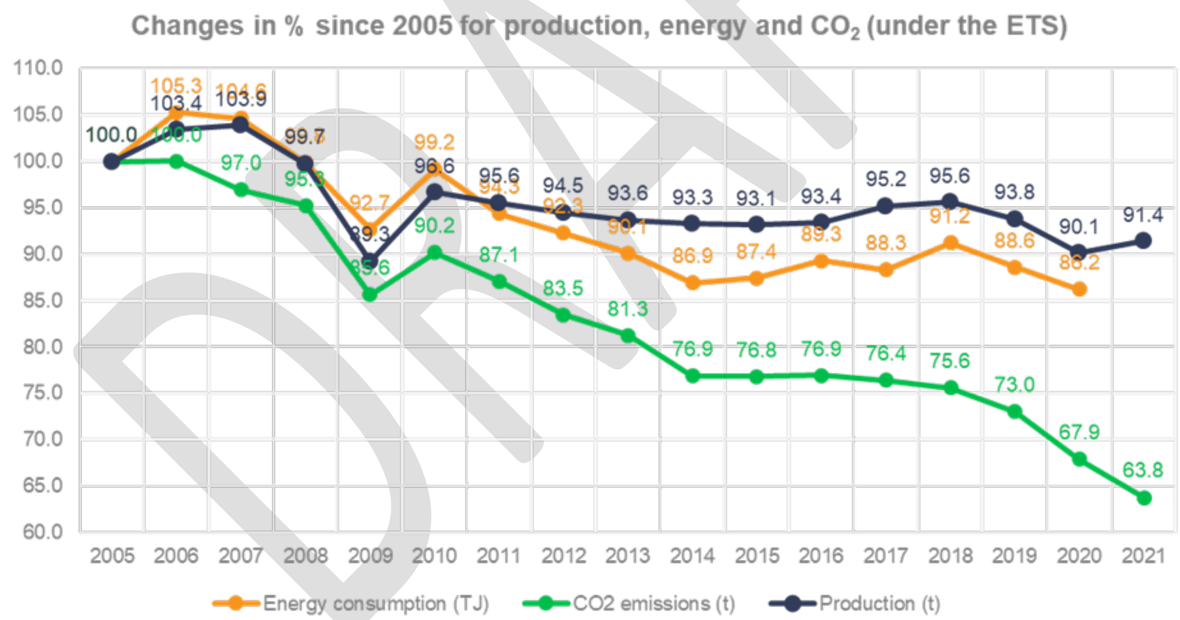
The specific primary energy consumption, that is the primary energy consumption per tonne of product, has decreased in the last 30 years by 16.3 percent. Data provided by Cepi demonstrates that biomass is the largest source of primary energy in paper mills, followed by natural gas. Fuel oil, coal and other fossil fuels played a bigger role in the past but today are used only marginally as the industry had to cut down on emissions. More than 60 percent of the pulp and paper industry's fuel consumption in 2021 was biomass compared to 45 percent in 1991 (Cepi, Annual Statistics 2021, 2022).

The share of biomass in pulp and paper industry energy generation is even higher at the global level. Some 63.7 percent of the onsite energy needs of the International Council of Forest and Paper Association's (ICFPA) pulp and paper industry members were met by biomass and other renewable fuel sources in 2021, a strong increase from 53 percent in 2004. The total onsite energy intensity has, however, only decreased by 1.5 percent over the same period (ICFPA, 2023).

The described reductions and shifts in the use of energy are crucial to decarbonize the pulp and paper industry and have helped the industry to be successful in decoupling pulp and paper production growth from CO_2 emissions. Since the 2000s, CO_2 emissions have decreased in the global pulp and paper industry and the industry's GHG emission intensity also decreased by 23.5 percent between 2004 and 2021. During the same period, the percentage of bioenergy and renewable fuel used to meet the onsite energy needs of pulp and paper mills increased from 53 percent in 2004 to 63.7 percent in 2021. This was a result of investments in state-of-the-art production technologies (ICFPA, 2023).

Taking a closer look at the European Union, statistical data between 2005 and 2021 (Figure 14) shows a decrease in absolute CO_2 emissions (down 36 percent from 2005) and an even more significant decrease when expressed in emissions per tonne of product (down 47 percent) (Cepi, Annual Statistics 2021, 2022).

Figure 14 Changes in energy consumption, pulp and paper production and CO2 emissions under the EU ETS



Source: Cepi analysis based on verified ETS data (European Commission)

Next to investments into state-of-the-art production technologies, the reduction of overall emissions in the industry is notably a consequence of mills' increased use of their own process residues to generate renewable energy in CHP facilities on site coupled with a shift from mechanical to chemical pulping processes. This latter change was driven by market and product evolution. Papers manufactured from mechanical pulp, such as newsprint, have been suffering from reduced demand for years while the production of packaging and tissue papers, which are based on chemical pulp, has seen an upward trend. This has resulted in an increased demand for chemical pulp. In the mechanical pulp process, lignin is not separated from the cellulose and it stays in the product, making it unavailable as a source of bioenergy. In contrast, the chemical pulp process does remove lignin and this becomes a valuable side-stream residue that is used for onsite energy production. As they originate from wood, a biological material, they are considered CO_2 neutral for the energy balance (e.g. the Emissions Trading System in the European Union) and contribute to the lowering of the overall CO_2 emissions. In non-integrated paper mills and mills using paper for recycling, there is an expanding use of less carbon-intensive energy sources, such as natural gas, or carbon-neutral energy sources, such as bioenergy. A share of pulp and paper mills' energy needs are also covered by electricity bought from electricity grids. As the share of renewables is increasing in the electricity mix, this also contributes to the overall decrease of paper mills' emissions. A study entitled 'Energy Hubs. The paper industry's potential as a renewable energy producer' commissioned by Cepi to the consultancy firm AFRY showed that there is untapped potential for paper mills to function as renewable energy hubs. The authors of the study concluded that by 2030, the pulp and paper industry has the potential to increase its renewable onsite electricity and heat production to generate almost 31 TWh. This corresponds to a 30 percent increase in electricity production and almost a 6 percent increase in heat generated onsite compared to 2020. (AFRY, 2023).

This shows that, the European pulp and paper industry has taken major steps to become more efficient in its use of energy while simultaneously trying to decrease its CO_2 emissions through a mix of measures, including investments into state-of-the-art production technologies, the use of own-production residues to generate renewable energy and the application of CHP.

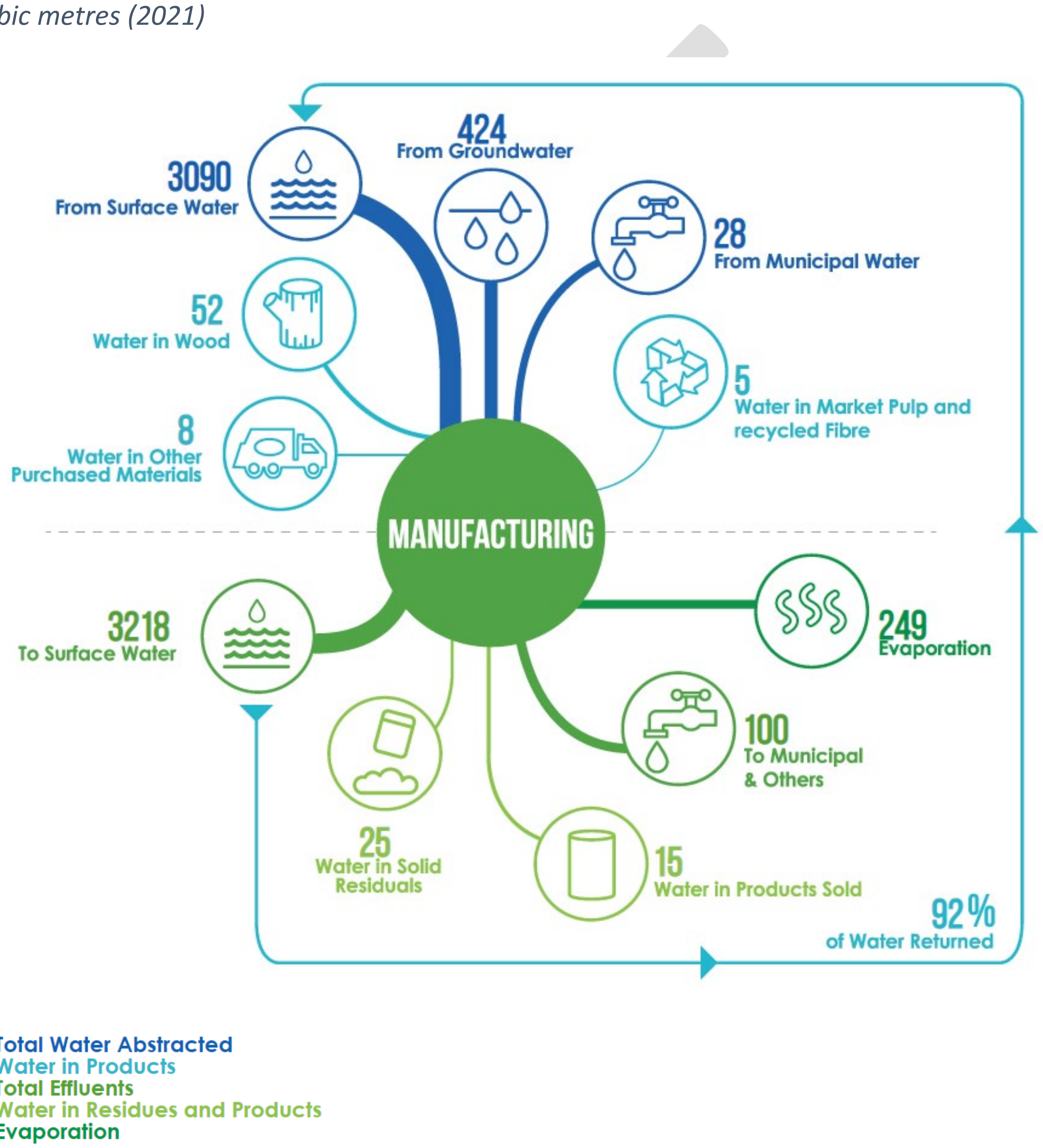
3.2.3. Water use

In addition to fibre and energy, water has been an important resource for the paper industry from the very beginning as it is one of the main elements required for paper manufacturing. For this reason, pulp and paper mills can typically be found next to suitable water sources. Over the years, there has been a lot of progress to reduce the water requirements of the industry and clean used water for returning it to its source. This has been achieved by closing water circuits in pulp and paper mills through the reutilization of used water. The water-quality requirements vary widely in the paper industry depending on the water's role in the production process (e.g. cooling water or process water), the product quality and the types of production processes employed in the given pulp and paper mill. Consequently, the raw water used, and its sources (groundwater, surface water) vary considerably between mills. In many European countries, the raw water used by pulp and paper mills is surface water, however, groundwater is also used for a portion of the process water in some European countries. (Suhr & al., 2015)

Data provided by Cepi demonstrates that in 2021 surface water (rivers and lakes) represented around 87.7 percent of mills' intakes. Some is taken from paper mills' own supplies of groundwater, which accounts for around 11.5 percent and the remaining 0.7 percent is drawn from municipal networks. Since 1991, the average water intake per tonne of paper produced has decreased by 47 percent. It is also important to recognize that intake does not equal consumption because most of the water intake is circulated within pulp and paper mills several times before it is returned to the environment. Before water is used, recirculated, and returned to the environment, it needs to be treated because it contains nutrients and organic matter. Various techniques are used in pulp and paper mills' own water treatment plants, such as filtration, sedimentation, flotation and biological treatment. Some 92 percent of the water used in the European pulp and paper industry is returned into the production process (having been reused within the mill before being suitably treated), with the remaining 8 percent either evaporated, left in the product or bound up in solid wastes. According to Cepi statistics, since 1991, there has been a 95 percent reduction in adsorbable organic halides (AOX) levels (a measure of toxicity due to chlorine compounds) and a 78 percent reduction in chemical oxygen demand (COD) levels (a measure defining how much oxygen is consumed by the decomposition of organic matter in the used water) (Cepi, Annual Statistics 2021, 2022).

The amount of fresh water used in paper production varies depending on the paper grade produced, the nature of the raw materials used and the final quality level within each paper grade. Looking ahead, in regions with scarce water resources or a drying climate, further reduction of water use per tonne of product will be essential to keep the capital-intensive production sites operational. Other driving forces for developing techniques to use less water will probably be the regional costs of raw and wastewater. (Suhr & al., 2015). For example, based on data provided by Cepi Figure 15 illustrates the sources and amounts of water that were used by the pulp and paper industry in 2021. Water going into the system is market in blue. The effluents, evaporation and water in products as well as the residues leaving the manufacturing process are illustrated in green.

Figure 15 Annual water inputs and outputs for the total pulp and paper industry in millions of cubic metres (2021)

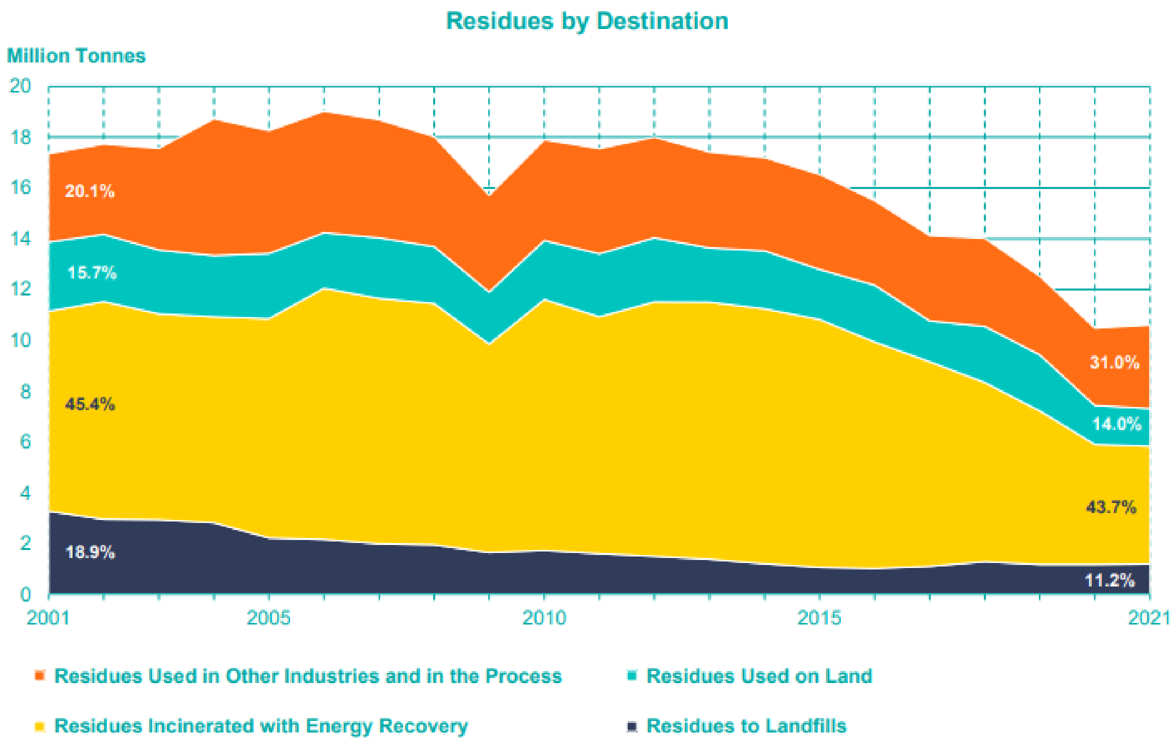


Source: Cepi

3.2.4. Pulp and papermaking residues

The industry has also optimized the use of production residues at different stages of the pulp and papermaking process. Residues are generated from, for example, the debarking of wood before the pulping process, the separating of cellulose from lignin in the pulping process as well as from removing ink and other non-paper components during the paper recycling process. Data provided by Cepi showed that between 2001 and 2021, the total amount of production residue was reduced by 37.9 percent (Figure 16). Most of these residues are used for energy recovery, for example, in recovery boilers to produce onsite energy. However, the share of residues reused in mills or by other industries increased from 20.1 percent in 2001 to 31 percent in 2021. This includes, for example, residues from the pulping process (also called pulping liquors) to produce chemicals and other products that can then be reused in pulp mills. The share of residues that are used on land, such as the use of wood ash for forest soil improvement, has remained relatively stable. Consequently, both the share and absolute amounts of residues that end up as waste in landfills significantly decreased during the same period.

Figure 16 Residues from pulp and papermaking by destination



Source: Cepi

3.2.5. Lightweighting

Lightweight papers include a variety of different types of low-thickness and high-opacity papers. They find their application in the production of voluminous printed works such as handbooks, dictionaries, encyclopaedias and in other uses that require low bulk or weight, for example, for material that will be mailed (Dewitz, 2015). Lightweight papers are also widely used in the packaging of shipments worldwide as commerce and industry seek economical and environmentally sustainable packaging solutions.

For example, corrugated cardboard is a structure with two solid liners outside and a light layer in the form of a wave between them, this combination provides low weight and high stiffness. It provides properties with economic and environmental advantages that are sought by industry and, therefore, the preference for corrugated paperboard packaging has seen an uptrend, often at the expense of other paperboard packaging. However, other paperboard packaging continues to be used for shipments since it has different advantages as, for example, it is more suitable for heavy-duty consignments, use in humid conditions and for frozen food. As less material is used in corrugated cardboard packaging, industries using it face lower shipment costs and costs related to managing the products' end-of-life through schemes such as extended producer responsibility. In extended producer responsibility schemes, responsibility for the end of life of the packaging is extended from the person who disposes of it to the actor that placed the packed good on the market. This means that the placer pays for the costs incurred once the packaging arrives at its end-of-life and needs to be collected, sorted and recycled.

Although the primarily sought-after goals of paper lightweighting were related to its utility functions and economic efficiency, over many years the lightweighting technique has allowed the industry to produce more square meters per kilo of paper. This has contributed to the circularity and resource efficiency along the pulp and paper value chain. Besides material efficiency, lightweighting in papermaking also reduces the use of energy per square meter of produced paper sheets as water is more quickly evacuated from the fibrous suspension in the papermaking process. As an example, a major board producer in Finland has reduced the weight of its board grades by 13.5 percent since the 1980s. In office papers, paper with a 75g or lower grammage, which is an alternative to heavier standard weights (80g per square meter), has seen an increase in demand.

3.3. Industry outlook

The COVID-19 pandemic had profound impacts on consumers use of electronic media, e-commerce habits and demand for hygiene-related products. As such, paper and paperboard consumption patterns continue to evolve and be influenced by these changes in consumption patterns. After the economic downturn caused by the pandemic that started in 2020, paper and paperboard consumption has rebounded by 3 percent. The pandemic and lockdowns in many countries during 2020 and 2021 (until December 2022 in China) have accelerated the structural trends in consumer behaviour, particularly the growth of online shopping, as described in the section on the evolution of production and consumption trends. Awareness of hygiene triggered by the pandemic led to an increased consumption of hygiene products made from paper while the decrease in the use of paper for printing and writing accelerated as publishers were confronted with logistics issues, which led to newspapers not being available on the day when consumers expected them. Consequently, even more consumers switched to electronic media and continued to use them after the pandemic. Even if this acceleration of trends is now slowing down, it is unlikely that it will reverse and consumers return to their pre-pandemic consumption patterns.

In this context, paper producers are forced to anticipate and adapt. In the printing and writing sector, there have been many closures and paper machines have been converted to produce packaging paper grades. Shutdowns of newsprint mills coupled with the even more pressing issue of higher energy, wood and raw materials costs, have led to increased prices for paper and paperboard following the strong post-pandemic recovery of the global economy (Chalmin & Jeroucel, 2022).

As printing and writing papers demand continues to trend lower, the risk of further paper-machine closures is high. While paper prices are dropping considering lower demand, the chances that end users return to using paper to the same level as before the pandemic are low given that the benefits, including cost-savings and the efficiencies of electronic communication, are significant. Furthermore, once printing presses and delivery systems are abandoned, reinvestment into such equipment becomes a non-starter prospect.

Figure 17shows the trends in paper and paperboard production in selected countries between 2010 and 2021 with a noticeable dip in 2020 and a rebound in 2021 in most cases.

Figure 17 Production of Paper and Paperboard 2010-2021

'000 tonnes	**2010**	**2015**	**2020**	**2021**
World Production	**394,006**	**406,706**	**404,999**	**423,419**
China	92,720	108,108	109,903	115,524
EU-27	90,145	87,035	81,849	86,913
United States	75,877	72,603	67,851	69,131
Japan	27,364	26,228	22,887	23,953
India	9,223	11,236	15,008	16,319
Indonesia	9,919	10,881	12,951	12,647
South Korea	11,105	11,602	11,328	11,595
Brazil	9,978	10,453	10,348	10,771
Russian Federation	7,582	8,061	9,489	10,086
Canada	12,790	10,328	8,580	8,671

Source: Fastmarkets RISI

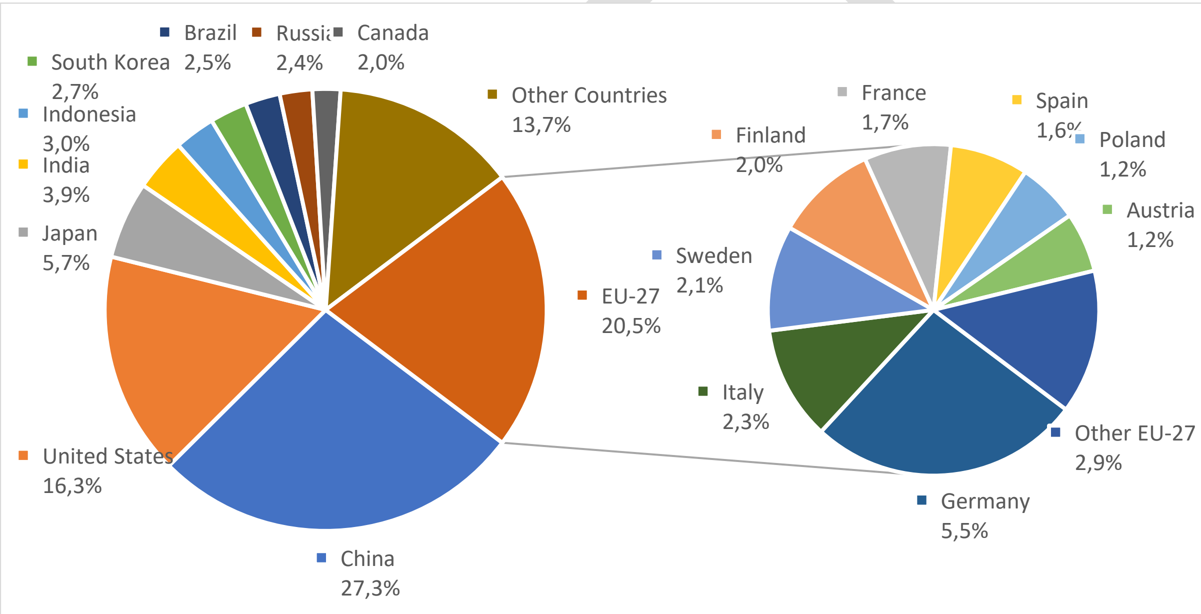
The future of packaging grades looks brighter than that of printing and writing papers given the physical need for the former and the absence of substitutes. Investment in recent years has created significant amounts of new or converted packaging-grade-papers capacity from newsprint and printing and writing paper grades. This, when coupled with the concentration of the industry, has allowed low-cost mills to thrive while leaving high-cost operations with the only option of permanent closure. In addition, the long-term use of packaging grades has been and will continue to be, facilitated by the recycling systems put in place by large end users as well as municipalities to efficiently collect used materials. For example, in 2021, despite the COVID-19 pandemic, the production of packaging grades increased by 3.7 percent in North America and 7.5 percent in Europe (UNECE/FAO, 2022).

In Eastern Europe, the Caucasus and Central Asia (EECCA), paper and paperboard production grew to 11.7 million tonnes in 2021, up 2.6 percent from 2020. The Russian Federation was by far the EECCA's biggest producer of paper and paperboard in 2021, accounting for 9.8 million tonnes of production, which was a 3.3 percent rise from 2020. Chemical wood pulp production in the EECCA in 2021 grew even more quickly to 6.9 million tonnes, up 3.9 percent from 2020, mainly due to capacity expansion in Belarus. There was, however, a largely corresponding increase in the apparent consumption of chemical pulp in the EECCA of 2.5 percent, to 4.5 million tonnes. The war in Ukraine has caused significant changes to the pulp, paper and paperboard industries in Ukraine and the Russian Federation. In Ukraine, factories have been running at a fraction of their 2020 levels owing to damage , abandonment by owners or a lack of personnel. (M.Valois, VVM, 2023). In the Russian Federation, sanctions imposed by foreign countries have resulted in lower exports of pulp, graphic papers and paperboard. Several Russian pulp and paper mills have reduced the amount of bleached pulp production due to a lack of chemicals and are now producing lower-brightness cut-size office papers. A further consequence of the sanctions is that formerly foreign sources for parts and equipment needed for the maintenance of existing machinery now have to be supplied by domestic factories (UNECE/FAO, 2022).

Trends in China have become increasingly apparent given the ongoing moves by large Chinese companies to invest outside China in securing fibre and building integrated pulping facilities. After China had banned the import of recovered paper in 2021, several mills started importing recycled brown pulp from Southeast Asian countries. China continues to announce domestic projects to build up pulp, paper, tissue, and packaging paper production capacity, making its capacity growth the strongest among any segment of the vast pulp and paper industry anywhere in the world (M. Valois VVM).

Figure 18 shows the relative weight of the individual countries in global paper and paperboard production in 2021. China, the European Union and the United States represent roughly 66 percent of global production. Within the European Union, Germany is the biggest producer, followed by Italy, Sweden, Finland and then France.

Figure 18 World paper and paperboard production in 2021



Source: Fastmarkets RISI

Looking ahead, progress in digitalization will likely lead to a further decline in demand for printing and writing papers, which began in the United States in the 2000's but for many other countries, this decline only started at the end of the 2000's. This will lead to either the closure of paper mills producing printing and writing papers or a repurposing of printing and writing paper machines for the production of packaging grades.

3.3.1. Focus on Paper for Recycling

Alongside developments in the demand for sustainable products and business models presented in the section on consumption of paper and board, the availability of sustainable and cost-effective raw materials to produce paper and paperboard is a driver of change. Such change may positively influence sustainability of the pulp and paper industry, however, there are also risks. While the collection of paper for recycling has reached high levels in many countries, there is still potential for more to be done. Studies have shown that 20 percent of paper products are either not collectible, e.g., rare books which may have a value even if they are in bad physical condition, or not recyclable, e.g., most hygiene papers, due to contamination which requires treatment or both, e.g., wallpaper (contamination and small quantities) (EcoPaperLoop, 2014) (Miranda R.).

While there is already a good practice in the development of guidelines on deinkability[6] and the removability of adhesive applications from printed paper products, a growing focus by brand owners, consumers and policymakers on further increasing the recyclability of packaging can generally be observed since the middle of 2010s. This growing focus on packaging design and recyclability is expected to further push recycling rates beyond 80 percent, however, doing so requires collection to be improved, especially collection from households.

In the United States in 2021, 94 percent of the population had access to paper collection (AF&PA, 2021). However, the Recycle Act was passed by Congress in 2021 and is set to improve household collection programmes as it requires the Environmental Protection Agency (EPA) to create a grant programme aimed at recycling education and awareness.[7]

Even though in many countries a large share of households has access to paper and paperboard collection schemes, significant amounts of paper waste are still discarded in the residual waste stream or recycling bins intended for other materials, meaning it is not recycled in the paper industry.

In countries with paper and paperboard recycling rates below 70 percent, there is significant potential for both quantitative and qualitative improvements in paper collection to make more used paper for recycling available for new paper and paperboard production. In cases where paper is not separately collected and remains in the mixed waste stream, it could become relevant as a source of energy, especially in countries where a waste hierarchy is not strongly applied and energy costs are high.

On the other hand, the potential for collection and recycling decreases in the graphic papers as further digitalization will continue to reduce the production of printing and writing papers and these grades are particularly important for producers of new white grades such as publication papers, sanitary papers, or packaging with surfaces to be printed on. Producers of these white-grade papers, who have been relying on the abundant availability of sorted printing and writing papers, will increasingly need to look for alternatives. These include a further sorting of mixed paper and board, using other grades of paper for recycling or switching to virgin raw materials.

Another area where separate collection is underdeveloped is the collection of paper and board packaging for away-from-home and on-the-go consumption.

It should be noted that even if collection and recycling rates are increasing, the overall paper loop needs a continuous inflow of virgin fibres. This is because material losses occur in consumption (paper products that cannot be collected or recycled), collection (paper products that are not correctly discarded by end consumers), sorting (paper products that are not directed into the right stream in sorting centres) and recycling (yield losses in paper mills). Ideally, this inflow of virgin fibres should take place in regions and through product applications where virgin fibres have clear advantages with respect to other sustainability aspects.

Industry experts expect the share of paper for recycling in the global raw materials use of the pulp and paper industry to increase to between 60 and 70 percent in the longer term. According to the Net Zero Emissions by 2050 scenario of the International Energy Agency, the share of paper for recycling in the

[6] Deinkability: Removability of ink and/or toner from a printed product to a high extent by means of a deinking process. This will restore as well as possible the optical properties of the unprinted product.

[7] S.923 - 117th Congress (2021-2022): The Recycle Act of 2021. (23 March 2021). https://www.congress.gov/bill/117th-congress/senate-bill/923

total mix of fibres in global paper production is set to increase marginally to about 60 percent by 2030 (IEA, (2022)).

3.3.2. The role of policies and regulations

Legislation and government strategies have a role in promoting circular approaches and have already been supporting the development of the production facilities of circular and biobased products. This has been done in different ways, for example, by incentivizing certain products designed to help with environmental protection and climate change mitigation. Legislation will continue to regulate or accelerate the phasing out of products considered harmful to the environment and climate or deemed as not contributing to sustainability or circularity goals.

In this context, public procurement regulations are important tools for promoting the sustainable use of natural resources, circular production models and the substitution of fossil-based materials with biobased ones. In the United States, BioPreferred is a public procurement programme from the Department for Agriculture (USDA BioPreferred, n.d.). The goal of the programme is to increase the purchase and use of biobased products, thereby decreasing reliance on fossil-based products that contributes to adverse environmental and human-health impacts. According to the programme, categories for federal purchasing include packaging, insulation and other categories in which paper and paperboard offer solutions with the required biobased content. Besides setting mandatory purchasing requirements for federal agencies and contractors, the programme offers a voluntary labelling initiative for biobased products.

In the European Union, the Plastic Bags Directive[8] was adopted in 2015 to deal with the unsustainable consumption and use of lightweight plastic carrier bags (i.e. plastic carrier bags with a wall thickness of below 50 microns), which are one of the top 10 litter items in Europe. The Directive required Member States to take measures, such as national reduction targets and introducing economic instruments (e.g. fees and taxes) as well as marketing restrictions (bans), to significantly reduce the consumption of such bags. (European Commission, n.d.). The implementation of the Directive has resulted in significant substitution of plastic bags with paper packaging and an increased demand for the latter.

In 2019, the Single-Use Plastics Directive[9] introduced the European Union's rules on single-use plastic products, these rules aim to prevent and/or reduce the impacts of certain plastic products on the marine environment and human health. They also aim to promote the transition to a circular economy with the increased use of more sustainable materials in innovative and sustainable business models, such as reuse models.

While reusable packaging solutions have been around for a long time, renewed interest in them has been sparked by the need for producers to offer more sustainable packaging solutions. So far, reusable packaging has mostly been used only in selective sectors employing reuse models and while these could be expanded, no strong expansion of such models is anticipated in the foreseeable future. Limiting factors here have been identified as being mainly linked to acceptance, the lack of infrastructure, a regulatory push for overall packaging reduction, maintaining product safety and the costs to change.

The global management consulting firm McKinsey (David Feber, 2022)concludes that it is difficult to forecast if reusable packaging will stay a niche product or become the new normal in some sectors. Sectors where reuse could get some traction include beverages, food service, packaged food, home

8 Directive (EU) 2015/720
9 Directive (EU) 2019/904

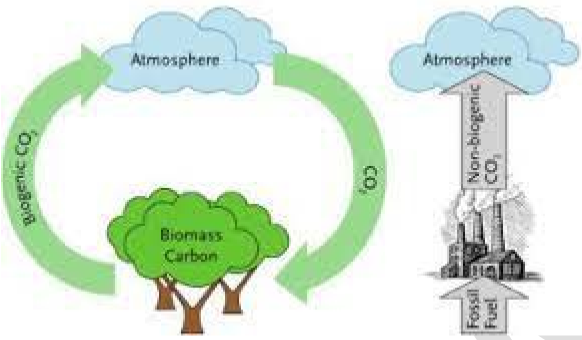
care, e-commerce packaging, retail secondary packaging and transport packaging. Government regulations are among the key enablers for stronger market penetration of such reuse models as they could allow banning certain disposable packaging categories or offering incentives to sustainable-product producers. (David Feber, 2022).

Looking into some of these sectors, such as food service and e-commerce more closely, a report from 2023 (Grunewald, Hornyai, & Jon Haag, 2023)has reviewed existing studies and draws on two case studies analysing the impact of switching from single-use paper to reusable plastics in the takeaway food service sector in Belgium and for the non-food e-commerce sector in Germany. The report found that imposing strict reusable packaging targets in these sectors by 2030 would considerably add to costs, water consumption and CO_2 emissions. The report also noted that at least 20 rotations of the reusable option would be needed to bring environmental benefits. (Grunewald, Hornyai, & Jon Haag, 2023). This confirms that increased circularity has its limitations and does not equal sustainability and, therefore, circularity's long terms benefits should be evaluated case by case. However, despite the existence of such exceptions, government programmes and legislation, including measures to increase reuse, will certainly have an impact on the demand for paper and paperboard.

Chapter 4: Recycling – the pulp and paper industry's most prominent circularity feature

The circularity of all forest-based industries is strongly related to forests and their closed cycles of biogenic carbon. As opposed to fossil carbon, biogenic carbon circulates in a cycle, as it is stocked, released and absorbed again by organic matter as shown below in Figure 19. This process occurs during photosynthesis, when organic flora removes carbon from the atmosphere and deposits it into its leaves, roots, stems and other structural systems. The carbon is then converted into cellulose, which acts as the building blocks for the plants' development.

Figure 19 Flows of biogenic and fossil carbon



Source: IEA bioenergy

Technical solutions can enhance carbon cycles and, in some cases, even lead to negative emissions. Pulp and paper mills are potential sites for carbon capture and storage (CCS) as well as carbon capture utilization (CCU) thanks to substantial CO_2 concentrations in mill operations and the availability of excess heat needed for the capture processes. Other potential sites to undertake CSS and CCU are bioethanol production facilities and power stations along with waste-to-energy facilities. Negative emissions can be achieved by combining bioenergy production with carbon capture and storage (BECCS) or bioenergy production with carbon capture and utilization (BECCU). However, these technologies are neither widely available nor economically viable for industry. IEA Bioenergy mentions that deployment of BECCUs will require public support at several levels, such as the European and national levels because there is a need for financing, co-financing and risk sharing to undertake such large industrial investments (Olle Olsson, 2020).

Circularity in the pulp and paper industry starts with sustainably managed forests. This ensures regeneration in the long term and the availability of forests' goods and services for future generations. (FAO Sustainable Forest Management, 2023).

tThe most valuable part of a tree is used by sawmills that produce off-cuts as a residue, these are also called sawmilling residues or wood chips. Such residues are sold to pulp mills or panel manufacturers to make pulp or wood-based panels.

Circularity continues with the way wood and its by-products are used in the pulp and paper industry and related sectors for added-value products or energy generation. Besides paper and paperboard production, the refining of biobased feedstocks is also an important circularity feature of the pulp and paper industry. Innovative cellulose-based products, such as textile fibres and nanocellulose, contribute to increased material efficiency and the creation of value-added products from side streams. Examples include chemicals, such as various additives and solvents used in the cosmetic and pharmaceutical industries, assorted materials, like textile fibres, polymers and resins as well as for food and animal feed. Often, these value-added products create sustainable alternatives for fossil-based products but have lower environmental footprints. (Richard Platt, 2021)

Circularity in pulp and paper industry processes also involves closed water cycles where water is recycled and reused within pulp and paper mills. After being removed from the wet paper web by gravity and vacuum in the wire section, then by mechanical dewatering in the press section, reclaimed water is reused for dispersing dry fresh pulp or paper for recycling. Some paper mills recover heat from the dryer exhaust with a scrubber, resulting in additional water for reuse.

Before reuse, any small remaining fibre particles are removed by flotation. These fine particles are reused in the pulper as an additional feedstock or transported to other paper mills for reuse in various paper products. Depending on the paper product from which it is reclaimed, the water may also need to be cleaned with aerobic or anaerobic wastewater treatment or with membranes to recover specific components, such as dyes. The sludges resulting from these treatments have several potential applications outside paper mills, for example in the chemical industry or in the construction sector. As such, water circularity already takes place, and can be further optimized, at the process level within mills, at both the mill and industry level as well as at larger scales that involve the value chains and economies at the national or international level.

Existing practice in the pulp and paper industry, as described throughout different sections of this study, builds largely on the material and economic efficiency of production processes. In addition to that, a growing recognition among businesses and consumers about the need for more efficient management and recycling of material streams has contributed to the intensification of the industry's resource efficiency trends over the last several decades (see Chapter 2).

While the benefits of this holistic approach are apparent, resulting in less waste, lower costs and reduced negative environmental impacts, the recycling of paper and paperboard stands out as the key circularity feature for the industry and a true accomplishment when compared to other industries.

In this regard, and as all graphic and packaging papers are recyclable, it is important to recover paper products and avoid their decay in landfills to avoid, among other things, a generation of emissions. Furthermore, as they can be used to manufacture new paper products in closed material loops, their recycling contributes to the broadening of the raw material base for all forest-based industries. However, as the use of recycled fibre is not a one-size-fits-all solution, its use should be based on an evaluation of both the economic and environmental consequences of the collection, sorting and recycling processes. These processes should be founded on good practice and case-by-case assessments. Prescriptive policies and guidelines that require maximizing recycling rates, setting minimums for recycled fibre content in paper products or controlling the flow of fibre markets without taking all these factors into consideration should be avoided.

For this reason, the evaluation of paper recycling prerequisites, existing practice, future potential, and possible limitations have been given a distinct consideration in this chapter.

4.1. Design for recycling

The UNECE/FAO study on circularity concepts in forest-based industries describes how circularity concepts are implemented at different stages of value chains, however, it points out that design for the end-of-life valorization is the single most important factor for all industries in the sector to successfully embrace circularity (UNECE/FAO, 2021).

The pulp and paper industry is not an exception to this rule as the high recycling rate of paper products at the end of their useful lives is largely facilitated by their design. These high recycling rates is in contrast with many other materials with similar use (e.g. plastic packaging) that are often made to serve only one purpose during a short life span. As regards other wood products, while they do not enjoy comparable recycling rates to paper and paperboard, they have other sustainability benefits facilitated by design, such as a long lifetime (e.g. mass timber) or being associated with carbon storage. (Eurostat Data Browser: Recycling rate of packaging waste by type of packaging, 2023). In contrast, paper and paperboard products, as an example of short-lived commodities, extend the lifespan of cellulose fibres through repeated recycling and reuse within the industry.

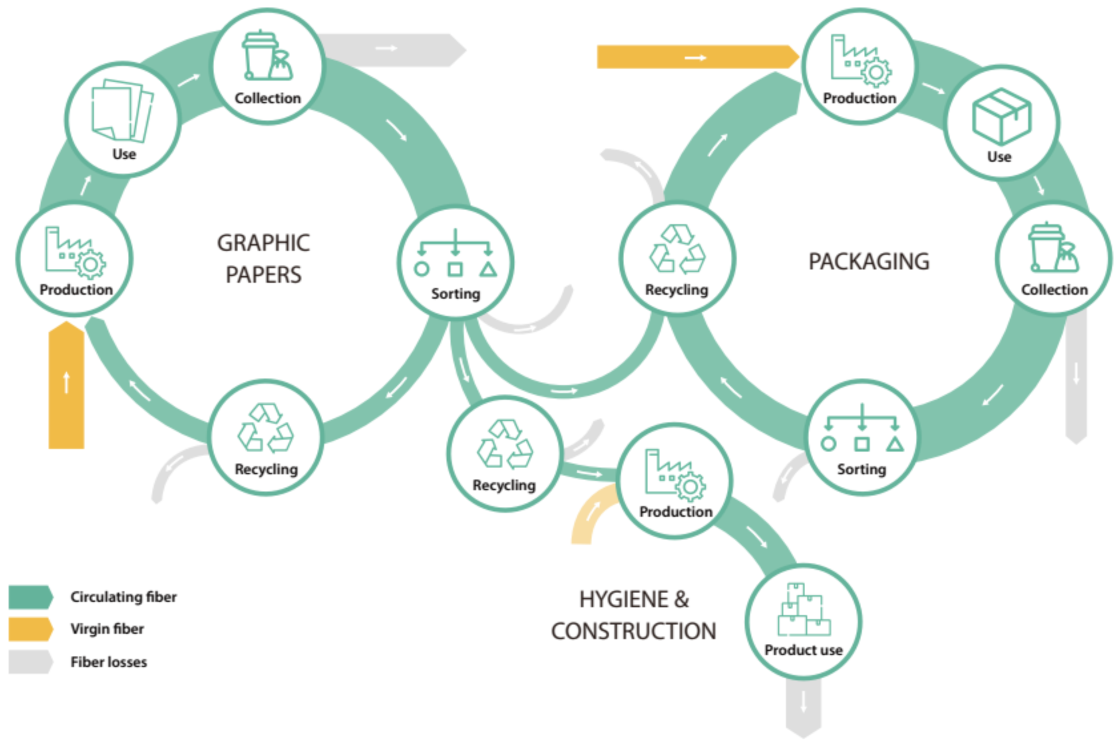
The circular design of paper products is crucial for the sustainable manufacturing of pulp and paper products and to ensure paper recycling continues to function. The concept of circular design for paper products goes beyond the general notion of recyclability. While recyclability is broadly defined as the capability of being useful at the end of life to minimize waste and resource use, the paper industry has closely linked recyclability not only to the suitability of paper products for their purpose but also to the compatibility of paper recycling processes to ensure that desired qualities of newly produced paper products from recycled materials is comparable with those obtained with virgin fibres.

For paper recycling to work, not only the paper substrate but everything else that is added to the paper in terms of adhesives, inks and other components should be compatible with the recycling processes. The European Paper Recycling Council (EPRC) defines paper recycling as the "design, manufacturing and converting of paper-based products in such a way as to enable a high-quality recycling of fibres and other materials in a manufacturing process". Consequently, the recyclable paper definition includes a design aspect in its explanation where it notes: "Paper and paper products designed, manufactured and converted respecting recyclability, which can be collected and sorted into grades of paper for recycling according to the European Standard List of Grades of Paper and Board for Recycling (EN 643)." (EPRC, 2021).

4.1.1. Standard paper recycling processes

The pulp and paper industry uses not only waste and residues of its own production processes but also the end products made of paper and paperboard which have been purchased by customers, used and then discarded. This practice is advantageous for the paper industry because of the material and economic efficiency of the industry's production processes. In paper recycling, there are two basic loops, namely a packaging loop and a graphic paper loop, which sometimes interact. Each contains a specific paper recycling process to which product design is linked. (Figure 20)

Figure 20 Cellulose-based fibres production cycle



Source: UNECE/FAO, adapted from WEF (2016).

Using paper for recycling to make recycled pulp and paper generally entails the slushing of the former in a pulper. In this wet process, paper for recycling is disintegrated, its fibres are separated from unwanted materials mechanically by centrifugal forces and are screened through plates with holes or slots. There are two basic paper recycling processes employed by the industry, although variations of them can be found.

The first basic process takes place in a standard paper recycling mill, which uses paper for recycling consisting mainly of paper and paperboard packaging or mixed papers (packaging and graphic papers), to produce new paper and paperboard packaging. This is often called a ‘brown process’. The different grades of paper for recycling are usually delivered as bales and kept in stock by the different grades, e.g. mixed paper or old corrugated containers. The different grades are mixed in the stock preparation according to the recipe requirements for each paper grade and grammage before being put on a conveyor belt to the pulper. Such mills produce high-quality end products with a classic low consistency pulper (5 percent fibre concentration) and often operate deflakers that separate fibre bundles into individual fibres as well as coarse and fine screening cleaners. This process aims to separate the fibres from other materials. The result is fibrous material suspended in water ready for papermaking (recycled pulp). Figure 21 details the typical process flow and steps of a standard paper recycling mill using packaging or mixed paper.

Figure 21 Typical recycling process using packaging or mixed paper

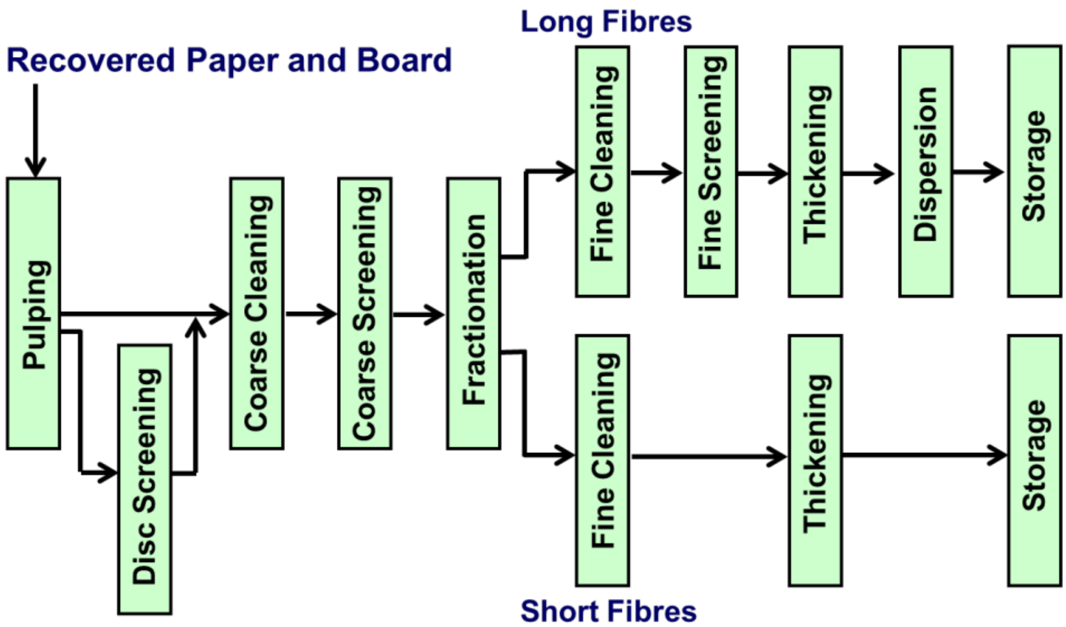


Figure 1: Typical layout for a recycling process to treat mixed and packaging paper for recycling[5]

Source: EcoPaperLoop Project

The second basic paper recycling process aims to create recycled pulp with higher brightness to produce recycled white printing and writing or tissue papers. This process is also called a 'white process' or a 'deinking process' (Figure 22). Here, the raw material consists of printing and writing papers, such as newspapers and magazines, that arrive at the paper mill in loose form. A 'white process' entails a deinking step which is required to remove printing inks and achieve the desired level of brightness. The deinking step consists of two stages:

- Detachment of the inks from the fibres in the pulper, usually with the help of chemical additives (sodium hydroxide, sodium silicate, hydrogen peroxide or soap).
- Separation of the ink particles detached by deinking, which is usually done in flotation cells. In flotation cells, air bubbles are passed through a pulp to catch the ink particles and transport them to the surface where they are skimmed or sucked off. A prerequisite for this flotation process is the hydrophobic character of the ink particles and their certain size range. In many European deinking plants, the operation of a disperser has become state-of-the-art and so has the internal treatment of the process water contributing to its reuse in the closed circular system. Deinking plants have at least one high consistency thickening step to separate the water from the deinking plant and that from the paper machine, which have different pH-levels. Where higher qualities are produced, one or two bleaching stages are also incorporated. (Ecopaperloop, 2014)

Figure 22 Typical deinking process

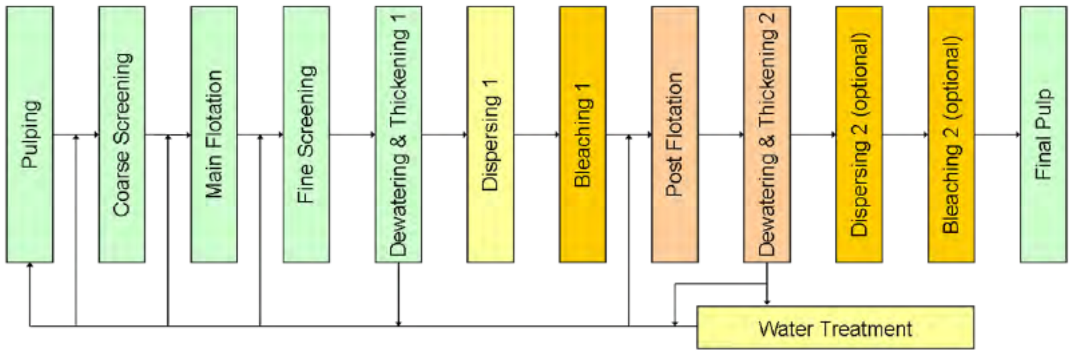


Figure 2: Typical layout for a deinking process (Green: Essential process steps in flotation deinking plants; Green and yellow: 1-loop deinking plant; Green, yellow and brown: Common 2-loop process design for standard grades; Orange: Additional options for higher qualities)[6]

Source: EcoPaperLoop Project

4.1.2. Specialized recycling processes

In individual mills, paper-recycling processes are sometimes complemented by pieces of equipment or adaptations to treat uncommon raw material qualities. Each recycling mill determines its optimal raw material mix (different grades of paper for recycling) and adds one or more pieces of dedicated equipment to achieve this, such as a horizontal high-density drum pulper, a separate batch pulper with longer pulping times, deinking, fine cleaners, hot dispersion, special process and wastewater systems. These adaptations are either added to a mill's continuous process or are process adaptations that are applied to specific batches. As such, mill set-ups can differ from the standard processes and, if they do so, such mills are sometimes called specialized mills. Such specialized recycling mills can treat paper-based packaging that has been layered with various non-water-soluble products such as wax, plastic film, aluminium, polyester and polyethylene, allowing such packaging to enter the recycling process in homogeneous lots. As in standard mills, the result of the process is a fibrous material suspended in water ready for papermaking (ACE, Cepi, Citpa, FEFCO).

4.2. Commitment to circularity and sustainability

While these two basic paper recycling processes are universally applied in the pulp and paper manufacturing industry, it is crucial that they are made consistently known to the different stakeholders in the value chain, those involved in the design and manufacturing of paper end products. Several guidelines and other tools have been developed by the industry actors concerned, sectoral associations and other organizations, either individually or throughout the relevant supply chains, to address this need.

For example, the World Economic Forum (WEF) published a white paper entitled Design and Management for Circularity – the Case of Paper" that has design recommendations addressed to each actor in a paper value chain, from papermaker to converter, printer and distributer of paper products. The recommendations come in the form of questions about the consequences of specific production-related decisions (e.g. the use of certain substances) on the recyclability of a paper product. The WEF's white paper also provides a checklist for specifiers (e.g. order initiators, who order or sell a final paper product) and procurement agents that is designed to help promote materials, substances and practices that increase circularity. (World Economic Forum, 2016).

Besides general recommendations at the industry level, more specific guidance on design for recyclable products in the two basic paper recycling processes is also available. These recommendations exist in the form of guidance documents based on assessments of individual products, tested on their recyclability.

4.2.1. Printing papers

In the area of printing and writing papers, the industry has a relatively long history of adhering to guidelines on collaboration along its value chains to achieve compatibility between the design and production of printed paper products and the recycling process. This has become necessary with the development of new printing techniques and increased variation of processes. Many of these developments and variations may negatively affect, for example, the deinking process and, consequently, the quality of white printing and writing papers produced from paper for recycling. More specifically, problems removing inks from the paper can occur with crosslinked inks (e.g. UV cured inks and varnishes) and with mineral oil-free inks. To address this, guidelines, evaluation protocols and scorecards for printed products were developed for actors in the industry's value chains.

The International Association of the Deinking Industry (INGEDE) has developed a method (INGEDE Method 11) that describes a laboratory scale test to find out how a given type of printed paper would behave in a recycling mill. (INGEDE, 2022). The method forms the basis for a scorecard which evaluates the deinkability of a printed product on a scale ranging from "good deinkability" to "not suitable for deinking". Following similar principles, the EPRC has also published a scorecard for the removal of adhesive applications, based on INGEDE Method 12. This method supports producers of printed paper products in the assessment of the removability of adhesive applications to optimize their products for circularity and ensure they can be recycled in the paper recycling process. (European Paper Recycling Council, 2017). The EPRC deinkability scorecard is used in several ecolabels related to printed products where deinkability is a precondition to being awarded sustainability labels, e.g. the Blue Angel label in Germany, or the EU Ecolabel for printed products. As ecolabels are tools commonly used in the public and private sectors' procurement of sustainable products, the EPRC deinkability scorecard provides an additional incentive for the circular design of paper-based products (Kowalska M., 2021).

4.2.2. Paper packaging

Until the 2000s, the circularity and sustainability focus in packaging aimed at the improvement of the collection, sorting and recycling rates. Since then, as the performance in all three criteria has effectively gone up and the higher potential for increased recycling of paper packaging was identified, attention has been moved to the design for recyclability.

Most paper packaging does not pose any constraints on the paper recycling process and, in the conversion to a final product, there are only minor additions to the product properties which could negatively impact recyclability, especially in secondary packaging (transport packaging). In addition, primary packaging, which is usually more heavily printed, did not pose challenges to the recycling process, as the recycling process for paper packaging does not include the necessity of deinking.

However, since the 2010s, and particularly since the early 2020s, further developments in packaging formats with increased functionalities, partly replacing plastic packaging products, have been taking place. Increasing functionality, e.g. resistance to grease or humidity, while keeping or improving recyclability can be a challenge as some of these new functional properties require packaging to be treated in different ways which may not contribute to a product's suitability for recycling. The pulp and paper industry is addressing this challenge in several ways that are seeing products increasingly developed with their end-of-life in mind. For example, product development includes recyclability tests in laboratories based on correlations with recyclability at an industrial scale and at an industrial scale to optimize packaging for its recyclability.

Industry actors also issue guidance on the recyclability of paper packaging. These actors include the American Forest and Paper Association (AF&PA) which has designed guidelines for packaging recyclability in the United States (AF&PA, 2021), while in Europe, Cepi and other paper-related organizations issued the "Paper-based Packaging Recyclability Guidelines" in 2019. Three years later in the United Kingdom, the "Design for Recyclability Guidelines" was issued by the Confederation of Paper Industries (Confederation of Paper Industries, 2022). In 2023, a European cross-industry association of over 100 members that are involved with the life cycle of fibre-based packaging – from retailers to designers, producers, brand owners and recyclers published its "Circularity by Design Guideline for Fibre-Based Packaging, Version 2" (4evergreen, 2023). When it comes to recyclability testing, test methods exist in the United States and Europe, e.g. in France, Italy and Germany. Current national test methods and recyclability evaluation protocols are still strongly linked to national circumstances while packaging is designed for various markets. To overcome this issue, Cepi generated convergence at the European level with its "Harmonized European laboratory test method to generate parameters enabling the assessment of the recyclability of paper and paperboard products in standard paper and paperboard recycling mills" (Cepi). In the United Kingdom, the harmonized test method is used as a basis for the Papercycle Certification Service provided by the Confederation of Paper Industries to assess the recyclability of paper-based packaging.[10]

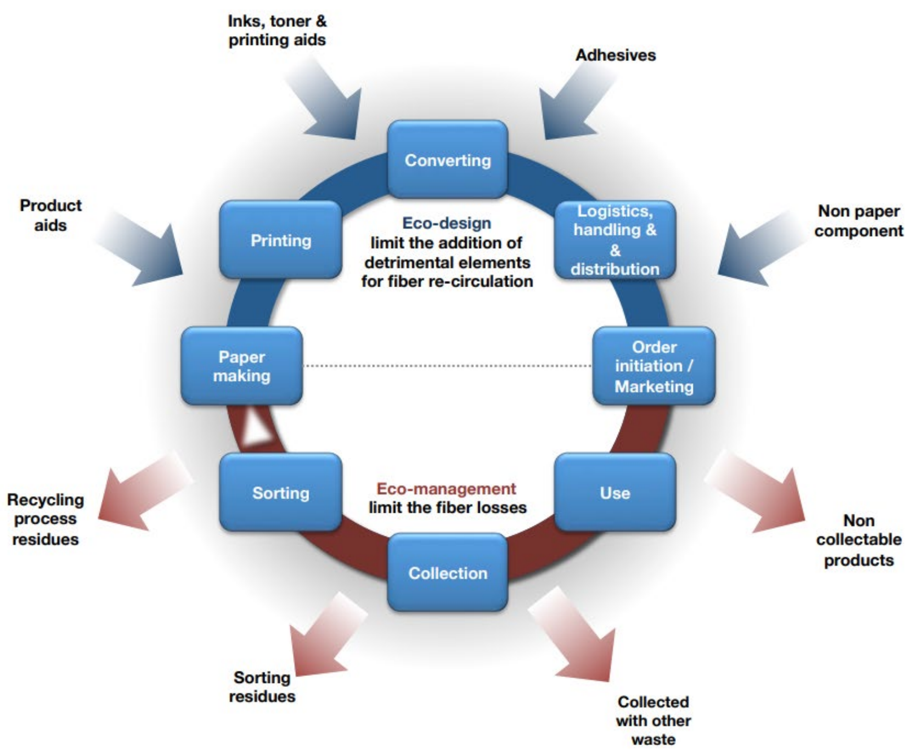
As previously noted, all paper mills are different, however, the core elements of their recycling processes are similar. While recycling is not a standardized process, knowledge about its basic functioning is a prerequisite for guiding paper products' design. If paper products are designed to be technically recyclable in a given mill, they will be recycled at scale, as the types of equipment used to do so are in widespread use globally. The only immutable prerequisite is that paper products are collected and sorted.

4.3. End-of-life management

While paper products design for circularity upstream is key to addressing the industry's downstream recycling needs, the use and end-of-life management of these products also play an important role in improving the overall circularity of pulp and paper value chains. Linking use, collection and sorting to the paper recycling process is essential to ensure that the right qualities of paper for recycling are effectively channelled into paper recycling mills. According to the WEF (World Economic Forum, 2016), the stages of design and production for circularity can be described as eco-design, while the stages of use, collection and sorting are referred to as eco-management (Figure 23).

[10] https://paper.org.uk/papercycle

Figure 23 Eco-design and Eco-management aspects of the paper recycling loop



Source: World Economic Forum

4.3.1. Collection

The collection of paper for recycling is a part of the life cycle of paper products which involves citizens directly. The collection of paper for recycling has developed organically and at different speeds in different regions of the world because of the demands for used paper by paper mills, often locally in the beginning. Since the 1990s, public environmental awareness has grown and many countries have enacted waste-related legislation that has also contributed to increases in the collection of paper for recycling. The sourcing of used paper started from pre-consumer sources, such as converting plants and other industrial and commercial sites, with collection from offices and households quickly following. Today, a wide variety of household collection systems exist for the separation of streams and, even more so, for the physical set-up, ranging from door-to-door collection to bring banks and recycling yards. When it comes to the separation of waste streams, three main groups of collection systems can be distinguished (ITENE, 2018):

- **Commingled collection:** This system is predominant in the United States (where it is also called single stream), Canada and some European countries, such as the United Kingdom and France. In this system, paper and paperboard are typically collected with other recyclables but separately from residual waste. Locally, graphic paper is still collected separately from paperboard and other packaging.
- **Separate collection of paper and paperboard:** This system is predominant in the European Union, e.g. in countries such as Germany, Italy, Spain and the Benelux countries. Paper and paperboard are collected separately from other recyclables such as glass, plastic, metal, and residual waste. In this system, composite packaging, such as beverage cartons, is usually collected separately from paper and paperboard.

- **Selective collection of paper and paperboard:** This system, predominant in Northern Europe, e.g. in Finland and Sweden, refers to the gathering of specific types of paper separately from other paper and non-paper materials. The paper, coming from industrial and commercial outlets as well as from households and offices, is collected separately from paperboard which is also collected separately from other packaging materials. This system generates the most homogeneous streams but requires more bins and, therefore, it is typically organized through bring bank systems rather than curb-side pickup.

All these systems have their origins, advantages and disadvantages. It is commonly argued that commingled collection has the advantage of being convenient for households and for municipality logistics, however, results of several studies show that the quality of paper collected from commingled systems is far lower than that of more selective systems (The resource association, 2012). Larger materials recovery facilities (MRFs) have also been explored and the conclusion was that the quality of the resulting paper for recycling improves with MRFs that are less saturated and have advanced sorting techniques. However, the quality is still far more contaminated than is typically found in selective systems, especially in terms of non-paper components (Miranda, 2013).

When evaluating costs and benefits between the three systems, not only should the collection convenience be considered but also the sorting and value of the material that will be input for papermaking again. A clear picture based on cost-benefit analysis is difficult to establish as so much depends on the operators in the collection, transport and sorting stages. Analyses by the French Environment Agency (ADEME), concluded that in a commingled system, the costs of collection are EUR 30 to 55 per tonne lower than in a separate collection system. However, in a separate collection system, the costs of sorting are EUR 20 to 60 per tonne lower than in a commingled collection system as the materials are pre-sorted by householders. The cost advantage between the different systems will, therefore, depend on other factors in the collection, transport and sorting (Agence de l'Environnement et de la maîtrise de l'énergie, 2016).

The EU-funded Horizon2020 project IMPACTPaperRec (2016-2018) is one example of promoting circular economy objectives by increasing the separate collection of paper and paperboard through appropriate schemes to avoid landfilling and incineration. The project evaluated different collection systems and published a best practice handbook to assist different European regions in increasing the amount of paper collected for recycling through the implementation of adapted collection procedures and practices. The project concluded that separate collection models were preferable, however, it notes that fully implementing this is limited by the need for more bins and the need to better inform citizens about its correct use (ITENE, 2018).

Based on the project's conclusions, the members of Cepi have confirmed their longstanding preference for the separate collection of paper for recycling at source and called for the eventual harmonization of their various collection systems towards a single separate collection system for paper and paperboard. In 2019, Cepi issued guidelines on the separate collection of paper and paperboard (Figure 24).

Figure 24 Paper and paperboard collection best practice according to the recycling process

How should paper and board be collected and sorted to reach the suitable recycling process?

CATEGORY	Product type	Estimated Discarded Tonnage in Europe	How should it be collected?	Under which paper grades for recycling should it be sorted (EN 643)?	Where will it be normally recycled?
Paper and board from households	Paper and board packaging	12 million	In the paper and board stream.	Into 1.01, 1.02, 1.04, 1.05	In standard board mills
	Printing and writing paper	12 million	In the paper and board stream.	Into 1.11	In deinking mills
Paper packaging that has been in contact with food	Used pizza boxes		If cleaned and only lightly stained in the paper and board stream. If food residues, discarded in the residual stream.	Into 1.01, 1.02,	In standard board mills
Multilayered board	Beverage cartons	under 1 million	With lightweight packaging (drink bottles and cans).	Into 5.03	In mills with special equipment which can use special grades (EN 643 Group 5)
Other layered board	Used coffee cups	100.000-200.000	In high streets or fast food restaurants, in a specific stream. In households, with lightweight packaging (drink bottles and cans).	Into 5.14	In mills with special equipment which can use special grades (EN 643 Group 5)
	Sandwich boxes, microwave trays, other food packaging made mainly from board with significant non-paper constituents		In high streets or fast food restaurants, in a specific stream. In households, with lightweight packaging (drink bottles and cans).	Into other grades of group 5	In mills with special equipment which can use special grades (EN 643 Group 5)

Source: (Cepi, 2020)

4.3.2. Sorting

Standardization is a key contributor to the implementation of circularity approaches along pulp and paper industry value chains. If products along these chains are specified according to standards, industry actors know what was produced at the preceding stage and what the next stage of manufacture requires in terms of product specifications.

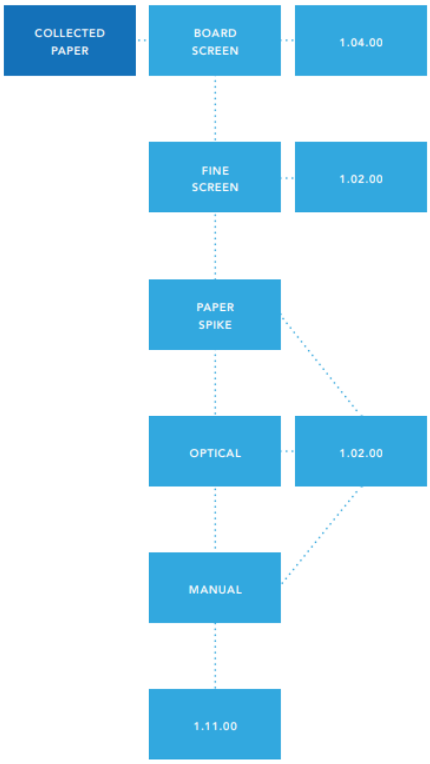
In the United States, recovered paper grades are defined by the Institute of Scrap Recycling Industries' (ISRI) scrap specifications circular. The ISRI specifications also highlight that the standards and practices put forward apply to paper stock for re-pulping. The circular includes a list of 58 grades of regular paper stock ranging from, for example, "Old Corrugated Containers" to "Sorted Clean News" that can be used in standard paper recycling mills. The ISRI specifications also include a list of speciality grades, including "Poly Coated Cup Stock" and "Silicone Release Liner", which may be used by mills with special equipment in place. The ISRI specifications are regularly updated to adapt to market conditions (ISRI, 2022).

In Europe, European standard EN 643 defines the term 'paper for recycling' and describes the paper and board deemed suitable for recycling. This entails different grades of paper and board that are separately collected from households, shops, offices and industry before being recycled by the pulp and paper industry. The standard classes such paper and board for recycling as a raw material for the manufacture of new paper and paperboard products in the pulp and paper industry. This standard, which is reviewed every five years and revised as necessary, also specifies tolerances for unwanted materials as well as the composition of paper and paperboard for recycling. Suppliers paper for recycling based according to the EN 643 grades may add company-relevant specifications in their procurement policy and contracts (DIN EN 643 - European list of grades of paper and board for recycling , 2014).

Sorting plants in different countries segregate paper for recycling grades according to the specifications of EN 643 or the ISRI specifications, although such processes vary depending on the raw material sourced and the collection system in place.

Figure 25 shows an example of a paper-for-recycling flow in a sorting plant. The used paper collected separately from households is transformed into different grades of paper for recycling according to the above-mentioned standardized classifications, for example, 1.02 - mixed paper and board, a grade used by (such as paper recycling mills producing packaging papers), 1.11 - deinking grades are used by deinking mills producing recycled printing and writing or tissue papers. (DIN EN 643 - European list of grades of paper and board for recycling , 2014)

Figure 25 Example of a paper for recycling flow in a sorting plant



Source: PTS - Papiertechnische Stiftung

The way paper products are collected at their end-of-life and sorted by grade to become a secondary raw material of high quality and quantity influences the pulp and paper industry's contribution to a circular economy. The sorting step can only be avoided by more granular sorting: In most cases, selectively collected paper and paperboard does not have to be sorted and can be delivered directly to the paper recycling mills.

An important enabler of circularity is scale as its effects ensure market pull for the different grades of paper for recycling at the national, regional and global levels. The global demand for paper for recycling helps to even out regional imbalances between the supply of collected and sorted material on the one hand, and the demand for paper for recycling by paper mills. Recycling rates have increased strongly over the last 20 years and have reached levels of just under 70 percent in North America and over 70 percent in the European Union (European Paper Recycling Council, 2021). New recycling mills have been built all over the world and the now vast capacity of paper mills to process paper for recycling suggests that there will be ongoing demand for it as a raw material, which contributes to paper fibres' reuse in a material loop.

This increase in demand has been achieved since paper recycling offered an economically viable alternative to virgin fibre-based paper production. Using paper for recycling has helped papermakers significantly reduce their raw material costs by, diverting it from landfills and incineration. There has been a strong demand for recycled paper, which in turn has created incentives to collect more, leading to increasing recycling rates. Consequently, paper for recycling demand has been growing in the long term leading to the a more than 240 million tonnes global market of secondary raw material.(Graves, 2020)

4.4. Environmental benefits and trade-offs

Increasing the production of paper from paper for recycling serves two main environmental purposes. First, it reduces the amounts of paper disposed of through incineration or landfilling and, second, it reduces the need for virgin wood fibres in papermaking, which diminishes the pressure on forests. Life Cycle Assessment (LCA) is a tool commonly used to evaluate the environmental footprint of different paper manufacturing processes based on different feedstocks on a case-by-case basis.

When comparing paper recycling with other disposal options, LCAs clearly demonstrate the benefits of paper recycling. The European Environmental Agency concluded that the majority of LCAs indicate that the recycling of paper has lower negative environmental impacts than the alternative options of landfill and incineration. This outcome is most striking in the comparison of recycling with landfilling and less pronounced but still significant when comparing recycling with incineration. (European Environment Agency, 2006).

Studies have also examined the environmental impacts and benefits of paper recycling based on other parameters, often in comparison with paper production based on virgin fibres. When it comes to comparing the environmental impacts of using virgin and recycled wood fibres with the effects of using more recycled fibres in specific paper products, the assessment is more blurred. However, LCAs can show comparable impacts in the life cycle of a product, even if only one parameter in a production system changes. Impacts compared with the situation before a given change can be shown if, for example, a paper producer plans a new production unit and seeks to determine what the environmental benefits would be. LCAs can also show the environmental externalities of fresh and recycled fibre production processes. Based on comparisons of these externalities, the World Business Council for Sustainable Development (WBCSD) concluded that there has been growing recognition that increasing the recovery and utilization of paper for recycling involves many environmental co-benefits as well as trade-offs. The WBCSD summarized these trade-offs between the use of fresh fibres and recycled fibres as follows (World Business Council for Sustainable Development, 2015):

- Recycled fibre processing releases lower amounts of air pollutants but generates significant amounts of solid waste.
- Fresh fibre production and processing usually require more energy than recycled fibre processing but relies on renewable energy to a greater extent than recycled fibre processing.
- The effects of the increased use of recovered fibre on forest carbon stocks are often unclear.
- A reduction in demand for wood can increase the risk of forests being permanently converted to other land uses.
- Single-stream recycling may increase the overall recovery rate but can cause adverse effects on fibre quality.
- Fibre characteristics dictate which types of virgin and recycled fibre can be used in each paper or paperboard product.

Despite their value, LCAs have their limitations as they are data intensive and, in the absence of data, rely on simplifying assumptions. This is evident in a WBCSD summary of the contribution of LCAs when analysing the environmental benefits and impacts of paper recycling. The WBCSD concluded that comprehending the overall impacts of increasing paper recovery and utilization requires understanding how fibre flows through the wood fibre system are affected by changes in the supply and demand for fibre and related products. Owing to the difficulty of modelling the market dynamics of these systems, simplified assumptions are usually made, often without understanding the potential impacts of these assumptions on the results of the analysis. This limits researchers' ability to draw conclusions about the environmental benefits of increasing paper recovery and utilization and complicates the ability to compare the environmental consequences of the use of virgin and recycled fibre.

The greatest benefit of paper recycling and its utilization for new paper products is in the broadening of the raw material base for such products. Therefore, paper recycling contributes to the circularity of the pulp and paper industry which, in turn, strengthens the cascading use of wood of the entire forest-based sector of which it is part. That benefit becomes obvious when compared to the definition of cascading use of wood as defined by Vis, Mantau and Allen who suggest it is the "efficient utilization of resources by using residues and recycled materials for material use to extend total biomass availability within a given system" (M. Vis, 2016).

Paper recycling contributes to one overarching goal, namely that virgin and recycled fibres circulate in different paper products that are capable of substituting fossil-based products. (World Business Council for Sustainable Development, 2015). One much-studied case of substitution is that of single-use plastic products following the adoption of the EU Directive on the reduction of the impact of certain plastic products on the environment. The Single-Use Plastic Products (SUPP) Directive aims to ban, reduce or otherwise control the use of SUPPs in the European Union. A study conducting a meta-analysis of previously performed LCA studies of products covered by the SUPP Directive suggests that the substitution of plastic products with those made of fibre-based materials, such as paper and cardboard, is expected to reduce negative environmental impacts across a range of impact categories, including climate change. On average, fibre packaging through its life cycle has lower negative climate impacts than packaging made of plastic, even if the material needs of fibre packaging are higher. However, when exploring the use of paper packaging instead of plastic packaging, the impacts due to the use and occupation of land, coupled with water use, should be addressed. Those impacts were shown to be higher in some studies than for comparable plastic products. However, the abovementioned study suggests that case-specific LCA studies of environmental impacts should be performed because study results comparing plastic and fibre-based products depend on various factors, such as the underlying methodological choices, the geographical scope of the study, the studied products and the end-of-life option chosen (Hohenthal & Deviatkin, 2019).

4.5. Role of policy

Supporting a transition to a circular economy in the paper recycling loop, requires the inclusion of paper design, production, converting and distribution, waste management, collection and sorting phases of production cycles. None of these functions can be seen in isolation but in the context of the wider economy and are subject to legislation regulating these different areas, be it product or waste-management related.

Waste-related policies have gained ground in many parts of the world since the beginning of the 2000s. Disposal in landfills is increasingly recognized as the least preferred waste-management option and a paradigm shift to a sustainable use of materials has taken place in developed countries and is also gaining momentum in developing countries. Legislation preventing recyclable materials from entering landfill streams is a basic enabler and national legislators have taken different strategies in that direction, such as landfill bans or making landfilling financially unattractive. Consequently, striking variations between countries remain or have emerged. For example, Germany and the United Kingdom greatly reduced their municipal solid waste disposal in landfills between 2001 and 2020, whereas, the United States and Türkiye have seen little change in the amounts of such waste since the early 2000s (OECD, 2023).

In many countries, moving up the waste hierarchy and setting recycling targets has proven effective in diverting paper waste not only from landfill but also from waste incinerators. In the European Union, there are recycling targets for municipal solid waste as well as for packaging waste and material-specific packaging waste. For example, the target for paper and paperboard packaging is set at 75 percent by 2025 and 85 percent by 2030 for all Member States, while it was already recycled at a rate of 81.5 percent in 2020 on average. (Eurostat Data Browser: Recycling rate of packaging waste by type of packaging, 2023).

As regards how paper and paperboard are collected from households, systems differ from country to country and local legislation has a role to play in prescribing the collection system employed. In some countries, such as France, the decision on how to collect is taken at the municipal level, while in other countries, such as Spain, a national approach has been introduced. The European Union-financed Horizon 2020 project IMPACTPaperRec has formulated recommendations in this respect at both the national and municipal levels. (ITENE, 2018)

A further limitation of increased paper recycling is its strong reliance on fossil-based energy. As described in the section on environmental trade-offs and benefits, production using recycled paper requires less energy than when using virgin fibre, however, it is often based on fossil resources. Therefore, policy has a role to play in promoting the provision of affordable carbon-neutral energy for the recycling industry. For example, a position paper by the Austrian Association for Renewable Energy suggested that Austria has sufficient potential for renewable energy to meet the country's energy needs. Accordingly, the association formulated the necessary measures, among which was the use of all sources of renewable energy (Erneuerbare Energie Österreich, 2022).

Product-related policies that enable better design for circularity could also offer the potential for further improvements to paper recycling where, for example, they could contribute to more clarity on the environmental benefits and trade-offs of different circularity approaches. Besides the difficulties in comparing LCA studies for drawing conclusions about the environmental benefits and downsides of recycled and virgin fibre-based paper products (see Environmental benefits and trade-offs section), the European Commission identified other difficulties. These include comparisons of the environmental performance of different products (including paper and paperboard) owing to the variety of schemes, standards and guidelines as well as the different scopes and system boundaries used. The European Commission recognized the need to be able to compare the environmental footprint of different products and has taken the initiative to develop a harmonized methodology, with a broad set of relevant environmental performance criteria based on LCA, to do so.

The objective of a harmonized methodology for environmental footprints is to enable consumers to choose sustainable products and fight against false green claims. In the European Union, pilot projects have been carried out on a wide range of product categories such as IT equipment, batteries and accumulators as well as on intermediate paper products. Consequently, the European Commission established the Product Environmental Footprint Category Rules (PEFCR). These rules complement the general methodological guidance set by the Commission's Product Environmental Footprint Guide by providing further specifications at the level of individual product categories. They provide detailed guidance to calculate and report on the environmental impacts generated during products' life cycles and focus on the most relevant impact categories. PEFCRs allow for the comparability between Product Environmental Footprint calculations within the same product category to some extent. For intermediate paper products, the scope includes the production of paper and paperboard and their inputs, thus covering the production of pulp (be it chemical, mechanical or recycled) as well as the upstream processes of paper for recycling, wood from forests, water, energy and other materials.

For each of these processes, datasets have been established and the most relevant impact categories (i.e. 'hotspots') have been identified. For intermediate paper products, these 'hotspots' are climate change, abiotic-resource (fossil-fuel) depletion, particulate matter and acidification. Combined, these categories account for more than 80 percent of the total environmental impacts of such paper products. The Product Environmental Footprint process is not yet finalized but it will eventually allow for more reliable comparisons of products, at least those within the same product category (e.g. intermediate paper products), including those that are based on virgin and recycled fibres.

Chapter 5 Conclusions

The benefits of increased paper recycling, the most prominent feature of sustainability and circularity in the paper and pulp industry, are not limited to the diversion of paper waste from environmentally damaging disposal options. The circularity of paper and paperboard products also has wider benefits for all forest-based industries as it broadens the availability of renewable raw materials for all forest-based products and reduces the dependence on virgin fibres from the forests. Using less virgin material pulp production, means that this virgin material can be directed to other applications, with a recognition that the long-term sustainability of supply depends on SFM.

This study also recognizes that circularity in the pulp and paper industry requires resource efficiency in a variety of raw materials accompanying the production processes, including closed water and residues (e.g., fibre-containing sludges) cycles, the effective use of processing chemicals as well as energy efficiency, including, when possible, bioenergy use. For that reason, although this study focuses mainly on the circularity of the cellulose-based raw materials, other accompanying materials and resources are duly mentioned where appropriate.

Overall, the study presents theoretical sustainable and circular economy concepts and how they are relevant to the pulp and paper industry. The analysis has been framed within a general industry context with an emphasis on the evolution of resource efficiency as well as sustainable production and consumption trends in the industry over the last few decades. The facts that were determined led to conclusions which are listed for further discussion in the following:

1. **The pulp and paper industry is a complex industry with many different processes and a growing trend to of refining bio-based feedstock into more value-added products**

The production processes of the pulp and paper industry require a significant number of natural resources, involving including natural raw materials, water, and energy. The basic virgin raw materials for pulp and papermaking are cellulosic fibres and consequently, circularity in the pulp and paper industry starts with closed carbon cycles ensured through SFM. The carbon is stored in wood products, such as the sawn goods used for construction or furniture and less valuable parts of the trees along with trees removed during thinnings, are used to produce pulp and paper or wood panels.

In the pulp and paper industry, a significant amount of wood fibre is also sourced in the form of wood chips, which are a by-product from of the sawmilling industry. Also, there is a renewed interest in the use of cellulose extracted from agricultural residues. Both increase the circularity of feedstocks.

In pulp making, different technologies can be used to extract cellulose from wood. In chemical pulp mills, inorganic chemicals are used to isolate cellulose fibres and the process leads to chemicals left over after the removal of the cellulose fibres. In the effort to increase resource efficiency by creating higher - value products, many chemical pulp mills have transformed into biorefineries where they transform by-products into different intermediary products such as fatty acids, rosins or sterols. They are then delivered to various industrial and consumer markets, where they provide an alternative to fossil- or and vegetable-based oils, such as detergents, soaps, or paints and various coatings.

2. **The changing industry context impacts the structure of the sector.**

Paper and paperboard products are part of people’s everyday lives, however the way they are used has been changing noticeably since the 2000s. While the use of printing and writing papers has greatly decreased, the use of paper-based packaging has soared. A lot of paper and paperboard is consumed in areas not visible to end consumers, namely in the supply chains and logistics of the global economy.

The Covid-19 pandemic and the related lockdowns accelerated the trend away from demand for printing and writing papers to packaging papers.

The study showed that the sustainability efforts by companies have caused a shift from plastic to paper-based packaging in many fields, also owing to strong progress in increasing its resource efficiency by the pulp and paper industry. This resource efficiency was observed in several areas that are hotspots for pulp and paper making. They include energy efficiency gains, increased use of renewable energy, the reduction of CO_2 emissions and the diversion of residues from landfills. Most notably, recycling rates have increased at the global level which has led to global paper and paperboard consumption being increasingly decoupled from the use of virgin pulp production.

3. **Further growth in packaging papers production will depend on the uptake of reusable packaging.**

The study's findings suggest that further decrease in the use of printing and writing papers will likely contribute to increasingly more conversions of paper machines into machines producing packaging papers. The demand for and production of packaging papers is projected to grow with the ongoing move towards more sustainable packaging solutions. Discussions on reusable packaging options complementing recycling as well as general waste reduction are emerging. However, it is not possible to predict if reusable packaging will stay a niche product or gain a significant market share in some sectors. The long-term benefits of reusable packaging will need to be evaluated on a case-by-case basis considering all sustainability aspects, beyond circularity.

4. **Paper recycling rates will keep increasing, however, paper production will still require a continuous inflow of virgin fibres.**

The study found that the availability of paper for recycling for the industry is reaching high levels in many countries; however, there is still growth potential, especially in the collection from households or consumer packaging disposed of away from home. Nevertheless, even with this remaining potential, a continuous inflow of virgin fibres is needed and should ideally be considered in regions and through product applications where virgin fibres have a clear advantage over other sustainability aspects. Industry experts expect the share of recovered paper in the global consumption of fibrous raw material of the pulp and paper industry to reach 60 – 70 percent in the near future.

5. **Pulp mills also implement circularity approaches through the development of innovative products in biorefineries.**

The study outlines that the transition of activities into biorefineries, which produce more added value products, e.g., cellulose fibres for textiles or bio-composites, is becoming a way of closing production loops in some pulp mills. It provides an opportunity not only for expanding the market portfolio of conventional pulp mills but also keeps the valorization of forest and sawmill residues in the sector, thus contributing to a higher value-added of the sector. This synergistic combination provides an attractive business case from a socioeconomic and environmental point of view. The biorefineries concept also allows for a more efficient use of all the production side streams, including residues of the pulping process, such as bark and black liquor.

The study highlighted that refining of bio-based feedstocks is an important circularity feature of the pulp and paper industry. Innovative cellulose-based products, such as pulp-based textiles or nanocellulose produced in biorefineries, contribute to the increased sustainability and circularity of the industry because they create value-added products from side streams which then become secondary raw materials. Often, these secondary raw materials can be used to create sustainable alternatives for fossil-based products but with lower environmental footprints.

6. **Circular design is key for both high recycling rates and high quality of products made from recovered paper.**

The study highlighted that the most prominent feature of circularity in the pulp and paper industry is the high recycling rate of paper products. What distinguishes paper recycling from other product recycling, including the cascaded use of wood-based products, is not only the high rate, but also the fact that paper products are recycled back at this high rate in a closed material loop. This means paper products are recycled in the paper industry and become recycled pulp and paper for new paper and paperboard products, instead of being used outside the sector.

The study also found that several factors contribute to the success of paper recycling as it involves many actors, including some that are outside the pulp and paper industry value chain. The study highlighted that there are two main factors contributing to the circular design of paper products and its link to their circular management. The first is the knowledge of designers of the production processes, not only a focus on the final product functionalities in their useful life. The second is their knowledge of paper recycling processes. for the products to be designed before further recycling. There are several examples of guidelines and scorecards to support this.

7. **Quality standardization is a compelling enabler for the circularity of paper and paperboard.**

The study concludes that when products along the value chain are specified according to standards, industry actors know what was produced at the preceding stage of the value chain and what the next stage of manufacture down the value chain requires in terms of product specifications. Standards, such as the Scrap Specifications Circular in North America (ISRI) or EN 643 (European list of standard grades of recovered paper and board) are widely used in the international trade also beyond these regions and enable a functioning and transparent global market.

In the collection of recovered paper, there are several models, each with its advantages and downsides. While it is argued by some that commingled collection generates higher amounts of recovered paper and is easy to use by households, the collection of paper and paperboard separately from other recyclables causes lower sorting costs and lower impurity levels. Consequently, contributing to achieving more standard qualities of paper for recycling.

8. **Paper recycling is a business case.**

The study found that paper recycling offers an economically viable alternative to the use virgin fibre for paper production. Therefore, using recovered paper has helped papermakers to significantly reduce their raw material costs and has simultaneously diverted that paper from landfill and incineration. There has been a strong demand for recycled paper, which has in turn created incentives to collect more, leading to increasing recycling rates. While generally most paper is recycled in the paper industry of the country where it has been consumed, its global demand is able to balance regional volatilities in supply and demand.

Alongside standardized recovered paper qualities, the global demand has contributed to the recovered paperbecoming a globally traded commodity with a market volume representing more than 244 million tonnes of recovered paper. The study concludes that improvements in circular design, collection and sorting could further support the functioning of this market in many countries and grow it globally to help meet the pulp and paper industry’s needs for raw material.

9. **The environmental performance of paper and paperboard made from virgin fibres and from recovered paper can be compared only case-by-case.**

The study concludes that assessing the overall sustainability of paper and paperboard products goes beyond circularity. Environmental benefits of paper recycling compared to its disposal options are obvious. However, when comparing recycled paper with virgin alternatives, the picture is less clear.

Recycled paper production uses less energy than virgin fibre-based paper production, but in many countries, the recycling processed are powered by energy that relies on fossil fuels. In contrast while virgin fibre-based paper production uses more energy in total, most of it is from renewable sources (forest residues, black liquor). Therefore, the comparison of the environmental performance of both processes needs to be done on case-by-case basis. The study also highlights that industry-wide picture would look different if there was a widespread availability of carbon-neutral energy, especially non-integrated mills, including recycling mills.

10. **Recycling paper and paperboard extends the raw material base substituting fossil-based products.**

The study points out that main benefit of increasing paper recycling is the extension of the raw material base for products that offer an alternative to fossil-based products. This is shown by various life cycle assessments (LCA) comparing plastic packaging with fibre-based alternatives. However, case-specific LCA studies on environmental impacts should be carried out for the comparison of individual products. This is needed because despite LCAs being a widely used tool, they are far from an optimal solution owing to the difficulty of comparing them.

11. **Adequate policy is needed for creating an enabling environment for circularity in the pulp and paper industry**.

The study showed that many countries have already put in place regulations guiding the end-of-life management of paper products, moving away from disposal options (landfill and incineration) to achieve higher recycling rates. This said, more policy support is needed to improve of the paper and paperboard collection from households as well as from away-from-home and on-the-go consumption.

This could be achieved by policies supporting a more consistent collection infrastructure alongside with clearer sorting instructions for consumers. Policy also has a role to play in increasing the transparency of information on the environmental and carbon footprint of pulp and paper products, including, but not limited to, circularity. Such policies, the study concludes, could promote science-based tools to enable comparisons between different products and assist consumers to make informed choices.

Building on these conclusions, this study proposes the following actions in support of a successful transition to a circular economy in the pulp and paper industry:

1) Continuous support for sustainable forest management. While recycling rates are high and they can be further increased in many areas, a steady inflow of virgin fibre will be needed, and it must be sourced from sustainably managed forests;
2) Promotion of the use of recycled fibres to widen the sustainable raw material base for renewable products substituting fossil-based ones. However, promotion campaigns on paper recycling should avoid associating the use of virgin fibres with misleading information on deforestation.;

3) Divert, as much as possible, waste streams including valuable raw materials such as paper and paperboard from landfills and other disposal options to keep materials circulating and creating added value in the economy;

4) Collect separately paper and paperboard from residual waste and other recyclables. There should be consistent waste collection programmes at least at national levels, although ideally this should be done in larger economic areas to enable the value of secondary raw materials to be maintained;

5) Provide clear sorting instructions for the end consumer of pulp and paper products along with the legally required information concerning the origin;

6) Publish science-based environmental footprint information to improve reliability and comparability of claims on products;

7) Link waste management policies, including collection and sorting, to the product design and production policies to allow for closed material loops in which products are designed in full knowledge of the recycling processes that keep them in use;

8) Further develop support policies (e.g., green procurement) to take into account the recyclability of products and the renewability of their raw materials to favour nature-based material over fossil fuel-based ones;

9) Encourage product and energy efficiency innovation and access to research and development. This would support the continued development of mills into biorefineries, producing more value-added products from side-streams and other waste;

10) Encourage paper mills to use their potential to become more energy self-sufficient by producing renewable energy onsite using e.g., waste and residues for bioenergy in line with the cascading use of biomass. For the remaining energy needs, provide access to affordable clean energy is crucial to increase the synergy between increasing circularity and efforts to mitigate climate change;

11) Promote cooperation among different actors across value chains and the establishment of industrial ecosystems to facilitate exchange along supply chains and make them more circular, i.e. turn the linear supply chains into supply circles;

12) Encourage industrial associations and policy makers to analyse various value chains to identify their potential for increased circularity while keeping in mind all associated environmental impacts and sustainability aspects.

References

(n.d.). Retrieved from https://iweerbeek.nl/circulair-eerbeek/.

(n.d.).

(n.d.). Retrieved from https://www.congress.gov/bill/117th-congress/senate-bill/923

4evergreen. (2022). *Circularity by Design Guideline for Fibre-based Packaging.* Retrieved 06 13, 2023, from 4evergreen: https://4evergreenforum.eu/wp-content/uploads/4evergreen-Circularity-by-Design-2.pdf

4evergreen. (2022). *Fibre-based packaging recyclability protocol.*

ACE, Cepi, Citpa, FEFCO. (n.d.). *Paper-based packaging recyclability guidelines.* Retrieved from https://www.cepi.org/paper-based-packaging-recyclability-guidelines/

AF&PA. (2021). *Access to Recycling Study.* AF&PA.

AF&PA. (2021). *design guidance for recyclability.* AF&PA.

AFRY. (2023, 05 02). *Energy Hubs*. Retrieved from Cepi: https://www.cepi.org/wp-content/uploads/2022/11/Cepi_Executive-summary-Energy-hubs_29112022.pdf

Agence de l'Environnement et de la maîtrise de l'énergie. (2016). *Organisation de la collecte des déchets d'emballages ménagers et de papiers graphiques dans le service publique de la gestion des déchets.* Paris: ADEME.

American Forest and Paper, A. (2023). Retrieved from https://www.afandpa.org/paper-wood-products/packaging

Bernstein, L., J. Roy, K. C. Delhotal, J. Harnisch, R. Matsuhashi, L. Price, K. Tanaka, E. Worrell, F. Yamba, Z. Fengqi, 2007: Industry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bioenergy, I. (2007). Black Liquor Gasification - Summary and Conclusions from the IEA Bioenergy ExCo54 Workshop.

Bousios, S. (2016). *Side Streams of Paper and Board Production.* Cepi.

Camia A., G. J. (n.d.). *The use of woody biomass for energy purposes in the EU.* Luxembourg: Publications Office of the European Union.

Catharina Hohenthal, I. D. (2019). *Literature review of LCA studies comparing fibre products with plastics ones in the field of SUP.* Cepi.

CEN. (2014) DIN EN 643 - European list of grades of paper and board for recycling

Cepi. (2017). *Framework for carbon footprints for paper and board products.*

Cepi. (2020). Retrieved from https://www.cepi.org/wp-content/uploads/2020/10/19-2905_Industry-position-paper-on-separate-collection_A4_20190903.pdf

Cepi. (2021). *Origin of Fibre Report.*

Cepi. (2021). *Pulp and Paper Industry - Definitions and Concepts.*

Cepi. (2022). *Annual Statistics 2021.*

Cepi. (2022, 09). *Harmonised European laboratory test method to generate parameters enabling the assessment of the recyclability of paper and board products in standard paper and board recycling mills.* Retrieved 05 14, 2023, from Cepi: https://www.cepi.org/wp-content/uploads/2022/10/Cepi-recyclability-laboratory-test-method_FINAL.pdf

Cepi. (2022). *Key statistics.* Cepi.

Cepi. (n.d.). Harmonised European laboratory test method to generate parameters enabling the assessment of the recyclability of paper and board products in standard paper and board recycling mills.

Cepi, FEFCO, ACE, Citpa. (2019). *Paper-based packaging recyclability guidelines.*

Commission, E. (2018). *Guidance on cascading use of biomass with selected good practice examples on woody biomass.*

Commission, E. (2021). *Commission Staff working document minimizing the risk of deforestation and forest degradation associated with products placed on the EU market.*

Commission, E. (2021). *New EU forest strategy for 2030.* Brussels: European Commission.

COST Action E48 - The future of Paper Recycling in Europe: Opportunities and Limitations. (n.d.).

David Feber, F. G. (2022). *Reusable packaging: Key enablers for scaling*. Retrieved from McKinsey: https://www.mckinsey.com/industries/paper-forest-products-and-packaging/our-insights/reusable-packaging-key-enablers-for-scaling

Dewitz, A. (2015). *The Free Encyclopedia of Print*. Retrieved from Lightweight Paper: http://printwiki.org/Lightweight_Paper

DIN EN 643 - European list of grades of paper and board for recycling. (2014). Beuth Verlag.

Directorate-General for Environment (European Commission). (2021). *EU biodiversity strategy for 2030.* Retrieved from https://op.europa.eu/en/publication-detail/-/publication/31e4609f-b91e-11eb-8aca-01aa75ed71a1

EcoPaperLoop. (2014). *EcoPaperLoop.* Retrieved from http://www.ecopaperloop.eu/outcome/2.3.2.d%20-%20Guideline%20Document-Policy-Engl.pdf

EcoPaperLoop. (2014). *Guideline Document: Recyclability of Paper-based Products*. Retrieved 5 June 2023, from EcoPaperLoop: http://www.ecopaperloop.eu/outcome/2.3.2.a%20-%20Guideline%20Document-Recyclability-Engl.pdf

EPRC. (2021). *European Declaration on Paper Recycling 2021-2030.* Brussels: EPRC.

EPRC. (2021). *Monitoring Report.*

Erneuerbare Energie Österreich. (2022). *Österreich Klimaneutral: Potenziale, Beitrag und Optionen zur Klimaneutralität mit Erneuerbaren Energien.* Wien.

European Commission. (n.d.). Retrieved from https://environment.ec.europa.eu/topics/plastics/plastic-bags_en

European Commission. (2018). *A European Strategy for Plastics in a Circular Economy.*

European Environment Agency. (2006). *Paper and cardboard - recovery or disposal? EEA Technical report 05/2006.* Luxembourg: Office for Official Publications of the European Union.

European Paper Recycling Council. (2017). *Assessment of Printed Product Recyclability.* Retrieved from European Paper Recycling Council: file:///C:/Users/UL/Downloads/WithAnnexAssessment-of-printed-product-recyclabilitywebview.pdf

European Paper Recycling Council. (2017). *Assessment of Printed Product Recyclability.* Retrieved 06 13, 2023, from European Paper Recycling Council: file:///C:/Users/UL/Downloads/WithAnnexAssessment-of-printed-product-recyclabilitywebview.pdf

European Paper Recycling Council. (2021). *EPRC Monitoring Report.* Brussels: Cepi.

Eurostat Data Browser: Recycling rate of packaging waste by type of packaging. (2023, 05 12). Retrieved from Eurostat: https://ec.europa.eu/eurostat/databrowser/view/CEI_WM020__custom_354860/bookmark/table?lang=en&bookmarkId=bc39f400-65cd-40a8-bf14-c995c729e2a5

FAO. (2020). *Global Forest Resources Assessment 2020. Main Report.* Rome: FAO.

FAO Sustainable Forest Management. (2023, 05 14). Retrieved from FAO: https://www.fao.org/sustainable-forests-management/en/

FEFCO. (2018). *European Database for Corrugated Life Cycle Studies*. Retrieved 05 06, 2023, from FEFCO: https://www.fefco.org/sites/default/files/documents/LCA%20Report%202019_revised_%20p%2037.pdf

Graves, M. (2020, 12). *Old Corrugated Containers (OCC) - A new era dawns.* Retrieved 05 24, 2023, from Norexeco.com: https://norexeco.com/wp-content/uploads/2020/12/Fastmarkets_RISI_OCC_Futures_Norexeco.pdf

Grunewald, F., Hornyai, F., & Jon Haag, O. L. (2023). *McKinsey*. Retrieved from https://www.mckinsey.com/industries/paper-forest-products-and-packaging/our-insights/the-potential-impact-of-reusable-packaging

Hohenthal, C., & Deviatkin, I. (2019). *Literature review of LCA studies comparing fibre products with plastics ones in the field of SUP.*

https://forestbiofacts.com/. (n.d.). Retrieved from https://forestbiofacts.com/

ICFPA. (2023). *ICFPA*. Retrieved from Sustainability update 2022/2023.

ICFPA. (2023). *ICFPA 2022-2023 Sustainability Progress Report.*

IEA. ((2022)). *IEA Pulp and Paper Tracking Report September 2022*. Retrieved from IEA: https://www.iea.org/reports/pulp-and-paper

INGEDE. (2022). *Ecolabels and Methods.* Retrieved from INGEDE: http://pub.ingede.com/en/ecolabels-and-methods/

ISRI. (2022). *ISRI Scrap Specifications Circular.*

ISRI. (2022). *ISRI Scrap Specifications Circular.* Retrieved from https://www.isri.org/membership/isri-chapters/paper-stock-industries-chapter/psi---scrap-specifications-circular

ISRI (2019) The Economic Impact of the Scrap Recycling Industry in the United States. Paper. Factsheet based on the "2019 Economic Impact Study, U.S.-Based Scrap Recycling Industry", John Dunham & Associates.

ITENE. (2018). *Collection systems for paper for recycling*. Retrieved 05 09, 2023, from IMPACTPaperrec: https://impactpaperec.eu/en/best-practices/collection-systems-for-paper-for-recycling-2/

ITENE. (2018). *Good and best practice handbook for the collection of paper and board for recycling.*

Junca. (2002). *Pulp and paper.*

Kowalska M., D. S. (2021). *EU Ecolabel Criteria for printed paper, stationery paper, and paper carrier bag products.* Luxembourg: Publications Office of the European Union. Retrieved from file:///C:/Users/UL/Downloads/pubsy_jrc123180__euel_printed_paper_stationery_paper_and_paper_carrier_bags_v2.pdf

Lettner M., B. M. (2017). *Szenarien zu CO2 Einsparungen bei der Produktion von Holzprodukten.* Vienna: BOKU.

M. Vis, U. M. (2016). *Study on the optimised cascading use of wood.* Luxembourg: Publications Office of the European Union.

Maarten Dubois, E. S. (2020). *Guidance for separate collection of municipal waste.* Luxembourg: Publications Office of the European Union.

McKinsey. (n.d.). Retrieved from mainly linked to acceptance, lack of infrastructure, regulatory push for overall packaging reduction, product safety, and cost.

Michael Suhr, G. K. (2015). *Best Available Techniques (BAT) Reference Document for the production of Pulp, Paper and Board.* Luxembourg: Publications Office of the European Union.

Miranda R., B. E. (n.d.). *Miranda R., Bobu E., Grossmann H., Stawicki B., Blanco A. (2010). Factors influencing a higher use of recovered paper in the European paper industry.*

Miranda, R. M. (2013). Analysis of the quality of the recovered paper from commingled collection systems. *Resources, Conservation and Recycling, 72*, 60-66.

Moya, J. A. (2018). *Energy efficiency and GHG emissions: Prospective scenarios for the pulp and paper industry.* JRC.

nova-Institute. (2022). *Non-wood Fibre Use in the European Pulp and Paper Industry (executive summary).* Cepi.

OECD. (2023, 05 12). *OECD.Stat.* Retrieved from Municipal Waste Generation and Treatment: https://stats.oecd.org/Index.aspx?DataSetCode=MUNW

P. Chalmin, Y. J. (2022). *World Commodity Markets Cyclope.* Paris: Economica.

Paperchain. (2023, 05 04). *Paperchain Circular Cases*. Retrieved 05 04, 2023, from Paperchain: https://www.paperchain.eu/

Partnering, N. (2021). Biorefineries in Europe.

Processum, R. (2017). *PPI waste streams valorisation potential.* European Commission. Retrieved from https://www.paperchain.eu/

Richard Platt, A. B. (2021). *EU Biorefinery Outlook to 2030.* Luxembourg: Publication office of the European Union.

Schier, F., Iost, S., Seintsch, B., Weimar, H., & Dieter, M. (2022). *Assessment of Possible Production Leakage from Implementing the EU Biodiversity Strategy on Forest Product Markets. Forests 2022*. Retrieved from https://doi.org/10.3390/f13081225

The Quality of Paper for Recycling in Europe: Optimising Paper Products, Packaging and Collection Systems. (2014).

The reinvented paper towel. (2023, 5 03). Retrieved from essity: https://www.essity.com/company/breaking-barriers-to-well-being/stories/products-talk-sustainability/the-reinvented-paper-towel/

The resource association. (2012). *The costs of contamination report.* Retrieved 05 08, 2023, from https://op.bna.com/env.nsf/r?Open=aada-93cpg7

UNECE/FAO. (2021). *Circularity concepts in forest-based industries.* Geneva: UNECE/FAO.

UNECE/FAO. (2021). *Forest Products Markets Annual Review.*

UNECE/FAO. (2022). *Forest Products Annual Market Review 2021-2022.* Geneva: UNECE/FAO.

USDA BioPreferred. (n.d.). Retrieved from https://www.biopreferred.gov/BioPreferred/

WBCSD. (2015). *Facts and Trends Fresh and Recycled Fiber Complementarity.* Geneva.

World Business Council for Sustainable Development. (2015). *Facts & Trends. Fresh & Recycled Fiber Complementarity.* Geneva: WBCSD.

World Economic Forum. (2016). *White paper: Design and Management for Circularity – the Case of Paper.* Geneva: World Economic Forum.

J. Raimo Alén, 2019 Pulp and PapA. Atiqah, M. Asrofi, 2022, Nanocellulose composites for electronic applications

Pratima Bajpai, 2018 Pulping Fundamentals

(Pratima Bajpai, 2016), Pulp and Paper Production Processes and Energy Overview

Pratima Bajpai, 2016a, Pulp and Paper Industry Chemicals

J.N. Chakraborty, 2012 Understanding and Improving the Durability of Textiles

CEPI (2017), Key statistics 2016, European pulp and paper industry, 2017a, available at:

http://www.cepi.org/system/files/public/documents/pressreleases/forest/2011/roadmap_

press_release-20111114-00002-01-E.pdf

Denny K.S., 2017 Sustainable Water & Energy Systems

Dick Carlsson, Sophie D'Amours, Alain Martel, Mikael Rönnnqvist, 2006 Supply Chain Management in the Pulp and Paper Industry.

EPA, 2022, https://www3.epa.gov/ttnchie1/ap42/ch10/final/c10s02.pdf, last accessed 24 March 2023

European Union, 2000, PROCESSES IN WOOD, PAPER PULP, FOOD, DRINK

AND OTHER INDUSTRIES https://www.eea.europa.eu/publications/EMEPCORINAIR5/B462vs2.0.pdf

H.L. Hintz, Sunday A. Lawal, 2018 Paper: Pulping and Bleaching☆

Hubbe, M. A., and Gill, R. A. (2016). "Fillers for papermaking: A review of their properties, usage practices, and their mechanistic role," BioRes. 11(1), 2886-2963.

IEA (2022), Pulp and Paper, IEA, Paris https://www.iea.org/reports/pulp-and-paper, License: CC BY 4.0

https://www.iggesund.com/globalassets/iggesund/services/knowledge/iam/reference-manual/rm-pdf---en/1.-from-forest-to-market/differences_paper_and_paperboard_en.pdf

Moya J. A. and Pavel C. C., 2018, Energy efficiency and GHG emissions: Prospective scenarios

for the pulp and paper industry, EUR 29280 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-89119-9, doi:10.2760/035301, JRC111652

R.A. Ilyas, Norizan Mohd Nurazzi, 2022 Introduction to nanocellulose production from biological waste

https://www.itcportal.com/businesses/paperboards-and-specialty-papers.aspx

Jayasankar Janeni, Nadeesh M. Adassooriya, 2021, Nanocellulose biopolymer-based biofilms: Applications and challenges.

Jack Reese, Liang-Shih Fan, 1999, Industrial Applications of Three-Phase Fluidization Systems

https://legionpaper.com/alternative-fibers#:~:text=There%20are%20many%20alternative%20fiber,the%20options%20available%20to%20you.

Mohammed Nasir, 2017 Nanocellulose

https://www.nisshametallizing.com/en/exploring-science-paper#:~:text=Birch%2C%20Beech%2C%20Poplar%20and%20Aspen,into%20papers%20to%20improve%20printability.

Novidon 2023 https://www.novidon.com/en-US/sustainability/the-circular-approach/

Oliveira Luciano, 2017 https://www.linkedin.com/pulse/water-consumption-pulp-mills-luciano-oliveira/

Paperchain, 2023 https://www.paperchain.eu/

Paperpulping.com https://www.paperpulping.com/news/what-is-the-type-and-process-of-pulp.html https://www.pgpaper.com/types-of-paper-used-for-packaging/#:~:text=Kraft%20paper%20%E2%80%93%20kraft%20paper%20is,used%20for%20bags%20and%20wrapping.

https://www.nipponpapergroup.com/english/products/special/

Nirmal Sharma a b, Nishi K. Bhardwaj a, Ram Bhushan Prashad Singh, 2020. Environmental issues of pulp bleaching and prospects of peracetic acid pulp bleaching: A review, published in Journal of Cleaner Production, Volume 256, 20 May 2020, 120338

https://niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/land-use/foresry-processing/pulp-and-paper#:~:text=A%20pulp%20mill%20is%20a,chemical%20or%20fully%20chemical%20methods.

https://www.pulpandpaper-technology.com/articles/pulp-and-paper-manufacturing-process-in-the-paper-industry

ResearchAndMarkets.com, Global Graphic Paper (Printing & Writing and Newsprint) Market Insights, Trends and Forecast Report 2019-2023

Samcotech.com https://samcotech.com/reduce-water-usage-in-pulp-and-paper-industry/

James G. Speight, in Heavy Oil Recovery and Upgrading, 2019

https://www.tissueasy.com/_tissue-parent-reels.php

Walker, J. C. F. (2006). Primary wood processing: principles and practice (2nd ed.). Dordrecht: Springer. ISBN 9781402043932. OCLC 209934701.

U.S. Congress, Office of Technology Assessment, Technologies for Reducing Dioxin in the Manufacture of Bleached Wood Pulp, OTA-BP-O-54 (Washington, DC: U.S. Government Printing Office, May 1989),

Vakkilainen, 2017. Esa Kari Vakkilainen, in Steam Generation from Biomass, 2017

Annex 1 Examples of Good Practice

This chapter provides an overview of currently observed strategies and activities undertaken by different actors that have an impact on the pulp and paper industry. These strategies, approaches and activities showcase efforts made by policy, research and industry actors alike in the planning, production and recovery processes. They aim to reduce resource consumption, including water and energy consumption, while extending the life of products and reducing negative environmental impacts.

These tangible projects and case studies implement principles of circularity and sustainability in the pulp and paper industry and have been collected by the authors of this study with sector professionals in different countries. Their accuracy and veracity have been verified by the contributors to this chapter cited in the "contacts and sources" of each case study, as such, full responsibility for the details cited remains with the contributors.

American Forest and Paper Association Design Guidance for Recyclability of Paper-based Packaging

Introduction/Background

The American Forest & Paper Association developed the Design Guidance for Recyclability of Paper-based Packaging. This tool helps packaging manufacturers, designers and brands create and manufacture packaging that meets their customers' needs in terms of recyclability. With increased interest among consumer products companies to provide more recyclable packaging for their customers, the paper-based packaging industry recognized the opportunity to bring clarity to how packaging gets recycled in paper mills and how various non-fibre elements affect the recyclability of paper-based packaging.

The Design Guidance covers products such as corrugated packaging, bleached and unbleached paperboard cartons, carrier stock cartons, kraft paper bags, multiwall shipping sacks and moulded fibre containers. The Design Guidance examined numerous non-fibre elements, including inks, dyes, adhesives, tapes, labels, coatings and barriers as well as metals, plastics, foils, wet strength and non-tree fibres.

Circular approaches and practice applied

- Design
- End-of-life management
- Material substitution
- Raising awareness

Results and benefits

The project is a result of extensive stakeholder collaboration in the paper-based packaging value chain, academics, NGOs, non-fibre element manufacturers and consumer brands. The Design Guidance had media coverage, including stories in *FastCompany*, *The Dieline*, *Recycling Today*, *PaperFirst*, *Resource Recycling* and *PaperAge*. Multiple associations that have distributed the Design Guidance to their members include the American Frozen Food Institute, the National Waste and Recycling Association (Recycling Committee) and the Foil and Specialty Effects Association.

Key findings include:

- Every combination of type of packaging and non-fibre element tested is recyclable in some mills.
- Non-fibre elements may present a 'challenge' when recycling if they slow down the mill's pulping process, plug screening systems or leave residues on finished paper or paperboard.
- However, innovations in packaging design and materials, as well as improvements in recycling technology, can make the treated paper easier to recycle.
- Being a 'challenge' does not mean unrecyclable.

Quantitative

- Design Guidance has been downloaded nearly 1400 times since its launch in 2021; and
- 144 people attended the launch webinar.

Unique or can be replicated

Unique

Contacts and sources

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Design Guidance for Recyclability: https://www.afandpa.org/sites/default/files/2021-08/AFPADesignGuidanceforRecyclability_FINAL_031621.pdf

Press Release: AF and A Releases New Guide to Further Advance Paper Recycling
https://www.afandpa.org/news/2021/afpa-releases-new-guide-further-advance-paper-recycling

Austria’s policies in the pulp and paper industry

Introduction/Background

Austria's pulp and paper industry is a key economic sector that makes a sizable contribution to the national economy. However, the industry faces difficulties with its operations in terms of energy use and environmental impact. Austria has put in place a variety of regional rules and regulations as well as international agreements to address these issues and ensure ethical business practices.

Circular approaches and practice applied

Regional Laws in Austria

- **Environmental Impact Assessment Act (UVP-G)** ensures that projects, plans, and programs that could significantly impact the environment are subject to a comprehensive examination before being approved or executed. By taking into account potential effects and implementing suitable mitigation measures, it seeks to safeguard and improve environmental quality [2]. UVP-G is also essential for ensuring that initiatives in the pulp and paper sector and other industries are carried out in an environmentally friendly manner. By evaluating potential effects, including mitigation strategies, and encouraging communication among stakeholders, it encourages transparency, public engagement, and sustainable development.

- **Water Act (WRG)** seeks to ensure the responsible use and preservation of all water resources, including groundwater and surface water bodies. It enacts laws and policies to stop pollution, preserve the quality of the water, and protect aquatic habitats [10]. The industry can reduce its influence on water resources, ensure sustainable water usage, and contribute to the general protection and conservation of Austria's water bodies by adhering to the act's rules.

- **Waste Management Act (AWG)** seeks to ensure the responsible and long-term management of waste. To reduce the negative effects on the environment and health concerns related to disposal of waste, it encourages waste prevention, recycling, and effective garbage treatment.

International Labor Organization (ILO) Standards.

Although the paper and pulp industry is not specifically covered by any legislation created by the ILO, its general principles and labor standards offer a framework for advancing employees' rights, occupational health and safety, social interaction, and sustainable development. The industry's adherence to ILO criteria serves to guarantee just and moral behavior, safeguard workers, and contribute to a responsible and sustainable paper and pulp sector [6].

Results, benefits and challenges

There are various advantages to using regional and international rules in the pulp and paper business:

- **Environmental Protection.** Sustainable practices and environmental protection are governed by international and regional laws. Standards for emissions, pollution control, waste management, and the preservation of natural resources are established by these regulations. These regulations' observance aids in minimizing the industry's ecological footprint, protecting ecosystems, and preserving biodiversity.
- **Market Entry and Competitiveness**. Companies can enter foreign markets that place a premium on sustainability by adhering to international rules and standards, such as FSC certification. Many clients want ethically sourced and environmentally sustainable products, notably in Europe and

North America. The industry's reputation is improved, market prospects are increased, and competitiveness is improved by compliance with international standards.

- **Circular Economy and Resource Efficiency**. International and regional legislation support the development of a circular economy as well as resource efficiency. Regulations support activities for trash reduction, recycling, and sustainable industrial methods. By lowering waste production and maximizing resource use, this also lowers costs and fosters long-term sustainability.
- **Worker Protection and Social Responsibilities**. Regional and international labor laws and regulations ensure that workers are paid fairly and have their rights upheld. The observance of these regulations promotes a secure and welcoming workplace, improving the health and morale of the workers. Additionally, upholding social responsibility standards shows a business' dedication to moral business conduct, which benefits both employees and the community.

Challenges

- Industries reliant on natural resources, like the pulp and paper industry, are subject to stringent environmental regulations, which impose emission reduction targets for the future that cannot be satisfied by employing currently existing "off-the-shelf" technologies [7].
- These tightening restrictions may represent both an opportunity and a challenge for the sector. For this reason, it's critical to find policies that can support sustainability transitions (such significant emission cuts or new green value chains) without endangering the industry's capacity to compete [9].
- There is a need for technological advancements to meet future emission reduction targets and the potential challenges posed by tightening environmental restrictions.

Unique or can be replicated

Can be replicated

Literature and used sources

[1] *EU Emissions Trading System (EU ETS)*. Climate Action. (n.d.). https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets en

[2] Federal Act on Environmental Impact Assessment (Environmental Impact Assessment Act 2000 – UVP-G 2000). (1993). https://www.ris.bka.gv.at/Dokumente/Erv/ERV1993697/ERV1993697.html

[3] Federal Ministry of Agriculture, Forestry, Regions and Water Management. (1975). Forest act . https://info.bml.gv.at/en/topics/forests/austrias-forests/forest-law/forest-act-1975.html

[4] *In-house waste management - general information on the Waste Management Act*. WKO. (2002). https://www.wko.at/site/mehrsprachigeinfo/In-housewastemanagement.html

[5] Kärntner Naturschutzgesetz. (2002). https://faolex.fao.org/docs/pdf/aut92130.pdf

[6] Labour standards. (n.d.). https://www.ilo.org/global/standards/lang--en/index.htm

[7] Nentjes, A., de Vries, F. P., & Wiersma, D. (2007). Technology-forcing through environmental regulation. *European Journal of Political Economy*, *23*(4), 903–916. https://doi.org/10.1016/j.ejpoleco.2007.01.004

[8] *Reach regulation* . Environment. (n.d.). https://environment.ec.europa.eu/topics/chemicals/reach-regulationen#:~:text=The%20Regulation%20on%20the%20registration,can%20 be%20posed%20by%20chemicals.

[9] Söderholm, P., Bergquist, A.-K., & Söderholm, K. (2019). Environmental regulation in the pulp and Paper Industry: Impacts and challenges. *Current Forestry Reports*, *5*(4), 185–198. https://doi.org/10.1007/s40725-019-00097-0

Water Rights Act WRG. Federal Ministry of Agriculture, Forestry, Regions and Water Management. (1959). https://info.bml.gv.at/en/topics/water/water-in-austria/water-law/water-law-1959-wrg1959.html

4evergreen initiative: A cross-industry alliance for circularity in fibre-based packaging

Introduction/Background

4evergreen is a an international cross-industry alliance of over 100 members whose activities cover the entire life cycle of fibre-based packaging – from forest managers to designers, producers, brand owners and recyclers. Together, they want to contribute to a climate-neutral society by perfecting the circularity and sustainability of fibre-based packaging.

Fibre-based packaging –ranging from paper cups to cardboard boxes – is already a crucial enabler of circular growth and has the highest recycling rate in Europe (81.6 percent) when compared to other materials. However, 4evergreen members are looking for further improvements and hope to raise it to 90 percent by 2030.

Circular approaches and practice applied

Driving the sector towards circularity

To achieve this 90 percent recycling rate, four key areas have been targeted: evaluating packaging recyclability, designing for circularity, advising effective collection and sorting and, finally, exploring innovative recycling and sorting technologies and techniques.

For each area, a toolbox of guidelines and protocols is being developed, including:

- The Recyclability Evaluation Protocol, a landmark industry tool that enables a harmonized and objective assessment of different fibre-based packaging solutions' suitability for efficient recycling.
- The Circularity by Design Guideline, which tackles the optimization of packaging to fit into the proper waste stream for optimal recycling by providing specific recommendations on packaging design.
- The Guidance on Improved Collection and Sorting, which offers an overview of existing systems and practical recommendations to enhance the collection and sorting of different types of fibre-based packaging.

  These tools are a culmination of cross-industry expert-led research, intense discussions and robust data derived from testing.

The crucial role of innovation in perfecting circularity is also recognized by the alliance, which has established a working group to accelerate the development of new technologies and processes that can raise the circularity of fibre-based packaging.

Results and benefits

The first versions of the Recyclability Evaluation Protocol, the Circularity by Design Guideline and the Guidance on Improved Collection and Sorting are already available and aim to tackle the largest proportion of fibre-based packaging. Ongoing and future versions will include recommendations for fibre-based packaging that require reprocessing in specialized recycling mills and floatation-deinking mills.

Unique or can be replicated

Can be replicated.

Sharing knowledge and driving impact in Europe with a holistic approach

By collaborating with relevant stakeholders like consumer goods companies, retailers, recyclers and paper-producing and recycling factories in Europe, 4evergreen is committed to increasing consumer awareness and promoting the right incentives to boost circularity.
With its toolbox of guidance and protocols, 4evergreen also ensures the involved industries meet the demands of recent and future packaging-focused regulations and plays a positive role in shaping Europe's climate-neutral future.

Contacts and sources

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University of Helsinki analysis of added value from wood-product industries' by-products

Introduction/Background

In Finland, 50% of wood flows is coming from industrial side-streams, therefore it is important to analyse their utilization patterns as well as their economic, social and environmental impacts. To date, valuable by-products, including wood chips, sawdust, bark and black liquor, resulting from the chemical pulping process and sawmilling are mainly used in energy generation and only partly in the pulp industries and, for example, in panel production.

In Finland, no by-products are landfilled and energy use contributes to forest-industry mills' energy needs with surplus energy production being used for district heating and combined heat and power (CHP). Thus, the current utilization pattern could be considered a cascading use already, however, there is a range of potentially higher value uses in the biofuel and modified wood industry. Therefore, new utilization patterns are constantly being explored to define preferred uses that could bring both added economic and environmental benefits.

The research summarized in this case study is a part of the FORBIO – Sustainable, climate-neutral and resource-efficient forest-based bioeconomy, a project funded by the Strategic Research Council at the Academy of Finland and FutureForest2040 – Structural changes, market and employment prospects in the Finnish forest sector up to 2040, a project funded by the Metsämiesten Säätiö Foundation.

In addition to exploring preferred and possible wood-use scenarios, this work aimed to gain insight into which structural drivers and barriers, such as international policies, investments in R&D, cross-sectoral cooperation and consumer awareness, are needed to enable them in the future.

Circular approaches and practice applied

Circular approaches in the FORBIO and FutureForest2040 research included:

- Development of a material-flow model describing current wood uses in Finland, including forest harvesting, primary industries and by-product formation, secondary industries and intermediate products as well as their end-use scales;
- Substitution impact analysis measured by displacement factors (DF). Substitution refers to the avoided fossil-based GHG emissions when a wood product substitutes a non-wood product in a specific end use. This part of the work includes DF review (product specific substitution) and decarbonization scenarios:
    - Weighting the DF's based on end-uses to evaluate how much one unit of harvested wood can avoid fossil emissions under certain market structure.
    - Analyses of the changes in the product -level DFs due to energy-sector decarbonization and non-wood material recycling (DFs decrease when there are less overall fossil emissions assumed in the future in the non-wood sectors).
- Creation of expert panels for scenario formation involving experts from national forestry, non-wood industries, research, interest groups and policy areas.
- Scenarios:
    - Possible and preferred;
    - Combining qualitative scenario pathways and quantitative illustrations of wood-flow changes;
    - Substitution impact analysis (weighted DFs for Finnish wood-product portfolios in the scenarios);

- Policy recommendations and support for industry strategies; and
- Raising awareness through media (newspaper and television interviews, podcast series, social media and video clips).

Results and benefits

Research results can be summarized as follows:

- Multi-stage cascading and shifting secondary wood flows, such as industrial side streams and end-of-life wood-based products from energy uses to material uses that result in increased climate benefits through substitution and prolonged carbon storage, may increase economic benefits in terms of revenues.
- Shifting by-products from energy uses to material uses requires high investments in the renewable energy sector. The economic feasibility of the wood utilization scenarios where material utilization is emphasized depends on the energy price.
- National policies can support shifting by-products from energy use to material uses only to a limited extent, thus, international agreements restricting fossil fuels and supporting by-products circulation based on GHG emission savings are needed to make wood-based material applications more competitive.
- Cross-sectoral cooperation in research, product piloting and risk distribution in new investments are needed to enable new innovations and market development.
- Process automatization and digital solutions should be adopted to ensure resource-efficiency and cost-competitiveness.

Unique or can be replicated

This scenario work and substitution impact analysis can be replicated in any country, however, the scenarios may vary depending on the circumstances at hand and the experts recruited to the panels. Country-specific circumstances will define the possible market structures and possibilities to utilize wood materials.

Contacts and sources

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Preferable utilization patterns of wood product industries' by-products in Finland. Forest Policy and Economics, 110(2020). https://doi.org/10.1016/j.forpol.2019.101946
Targeting net climate benefits by wood utilization in Finland: Participatory back-casting combined with quantitative scenario exploration. Futures, 134(2021). https://doi.org/10.1016/j.futures.2021.102833
FutureForest2040 –Suomen metsäalan rakenteelliset muutokset sekä markkina- ja työllisyysnäkymät vuoteen 2040". ETLA Report No 131. https://pub.etla.fi/ETLA-Raportit-Reports-131.pdf

Georgia-Pacific recycling technology

Introduction/Background

Georgia-Pacific LLC is one of the world's largest manufacturers and distributors of pulp, tissue products, paper, packaging and building materials. It also operates material recovery facilities (MRF) throughout the United States to recycle recovered fibre for use in the manufacturing of new tissue, paper and packaging products.

In 2013, Georgia-Pacific began to pilot a new technology called Juno to prove the concept of recycling municipal solid waste (MSW) from airports, office buildings, theme parks and sports stadiums. In 2021, the first commercial-scale Juno facility began operations at Georgia-Pacific's MRF in Toledo, Oregon.

The Juno technology can recover up to 90 percent of the waste it processes by filtering out recyclable materials, including paper fibres, metals and glass. Recovered paper fibre is used in a nearby Georgia-Pacific mill to make new paper products while other recyclable materials are sold into their respective markets. Food waste and leftover materials are further converted into biogas for a variety of renewable energy applications.

Circular approaches and practice applied

- Design;
- End-of-life management;
- Reuse at the highest value; and
- Renewable energy generation.

Results and benefits

Qualitative

The operation of the first commercial Juno facility created 10 new jobs in addition to the benefits to the paper industry of recovering a raw material that is currently being lost to landfills. Diverting usable and recyclable material from landfills also benefits society by providing cities with an option to progress toward landfill diversion goals.

Quantitative

- Before the Juno facility became operational in Toledo, the city's landfill diversion rate was 23 percent. This rate increased to 66 percent by processing local waste through the facility which, based on 2019 data, gave Toledo the highest waste recovery rate in Oregon.
- The Juno unit in Toledo can process up to 64 000 tonnes of waste annually with feedstock sourced through waste collection processes across the region. In its first 10 months of operation, the facility processed more than 12 000 tonnes of waste.
- The facility currently recovers about 18 tonnes of paper fibre per day, which is mixed with old corrugated containers (OCC) and used to make containerboard. Juno™ Fibre meets the criteria for safe food contact in the United States and every tonne of waste processed through the facility can represent up to 1 ton of CO_2e net reduction according to the US Environment Protection Agency (EPA) WARM model V15, which provides high-level estimates of potential GHG emissions reductions, energy savings and economic impacts from several different waste management practices.

Unique or can be replicated

The Juno technology can be implemented in other communities.

Contacts and sources

Juno Website: https://gpjuno.com/

2022 AF and PA Innovation in Sustainability Award: Georgia-Pacific Juno Technology
https://youtu.be/Fpay0z5GiUM

AF and PA Update in Brief: Juno is an Innovative Recycling Technology
https://www.afandpa.org/news/2022/juno-innovative-recycling-technology

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Ibema paperboard from recovered fibres

Introduction/Background

According to Abrelpe, the Brazilian Association of Public Cleaning Companies,[2], there are more than 2,868 cities with irregular landfills in Brazil that emit around 27 million tons of CO_2e per year [3]. Hence, increasing the paper recycling rate is an important action to improve circularity and reduce negative environmental impacts overall. Selective paper recycling is partially the responsibility of the private sector in Brazil under the auspices of the National Solid Waste Policy (PNRS) which obliges consumer packaged goods (CPG) companies to correctly dispose of at least 22 percent of their packaging.

In this context, Ibema, a Brazilian paperboard company developed a specific paperboard, called Ibema Ritagli, which is produced using post-consumption fibres.

The new paperboard contains 50 percent recycled fibres, 30 percent of which are post-consumption fibres (this is planned to rise to 35 percent in the future). It finds application in the pharmaceutical, perfumery and cosmetic industries. This circular and sustainable solution turns fibres into a secondary raw material for industry, preventing them from being sent to landfills.

Circular approaches and practice applied

Ibema's Ritagli paperboard was developed as a solution designed to reduce the environmental impacts of landfill disposal. It was developed jointly with several players in the paper supply chain, including recyclers, start-ups, CPG companies and printing companies.

These actors collaborated on the development of a logistics system and training cooperatives to define a new standard for recycled material that could be commercialized. The initiative started as a small-scale operation and gradually gained the acceptance of clients and partners.

Results and benefits

Ibema's Ritagli paperboard helps CPG companies fulfil their obligations under the PNRS. Since its release, more than 9 000 tonnes of this paperboard have been sold to the packaging industry, this translates into more than 2 000 tonnes of post-consumption paper fibres being recycled and used as a secondary raw material for paper production, preventing this volume of material from being sent to landfills.

Unique or can be replicated

Can be replicated.

Contacts and sources

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REFERENCES

[1] ECKHART, Rene. Recyclability of Cartonboard and Carton. December 2021. Available at: < https://www.procarton.com/wp-content/uploads/2022/01/25-Loops-Study-English-v3.pdf >
[2] ABRELPE, Panorama 2021. Available at: < https://abrelpe.org.br/panorama-2021/ >

[3] CNN, cnnbrasil 03/11/2021. Available at: < https://www.cnnbrasil.com.br/nacional/lixoes-no-brasil-provocam-27-milhoes-de-toneladas-de-co2-no-planeta-diz-estudo/ >

Klabin– circular by-products management

Introduction/Background

Pulp and paper mills generate organic and inorganic by-products. Some of these by-products are dregs, grits and ash created during production processes in integrated pulp and paper mills.
Dregs are generated during the chemical recovery process while grits, which refers to a yellowish, solid-granular waste that is odourless and sparingly soluble, result from the calcination process of lime mud and limestone in lime kilns. The third by-product cited above, ash, is produced in the auxiliary power boilers.
At Klabin S.A, Brazil's largest paper manufacturer and exporter, dregs, grits and ash represented 2.79 percent of the by-products generated in industrial processes which were, in previous years, sent to landfill.
In 2020, the company committed to eliminating by-products sent to landfills by 2030. This required research on the reinsertion of dregs, grits and ash into the productive system.

Circular approaches and practice applied

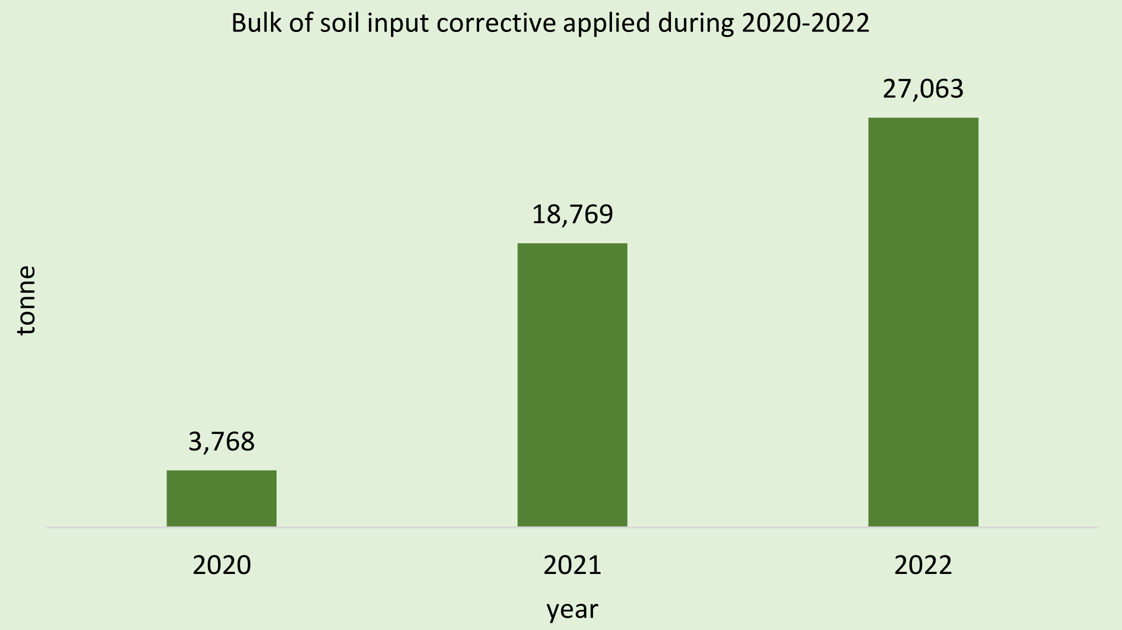
- Material substitution
- End-of-life management

Results and benefits

Since 2018, together with other companies, Klabin has been developing new applications for dregs, grits and ash.
One of these applications is a soil corrective input that is a source of calcium and magnesium for planting eucalyptus, which is an alternative to dolomitic limestone, mining of which causes widespread disturbance in the environment, including changes in land use pattern, habitat loss, higher noise levels, dust emissions and changes in aquifer regimes.
The basic composition of the soil corrective input comprises 30 percent ash, 40 percent dregs, 5 percent grit and 25 percent limestone. The chemical composition is shown in the table below.

Component	Percentage (%)
CaO (%)	30 to 35
MgO (%)	5 to 10
Na (%)	< 2.5
Humidity (%)	< 25

The soil corrective is applied to planted areas at a rate of 1.5 to 3.0 tonnes per hectare.
In the last three years, the utilization of this soil corrective entered the commercial scale and has shown an increase in utilization in this period, according to the graphic below.



For 2023, the estimated use of soil corrective input is 75 to 85 percent of the areas to be planted with eucalyptus.

The financial cost of developing the soil corrective input has the potential to avoid costs of BRL 269.2/t[11] associated with sending dregs for co-processing[12]. Considering the composition of the soil corrective input (40 percent dregs), the saving is greater than BRL 5 000 000.00[13].

Unique or can be replicated

This process can be replicated in all pulp and paper mills.

Contacts and sources

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[11] Approximately USD 50.55. Calculated value on 15 March 2023 by website Conversão entre Real e Dólar (conversor-dolar.com.br).

[12] Does not consider grits and ash costs because these industrial by-products can be absorbed in other applications in the company.

[13] Amounts greater than USD 1 000 000. Calculated value on 15 March 2023 by website Conversão entre Real e Dólar (conversor-dolar.com.br).

University of St. Petersburg ecopaper from unbleached hardwood pulp and aspen

Introduction/Background

Most copy-paper users can do with a substantially lower brightness level as the life cycle of many types of bureaucratic paperwork (receipts, contracts, bills, invoices, certificates, etc.) is very short, and the cheaper they are, the better. The excessive brightness of paper treated with optical brighteners is even harmful to human eyes (the brightness of school exercise books should not exceed 80 according to the ISO health standards). The brightness standard for C-grade paper in the United States was 84 until the mid-2000s. Although under pressure from competitors in Asia and Latin America, the International Paper company announced increasing brightness to 92. Paper brightness comes from bleaching and all types of pulp bleaching cause major environmental problems: increased water and energy consumption, GHG emissions, poor industrial-effluent quality and significant investments to comply with best available technology (and the requirements of regulatory agencies.

The Pulp and Composite Materials Department of the Higher School of Technology and Energy at the St. Petersburg State University of Industrial Technology and Design and the Svetogorsk pulp and paper mill developed a total chlorine free eco-paper manufactured using unbleached hardwood pulp, bleached chemical-thermomechanical pulp (BCTMP) and mineral fillers. The quality of such paper meets all copy-paper requirements while allowing a more sustainable and efficient use of natural and industrial resources coupled with the preservation of valuable wood species and an improved environmental profile for pulp and paper mills from their lower water and energy consumption, lower GHG emissions and higher industrial effluents quality.

Circular approaches and practice applied

Every sheet of ecopaper has a natural colour due to less bleaching agents being used. No chlorine dioxide has been used to produce the aspen pulp as it only receives an alkali-oxygen treatment. At the same time, sufficient brightness and purity of the pulp allow for a reduced consumption of chemicals for retention and sizing. There is no need for optical brighteners at the paper machine stage. The inclusion of precipitated calcium carbonate with over 90 percent brightness, and BCTMP, with 80 percent brightness, is enough to produce 60 percent ISO brightness paper – sufficient to serve as a means of information storage. There are no fibre losses due to chemicals, meaning up to 10 percent more paper can be made from the same amount of raw material. Just like traditional copy paper, the ecopaper is compatible with any currently commercially available printers and copy machines having all the properties required for high-quality printing. The paper's high opacity ensures good readability when duplex-printing while its stiffness eliminates paper jams and optimum moisture content prevents sheet rolling. The ecopaper manufacturing technology reduces negative environmental impacts, including a lower carbon footprint and emissions. An all-hardwood pulp provides for more sustainable use of wood resources. Manufacturing of the ecopaper also excludes the use of many chemicals.

Results and benefits

The technology of manufacturing paper from partially bleached pulp allows for reduced negative environmental impacts, including a lower carbon footprint and air emissions. Early estimates show a 35 percent reduction in GHG emissions while the use of all-hardwood pulp and BCTMP ensures a more sustainable use of forest resources and enhances effluent-treatment quality. Reduced wood cutting age: 40+ years for aspen, 60+ years for birch and 80+ years for pine. Reduced wood consumption to produce raw fibres – from 4.2 m3/ton for hardwood pulp to 2.7 m3/ton for aspen BCTMP. There is also reduced raw fibre consumption due to the inclusion of BCTMP, which results in pulps retaining their bulk. Reduced energy and chemical consumption, specifically due to the absence of ClO_2 bleaching. Reduced energy consumption for drying due to higher paper bulk. Reduced energy consumption for drying softwood pulp that is more hydrophilic than hardwood pulp. Increased biofuel usage due to deeper delignification while cooking (Kappa number from 15-16 to 10).

The performance properties of the ecopaper meet all C-grade copy-paper requirements, with elastic and relaxation properties meeting requirements for all copy-paper grades. That allows ecopaper to be used in all types of printers, including those that are high-speed. Aspects of using aspen with trunk rot in the pulp and paper industry have been studied and further granted Russian patent protection.

It was found that the carbon footprint of the new ECO copy paper is about 1.2-1.5 times lower than that of other A- and B-grade copy paper. The transition to manufacturing the new ecopaper will reduce the negative environmental impacts of the enterprise as, for example, the chemical oxygen demand of effluents after treatment will be lowered by 33 percent.

Over 90 000 tonnes of ecopaper were produced in 2022 and it is now recommended for state and municipal procurement.

Unique or can be replicated

Can be replicated by many office paper companies to reduce the carbon footprint of their products

Contacts and sources

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Suzano nurseries paper pots become fertilizer for surrounding communities

Introduction/Background

Suzano is a Brazilian company developing products made from planted eucalyptus forests and one of the largest vertically integrated producers of eucalyptus pulp and paper in Latin America. In 2017, it introduced a propagation system using biodegradable paper pots in its nurseries called the Ellepot system. Thanks to this system, Suzano can propagate seedlings and reduce its use of conventional plastic pots, advancing its long-term sustainability target of reducing the company's industrial solid residues sent to landfill by 70 percent.

Paper pots decompose in the soil when planted directly in a field and tests showed that their carbon footprint is more than 20 percent lower than comparable plastic pots. They are also easy to plant out and there are no plastic pots/bags to remove or pick up which contributes to up to 40 percent faster planting process and a decrease in seedlings lost.

At the end of their life cycle, residues of the Ellepot propagation system are donated to local communities, so that they can be used as a soil fertilizer. The Ellepot organic paper is made from 100 percent compostable and biodegradable materials (6 to 8 weeks decomposition), natural raw materials from FSC-certified forests and it is approved as an input material for organic crops in Denmark, Sweden, the Netherlands and Canada.

Circular approaches and practice applied

Through this initiative, Suzano raises awareness about and promotes plastic substitution in the sector as paper pots:

- have a circular design as they are 100 percent compostable and biodegradable;
- substitute plastic pots;
- reduce resource use, including energy, water, plastic and labour;
- reduce the loss of seedlings; and
- will decompose in the field at their end of life, biodegrade in landfills or will be donated to local communities to be used as fertilizer.

Results and benefits

Qualitative

Thanks to the Ellepot system, Suzano is advancing in the implementation of its long-term sustainability targets:

- Reduce the industrial solid residues sent to landfill by 70 percent;
- **Reduce the intensity of the GHG emissions of GHG Protocol Corporate Standard scopes 1 and 2 by 15 percent (Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy), per tonne of production.**
- **Lift 200 000 people out of poverty.**

In addition, family landowners benefit from the use of Ellepot residues as they can be used as compost to increase soil productivity and decrease production costs.

Quantitative

- Suzano owns 6 Ellepot machines: 2 machines in Três Lagoas, 2 in Campo Grande and 2 machines in Ribas do Rio Pardo (Cerrado self-sufficient pulp plant project[14])
- The Cerrado project aims to produce 75 million seedlings starting from 2025, in Ribas do Rio Pardo (35 million) and Campo Grande (40 million). During the same period, the Cerrado project will also purchase 30 million seedlings from paper pots.
- In Três Lagoas, 4 million paper pots are utilized each month, t**hus** avoiding the use of 4 million plastic pots.
- Ten communities and around 100 families benefit from the donation project in Mato Grosso do Sul state.

Unique or can be replicated

The technology is more expensive than using plastic pots but shows significant environmental, social and economic benefits and be replicated at scale.

Contacts & sources

Contacts

- Rodrigo Zagonel, Gerente Executivo Operações Florestais Colheita Cerrado;
- Hamilton Zanola, Gerente de Meio Ambiente Industrial Corporativo;
- Israel Batista Gabriel, Coordenador de Desenvolvimento Social;
- Camila Reggiani, Consultora de Meio Ambiente II; and
- Nina von Lachmann, Analista de Sustentabilidade e Comunicação.

Sources

- Ellegaard, Ellepot technology: Ellepot: A sustainable solution for propagation;
- Video demonstration for Suzano: Ellepot client video Forestry company Suzano (previously Fibri–) - YouTube;
- Suzano Annual Report 2021;
- Sustainability Center; and
- Article in Remade, Rema–e - Notíci–s - Fibria substitui tubetes plásticos por papel degradável.

[14] https://www.suzano.com.br/en/projetocerrado/#sobre

WestRock innovative paper packaging

Introduction/Background

WestRock is a provider of paper and packaging for industrial and retail customers. It manufactures and distributes containerboard and paperboard products, such as folding cartons, bleached paperboard, coated recycled paperboard, retail displays and pulp products.

The company developed an innovative paper-packaging system for the readymade food market called Sustainable Ready Meals. The paper-packaging system includes a pressed paperboard tray/bowl that replaces the Crystalline Polyethylene Terephthalate (CPET) plastic equivalent that is commonly used in the readymade food market. The system uses a fibre-based wrap instead of a fully enclosed carton and the case pack as a shelf-ready package.

This results in a 90 percent reduction in plastic use per food bowl. The fibre -based wrap also has a 30 to 40 percent smaller carbon footprint compared to full wrap cartons. In addition, the new paper wraps are flat-packed rather than glued, eliminating the need for a corrugated shipper. This translates to a 40 percent reduction in freight costs at times.

The entire new paper-packaging system is automated, contributing to reduced labour costs and manufacturing footprint. WestRock's CP eMerge Combo Machine applies a fibre-based wrap around a fibre-based tray or bowl and then case packs them into a shelf-ready package with a wrap-around case packer. Typically, the CP eMerge Combo machine can be operated by one worker.

Circular approaches and practice applied

- Design
- Material substitution
- Automated-manufacturing system

Results and benefits

Qualitative

As consumer demand for sustainable packaging continues to grow, WestRock's innovation delivers a sustainable, recyclable packaging solution without increasing cost. Local communities benefit by having less plastic packaging in their value stream and more environmentally neutral fibre-based packaging.

Quantitative

- The fibre-based packaging system can be as much as 30 to 40 percent smaller in material footprint than the alternative it replaces.
- Freight cost savings of up to 40 percent due to improved pallet utilization and reduced trailers.
- There is a 90 to 98 percent reduction in plastic use when moving from the CPET to the fibre-based bowl/tray.

Unique or can be replicated

Can be replicated.

Contacts and sources

WestRock CP eMerge™ Combo | Food Packaging Automation
https://www.youtube.com/watch?v=wNOqlVtsFqQ
2022 AF&PA Sustainability Award for Circular Value Chain: WestRock Sustainable Ready Meals
https://youtu.be/kEhCFlpL5EY
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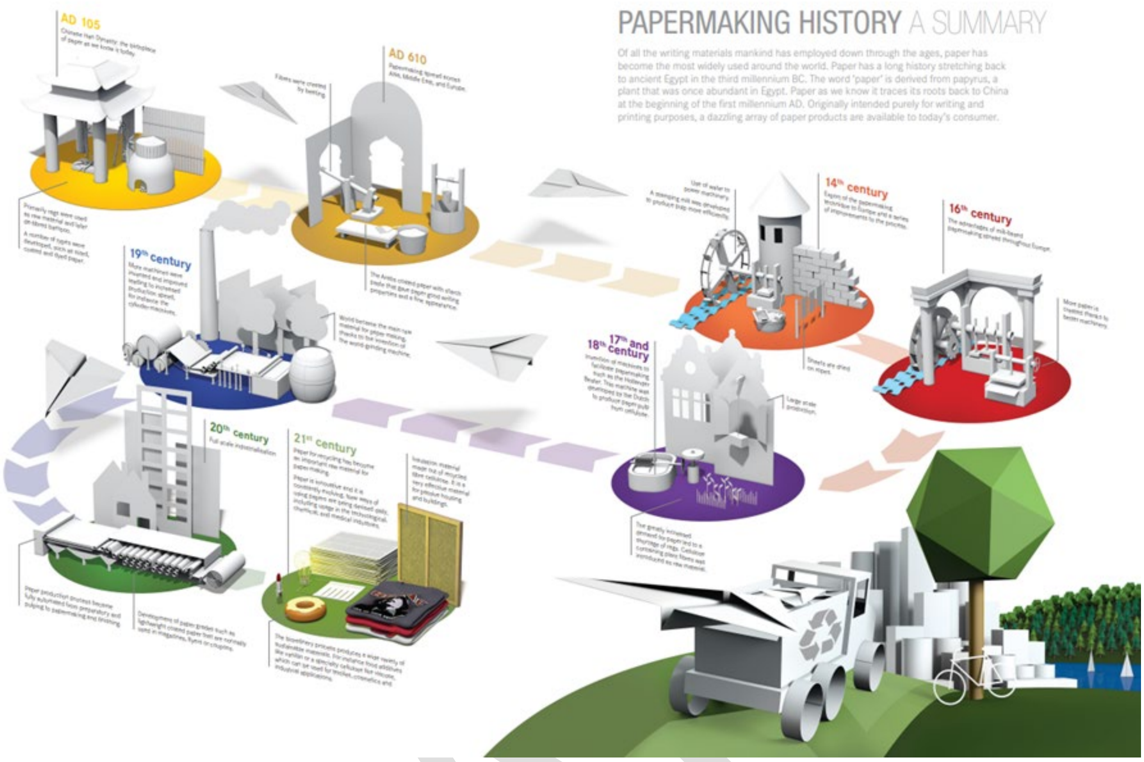
Annex 2



Source: CEPI