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AGENCY FOR ECOLOGICAL TRANSITION

SECTORAL TRANSITION PLAN FOR THE FRENCH PULP & PAPER INDUSTRY

EXPERTISES

PULP AND PAPER
Summary report

MARCH 2025

With the contribution of the European Union LIFE programme

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ADEME
20, avenue du Grésillé
BP 90406 | 49004 Angers Cedex 01

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Technical coordination - ADEME: Martin MANGEART and Adeline PILLET
Division/Department: Business and Industrial Transitions Division / Industry Decarbonisation and Hydrogen Department

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Sylvain WASERMAN Chairman and Chief Executive Officer of ADEME

The pulp and paper industry is part and parcel of our industrial heritage, having produced the first writing and later print materials, before becoming an essential player in hygiene and logistics through the manufacture of packaging. The paper industry has greatly evolved to meet our society's needs, with bio-based and mostly recycled products. Today, the sector is responsible for 3% of industrial greenhouse gas emissions, mainly from the natural gas used to produce heat for paper drying, and needs to build on the work already done towards meeting our climate commitments by 2050.

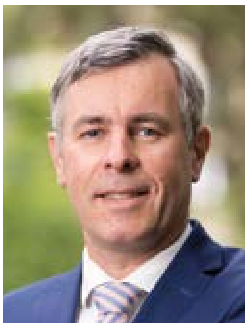
With the help of CITEPA, ADEME has used its expertise and modelling capabilities to come up with transition scenarios for the pulp and paper industry. Based on dialogue with stakeholders in the industry, we have produced three scenarios highlighting the technological and economic challenges of decarbonising the industry.

The study shows that firms in the sector can rely on mature energy efficiency technologies and biomass to meet intermediate decarbonisation targets. The next step will be to diversify the solutions adopted by ramping up process electrification thanks to high-temperature heat pumps and electric boilers or air dryers. Other thermal renewables or breakthrough technologies may offer additional solutions, depending on their level of maturity and the local context. Finally, this study calls for us to address market risks and opportunities as we shape the future of the French pulp and paper industry: the development of digital technology, reuse of packaging, and substitute for single-use plastics.

ADEME's Sectoral Transition Plans show that there are concrete, effective solutions for reducing industrial greenhouse gas emissions while maintaining competitiveness and the ability to meet the needs of society. They can be used to assess different technological trajectories and their costs, and also to anticipate certain market trends.

We would like to extend our warmest thanks to all those who contributed to this work, particularly the industry professionals and the French Union of Board, Paper, and Cellulose Industries (COPACEL).

Paul-Antoine LACOUR Managing Director of COPACEL



Between 2005 and 2023, greenhouse gas emissions from the French pulp and paper industry decreased from 4.3 Mt to 1.65 Mt, representing an annual reduction of 5%. This decrease can be attributed to improved energy efficiency in processes, extensive use of energy sources that do not emit fossil CO_2 (biomass used in boilers and cogeneration facilities), and, unfortunately, plant closures.

The Sectoral Transition Plan presented here assumes an acceleration of this reduction in greenhouse gas emissions, aiming for an annual rate of nearly 10.5% (twice the rate observed between 2005 and 2023), while also increasing paper production capacity (varying according to scenarios). For such a significant change to be feasible, four conditions must be met simultaneously.

The first condition is access to competitive decarbonized electricity, which is essential for the electrification of processes. France has a major advantage in this area due to its nuclear power plant. Therefore, it will be crucial to establish a favorable "post-ARENH" framework by 2025 to support such electrification.

The second condition relies on the availability of cost-competitiv energy from wood combustion, despite strong demand from various stakeholders (district heating, tertiary and industrial facilities). This must be balanced with the priority of using wood as a raw material over its use as an energy source.

The third condition involves access to public funding to help companies finance the additional costs of low-carbon technologies. Similar to incentives for electric vehicle development, many low-carbon technologies will only be implemented with the support of incentive mechanisms.

Finally, the fourth condition concerns the European framework, which, due to its rapid reduction in emission caps, is driving deindustrialization and the relocation of production in regions with less stringent carbon constraints (a phenomenon known as "carbon leakage").

Background

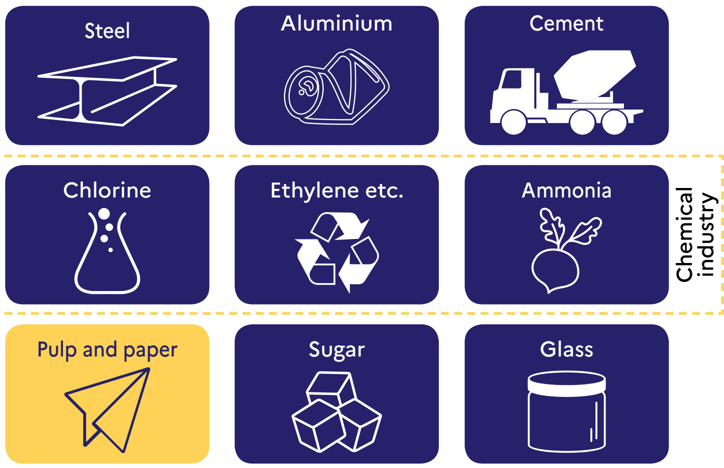
From the National Low-Carbon Strategy to the Sectoral Transition Plan

The current National Low-Carbon Strategy (SNBC 2) sets out the path France intends to take to achieve carbon neutrality by 2050, a commitment it made following the 21st Conference of the Parties (COP 21) convened under the United Nations Framework Convention on Climate Change (UNFCCC). For industry, this trajectory translates to an 81% reduction in greenhouse gas emissions (GHG) compared to 2015. An intermediate target of a 35% reduction in emissions has been set for 2030. While a number of guidelines have been put forward (e.g. giving priority to low-carbon energies, improving energy efficiency, developing breakthrough technologies, etc.), there have so far been no details on timeframes and the way they will apply to different sectors. Yet the challenges of decarbonising industry vary greatly from one sector to another. Moreover, industry needs forward visibility to make investments: industrial plant has a lifespan of several decades, so the effects of today's investments will continue until 2050. The Sectoral Transition Plans are intended to address this need for visibility going forward to 2050. For the government, the aim is to put forward effective policies aimed at encouraging the investment needed to achieve carbon neutrality by 2050.

By drawing up these Sectoral Transition Plans (STPs) in consultation with key stakeholders in the sectors concerned, ADEME aims to provide visibility for both manufacturers and investors, as well as the government. The project is therefore a continuation of the work carried out for the SNBC, breaking down heavy industry into nine sectors (Figure 1) in order to tailor decarbonisation solutions for each one.

Part of a European LIFE programme called Finance ClimAct, the aim of these transition plans is to explore different decarbonisation scenarios in order to identify the transformations in industrial sectors required for a carbon-neutral society. This project takes a 360° view, looking not only at the technological aspects but also at markets, funding, costs and jobs. This work should lead to the formulation of proposals for "public-private" actions to accelerate transition in these key sectors.

Figure 1.
The 9 industries with STPs.



This document summarises the main results of the Sectoral Transition Plan for the paper & board industry.

Box 1

STP method

Phase I: Survey of the industry. This phase entails mapping the market (consumption, imports-exports, production) and building a model representing the energy consumption, GHG emissions and production costs of French industry in 2015.

Phase II: Projections. Each scenario is based on (i) the projection of a transition environment, (ii) the formulation of assumptions about market trends and the implementation of decarbonisation technologies, (iii) modelling and (iv) analysis of the results.

Phase III: Development of action plans.

The method, tools and assumptions used are described in greater detail in the full report.

In a dedicated guide, ADEME sets out the method used to construct the various STPs, step by step, illustrated by feedback on STPs carried out by ADEME[1].

[1] ADEME. Methodological guide to drafting a sectoral transition plan for the decarbonisation of industry. 2023.

Project

Finance ClimAct

With the contribution of the European Union LIFE program

30

people working full time on the project

18

million euro budget

5

years

Projet partners

ACPR, AMF, Banque de France, Institute for Climate Economics, Ministry of Ecological Transition, 2° Investing Initiative, Institut de la Finance Durable, RMI (Rocky Mountain Institute)

Main limits of the study

All of the results presented are based on an ambitious modelling exercise to map decarbonisation trajectories for the paper & board industry going forward to 2050, using an innovative methodology that is, however, subject to limitations, particularly in terms of scope and access to data. Readers should take this into account when looking at this document, especially in terms of the conclusions that they may draw from it. In particular, it is important to consider the following:

• A common emissions reduction target for different industrial sectors.

The SNBC's[2] target of reducing industrial GHG emissions by 81% from 2015 levels by 2050 was applied to the pulp & paper sub-sector as an input constraint for the scenario-building exercise. This has the advantage of defining a common framework for all the sectors covered by a Sectoral Transition Plan. However, this assumption closes the door to a more flexible allocation of emissions reduction targets between industrial sectors for which abatement potentials and associated decarbonisation efforts may be different. An analysis of all sectors could eventually contribute to defining more appropriate targets.

• A limited objective that does not take into account all the criteria for the ecological transition.

The current National Low-Carbon Strategy's (SNBC2) target for the manufacturing industry focuses on direct GHG emissions (category 1) and therefore does not take into account emissions from power generation (category 2) or indirect emissions upstream and downstream of the value chain (categories 3, 4, 5 and 6). Similarly, the target does not take into account carbon footprint variations resulting from increases or reductions in imports of paper, board and pulp. Finally, this single-criterion target does not take account of impact transfers to other types of pollution (air, water, resources, and human health).

• A broad-brush view of a paper & board sector heavily dependent on external factors.

The aim of this exercise is to provide an overview of the factors affecting GHG emissions from the manufacture of paper & board. It was therefore necessary to make assumptions about parameters outside of the sector, such as such as demographics and changing consumer behaviours. To enable comparisons, energy and CO_2 price trajectories were set in the same way in all the scenarios, with an accompanying sensitivity analysis. An analysis of the way these factors impact the competitiveness of the pulp and paper industry is, however, a different exercise, and requires an in-depth study looking at how supply chains for paper and board, pulp, and recovered paper and board are organised.

This sectoral approach could be further enhanced by other factors determined by other economic actors.

Since the pulp and paper industry is a node in a complex economy that interacts with upstream and downstream entities (themselves evolving), an exhaustive, systemic approach to decarbonising the sector would require adopting a vision that goes well beyond the scope of this sector, and therefore numerous assumptions about other nodes in the system. This is the goal of ADEME's broader outlook project, entitled "Transition(s) 2050"[3], published at the end of 2021.

• As in any foresight exercise, the range of assumptions and combinations of assumptions is infinite, and each scenario could be "challenged" further.

While they are not predictions, these scenarios are essentially the product of internal work done by ADEME that has been put to industry stakeholders for their feedback. They reflect possible situations that are technically plausible, and more or less desirable. The aim is to help industry stakeholders take ownership of the exercise, each within the realm of their own prerogatives and with the same requirement for transparent assumptions and scenarios, while acknowledging the limitations of this exercise. These elements of analysis are based on extensive bibliographical research and information in the public domain, as well as interviews with industry stakeholders, and are intended to be as objective as possible, given the cross-referencing of all these sources by the authors.

Incidentally, the full report that accompanies this summary provides additional information on the context of the scenarios and the way in which the transition could occur in terms of jobs or potential industrial strategies. The aim is to broaden the scope of reflection in relation to the various results of the summary. These analyses, which can be described as academic, are based on extensive bibliographical research and information in the public domain, as well as interviews with industry stakeholders, and are intended to be as objective as possible, given the cross-referencing of all these sources by the authors.

[2] The current revision of the National Low-Carbon Strategy (3rd edition) will potentially result in the definition of new sectoral objectives.

[3] For more information, visit the dedicated website: https://transitionH2050.ademe.fr/

Key figures for the French pulp and paper industry

82

Number of pulp, paper and board plants in metropolitan France in 2021[4]

operated by 72 different companies

1.6 million tonnes

Volume of pulp produced in 2021[5]

7.3 millions tonnes

Volume of paper and board manufactured in 2021[6]

16.000 direct jobs in 2021[7]

8 TWh PCI

Annual natural gas consumption by the pulp and paper industry in 2021. That figure represents 6% of national industrial gas consumption, and 2% of total French gas consumption[8]

[4, 5, 6, 9, 10, 11, 12, 13, 14, 16, 17] Copacel
[7] URSSAF
[8] SDES and GEREP
[15] CEREN

60 %

Share of French national paper and board

consumption imported in 2021[9]

54 %

Share of French national paper and board

production exported in 2021[10]

France is the 5th largest producer of paper and board in the European Union and 14th worldwide[11]

64 %

Share of French national pulp

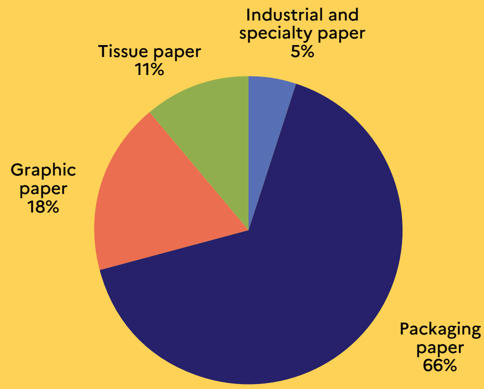
consumption imported in 2021[12]

26 %

Share of French national pulp

production exported in 2021[13]

Share of paper and paperboard production in 2021 by segment[14]



75 %

Share of thermal energy used for drying processes[15]

in paper and paperboard manufacturing

2 $MtCO_2e$

Fossil-based GHG emissions from pulp, paper and paperboard plants in 2021[16]
(approx. 3% of total industrial GHG emissions)

4.5 $MtCO_2$

Biogenic CO_2 emissions from pulp, paper and paperboard plants in 2021[17]

Summary for policymakers

The pulp and paper sector: bio-based and recycled products

The pulp and paper industry encompasses both the production of pulp and the production of paper and board from virgin fibres (wood) or recycled fibres (recovered papers and paperboard – RCP). It lies in the centre of a value chain that stretches from sourcing of bio-based materials (forestry, collection and sorting of paper and board waste) at the top, all the way down to the transformation of cardboard and paper rolls into finished products (box making, printing, etc.). The paper industry has an unusually high circularity rate with finished products containing an average of 77% recycled materials in 2023.

In 2021, the French pulp and paper industry produced 1.6 million tonnes of pulp and 7.3 million tonnes of paper and board. Some 85% of manufacturing output comes from large international groups, mainly based in Europe. Paper pulp is traded on a global market, whereas paper and board are mostly bought and sold within Europe owing to the impact of shipping costs on overall product costs. Within the pulp & paper industry, products are divided into four categories based on their target market and properties (strength, grammage, texture):

• Packaging paper and board (corrugated containerboard, boxboard, paper bags);

• Graphic papers (printed advertising materials, office papers, press and magazines, books);

• Tissue and sanitary papers (lavatory paper, paper towels, paper handkerchiefs);

• Industrial and specialty papers (banknotes, baking paper, cigarette papers).

In France, there were 82 sites manufacturing pulp, paper and board in 2021:

• Four produce pulp only, three from wood (virgin fibres) and one from recovered papers (RCP), supplying other plants in France and abroad – this is known as "market pulp";

• Eight produce wood pulp and also manufacture paper and board from that same pulp – these installations are known in industry parlance as "integrated paper mills", and only make paper and board from virgin fibres.

• Seventy produce exclusively paper and board products, either from pulp (virgin or recycled fibres) sourced from other suppliers (34 sites), or from bales of recovered papers that are processed on-site (32 sites), or from both types of raw material (four sites).

The manufacture of pulp from virgin fibres uses either a mechanical or chemical (cooking) process to separate the cellulose from the other components of wood (hemicellulose, lignin), depending on the pulp's desired attributes.

Recycled pulp or paper and board are manufactured by means of a three-stage process:

1. Ready-to-use pulp (obtained from wood or recycled fibres) or bales of recovered papers are mixed with water to form a "slurry". This stage involves separating the cellulose fibres by a process called pulping, then binding the fibres and purifying the mixture by refining and purification. If recovered papers are used as a feedstock, they are decontaminated and deinked to manufacture tissue and sanitary papers or graphic papers;

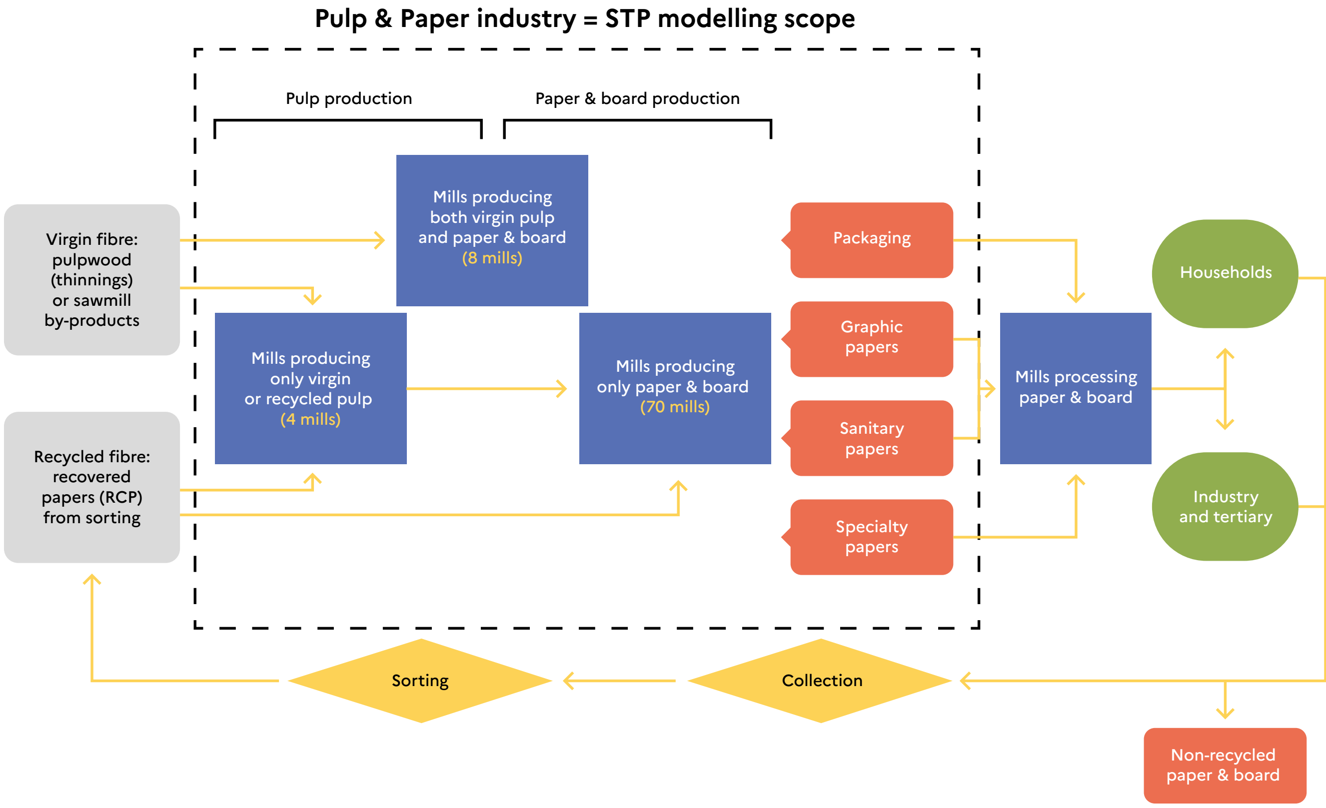
2. The slurry is dewatered, pressed, and dried in machines. The drying stage is the most energy-intensive part of the process of manufacturing recycled pulp, paper and board;

3. To finish, the paper is cut into sheets and wound onto rolls. For some types of paper, additional treatments are applied, such as coating or calendering, to obtain specific characteristics (strength, opacity, gloss, smoothness).

In 2021, the sector emitted 4.5 Mt of biogenic CO_2, some 90% of which came from sites manufacturing pulp from virgin fibres. The eleven mills concerned use almost exclusively by-products (bark, black liquor, etc.) obtained from biomass to fuel the process's energy requirements.

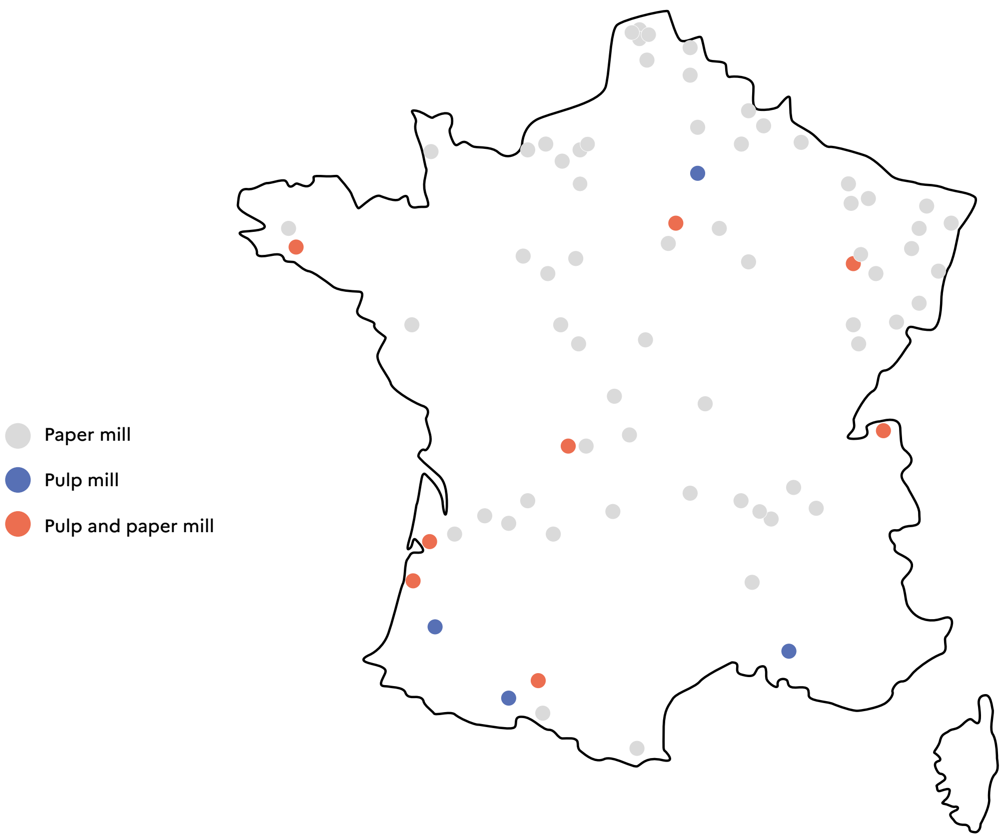
Meanwhile, the paper industry generated around 2 Mt of fossil greenhouse gas emissions, representing approximately 3% of total French industrial emissions. These emissions are concentrated at the 70 paper mills that source pulp (wood or recycled) from third parties or use recovered papers as a raw material, and at the only recycled pulp mill that is not self-sufficient in energy. Most of these emissions come from the combustion of natural gas to make steam, used mainly to dry the recycled pulp and paper.

Figure 2. Pulp and paper value chain.



Given that the production of pulp and paper accounts for more than 85% of emissions, the modelling developed for the Sectoral Transition Plan focus on these two phases.

Figure 3. Map of France's 82 paper mills in 2021.
Source: Copacel



Market prospects guided by regulations on packaging for paper and paperboard, and access to biomass for pulp

Paper and paperboard

Positioned in a heavily Euro-centric market, paper and board production in France has evolved in contrasting directions depending on the segment concerned:

• There has been a structural decline in the use of graphic paper owing to the rise of digital media.

• A structural rise in the use of paper and board packaging (for logistics in industry and the food sector, e-commerce, as a substitute for single-use plastics)

The gradual decline in the use of graphic papers is already well established, and the general trend towards digitisation suggests with relatively high confidence that this is likely to continue for products such as direct mail printed advertising materials, office paper, and newsprint and magazine-grade paper. The outlook for paper and board packaging, however, is less certain. More specifically, there are two key trends at play:

1. The use of paper and moulded fibre as a substitute for single-use plastics

2. The reuse of industrial and commercial packaging

The move towards paper and cardboard as a replacement for plastic packaging is an important factor for the future of the packaging industry generally. There is a growing consensus around the need to move away from disposable plastics. In France, the law combating waste and promoting the circular economy (known informally as the "AGEC" law) will gradually phase out the use of single-use plastics by 2040, and pave the way for the development of alternatives made from paper, paperboard, and moulded fibre (packing materials, wrapping, water- and grease-resistant food packaging, etc.).

At the same time, the AGEC law has introduced a target of reusing 10% of packaging sold in France in 2027. Although this applies to all types of packaging made from any materials, the movement has already begun to affect the paper and board sector as fast-food chains replace disposable plates and utensils with reusable versions (including cups and fries containers made from cardboard). In addition to flexible packaging, new requirements could also encourage the reuse of shipping boxes and other forms of industrial and commercial packaging in good condition, or their replacement with other materials.

The regulations currently applicable in France and the European Union are different. The EU's Packaging & Packaging Waste Regulation (PPWR) does not set specific reuse targets for secondary and tertiary shipping packaging, instead focusing on plastic packaging. These regulatory divergences serve to highlight the uncertainty surrounding the optimum balance between reduction, recycling, and reuse of packaging, which depends on the environmental benefits identified by life cycle analyses of the different options, based on different uses.

Virgin and recycled pulp

Operating within a global market, the French virgin pulp production sector is up against fierce international competition and must secure supplies of raw material (newly harvested roundwood or sawmill by-products) at rates that allow it to compete with rivals in Europe and South America. With 64% of domestic demand met by imports, maintaining French production capacity is a sovereignty issue requiring the use of imported pulp to be limited, particularly from outside of the EU which accounts for half of French imports. If France is to maintain its virgin pulp production capacity, it will be vital to ensure that the correct balance is found between using wood biomass as a raw material for energy generation or for manufacturing.

Meanwhile, recycled pulp production, and more so the production of paper and board from recovered papers, will need to overcome the challenge posed by changes in the way paper and cardboard are used generally. The fibre quality of recovered papers and the way they are processed differ, depending on whether they come from packaging, office papers, or advertising mail. Fibres obtained from graphic papers are highly sought-after for manufacturing new graphic or sanitary papers, whereas packaging incorporates all kinds of papers. The declining use of graphic papers could cause supplies to become scarcer, requiring production lines in graphic and sanitary paper mills to be adapted. This in turn could prompt operators in those sub-sectors to focus on product innovation.

Ambitious decarbonisation targets made possible by two key measures: scaled use of biomass by 2030, followed by a move to electrification

In recent years, a decarbonisation strategy built on the use of biomass has taken shape in the paper and board sector, drawing on a variety of resources:

• **Wood by-products (black liquor, bark) used as a source of energy** by mills manufacturing virgin pulp, with biomass accounting for 95% of their thermal energy mix in 2021.

• **Energy-grade fuelwood (grade B waste wood and wood chips)** used as a substitute for gas in mills that do not manufacture virgin pulp (i.e. recycled pulp mills and non-integrated paper mills that source pulp from third parties or use recovered papers as a feedstock). These mills are where the majority of the decarbonisation effort will be made, with biomass accounting for 21% of their thermal energy mix in 2021 (and natural gas 75%), a figure that should rise to 40% by 2030 as new boilers are deployed with help from government-backed schemes launched in recent years.

There are, however, two limitations to this strategy:

1. By-products are already exploited at close to their maximum energy potential.

2. Waste wood and wood chips are much sought-after beyond the paper and board industry, and supply is no longer able to keep up with demand in some regions (particularly the Grand Est region). In the medium to long term, the volume of additional virgin wood harvested will need to be adjusted to take account of climate impacts on forests, the success of replanting plans, and the size of the carbon sink needed to achieve France's climate targets by 2030, 2040, and 2050. Consequently, it is uncertain how quickly fuelwood biomass energy systems will be deployed in the paper industry after 2030, but this will depend on what uses are prioritised for biomass feedstock and, also on the resource's capacity for regeneration.

Other avenues are therefore being examined, to allow the sector to cut its emissions while limiting the use of fuelwood.

The first possibility is to **continue with measures aimed at improving energy efficiency** at every stage in the manufacturing process (for pulp, paper and board). This entails leveraging technologies to optimise the refining, dewatering, pressing, and drying stages in paper machines, making adjustments to steam networks, and optimising the lime kilns used in virgin pulp mills.

The second possibility is to **electrify the drying stage of the paper and board manufacturing process** using high-temperature heat pumps and electric boilers.

Combining high-temperature heat pumps with the use of mechanical vapour recompression systems is a potentially highly effective solution for reducing the amount of steam needed by boilers, by recycling condensate in the paper dryer. Numerous demonstrators have been built in Europe and provided conclusive evidence that the technology works. It could be rolled out industrially by 2030.

Electric boilers generate heat at the temperature required by paper machines (mainly 150°C) and are already deployed industrially in Europe, but are hampered by the relatively high prices of electricity compared with natural gas and fuelwood. Their operating flexibility means they can not only be used as a baseload energy source by industrial plants, but also in hybrid mode in tandem with a supplementary source or heat storage solution during periods when electricity prices are high.

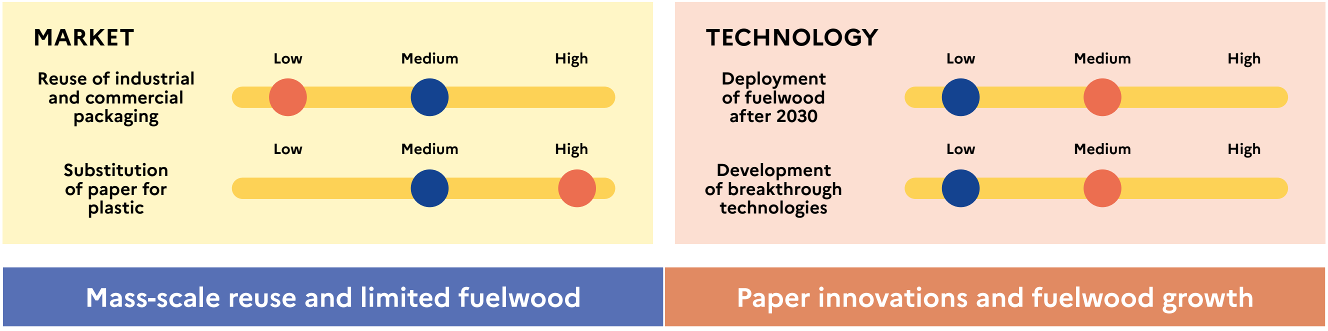
The third possibility involves **developing other renewable thermal energy sources** such as solar thermal, deep geothermal, and anaerobic digestion of solid and liquid residues from the paper industry. These technologies could be integrated locally at certain sites (essentially paper mills) provided certain conditions are met, i.e. there must be sufficient available land, a viable deep geothermal resource, residues with biochemical methane potential.

The fourth possibility lies in **breakthrough technologies** that have not currently reached maturity. These mainly concern paper and board mills. Various institutes of technology and industrial R&D centres in Europe are working on pioneering solutions for the paper manufacturing process, such as compression refining, dry fibre technology, using superheated steam for drying, or electro-osmosis dewatering. Other breakthrough technologies could support efforts to decarbonise the paper industry. These include small modular reactors (SMRs), a prototype of which could potentially be deployed for industrial purposes by 2030. The maturity of this particular technology is not the only determining factor, however, as other aspects will need to be approved by France's nuclear safety authority (ASN) before these reactors can be deployed: industrial safety, fuel availability and management, and the certification of sites using or building SMRs.

In addition to helping reduce the carbon footprint of its plants, the paper industry has the ability to capture the large quantities of biogenic CO_2 emitted by virgin pulp mills. At some sites, it could be used to make synthetic fuels for the aviation or maritime sectors, or stored underground to increase national carbon sinks, depending on how close the sites concerned are to the necessary infrastructures.

Two scenarios to illustrate the economic and technological challenges posed by ambitious decarbonisation targets for the sector

Figure 4. Key factors in the two STPs for the paper and board sector.



As part of the prospective study, four key factors were identified as being likely to influence market dynamics and technological developments. These factors were incorporated into each of the two scenarios in differing ways, to reflect the variables and uncertainties specific to each transition context.

In 2050, in the **Mass-scale reuse and limited fuelwood** scenario, the number of new shipping boxes in circulation is reduced by a combination of increased reuse for both cardboard and plastic boxes. At the same time, single-use plastics are partially replaced by paper and board products (packing materials and food packaging), and also by reusable plastic and glass products. In technological terms, the use of fuelwood is gradually limited to high temperature applications for which there are no alternatives, significantly reducing the rate at which wood-fired boilers are deployed after 2030. Paper mills mainly benefit from the deployment of other solutions (high-temperature heat pumps, electric boilers, solar thermal energy, deep geothermal heat, and biogas from anaerobic digestion of solid and liquid residues), whereas virgin pulp mills improve the efficiency of the kraft process, modernise lime kilns, and recycle biomass by-products to offset their idle energy consumption (i.e. power drawn by facilities when not operating).

In 2050, in the **Paper innovations and fuelwood growth** scenario, paper and paperboard continue to be used in greater volumes in the logistics chain. Meanwhile, newly developed paper materials with water- and grease-resistant properties are used as a direct substitute for a large number of plastic packaging types, such as bottles, food packaging materials, and pallet wrap. In terms of technology, the use of fuelwood is prioritised for medium and high temperature applications, and consequently it continues to be employed on a larger scale in paper mills.

Table 1. Summary of the main assumptions and technical and economic results of the Sectoral Transition Plan for the paper and board sector.

	Mass-scale reuse and limited fuelwood	Paper innovations and fuelwood growth
Variation in paper and board production in 2050 compared with 2023	+0 %	+20 %
Variation in pulp production in 2050 compared with 2023	+20 %	-20 %
Level of decarbonisation achieved in 2050 compared with 2015	-98 %	-98 %
Investment in decarbonisation between 2022 and 2050	2 000 MEUR	2 100 MEUR
Production cost increase between 2021 and 2050 (excl. raw materials)	+11 %	+6 %

At the same time, high-temperature heat pumps, biogas from anaerobic digestion of solid and liquid residues, and certain breakthrough technologies are deployed, reducing paper mills' reliance on natural gas. Virgin pulp mills employ the same decarbonisation solutions in both scenarios.

These two scenarios allow us to explore decarbonisation trajectories in transition scenarios that differ in terms of technology and markets. This simplified, non-predictive approach reveals four essential steps to decarbonising the paper industry:

- The use of fuelwood and energy efficiency measures to achieve rapid, deep decarbonisation by 2030;
- The need to diversify the technological solutions employed after 2030 to achieve full decarbonisation;
- The need to anticipate tightness in the supply of fibres (both virgin and recycled);
- The need to anticipate major changes in markets further down the value chain (packaging and graphic papers).

Essential steps to decarbonising the paper industry!

Deep and rapid decarbonisation possible by 2030

This decarbonisation is centred mainly on sites without sufficient volumes of biomass by-products (black liquor and bark), i.e. those that do not produce their own virgin pulp. These sites will need to rely on two other solutions:

• Continued deployment of proven energy efficiency measures

- by deploying a range of available technological solutions that have proven effective at improving energy intensity: high efficiency refining, new pressing technologies, optimised heat recovery and recycling in drying units.

• Continued deployment of biomass boilers and recycling of residues for energy

- by focusing on replacing gas boilers with wood-fired versions and using solid and liquid residues (muds, effluents) from paper mills as a source of energy.

There are several ways to reduce the fossil fraction of CO_2 emissions from virgin pulp mills, such as extending the use of multiple-effect evaporators (MEEs) for black liquor, modernising lime kilns by installing new lime mud dryers, and using available by-products to generate power.

This rapid decarbonisation by 2030 will require sustained investment of around 85 million euros annually, equivalent to 50% of the paper sector's total CapEx on technical equipment and industrial plant over the period 2019 to 2021[18].

Courses of action

1. Continue providing state support for decarbonisation of industrial site based on capital expenditure, while also taking into account longer-term developments in operating expenditure on energy.

2. Promote power purchase agreements that take account of France's specific electricity cost environment.

3. Support the development of innovative technologies to capture CO_2 from fumes exhausted by biomass boilers, and breakthrough solutions in the paper manufacturing process.

4. Encourage national paper manufacturing groups to join international industry initiatives working to decarbonise the paper industry (CEPI's Energy Efficiency Solutions Forum) and to produce or assess transition plans (PACTE Industries, ACT Evaluation).

After 2030, electrification, other renewable thermal energies, and breakthrough solutions will help limit the use of fuelwood

In order to avoid an overconsumption of biomass, other options may ultimately prove to be useful and complementary:

• Electrification of the paper drying process will play a key role in 2030 thanks to the development of high-temperature heat pumps, possibly used in combination with mechanical vapour recompression (MVR). Meanwhile, provided electricity is competitively priced, power-to-heat systems and air dryers could also help to reduce gas consumption;

• Other thermal renewables such as solar thermal, deep geothermal, and anaerobic digestion of solid and liquid residues may in certain cases cover a portion of the heat energy requirements of paper mills, depending on the potential of each site;

• Breakthrough innovations in processes could – provided they reach maturity – add to the range of solutions available to decarbonise the sector fully by 2050.

Finally, by virtue of the fact that it transforms and uses biomass (as a raw material in manufacturing and as a source of energy), the paper industry can contribute to decarbonisation efforts more generally by capturing and either recycling or storing the biogenic CO_2 emitted by production facilities, mainly virgin pulp mills.

Supply-side tightness expected for virgin and recycled raw materials

Virgin pulp manufacturers will have to compete for supplies of biomass with the energy sector, and consequently the priority given to each use in the future will be crucially important for their prospects. If they have preferential access to large volumes of biomass at low prices, they will be able to maintain pulp production capacity, thereby reducing French reliance on imported pulp, particularly from outside the EU.

Meanwhile, for manufacturers of paper and board from recycled fibres, the growth of digital technology should reduce the volumes of office papers entering sorting centres, shrinking the available supply of a type of recovered paper that is particularly sought-after for its quality fibres (high grade category). Manufacturers of graphic and sanitary papers (the main consumers of this category of recovered papers) will therefore have to adapt their production lines to incorporate other categories of recovered papers (as with the MPH1865 MAP-HY project[19]).

Courses of action

1. Strengthen biomass governance to guarantee cascading use of wood resources (i.e. using wood primarily as a manufacturing raw material rather than as fuel), establish a resource use hierarchy, and monitor all flows regardless of utilisation (biomass SIG, regional biomass units).

2. Provide incentives to improve the quality of recovered paper as part of EPR programmes extending from the point at which materials arrive at sorting centres to the moment they are recycled, and encourage the principle of sorting RCP into different types, to promote production of those considered most useful.

3. Require applicants for grants for new biomass boilers to carry out a multi-energy and energy efficiency survey to ensure that new installations are appropriately sized.

The need to reorganise the pulp and paper sector in response to changing end uses

The pulp and paper industry will need to continue reconfiguring its downstream markets, building on an existing process currently driven by two contrasting trends:

The downward trend is driven by the rising use of digital materials as a substitute for paper media (printed advertising materials, office paper, sales brochures). In addition, the requirement to reduce the quantity of packaging in circulation is leading to greater reuse, posing a risk to an industry that mostly manufactures single-use products. It will be up to the industry to turn that risk into an opportunity to develop products that are bio-based while also capable of being recycled or reused, particularly for logistical purposes.

Conversely, the rising trend is due to the penetration of paper and board packaging in household, industrial, and commercial packaging, expected to continue with the development of new packaging types made from paper or moulded cellulose (especially those with water- and grease-resistant properties) as a substitute for single-use plastics (food packaging, wrapping, packing materials).

Courses of action

1. Make it easier to convert graphic paper mills to manufacture products for other markets (such as packaging, sanitary, or speciality papers).

2. Produce a roadmap for the production of paper and board packaging capable of replacing single-use plastics, including comparative LCA studies to inform debate on these new end uses.

3. Support initiatives promoting the reuse of paper and board packaging for all end uses where there is a proven environmental benefit.

[18] INSEE, Esane, Investissements des entreprises. French standard NAF 171 – Pulp, paper and board industry

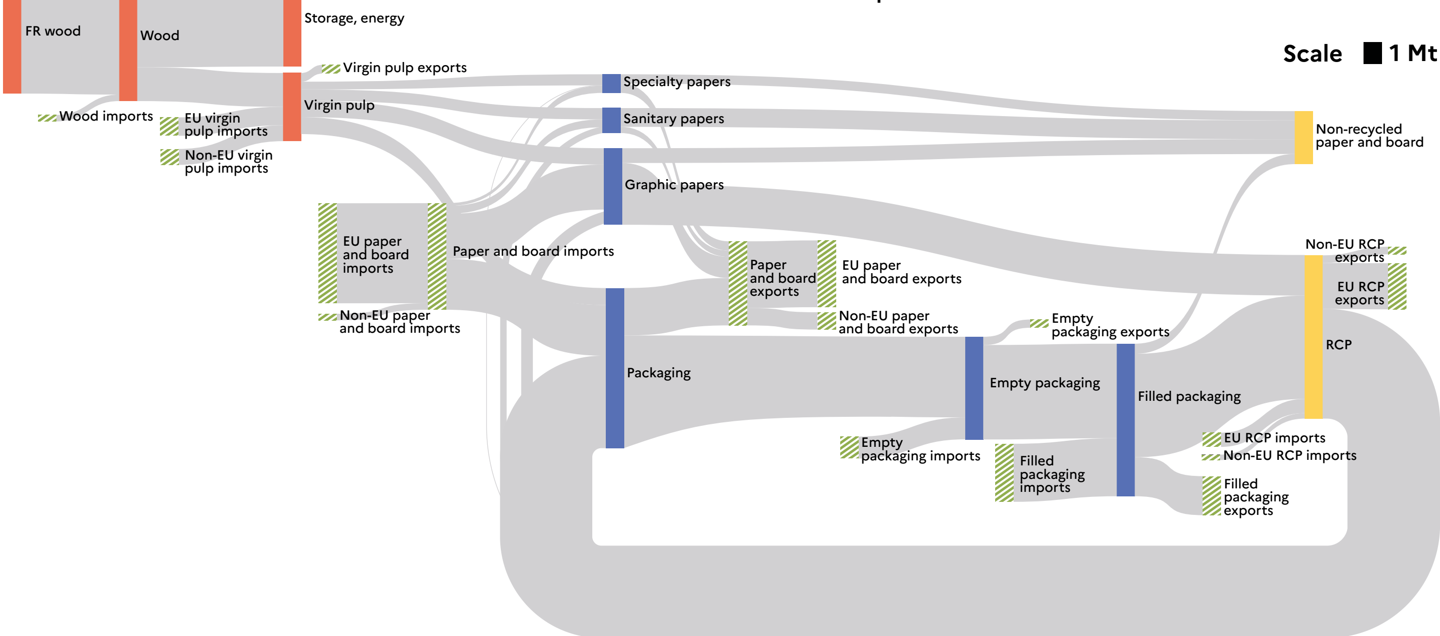
[19] ADEME (2024). MAP'HY Project – Sanitary Paper Recycling.

1. The challenges of decarbonising the paper industry

1.1. Market prospects

1.1.1. A market dominated by recycled packaging with significant European trade

Figure 5. Material flows in the French paper and board industry, 2021 figures Copacel and ADEME.



The paper industry value chain can be viewed in terms of five building blocks:

1. Supply of cellulose (wood and recovered paper)
2. Manufacture of paper pulp (virgin or recycled fibres)
3. Manufacture of paper and board from pulp (virgin or recycled fibres) or RCP bales
4. Processing of paper and board (into packaging, print materials, etc.).
5. Collection, sorting, and recycling of paper and board

The French paper industry currently sources 72% of its fibres from waste recovered paper, most of which is collected in France. This is made possible by the growth of the packaging sector, which accounts for no less than 85% of all recycled fibres in the paper industry. Other mills, using virgin fibres, source 65% of their pulp from abroad, and half of that volume comes from non-EU countries. Despite the high use of recovered paper sourced essentially from the domestic market, like the wood used to make pulp in France, the French paper industry remains heavily reliant on imports of pulp from the EU and beyond (Latin America).

The production and consumption of paper and board is largely focused on the packaging market, which accounted for two-thirds of volumes in 2021. With the exception of specialty papers (which represent only a small part of the market), France runs a trade deficit in the other segments, particularly for graphic papers where it imports 1.5 times more than it produces. Given that shipping represents such a large proportion of the cost price, this deficit is essentially compensated by European imports (95%).

After paper and board are processed at dedicated sites (printworks, cardboard factory) and the finished products from France or overseas have been used, 82% are collected and sorted into different categories, depending on their quality and how they are to be recycled. Bales of sorted recovered paper of various grades are then redirected to mills, where they are used as a feedstock.

1.1.2. Recovered paper: a source of sovereignty against biomass imports

Cellulose supplies are obtained from wood (used to make virgin pulp) and recovered papers (RCP), mostly sourced in France. Next, imported pulp accounts for half of consumed volumes (equivalent to our production volumes). It mainly comes from Brazil (35% of imports), and the Nordic Region, specifically Finland and Sweden (25% of imports). Following along with the increased use of recycled fibres, it is vitally important for pulp producers to be able to access wood as a material, in volume and at competitive prices, if they are to maintain production capacities and reduce reliance on imports.

For the paper industry as a whole, the average circularity rate for recycled fibres is around 75%, but this figure masks wide disparities between different segments. Packaging products consume 85% of RCP, with recycled material making up 92% of those products. Graphic papers and sanitary papers respectively consume 10% and 5% of all RCP, with circularity rates of 33% and 66%. These lower circularity rates are partly due to the limited supply of recycled fibres suitable for these segments for obtaining certain properties (whiteness, smoothness, or absorbency), and also partly due to the fact that high quality recycled fibres are not that much cheaper than virgin pulp. Most of the recycled fibres used by manufacturers of graphic and sanitary papers come from higher quality papers that require deinking. They are mostly sorted graphic papers, and are generally more expensive than other kinds of recovered papers. These criteria raise the question of whether these two segments are capable of adapting their production lines to incorporate other types of RCP and addressing the smaller volumes of graphic papers available.

The average circularity rate of recovered papers should continue rising in the future, with paper and board packaging expected to account for a rising share of national output, keeping in mind that paper and board packaging can be made with all kinds of recovered papers. This rise in the recovered paper circularity rate will not automatically be accompanied by a reduction in greenhouse gas emissions. Most sites manufacturing paper or board from recycled fibres have a thermal energy mix with a larger carbon footprint than virgin pulp mills, which use their own bio-based by-products as an energy feedstock (black liquor, bark). However, the increased circularity rate of recovered papers will help to reduce the paper industry's overall energy use, and in turn ease the reliance on virgin pulp imports.

Figure 6. Pulp production/consumption and RCP consumption between 2011 and 2023.
(Copacel figures)

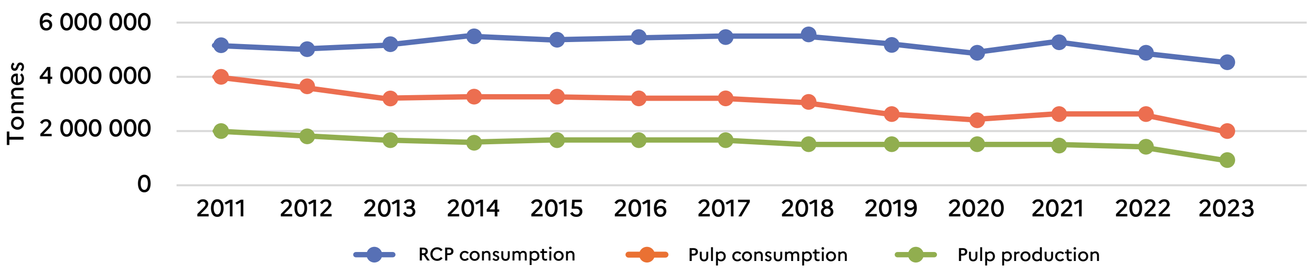
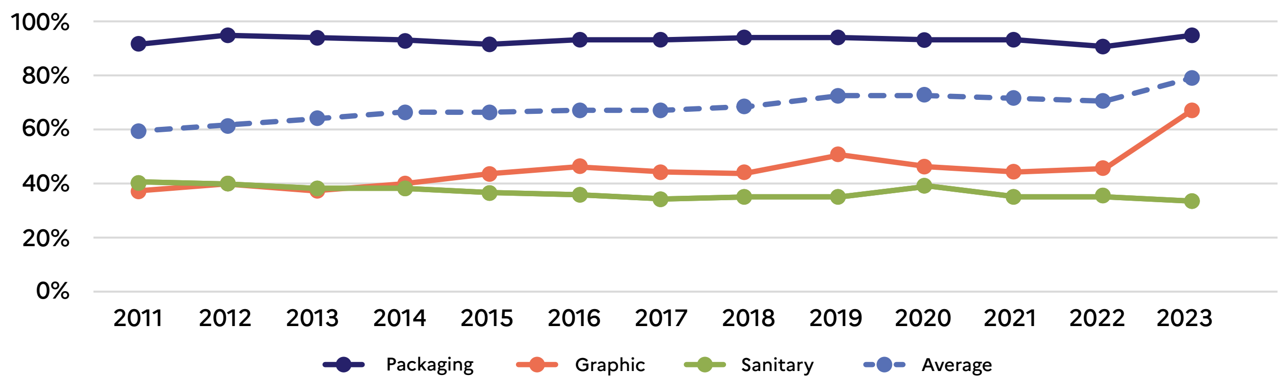


Figure 7. RCP circularity rate by segment between 2011 and 2023.
(Copacel figures)



1.1.3. The changing shape of the paper and board market

The French paper and board industry is dominated by the packaging segment, which accounted for 70% of tonnages produced in 2021. This segment has been growing for over ten years, although the trend began to slow somewhat in 2021, partly due to a combination of rising energy prices and inflation in 2022 and 2023 that impacted both packaging manufacturers and consumers alike. Meanwhile, having previously been consistently at levels close to those of packaging in 2011, graphic paper production plummeted from 3.5 Mt to less than 1 Mt by 2023. Production of sanitary, specialty, and industrial papers have remained relatively stable.

Overall, despite the collapse in the graphic paper market, the sector has kept going thanks to the growth in paper and board packaging.

In terms of external trade, the paper industry is a net exporter of specialty papers, and is close to equilibrium in packaging and sanitary papers, but runs a deficit overall owing to the negative trade balance in graphic papers.

Figure 8. Paper and board production in France between 2011 and 2023.
(Copacel figures)

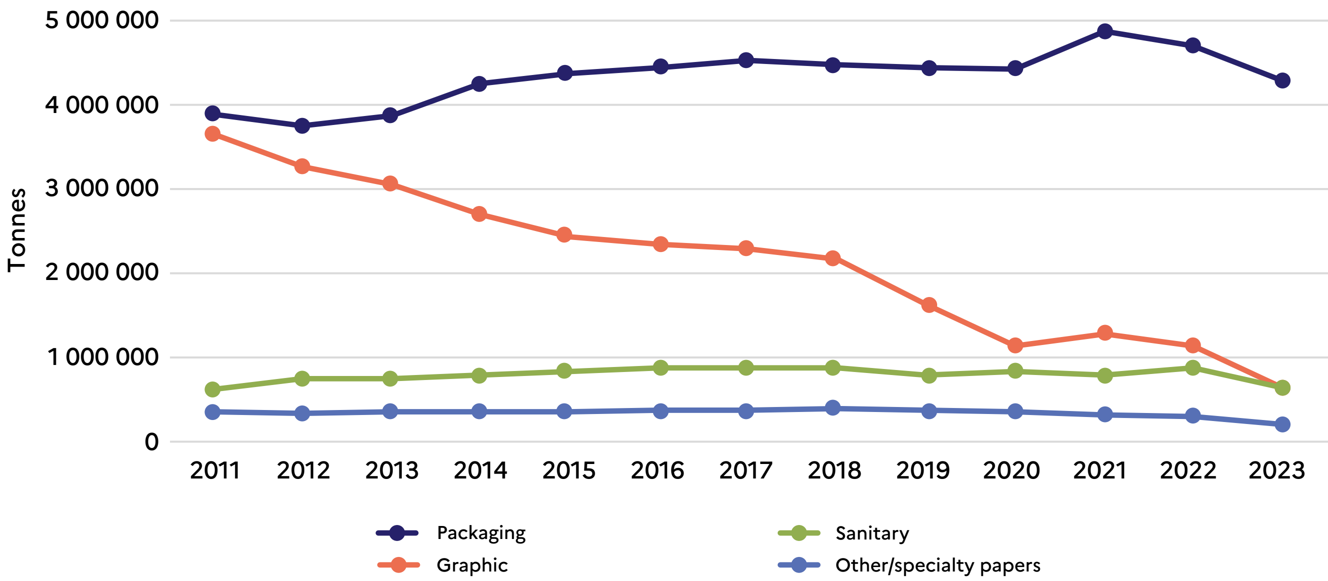
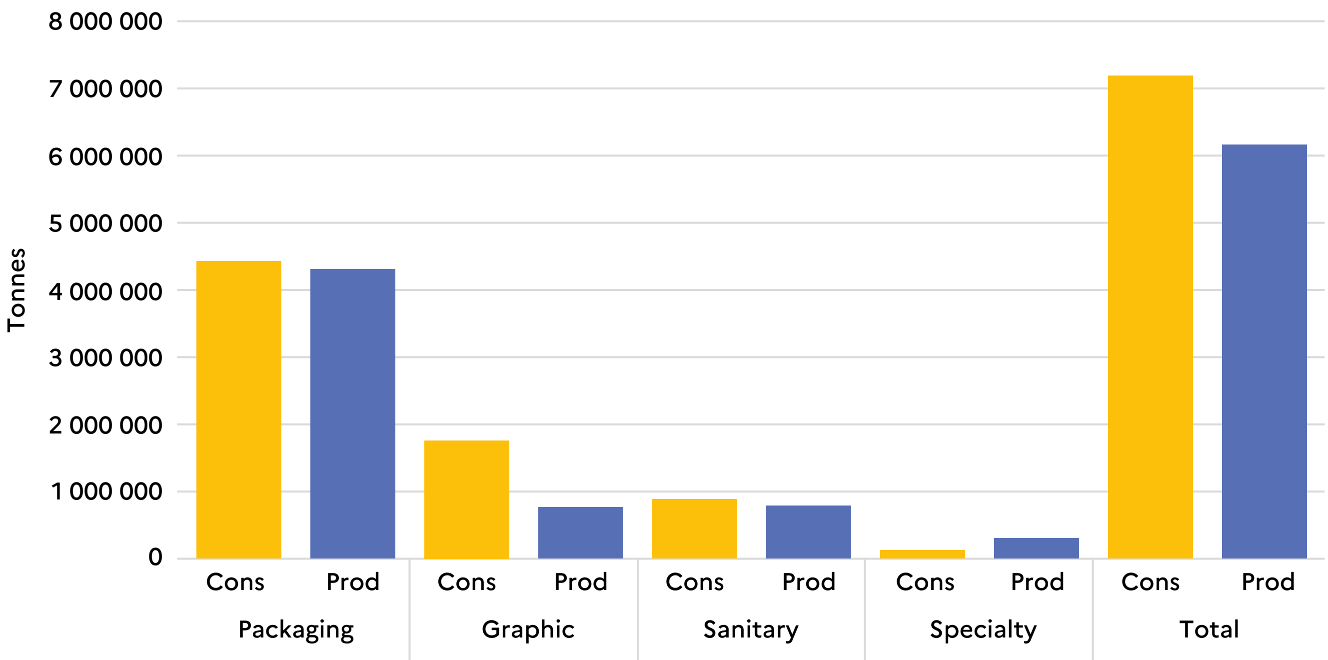


Figure 9. Production and consumption of paper and board in France in 2023, by segment.
(Copacel figures)

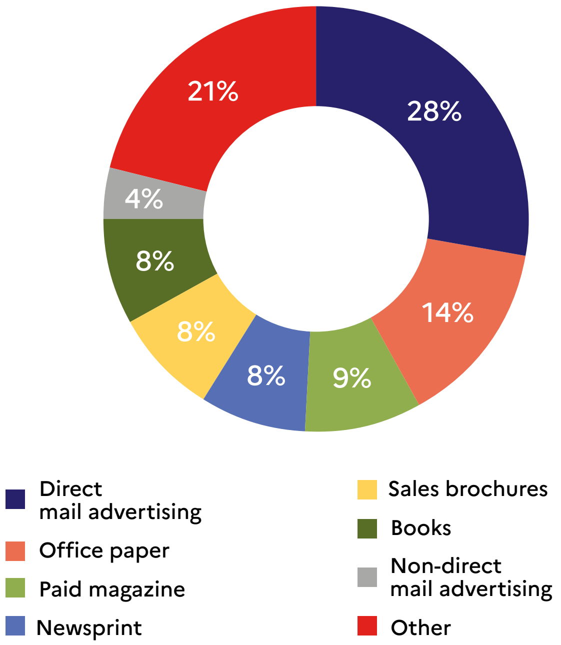


Digital materials replacing graphic papers

Around a third of graphic papers produced today are used for advertising materials, mostly direct letterbox mail. The leading consumer retail groups, which buy 90% of graphic papers sold for this purpose, have announced they intend to abandon the use of printed advertising materials in their marketing strategies. At the same time, the French Climate and Resilience Law (2021) introduced a trial "opt-in" scheme in 14 areas of the country, where only householders who placed a "Oui Pub" (Yes to Advertising) sticker on their mailboxes would receive unaddressed advertising materials. Based on an assessment of the results in late 2024, the scheme may be extended to the rest of the country.

As regards the other downstream markets, the rise of digital technology is doing much to drive down the use of sales brochures, office paper, newsprint, and magazine print. The fate of these products will depend on the extent to which digital media penetrates these segments as a substitute for paper, although the environmental impact of switching to online materials will need to be assessed on a case-by-case basis.

Figure 10. Breakdown of graphic papers sold in 2021. (ADEME figures)



New markets for packaging, but just how big are they?

Packaging paper and board are mostly intended for industrial and commercial uses, which accounted for 75% of tonnages sold in 2021. In particular, corrugated board (representing almost two-thirds of tonnages) is used as a single-use packaging material for shipping, with 60% used to package food products[20].

The future will see two contrasting trends. On the one hand, new markets will open up with the AGEC law (2020) combating waste and promoting the circular economy, which will ban the sale of single-use plastics by 2040. New paper, board and moulded cellulose products, bio-based, recyclable and with barrier properties, will need to be developed for use in place of single-use plastics. On the other hand, the same law aims to promote the principle of reuse and requires 10% of packaging (paper, board, glass, plastic, aluminium) sold to be reused. New initiatives like the "Carton Vert" scheme are designed to encourage the reuse of containerboard boxes by acting as a "broker", bringing together customers with used boxes and retailers looking for boxes to package their products[22].

In Europe, the Packaging and Packaging Waste Regulation (PPWR) currently excludes cardboard packaging from the reuse targets in the resolution adopted on 24 April 2024. This divergence between the European and French approaches highlights the uncertainty as to what constitutes the right balance between reduction, reuse, and recycling (the 3Rs strategy), which is determined by the environmental benefits of each option according to LCAs.

Figure 11. Breakdown of filled packaging sold in 2021, by target market. (ADEME figures)

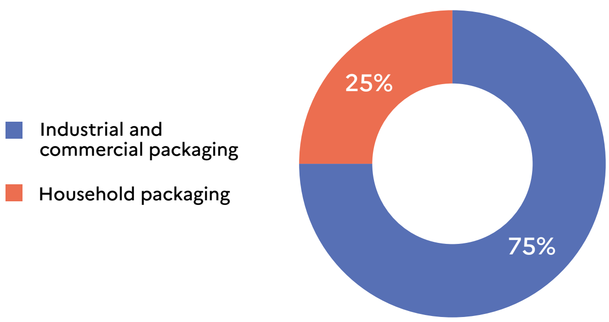
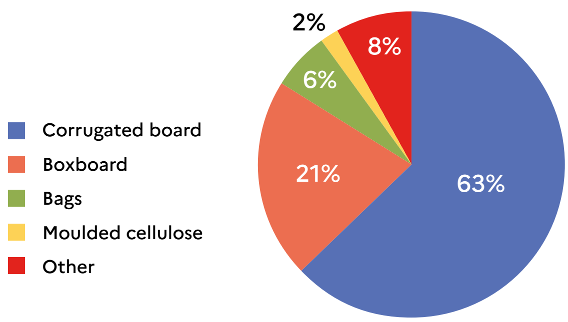


Figure 12. Breakdown of filled packaging sold in 2021, by product. (ADEME figures)



[20] COFEPAC (2024). The paper and board packaging sector: facts and figures.

[21] The CTP-led BIOCUP chromatogeny project or the development of the French startup Papkot are just two of the promising initiatives aiming to add barrier properties to food-grade paper products.

[22] The bio-based additives BioWet and BioGraft developed by the startup FunCell could also enable paper manufacturers to offer cardboard products that are more resistant when both dry and wet and give papers hydrophobic properties, thereby making cardboard suitable for multiple applications.

1.2. Manufacturing paper while using less gas and more electricity, and limiting the use of fuelwood

1.2.1. Pulp, paper, and board production

The pulp and paper industry is segmented into two main activities: pulp production and paper and cardboard manufacturing. In France, there were 82 sites manufacturing pulp, paper and board in 2021, including four dedicated to pulp production (3 from virgin fibres and one from recycled fibres), eight integrated paper mills producing both pulp from virgin fibres and paper-cardboard on the same site, and seventy plants producing only paper and cardboard. This last category can use either pulp (virgin or recycled fibres) bought from other suppliers (34 plants), bales of recovered paper transformed on site (32 plants), or both material feedstocks (4 plants).

The virgin pulp production process involves separating the cellulose fibres contained in wood to make cellulose pulp. The process can be mechanical, chemical, or semi-chemical. Currently, the chemical route is the most common in France, used by eight of the eleven sites concerned.

Pieces of roundwood are first fed into machines where they are stripped of their bark and cut into chips.

In the chemical process, the wood chips are "cooked" at a temperature of 180°C for several hours, in a bisulphite or sulphate solution (kraft process). The cooking by-products are then washed with quicklime to regenerate the caustic soda needed for the kraft process, and reintroduced into the cooking stage to separate the cellulose from the lignin. The process has a material yield below 50%, but allows black liquor and bark to be recovered and recycled as fuel.

In the mechanical process, roundwood is ground in a mill with the chips passing through a disk refiner. The process has the advantage of a material yield greater than 80%, and allows bark to be recovered and recycled as fuel.

The pulp can then be treated with a variety of bleaching agents (oxygen, hydrogen peroxide, chlorine dioxide) alternated with caustic soda, before being dewatered, pressed, dried, cut, and finally packed.

Recycled pulp and paper are manufactured according to the following sequential method, albeit with numerous variants:

Cellulose fibres, obtained either from pulp (virgin or recycled) or from recovered papers, are first placed in a water-based suspension in a pulper at concentrations of between 5 and 20%, to separate them. If recovered papers are used as a feedstock, they are decontaminated. They will also be deinked, but only if they are destined to be used to manufacture either sanitary papers or graphic papers.

The bonds between the fibres are strengthened by mechanical refining in an aqueous medium, then purified in centrifugal cleaners or using mesh or perforated plates.

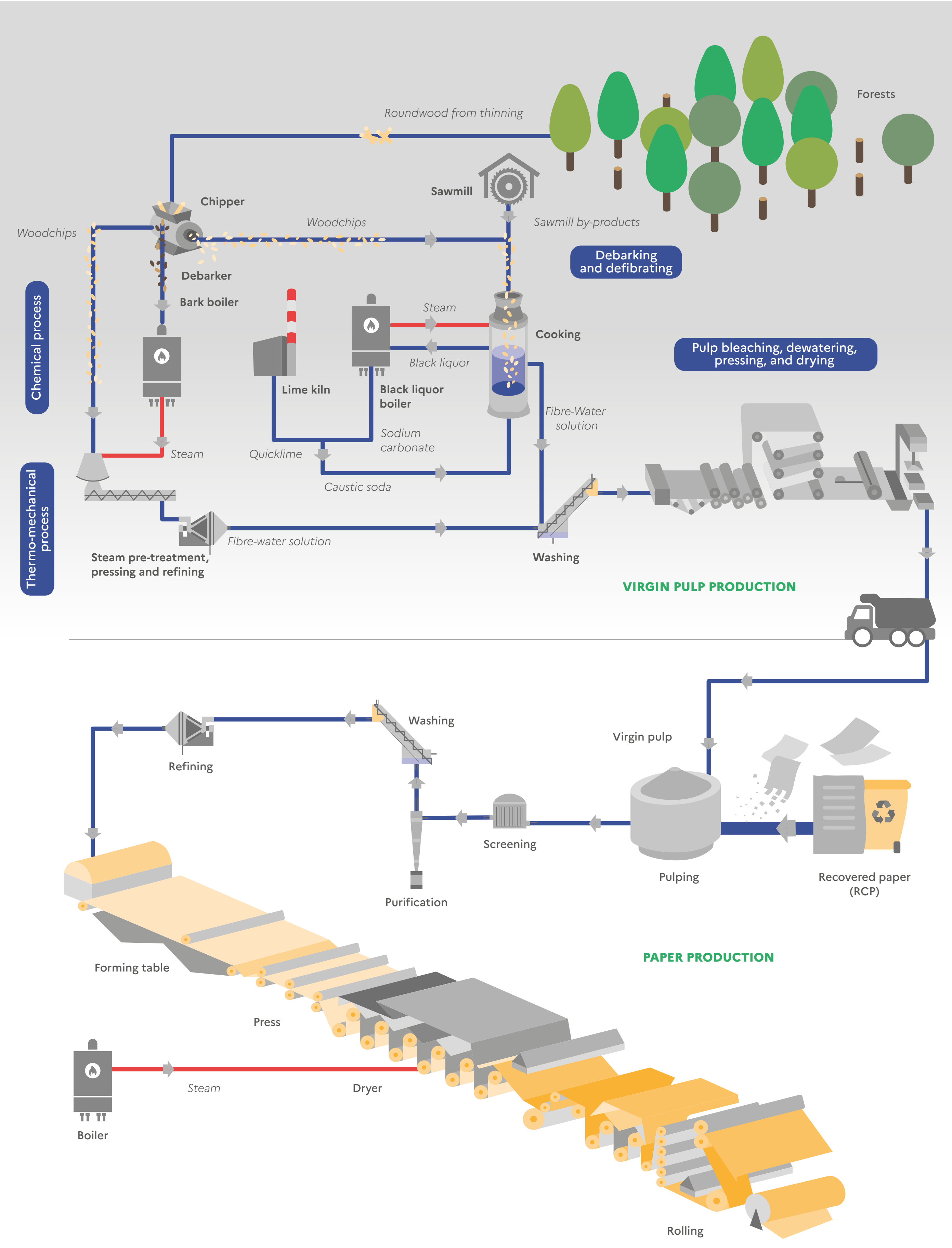
The heavily diluted fibre solution is poured into the headbox, where the fibres are deposited on the forming fabric, creating a wet sheet. The water is then removed by gravity and by the action of the dewatering machine/pulp press, increasing the dry matter content of the sheet from 20% to 45%.

Any remaining water is then evaporated by passing the sheet through steam-heated cylinders at 135°C, reducing the residual moisture content to 5%. This is the most energy-intensive of all the processes described here, and therefore also generates the most emissions.

The final stage sees the recycled pulp cut or formed into rolls, before being packed and shipped.

Paperboard may also undergo additional treatments, for example a layer of polymer may be applied in a size press, organic or mineral-based coatings may be added, or the paper may be calendered, depending on the desired specifications.

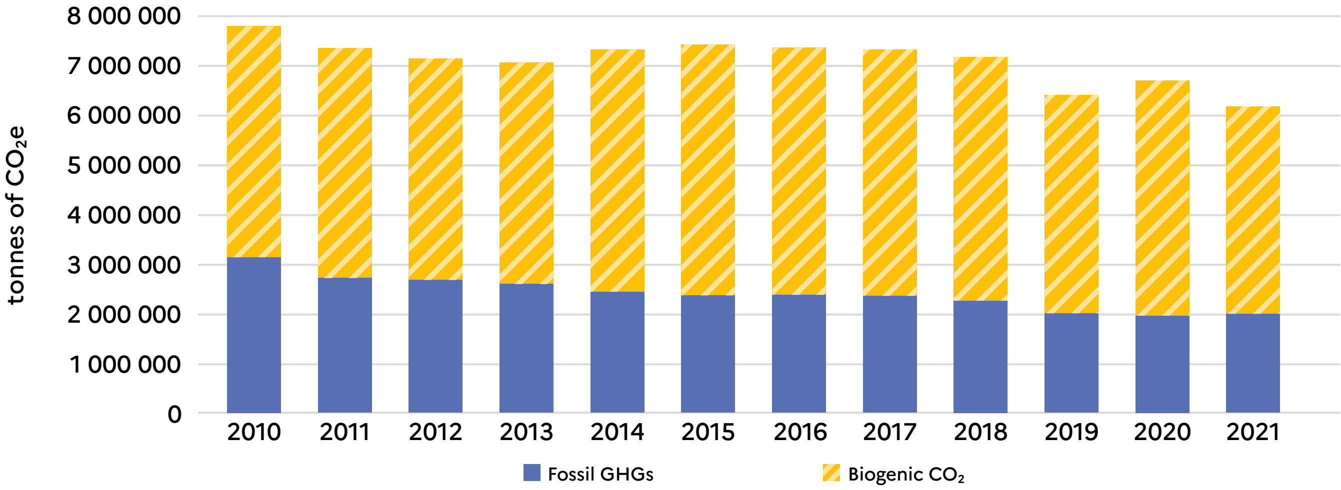
Figure 13. Pulp and paper/board manufacturing process.



1.2.2. Most greenhouse gas emissions are generated by paper mills that do not manufacture virgin pulp

The paper industry emitted around 2 Mt of fossil-based greenhouse gases in 2021. That figure represented a reduction of 35% compared with 2010, made possible largely by efforts to decarbonise the thermal energy mix, but also by cuts in production. At the same time, emissions of biogenic CO_2, which currently represent twice the volume of fossil emissions, were reduced by 10% between 2010 and 2021.

Figure 14. Non-biogenic GHG and biogenic CO_2 emissions evolution between 2010 and 2021.



Biogenic CO_2: an additional contribution by the pulp and paper industry

The pulp and paper industry generated over 4 Mt of biogenic CO_2 emissions in 2021, more than twice the volume of fossil-based CO_2 emissions. Specifically, seven pulp mills (market pulp and integrated sites) accounted for 90% of the sector's total biogenic CO_2 emissions. Meanwhile, new biomass boilers due to enter service between 2020 and 2030 (partly financed by ADEME's Heat Fund) are likely to generate an additional 1 Mt of biogenic CO_2 over the coming years.

Biogenic CO_2 could contribute to the development of carbon sinks or help to decarbonise other sectors, in two ways:

• Biogenic CO_2 can be captured and stored underground (geologic sequestration), thereby ensuring that CO_2 captured by trees as they grow is isolated for long periods, and helping to build France's carbon sinks;

• Biogenic CO_2 can be captured and utilised to make substitutes for fossil resources, such as synthetic fuels manufactured from renewable or low-carbon electrolytic H_2 and CO_2.

From 2041 onwards, only synthetic fuels made from biogenic CO_2 will officially qualify for "sustainable" status in the European Union[23]. Biogenic CO_2 should therefore see an increase in value as it contributes to the decarbonisation of the aviation industry.

According to a 2024 government report outlining the current state of play and future prospects for the deployment of carbon capture, utilisation, and storage in France, around 3 to 3.5 Mt of CO_2 from the pulp, paper and board sector is expected to be captured and either stored or utilised in 2050[24].

Technological advances will be required to optimise the capture of biogenic CO_2 emitted by the biomass combustion process, which produces fumes with low carbon content but numerous impurities (tars and aromatic hydrocarbons) that need to be removed. Meanwhile, the other links in the carbon capture-transport-storage-utilisation value chain need to be coordinated: CO_2 transport infrastructure, industrialisation of synthetic fuel production, identifying suitable sites and commissioning geologic storage facilities.

[23] Commission Delegated Regulation (EU) 2023/1185

[24] State of play and future prospects for the deployment of CCUS in France: https://www.entreprises.gouv.fr/files/files/industrie/etat-des-lieux-et-perspectives-de-deploiement-du-ccus-en-france.pdf

➜ Timber in a pine forest

Biomass fuels represent around 60% of the thermal energy mix in the paper industry. This explains why the majority of the sector's carbon footprint consists of biogenic rather than fossil CO_2 emissions. Natural gas from the grid accounts for just under 40% of the thermal energy mix, and is responsible for 95% of the sector's fossil emissions.

The use of biomass as a fuel is concentrated at eleven sites manufacturing virgin pulp (market pulp and integrated sites). The majority of these have the capability to achieve almost complete energy self-sufficiency, by using energy recovered from paper residues including black liquor (75% of biomass consumed) and bark (25% of biomass consumed). **The thermal mix of the 71 sites that do not produce virgin pulp consists of 75% gas and 21% wood and bark.**

Biomass by-product recycling in the paper industry is almost at maximum capacity. Mills using the kraft process to manufacture virgin pulp could potentially still use tall oil (a by-product of the kraft process) to heat their lime kilns instead of relying on fossil fuels, but this would mean the oil could no longer be used as a material feedstock. Meanwhile, other industrial sites that do not manufacture virgin pulp are betting essentially on fuelwood (wood chips and waste wood) to replace gas. Newly commissioned wood boilers (running on wood chips and waste wood) with a total rated capacity of 250 MW, partly funded by government grants, should enable the sector to increase the share of biomass in its energy mix from 21% to 40% by 2030 (for sites not producing virgin pulp). For the pulp and paper industry as a whole (pulp + paper and board), biomass' share of the energy mix would rise from 60% to 70%.

However, fuelwood resources (wood chips and waste wood) are almost at saturation point already in certain regions (particularly the Grand Est region). In the medium term, the General Secretariat for Ecological Planning (Secrétariat Général à la Planification Ecologique) issued an alert in 2024 warning that demand for solid biomass was predicted to far outstrip supply by 2030, and suggested taking action immediately not merely to strike a balance between using biomass as a material or energy feedstock, but to go even further and determine what specific energy uses should be prioritised, based on utility and the availability of alternatives[25]. In the longer term, in a prospective study published in 2024, the IGN and FCBA set out the implications of various potential developments in the forestry sector by 2050. The additional volume of virgin wood harvested and the way it is managed will need to be determined according to climate impacts on forests, the success of replanting plans, and the size of the carbon sink needed to achieve France's climate targets by 2030, 2040, and 2050[26]. A new scientific interest grouping on biomass (including ADEME, France AgriMer, IGN, INRAE) should provide the government with the information it needs to decide policy in this area. Consequently, is uncertain how quickly fuelwood biomass energy systems will be deployed in the paper industry after 2030, but this will depend on what uses are prioritised for biomass feedstock and, also on the resource's capacity for regeneration.

Figure 15. Thermal mix of sites manufacturing virgin pulp in 2021.

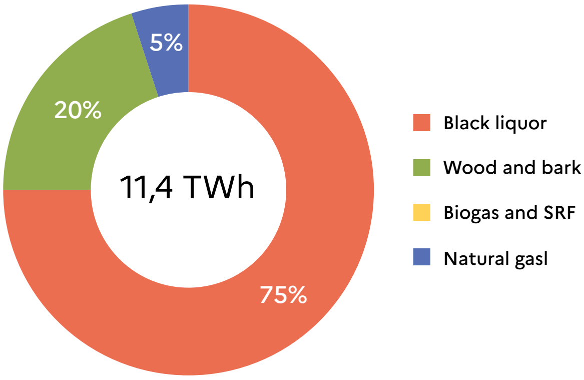
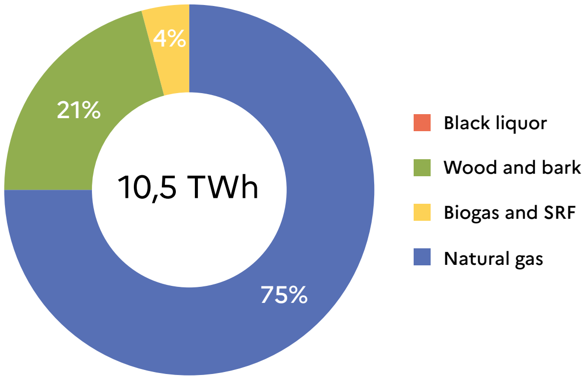


Figure 16. Thermal mix of sites not manufacturing virgin pulp in 2021.



[25] SGPE (2024). Supply-demand balance: challenges and strategies.

[26] IGN, FCBA (2024). Projected wood availability and carbon stocks and flows in the French forestry sector.

1.2.3. Limiting the use of fuelwood to decarbonise sites not producing virgin pulp: a realistic possibility

Mature energy efficiency solutions

Energy efficient practices are already well known to the pulp and paper manufacturing sector, but there is room for improvement. Solutions fall into two main categories: electric efficiency measures, and thermal efficiency measures. Electric efficiency can, for example, be enhanced by installing variable-speed motors for either drives or pumps. Other electric efficiency measures include optimising the pulp refining or vacuum dewatering processes, which can in turn serve to optimise downstream heat exchanges. Thermal efficiency encompasses global management with energy integration approaches, local modifications such as optimising heat distribution networks, as well as targeted improvements in processes that can have a big impact on steam consumption, such as dewatering (installing steam boxes and optimising dewatering blades on the forming table), pressing (installing shoe presses), and drying (recovering waste heat).

Most of these improvements apply to paper mills, but other solutions are available for virgin pulp mills (additional effects in the black liquor evaporation plant, optimising lime mud in the lime kiln).

➜ Combined hot water and steam high voltage electrode boiler © PARAT, groupe Babcock Wanson

Electrifying the paper drying process

High-temperature heat pumps (>100°C)[27], sometimes combined with mechanical vapour recompression units, are another solution with the potential to significantly reduce the volumes of steam required by boilers. They work by taking condensate from the dryer section in the paper machine at a temperature of 70°C and raising it to 140°C. Numerous demonstrators have been built to showcase the technology in Europe, especially in the pulp and paper industry, with five full-scale projects in the pipeline[28]. In order to optimise the performance coefficient of the Heat-pump+MVR system, it is necessary to increase the humidity and temperature levels of the heat-pump inlet (here the condensate from the dryers) and reduce the required level for the pressure exiting the MVR. This comes from both operational adjustments on the dryer and paper mill, and appropriate calibration of the steam network connected to the dryer

Electric boilers allow the temperatures required by paper machines (150°) to be reached easily, and have been deployed in the pulp and paper sector in Finland and Germany since 2023[29]. Currently, electric boilers are hampered by the relatively high price of electricity compared with fuelwood. However, their operating flexibility (they can reach full power within five minutes) means they can not only be used as a baseload energy source by industrial plants, but also in hybrid mode in tandem with a supplementary source or heat storage solution during periods when electricity prices are high.

Electric air dryers are a third option for electrifying the drying process. The solution involves installing heating elements in addition to the gas burners currently used at certain sanitary paper mills, or switching to infra-red dryers. This option is particularly suitable for sanitary paper manufacturers, who do not use steam-heated drying cylinders.

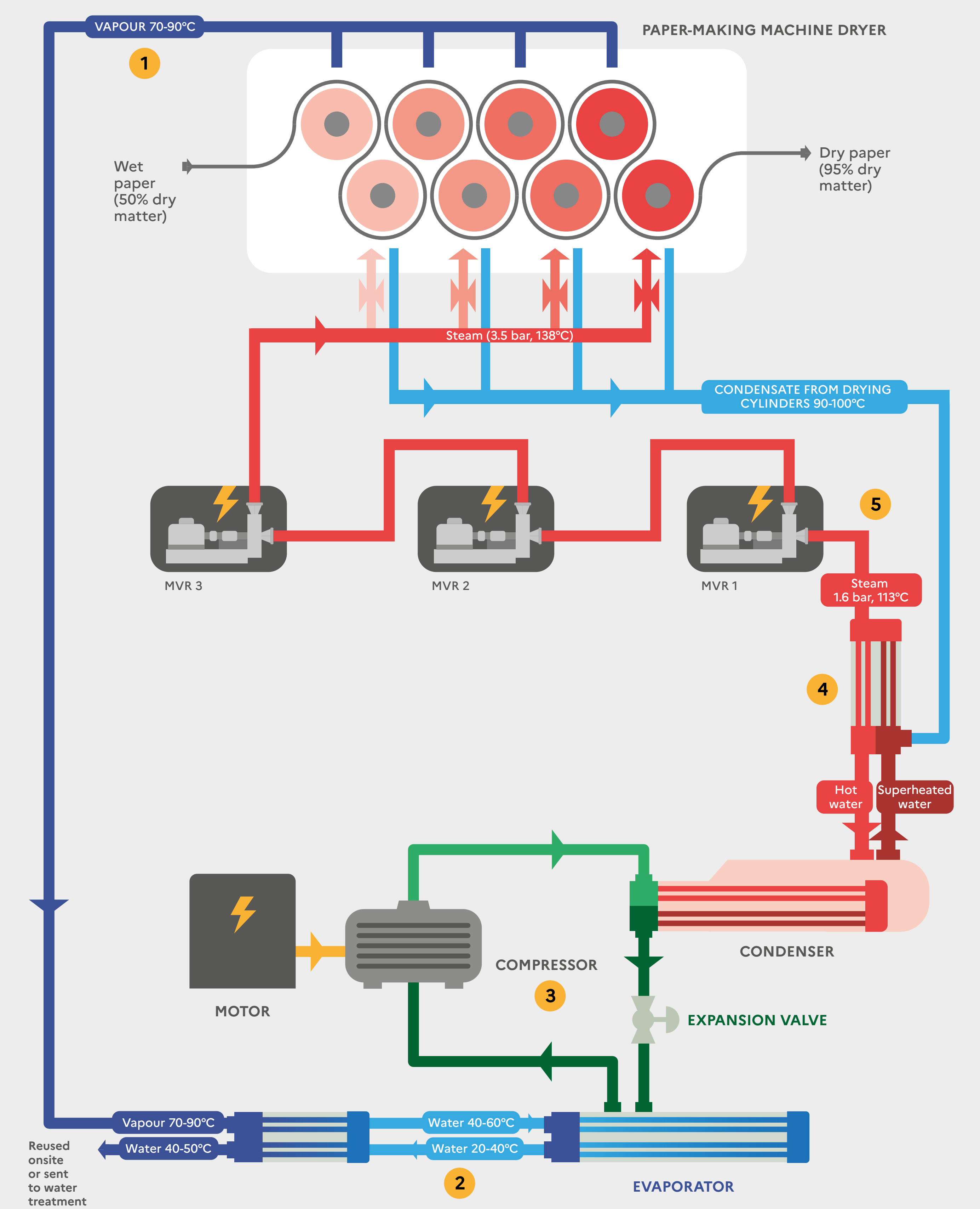
➜ Dalkia transcritical cycle-based high-temperature heat pump at WEPA Greenfield © Dalkia

[27] CEPI (2024). Heat pumps. Solutions for the decarbonisation of the pulp and paper industry.

[28] France, WEPA Greenfield x Dalkia / Czechia, Smurfit Kappa x Spilling Tech / Italy, Cartiere Di Guarcino x Enertime / Germany, Felix Schoeller x SPH / Finland, unnamed paper manufacturer x Turboden

[29] UPM invested in eight 50-60 MW electric boilers in Finland and Germany in 2023: https://www.parat.no/news/upm-invest-in-eight-large-power-to-heat-systems/

Figure 17. Simplified diagram showing an integrated high-temperature heat pump with three mechanical vapour recompression units.



1. The refrigerant enters the evaporator in liquid state.
2. The refrigerant captures the heat contained in the cold source and vaporises as the temperature rises.
3. The gas is drawn into the compressor, where its pressure and temperature are increased.
4. The hot gas is pumped into a condenser, where part of the heat it contains is transferred to the MVR via a secondary water circuit.
5. As it loses its heat, the refrigerant cools and condenses into liquid state. Its temperature is lowered by an expansion valve which releases pressure. The fluid is then directed back to the evaporator to restart the cycle.

Other thermal renewables

Besides biomass, there are four other renewable or part-renewable energy sources that can help to meet the energy requirements of paper manufacturers, each with their own advantages and drawbacks.

The production and self-consumption of biogas by anaerobic digestion of liquid and solid process residues (deinking and purification sludge) offers another avenue for decarbonising the sector. This process involves methanising effluents containing high amounts of fermentable organic compounds such as starch, obtained from the production of corrugated base paper from recycled paper. Although most sites manufacturing corrugated base paper are already equipped to methanise and recycle biogas, there is still room to do more, particularly in terms of new production capacities.

Thermal solar is a mature technology already deployed at a paper mill as a complementary energy source, that can optionally be combined with a storage system[30]. It has a range of potential applications, including preheating water for steam boilers and air flows in dryer hoods using flat-plate collectors, or producing steam using concentrating solar collectors. However, this technology is only likely to cover part of sites' thermal energy requirements, given the amount of space needed: 1 hectare of panels requires 2 hectares of land to generate between 5 and 10 GWh of power in France depending on local solar radiation levels, whereas a single paper mill uses between 150 GWh and 350 GWh of thermal energy every year.

Deep geothermal is a novel solution for the industry. This technology involves recovering the energy contained in deep-lying aquifers usually found at depths of 500 to 3,000 metres, at temperatures of up to 200°C. Geothermal plants require relatively little land and can go a long way towards covering energy needs, with projects of up to 100 GWh already being developed in other industries with temperatures of between 100°C and 150°C. Geothermal reservoirs are well distributed in relation to paper industry sites[31], although their potential should be assessed site-by-site, with geological surveys carried out where necessary.

Solid recovered fuels (SRF) are another competitive option for the sector, although they are not enough to decarbonise extensively since only a part of the components they contain are renewable.

Breakthrough solutions

A variety of breakthrough solutions are being looked at to reduce the thermal energy requirements of manufacturing sites. These include the use of electric technologies such as electro-osmosis to dewater pulp and paper without evaporation[32], and the use of superheated steam for drying[33]. These technologies are currently only at a moderate stage of maturity (TRL of 3 to 5), but offer promising potential thermal efficiency gains. Paper production with little or no water is currently limited to the manufacture of 3D cellular items such as trays, cutlery, or packing foam. However, these processes could potentially be extended to include the production of sheets for specific applications. Finally, compression refining[34] mainly targets electricity savings, but could also indirectly help to improve the thermal efficiency of processes at sites using fibre-refining technologies.

Small modular reactors could also be useful in decarbonising industrial heat, and a number of R&D initiatives are already under way, including in France with government support[35]. These innovations encompass relatively mature technologies (light water reactors, high temperature reactors) with prospective capacities of 10 to 50 MW, and other larger-scale CHP projects. Pilot projects are planned in the next few years, although they will require approval from the ASN, France's nuclear safety authority. However, this technology could not be included in decarbonisation trajectories for the paper and board industry, as its relative immaturity complicates the task of evaluating the associated CapEx and OpEx.

➜ Thermal-solar installation powering the Condat papermill (LECTA group)
© Newheat

[30] CEPI (2024). Solar heat. Solutions for the decarbonisation of the pulp and paper industry.

[31] Government (2023). Geothermal energy: an action plan to accelerate.

[32] ELECTRIFIED project in the Netherlands: https://www.wur.nl/en/newsarticle/electric-technology-to-save-energy-in-drying-processes.htm

[33] SteamDry project by VTT: https://cris.vtt.fi/en/projects/superheated-steam-drying-for-sustainable-and-recyclable-web-like-

[34] DEMO-COMP project by CTP: https://www.webctp.com/fr/demo-comp

[35] BPI (2022). France2030 call for projects, "Innovative Nuclear Reactors"

2. Two contrasting scenarios to illustrate decarbonisation issues

2.1. Two transition scenarios for achieving the National Low-Carbon Strategy decarbonisation target

2.1.1. How the scenarios were built

The method used to develop the two Sectoral Transition Plans (STPs) for the pulp and paper industry involved building a decarbonisation trajectory based on both projected demand and the deployment of existing technological solutions, the potential of which has been identified by industry stakeholders in two different transition situations. **The target for these two trajectories is to reduce greenhouse gas emissions by at least 81% from their 2015 levels by 2050**, in line with the objectives set by the current National Low-Carbon Strategy (SNBC2).

In the case of the Sectoral Transition Plan for the pulp and paper industry, four structuring factors described below were selected, the different combinations of which were used to construct two decarbonisation scenarios.

These two scenarios, dubbed **"Mass-scale reuse and limited fuelwood"** and **"Paper innovations and fuelwood growth"**, each come with specific challenges posed by these structuring factors:

Market factors:

• The reuse rate of industrial and commercial packaging, which could place downward pressure on demand for new boxes.

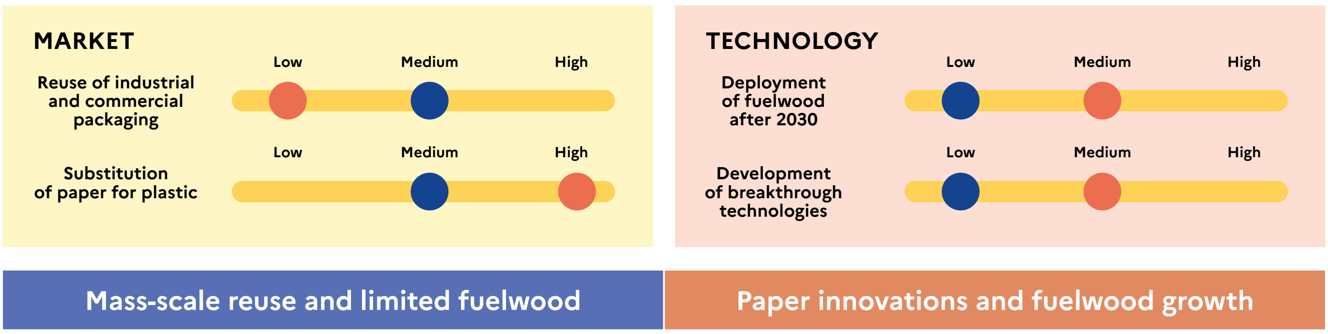
• The replacement of plastic with paper, which could stimulate higher demand for packaging made from paper, cardboard, and moulded cellulose.

Technological factors:

• The extent to which fuelwood is deployed in paper mills after 2030, depending on available supply in each region and the prioritisation of uses.

• The development of breakthrough technologies for the paper process.

Figure 18. The four structuring factors for both scenarios.



2.1.2. Overview of assumptions made for the scenarios

Table 2. Summary of the narratives for each scenario and the main assumptions made.

		Mass-scale reuse and limited fuelwood	Paper innovations and fuelwood growth
MARKET	Reuse of industrial and commercial packaging	★★☆ New shipping boxes partially replaced by used boxes	★☆☆ Regulatory exemptions for reusing boxes, current trends in demand for industrial and commercial paper and board packaging continue
MARKET	Single-use plastic packaging replaced by paper alternatives	★★☆ Plastic partially replaced by mature paper and moulded cellulose products (food packaging, packing materials)	★★★ Plastic widely replaced by mature and innovative paper and moulded cellulose products (bottles, wrapping)
MARKET	Demand for graphic papers continues to decline	★★☆ Trial 'opt-in' scheme for advertising rolled out nationally Digital-for-paper replacement trend bottoms out around 2040	★☆☆ 'Opt-in' scheme not rolled out nationally but major advertisers continue to move from print to digital materials Digital-for-paper replacement trend bottoms out around 2030
MARKET	Higher demand for sanitary papers driven by demographics	★☆☆ Single-use wipes widely replaced by reusable versions, but effect offset by demographics-driven demand in other markets	★★☆ No change in sanitary paper purchasing behaviours, demographic growth drives slightly higher demand
TECHNOLOGY	Development of fuelwood in paper mills after 2030	★☆☆ Limited use of fuelwood: role of biomass in decarbonising the industry replaced by other solutions	★★☆ Increased use of fuelwood: new biomass installations are commissioned after 2030
TECHNOLOGY	Access to wood as a feedstock for pulp production	★★★ Access to wood in terms of volume and price is encouraged for material uses, improving the competitiveness of the French pulp industry and enabling existing sites to maintain performance	★☆☆ Competing demand for wood resources for material and energy uses: pulp industry competitiveness suffers and pulp production volumes are reduced
TECHNOLOGY	Development of HTHPs	★★★ HTHPs developed to their full potential	★★★ HTHPs developed to their full potential
TECHNOLOGY	Alternatives to fuelwood deployed (excl. HTHPs)	★★★ Solar thermal energy, deep geothermal, and electric boilers gain a foothold in the energy mix	★☆☆ Deployment limited to alternatives that are currently available (biogas, SRF, etc.), which along with biomass contribute to decarbonising the industry's thermal energy mix
TECHNOLOGY	Development of breakthrough technologies	★☆☆ Breakthrough technologies have very limited effects: energy efficiency gains slightly below the historic average	★★☆ Certain disruptive technologies deployed that allow energy efficiency gains above the historic average

➜ Pulp mill, Fibre Excellence Saint-Gaudens @ Fibre excellence

In 2050, in the **Mass-scale reuse and limited fuelwood** scenario, the number of new shipping boxes in circulation is reduced by a combination of two things: reuse of boxes, and development of plastic boxes. At the same time, single-use plastics are partially replaced by paper and board products (packing materials and food packaging), and also reusable plastic and glass products.

In technological terms, the use of fuelwood is gradually restricted to applications that require higher temperatures than those needed by paper machines and with fewer alternatives. After 2030, the only non-virgin pulp mills to deploy new wood-fired boilers are those with very high temperature requirements, for example sanitary paper mills. Meanwhile, the full range of alternative solutions are deployed: high-temperature heat pumps, electric boilers, solar thermal, deep geothermal, and biogas produced by anaerobic digestion of liquid and solid residues. In a context where the supply of wood resources is tight, biomass boilers deployed before 2020 and which have reached the end of their lifespan are replaced by combinations of electric boilers and high-temperature heat pumps, so that fuelwood can be reallocated to other sectors. Virgin pulp mills improved the efficiency of the kraft process, modernised lime kilns, and recycle biomass by-products to offset their idle energy consumption.

In 2050, in the **Paper innovations and fuelwood growth** scenario, shipping boxes continue to be put into circulation. At the same time, newly developed innovative paper materials with water, grease, and contaminant-resistant properties are used as a direct substitute for a large number of plastic packaging types, including household items such as bottles and food packaging materials, and also industrial packaging such as pallet wrap and moulded cellulose packing materials.

In technological terms, fuelwood is prioritised for medium and high temperature uses, ensuring its use by non-virgin pulp mills continues to rise, albeit at a slower rate than over the period 2020-2030. Meanwhile, high-temperature heat pumps, biogas from anaerobic digestion of solid and liquid residues, and certain breakthrough technologies are deployed, reducing the extent to which sites not producing virgin pulp rely on natural gas. Whereas virgin pulp mills employ the same decarbonisation solutions as in the **Mass-scale reuse and limited fuelwood** scenario.

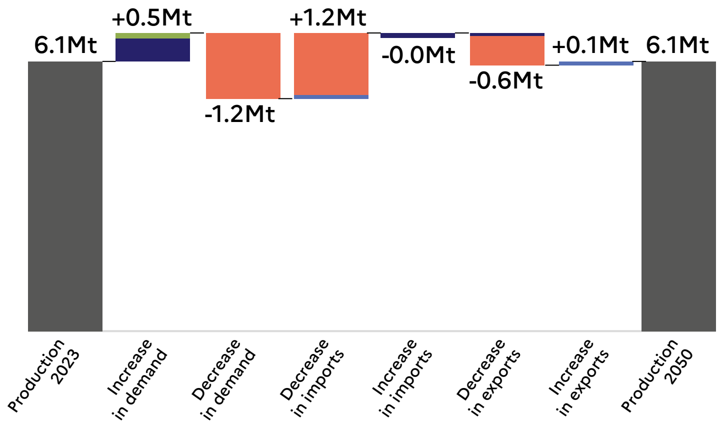
2.2. Results of the scenarios

2.2.1. Mass-scale reuse and limited fuelwood

Impacts are offset between segments, ensuring production remains stable

In the **Mass-scale reuse and limited fuelwood** scenario, paper and board production is affected by falling demand for graphic papers, with a moderate impact nationally and putting significant downward pressure on imports. At the same time, the two contrasting trends in the packaging segment effectively cancel each other out, leading French national packaging production to almost stagnate with substantial variations over the period studied. By 2050, production output stands at 6.1 Mt – the same as in 2023.

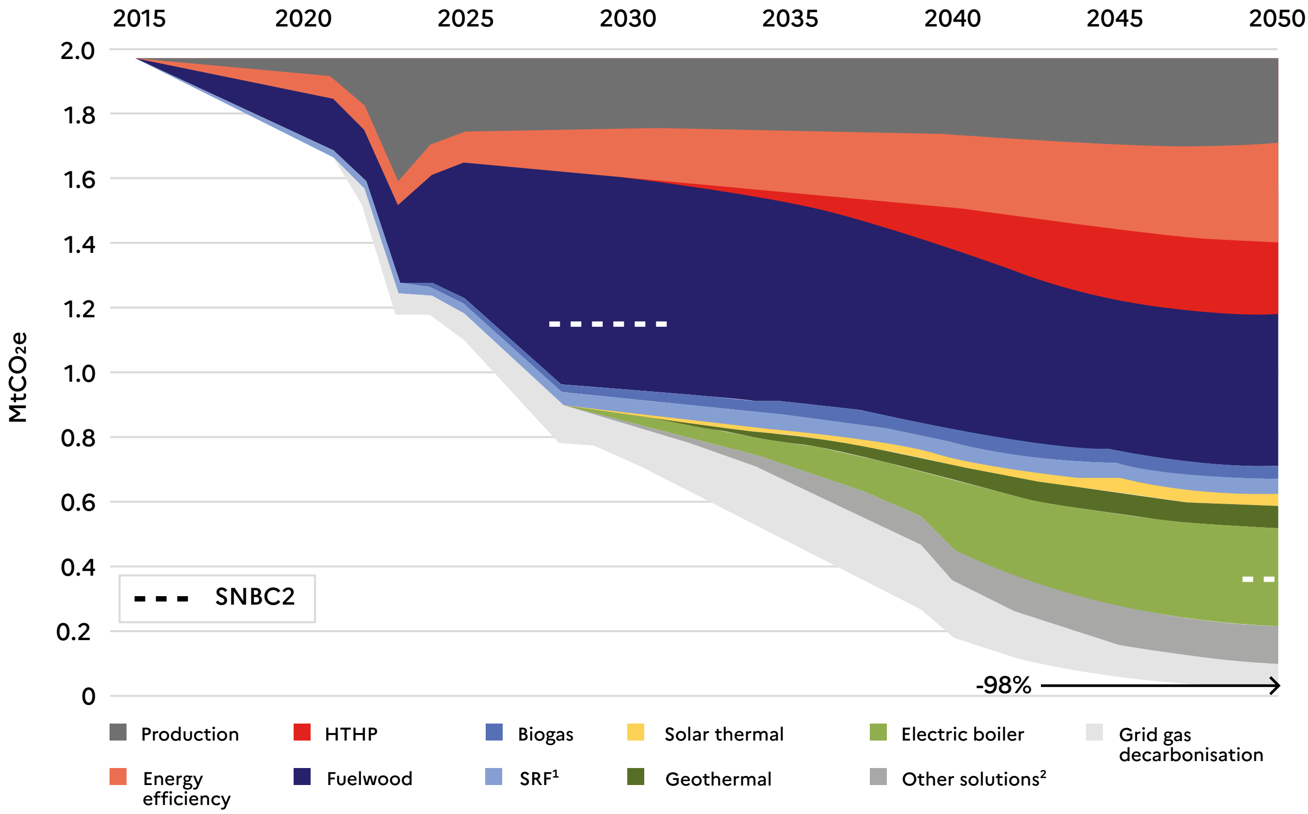
Figure 19. Paper and board production by segment between 2023 and 2050 with explanatory effects, "Mass-scale reuse and limited fuelwood" scenario.



Complementary solutions combine to ensure industry decarbonisation

Greenhouse gas emissions are impacted by the high use of fuelwood before 2030, and the move towards electric solutions (such as HTHPs and electric boilers) after 2030. **Greenhouse gas emissions are 60% down on their 2015 levels in 2030, and more than 95% lower by 2050.**

Figure 20. GHG emissions reduction trajectories, "Mass-scale reuse and limited fuelwood" scenario.



[1]SRF: Solid Recovered Fuels
[2]Waste incineration, hydrogen, recycling of by-products (pulp)

Investments similar to current trends

The investment trajectory in the **Mass-scale reuse and limited fuelwood** is split into two distinct phases – before and after 2030 – but investments in energy efficiency consistently remain close to current levels throughout the entire period.

Before 2030, the emphasis is on completing projects planned or already under deployment to replace gas boilers with wood-fired boilers.

From 2025 onwards, the availability of HTHPs gradually improves, prompting massive investment in this technology to recover waste heat and drive electrification after 2030.

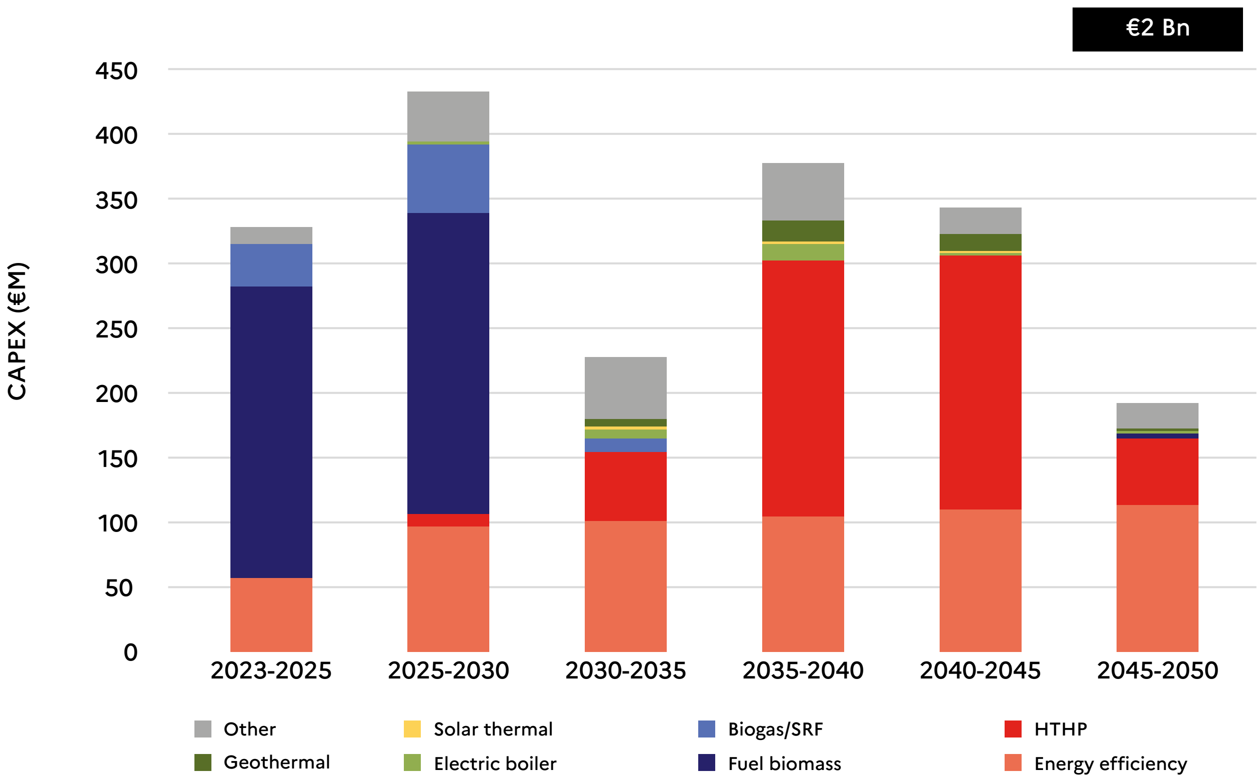
Over the period 2030 to 2050, some 450 million euros are invested in biomass boilers, and 500 million euros in high-temperature heat pumps.

After 2030, the move to prioritise the use of biomass resources has the effect of limiting new investment in this energy technology. The result is that other alternatives are preferred, such as power-to-heat solutions, although these have a modest impact owing to their relatively low CapEx cost. In addition, solar thermal and in particular deep geothermal energy reach maturity and become a viable solution for meeting part of industry's needs, but are highly capital-intensive and significant investment is needed to exploit their potential in the paper sector.

The overall rate of investment reaches around 85 million euros annually until 2030, equivalent to 50% of the paper sector's total capital expenditure on technical equipment and industrial plant over the period 2019 to 2021[36].

This amount slows to stabilise at an average of 60 million euros per year between 2030 and 2050, equivalent to 35% of the paper sector's total capital expenditure on technical equipment and industrial plant over the period 2019 to 2021[37].

Figure 21. Investment timeline, "Mass-scale reuse and limited fuelwood" scenario.



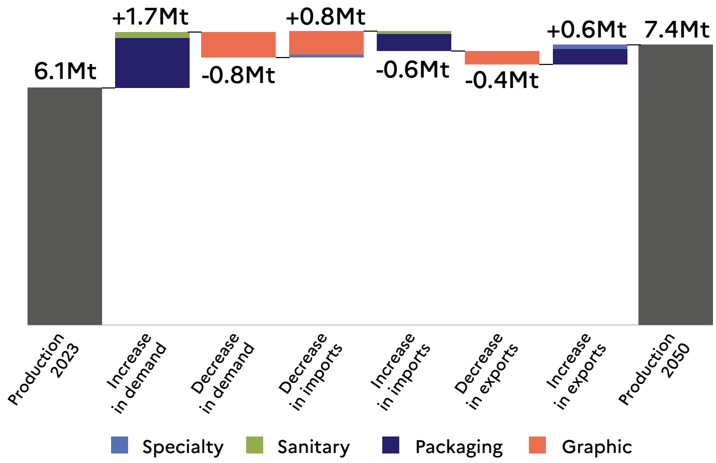
[36, 37] INSEE, Esane, Investissements des entreprises. French standard NAF 171 – Pulp, paper and board industry.

2.2.2. Paper innovations and fuelwood growth

Packaging: an engine driving higher production

In the **Paper innovations and fuelwood growth** scenario, paper and board production is marked by rising demand for paper and cardboard packaging (for industrial, commercial, and household uses), met by both domestic production and imports (mostly from neighbouring countries). As a result, import levels remain stable. The other key factor is the decline in demand for graphic papers, which in turn leads to lower imports but also lower levels of domestic production, which stands at 7.4 Mt in 2021 and in 2050.

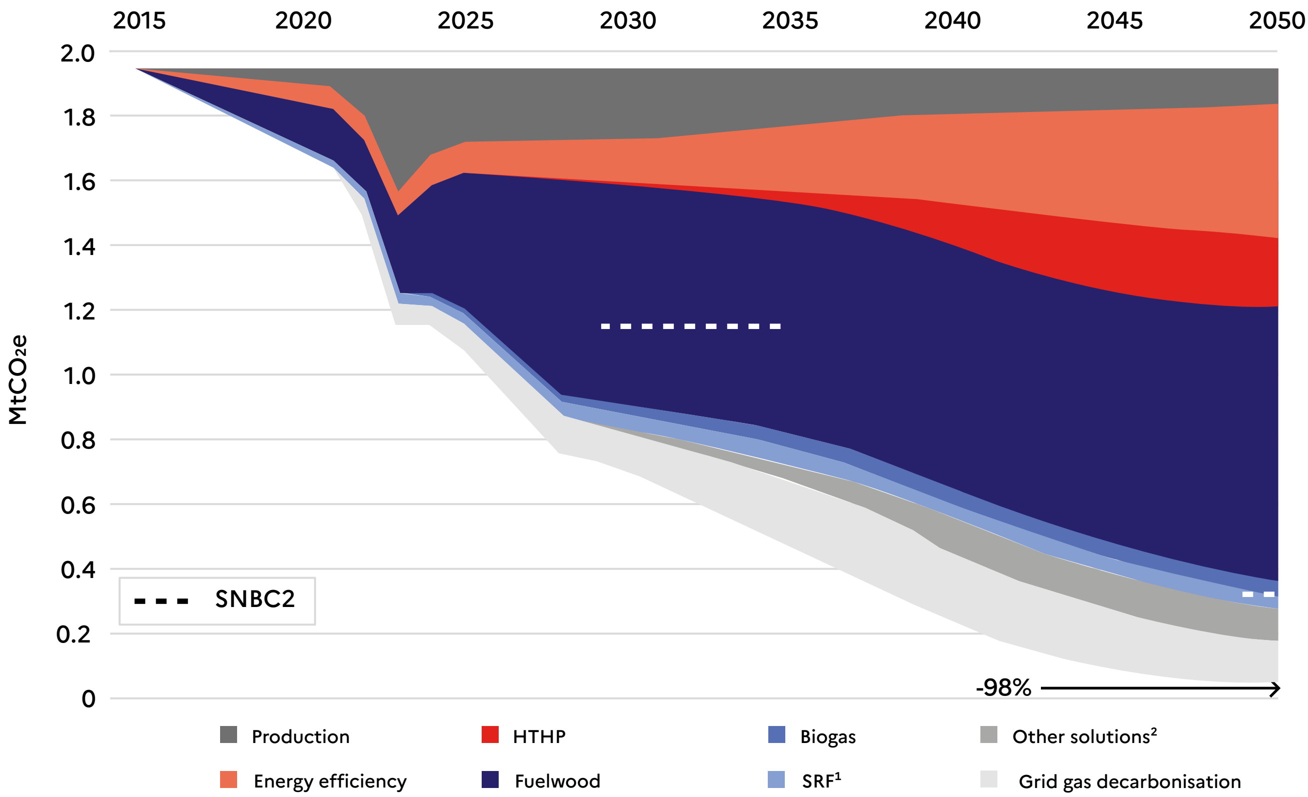
Figure 22. Paper and board production by segment between 2021 and 2050 with explanatory effects, "Paper innovations and fuelwood growth" scenario.



Fuelwood and breakthrough technologies drive decarbonisation

Similarly to the first scenario, greenhouse gas emissions are impacted by the increased use of fuelwood over the period leading up to 2030, a trend that continues to have an effect thereafter in tandem with the adoption of HTHPs and improvements in energy efficiency made possible by disruptive technologies. **Greenhouse gas emissions are 60% down on their 2015 levels in 2030, and more than 95% lower by 2050.**

Figure 23. GHG emissions reduction trajectories, "Paper innovations and fuelwood growth" scenario.



[1] *SRF: Solid Recovered Fuels*
[2] *Waste incineration, hydrogen, recycling of by-products (pulp)*

Investments similar to current trends

The investment timeline for the **Paper innovations and fuelwood growth** scenario has similarities with that of the first scenario, with overall totals slightly higher but still around the 2 billion euro mark.

The main differences are an increased financial commitment to energy efficiency measures, including the adoption of disruptive technologies as they reach maturity, a trend that becomes more acute after 2030. High-temperature heat pumps (HTHPs) play a more important role thanks to higher production, which results in a larger supply of waste heat. In contrast to the first scenario, investment in fuelwood continues throughout the period studied, although the amounts involved do fall sharply after 2030.

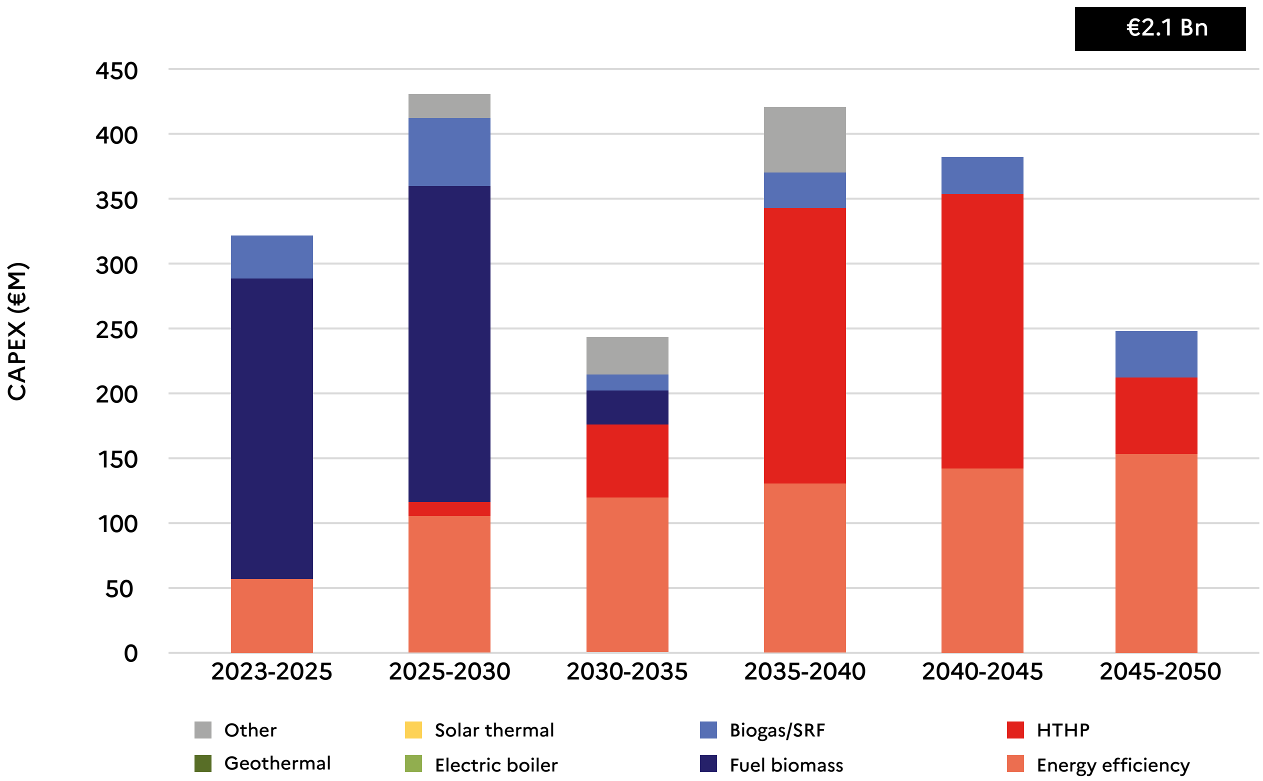
Over the period 2030 to 2050, some 600 million euros are invested in biomass boilers, and 550 million euros in high-temperature heat pumps.

Investment in biogas and other solutions with much more limited impacts is identical to the first scenario. No special investment is assumed in electric boilers, solar thermal, or deep geothermal in this scenario.

The overall rate of investment reaches around 85 million euros annually until 2030, equivalent to 50% of the paper sector's total capital expenditure on technical equipment and industrial plant over the period 2019 to 2021[38].

This amount slows to stabilise at an average of 60 million euros per year between 2030 and 2050, equivalent to 38% of the paper sector's total capital expenditure on technical equipment and industrial plant over the period 2019 to 2021[39].

Figure 24. Investment timeline, "Paper innovations and fuelwood growth" scenario.



[38, 39] INSEE, Esane, Investissements des entreprises. French standard NAF 171 – Pulp, paper and board industry.

2.3. General learnings: targets met with a reduced trade deficit but a new-found reliance on wood and electricity

2.3.1. Focus on downstream market developments

Pulp: limited or increased reliance on imports depending on availability and price of wood as a raw material

Consumption

Both scenarios assume stable recovered paper circularity rates for each segment of the sector, but with increased consumption in segments with higher circularity rates (packaging) and reduced consumption in those with lower circularity rates (graphic papers). This results in pulp consumption falling by 8% between 2023 and 2050 in the **Mass-scale reuse and limited fuelwood** scenario, and rising by 6% in the **Paper innovations and fuelwood growth** scenario.

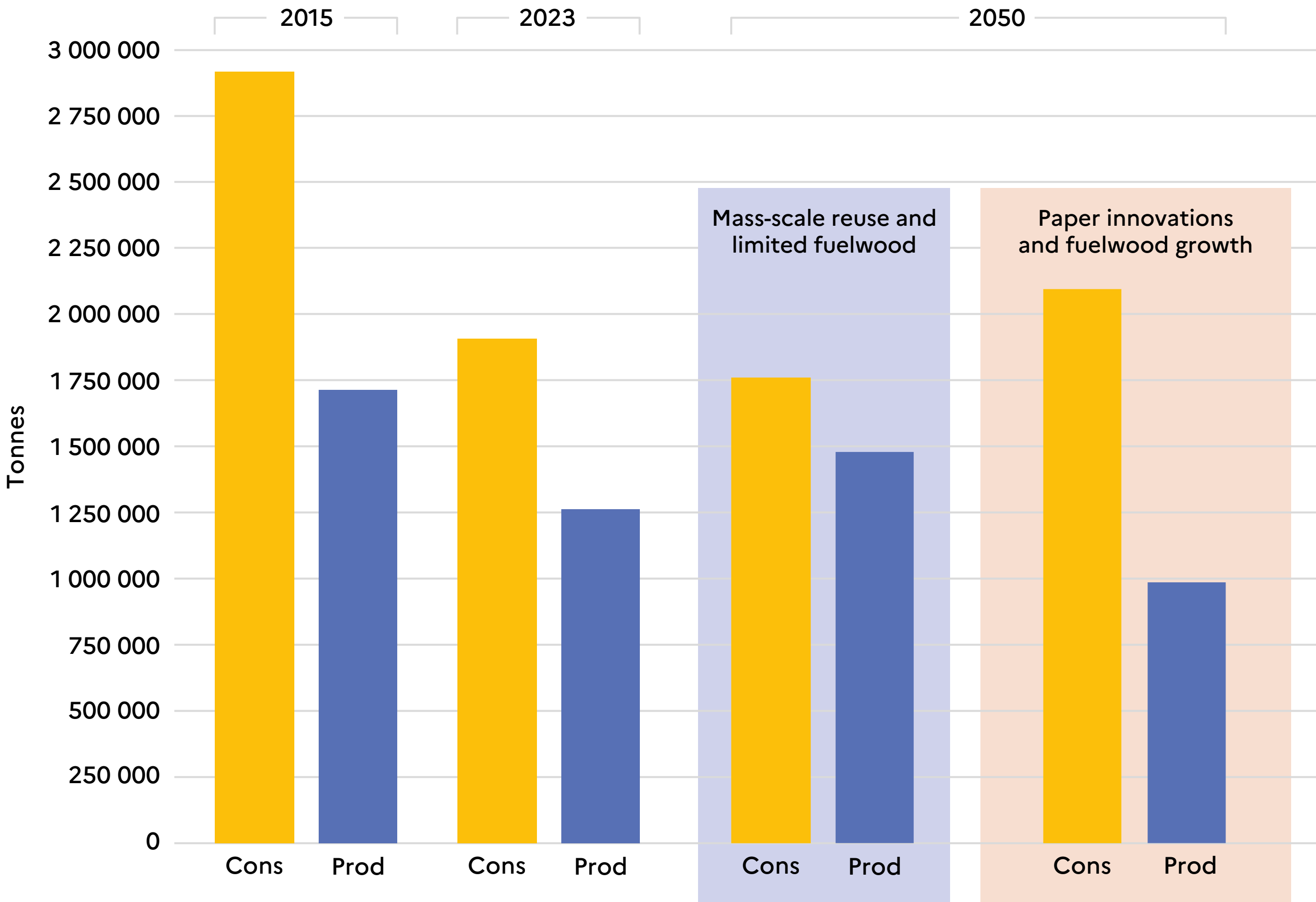
Production

Production behaves very differently between the two scenarios. In the **Mass-scale reuse and limited fuelwood** scenario, pulp mills are able to remain competitive by virtue of their preferential access to raw material in sufficient volumes and at low prices, and the economic value of biogenic CO_2: as a result, rises by 18% between 2023 and 2050. In the **Paper innovations and fuelwood growth** scenario, the cascading use of wood resources sees open competition between energy and material uses, leading to higher prices and lower volumes of wood available to French pulp manufacturers: as a result, production falls by 20%.

Trade balance

The trade deficit is heavily reduced in the **Mass-scale reuse and limited fuelwood** scenario, falling from 700,000 tonnes in 2023 to just 280,000 tonnes in 2050, whereas in the **Paper innovations and fuelwood growth** scenario it rises to 1.1 Mt in 2050.

Figure 25. Pulp consumption and production in 2015, 2023 and 2050 for each scenario.



Paper and board: demand for packaging is the key factor shaping the future of the pulp and paper sector

Consumption

Consumption of paper and board evolves strongly in both scenarios. While overall demand increases by 15% between 2023 and 2050 in the **Paper innovations and fuelwood growth** scenario, it falls by 10% in the **Mass-scale reuse and limited fuelwood** scenario.

Specifically, the scenarios differ in terms of the extent to which downstream markets evolve in the graphic paper and packaging segments. In the **Paper innovations and fuelwood growth** scenario, the 40% decline in graphic paper consumption is offset by a 35% rise in the consumption of packaging paper and board, particularly due to the latter's use as a substitute for single-use plastics and the continued use of single-use boxes in the logistics chain. However, in the **Mass-scale reuse and limited fuelwood** scenario, the 10% rise in consumption of paper and board packaging is insufficient to make up for the sharp 70% decline in graphic paper consumption, in a context where industrial packaging is increasingly reused and single-use plastics replaced by alternatives.

A striking reconfiguration of demand can be seen in both scenarios, with paper and board packaging accounting for around 75% of overall demand in 2050, compared with 60% in 2023.

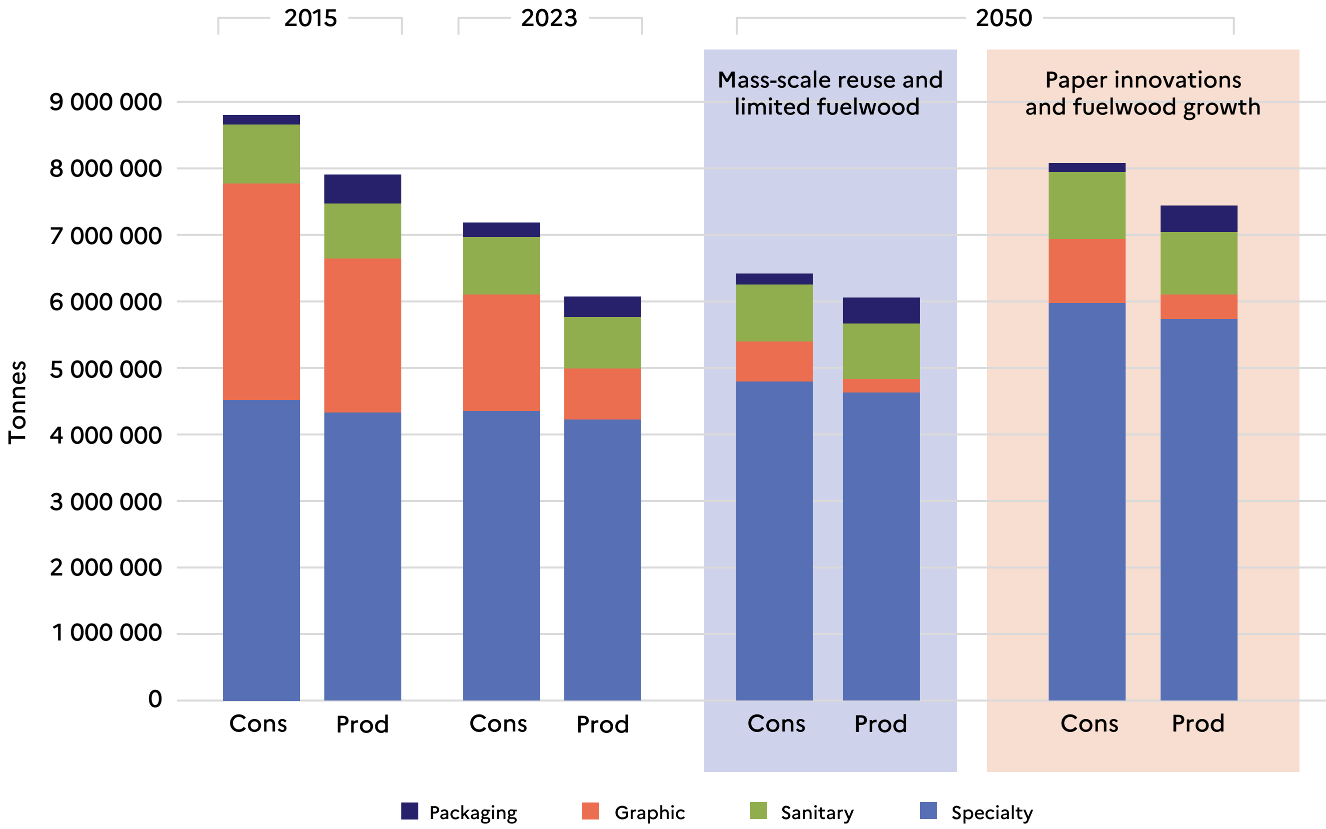
Production

Since the paper and board market is essentially regional, we did not look at the competitiveness of French mills compared with those in neighbouring European countries. Assuming imports and exports remain stable in each segment, the **Paper innovations and fuelwood growth** scenario sees paper and board production rise by 20% between 2023 and 2050. In the **Mass-scale reuse and limited fuelwood** scenario, the effects of rising packaging production are offset by the decrease in the production of graphic papers.

Trade balance

Starting from a trade deficit of around 1 Mt in 2023, both scenarios see that figure reduced, to 350,000 tonnes in the **Mass-scale reuse and limited fuelwood** scenario and 700,000 tonnes in the **Paper innovations and fuelwood growth** scenario. This is mainly driven by lower demand for graphic papers, which happened to be the segment that contributed most to the trade deficit.

Figure 26. Production and consumption of paper and board between 2015, 2023 and 2050.



2.3.2. An industry using less energy, but more electricity

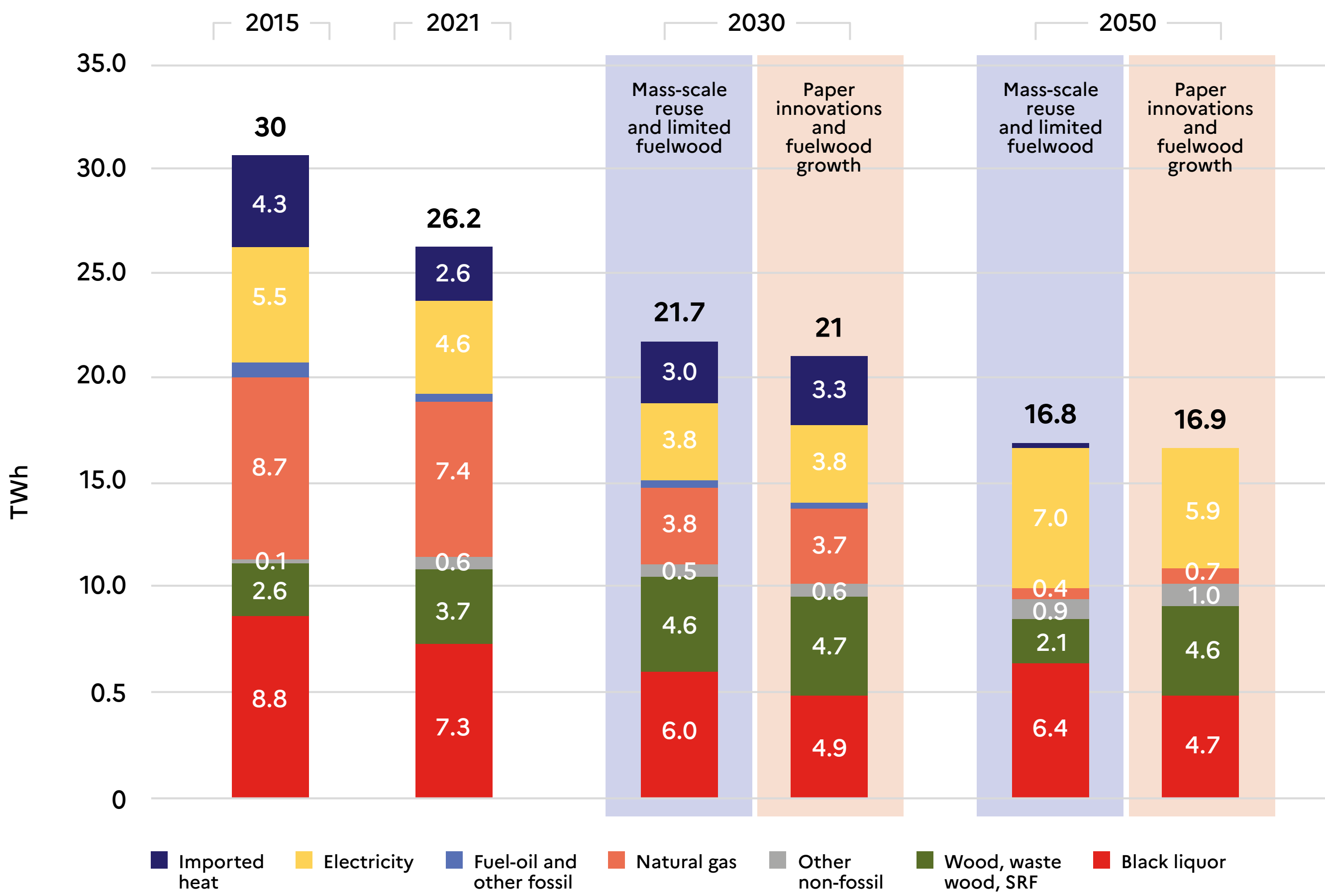
The first key point in this analysis is the **reduction in final energy consumption** by the paper industry, which falls by approximately 45% between 2015 and 2050 in both scenarios. There are multiple reasons for this, the first being the decline in production concentrated mainly between 2015 and 2023. Another factor is the ongoing improvement in energy efficiency with the deployment of high-temperature heat pumps in both scenarios, and particularly in the **Paper innovations and fuelwood growth** scenario where energy savings are able to compensate for the 20% rise in production between 2023 and 2050.

The second key point concerns **electricity consumption**. First, thanks to improvements in the performance of machines and pumps, the paper industry draws 30% less power from the network between 2015 and 2030. From 2030 onwards, these improvements are more than offset by the move towards electrification, with the deployment of high-temperature heat pumps (in both scenarios) and electric boilers (in the **Mass-scale reuse and limited fuelwood** scenario). Electricity consumption reaches 7 TWh in 2050 in the **Mass-scale reuse and limited fuelwood** scenario, and 6 TWh in the **Paper innovations and fuelwood growth** scenario.

The third key point concerns the **consumption of fuelwood**, waste wood, and SRF. In both scenarios, investment in numerous wood boilers between 2015 and 2030 should increase wood resource consumption in the paper industry by 2 TWh, with a corollary equal reduction in grid gas consumption. After 2030, fuelwood consumption stabilises in the **Paper innovations and fuelwood growth** scenario as new investments in wood-fired boilers are offset by energy savings, reducing sites' thermal energy requirements. In the **Mass-scale reuse and limited fuelwood** scenario, fuelwood consumption gradually declines owing to the low levels of investment in wood boilers, the rollout of electric boilers, and the adoption of high-temperature heat pumps, which allow biomass boilers financed between 2010 and 2025 to be downsized, with available resources redirected to other sectors that have no alternative means of generating high temperature heat.

Together, these developments combine to enable the pulp and paper industry (and particularly sites that do not produce virgin pulp) to **almost entirely eliminate their reliance on gas from the grid**, with consumption falling from around 9 TWh in 2015 to under 4 TWh in 2030 and less than 1 TWh by 2050.

Figure 27. Paper industry energy consumption in 2015, 2021, 2030, and 2050 (like for like).



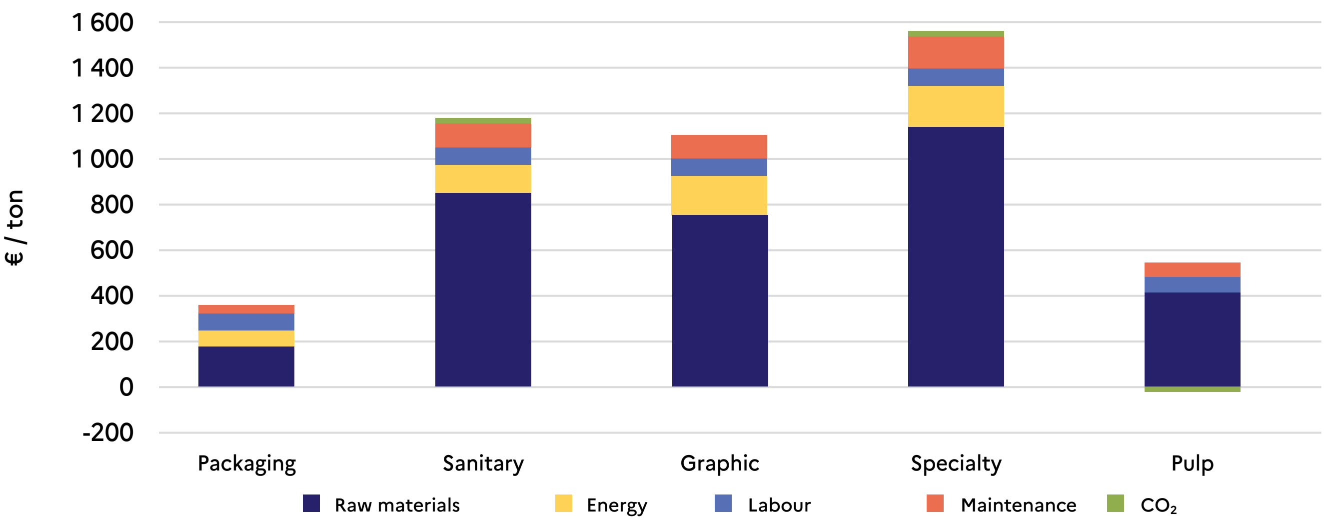
3. Economic analysis

3.1. Higher production costs

Operating expenditure (OpEx) in the paper and board sector is traditionally dominated by the costs of raw materials (recovered papers, recycled or virgin pulp, chemicals), and vary considerably from one segment to the next. The cost of energy is between €75 / tonne for packaging and €175 / tonne for specialty papers, and accounts for 20% of OpEx for packaging, compared with 10% for specialty papers.

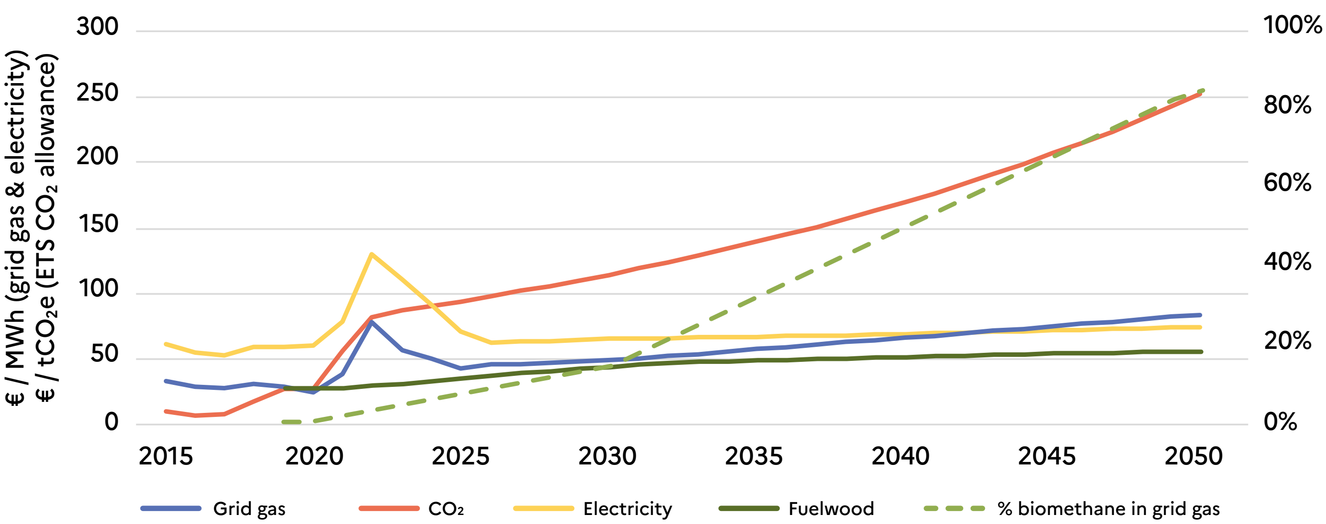
While certain pulp mills are not fully energy self-sufficient, others have a surplus of energy that they are able to sell back to the network. These sites' respective spending and income effectively cancel each other out, to give a neutral average energy cost. In addition, some virgin pulp mills with very small carbon footprints have spare free emissions allowances under the ETS Directive, enabling them to make a profit.

Figure 28. Production cost structure in 2021. (Source: STP models based on CEPI figures)



However, energy cost projections for the period up to 2050 could materially alter this OpEx structure. The cost of energy, and gas in particular, is expected to rise significantly by 2050. Upward pressure on operating costs would be further exacerbated by a combination of higher carbon allowance prices and a more rapid decline in free allocations (the exact arrangements for which are only confirmed until 2030 and are unknown thereafter).

Figure 29. Energy price and CO_2 assumptions for the pulp and paper sector between 2015 and 2050.

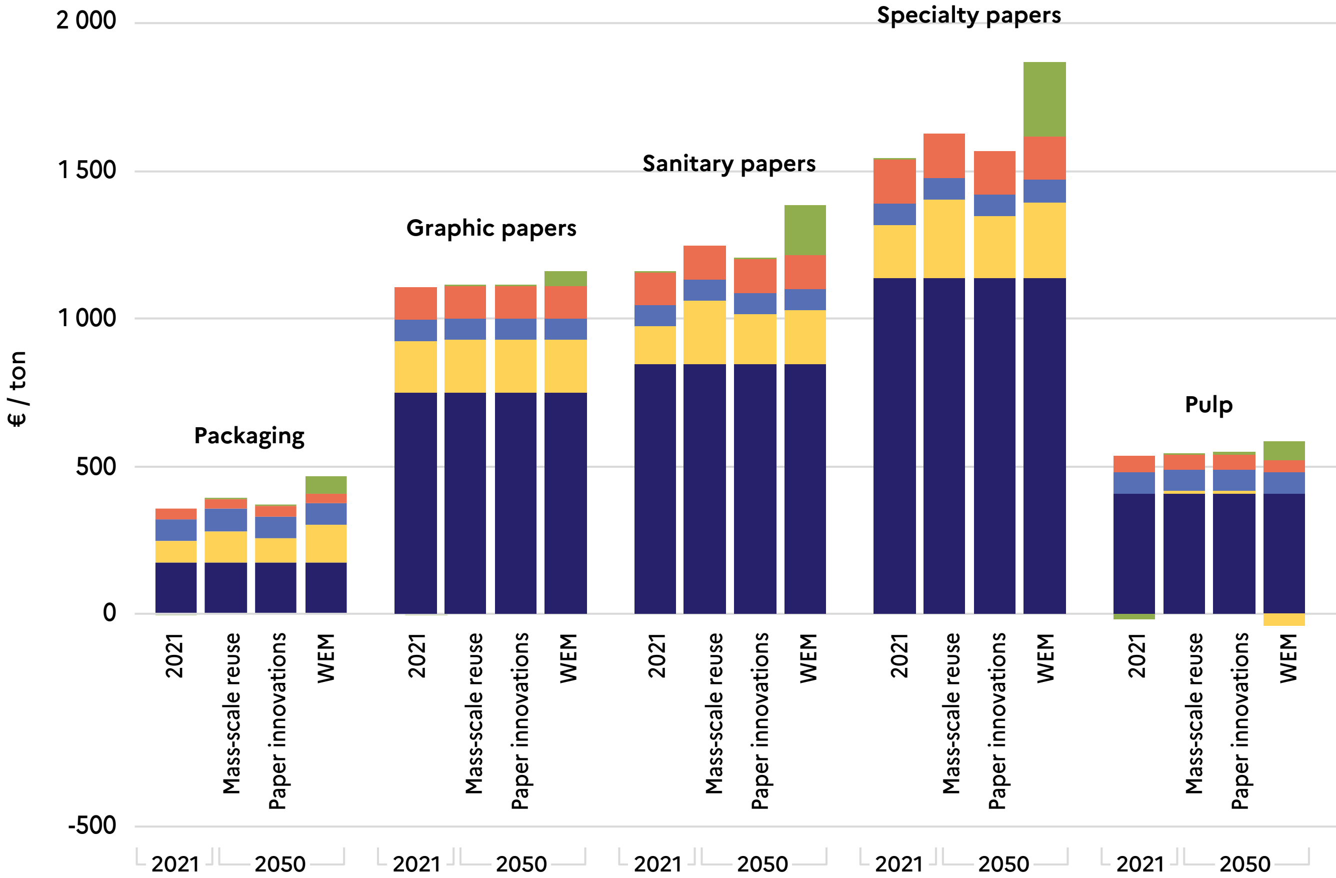


Rising energy and carbon costs pose a considerable risk for an industry already facing fierce competition from around the world in the pulp segment, and from European rivals in the paper and board segment. Strategic investments in decarbonisation could go some way to limiting the impact of these trends on OpEx, and help shore up the sector's ability to hold onto market share.

For example, in the **Mass-scale reuse and limited fuelwood** scenario, the increase in energy costs is mainly driven by higher grid electricity consumption as a result of the wider use of electric boilers and high-temperature heat pumps. Whereas in the **Paper innovations and fuelwood growth** scenario, the increase in energy costs is mainly driven by higher purchases of fuelwood, particularly after 2030, with a marked increase compared with 2021 levels.

The WEM (With Existing Measures) scenario, meanwhile, shows how the cost of production changes in each segment, by including only projects that have already been completed or are in the pipeline (mainly biomass boilers) and assuming that grid gas continues to be fossil-based. This illustrates how carbon allowances are likely to evolve as a proportion of OpEX if paper industry stakeholders restrict themselves merely to existing decarbonisation investment commitments.

Figure 30. Production costs by scenario and component.
(source: STP models)



The two scenarios examined in the STP show similar production cost trends for the packaging, graphic papers, and pulp segments.

Production costs for sanitary and specialty papers are higher in the **Mass-scale reuse and limited fuelwood** scenario than in the **Paper innovations and fuelwood growth** scenario. This is essentially due to the fact that the production process for these types of papers is more energy-intensive and has a more electricity-dominated energy mix owing to the use of electric boilers.

Finally, production costs in the WEM scenario are considerably higher than in either of the STP decarbonisation scenarios, confirming that action is very much worthwhile and underlining the relatively high cost of doing nothing. The WEM scenario's elevated production costs are largely due to carbon prices rising while gas consumption remains high. This trend is even clearer in segments with greater exposure to the reduction in free allowances and high energy-intensity and carbon emissions, such as specialty and sanitary papers.

3.2. Abatement costs as a benchmark for comparing solutions and gauging price sensitivity

The deployment of the various technologies is associated with an abatement cost. This is measured in €/tCO_2 and makes it possible to compare the average cost of deployment in a given sector. The estimated values are based on a calculation methodology that takes into account manufacturers' investment and operating costs, as well as a number of assumptions about changes in costs that are consistent with the modelling[40].

However, a raw analysis of abatement costs has certain limitations, particularly due to its sensitivity to variations in price assumptions. To address this uncertainty, a sensitivity analysis was carried out, focusing mainly on the impact of electricity price variations on the abatement costs of electro-intensive technologies. The full STP for the paper and board industry will include a more comprehensive analysis.

It is important to note that abatement costs are an extra economic angle from which to analyse decarbonisation solutions, but other aspects should also be considered in order to establish a complete picture of the options available. These include local specificities (land available for solar thermal or geothermal potential), the availability of resources (fuelwood), the energy potential of these solutions as compared with the needs of industrial sites and any resulting additional requirements (e.g. heat pumps and solar thermal energy) or and corporate strategies (reliance on the power grid).

Method – abatement cost of technologies

Two indicators can be used to compare the cost of developing technologies: their additional cost and their abatement cost.

The **additional cost** of a technology is defined as the difference between the expenditure associated with its application (the discounted sum, using a discount rate r, of the CapEx and OpEx over a fixed period T), and the expenditure in a baseline scenario where the technology is not applied.

This indicator is used to assess the profitability of a technology. If the additional cost is zero, it will be profitable at the end of the project. If it is negative, it will be profitable before the end of the project. If it is positive, the project is not profitable. In particular, if the operating cost savings are too small (or if ΔOPEX is positive), the investments may never pay for themselves, whatever the duration of the project.

$$Additional\ cost = \sum_{t=0}^{T-1} \frac{\Delta CAPEX_t + \Delta OPEX_t}{(1+r)^t}$$

The **abatement cost** of a technology is defined as the additional cost of that technology in relation to the cumulative quantity of CO_2 that it avoids over the life of the project, compared with the situation where the existing installations are maintained.

This indicator makes it possible to compare the cost-effectiveness of decarbonisation solutions with a view to prioritisation, but it must be supplemented by other indicators such as maturity, the level of decarbonisation enabled by each technology, or the way they are linked together[41].

$$Abatement\ cost = \frac{additional\ cost}{\sum_{t=0}^{T-1} \Delta CO2_t}$$

[40] These assumptions are detailed in the full Paper and board STP report.

[41] With the objective of total decarbonisation, rather than partial decarbonisation, the use of low-cost technologies that only partially reduce emissions can create a counter-productive technological lock-in.

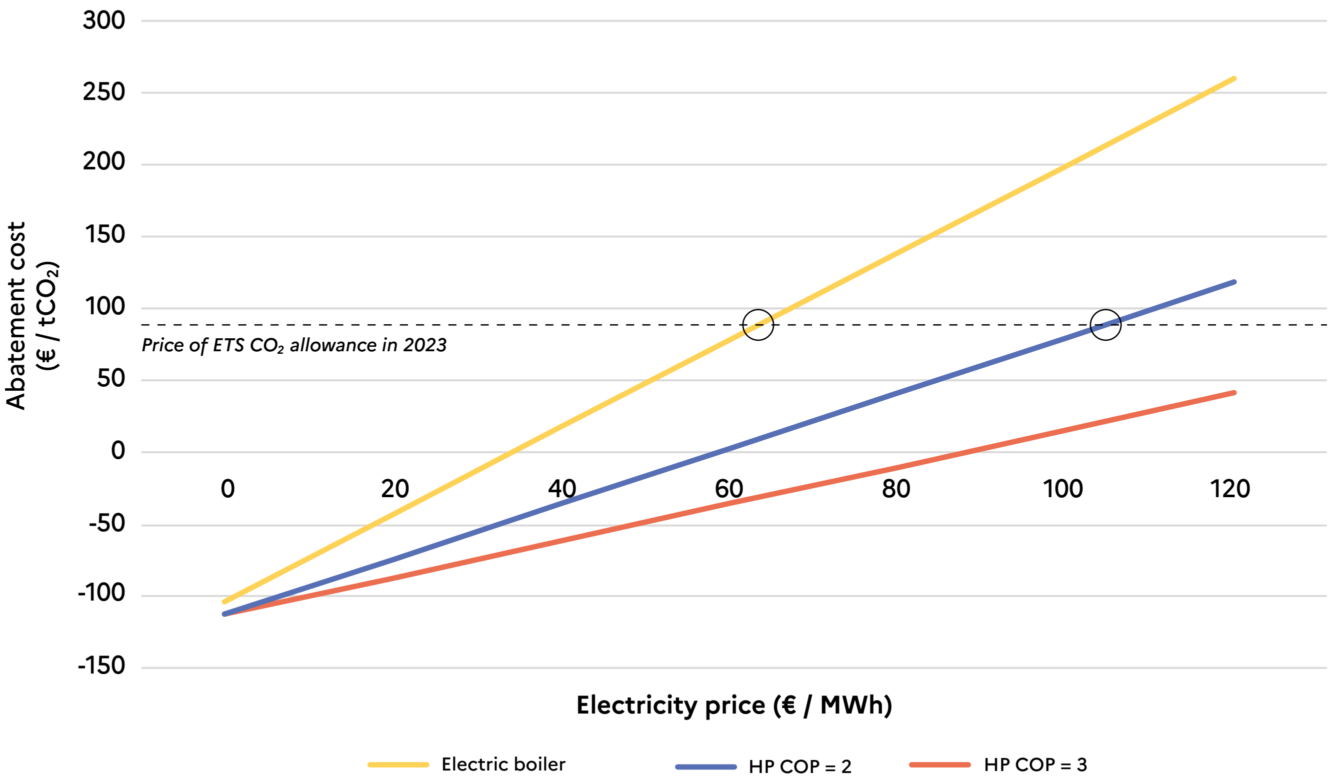
Assuming a grid gas price equivalent to 2023 (i.e. €40/MWh) and a plant payback period of 20 years, the sensitivity analysis, as one might expect, shows that the lower the electricity price, the greater the economic benefit of adopting high-temperature heat pumps (HTHPs) and electric boilers.

Based on the price of CO_2 allowances on the ETS market in 2023 (€85/tCO_2), a HTHP with a COP of 3 is profitable, i.e. its installation and running costs are lower than the cost of emissions from operating a gas boiler. For a HTHP with a COP of 2 to be profitable at this same carbon price level, the electricity price would need to be less than €110/MWh. For an electric boiler, the electricity price would need to be less than €65/MWh.

With an electricity price of €100/MWh, electric boilers have an abatement cost of close to €200/tCO_2. To counterbalance the high cost of electricity, industrial sites have every incentive to make their consumption profiles more flexible, by retaining a fuel-based boiler as a backup option for use when electricity prices are high, or alternatively to adopt energy storage solutions.

More generally, these abatement cost analyses should also anticipate a rise in grid gas prices. This is partly due to the fact that biomethane will increasingly be incorporated into the network and comes with a higher cost than conventional natural gas (around €100/MWh), and partly because the unit cost of the distribution and transmission system is expected to rise as national gas consumption falls. This will affect the production cost of plants that continue to rely on gas boilers, but will also increase the competitiveness of electricity-based solutions.

Figure 31. Sensitivity to electricity prices of the abatement cost of substituting power-to-heat technologies for gas boilers, based on a grid gas price of €40/MWh.



➜ Technician in a paper mill manufacturing corrugated base paper (for packaging)

3.3. Quantitative analysis of employment impacts

Figures from French social security body URSSAF show that in 2023, the paper and board industry employed a total of 16 000 people at 82 paper mills. The industry is spread fairly widely across the country, and is not concentrated in any particular region. The same applies to the jobs it supports. No single employer stands out from the rest in terms of workforce numbers. The largest headcount does not exceed 550 personnel, while 70% employ no more than 250 people. Meanwhile, the different types of paper produced are distributed evenly across the sector. The paper industry supports 6 470 upstream indirect jobs, associated with energy and feedstock production, 60% of which come from paper and board recycling. The industry also has a visible impact on the rest of the downstream value chain, with almost 15,000 establishments in the printing and cardboard sectors employing close to 65,000 FTEs[42].

Considering the differences in employment ratios depending on the type of product manufactured in the pulp and paper industry, each scenario presented in this STP leads to different preliminary estimates regarding employment. As an example, virgin pulp production requires 1.5 times more workforce than recycled pulp, per ton of product. A similar ratio is measured between the packaging and graphic papers segments. However, independently of the scenario chosen, the biggest impact on the sector's employment numbers is mostly determined by the extent to which the lower activity in the graphic paper sector is offset by the growth of packaging and sanitary papers production.

Thus, in the Paper innovations and fuelwood growth scenario, the estimated number of direct jobs supported by the paper and board industry reaches 16,250 in 2050, a 2% increase when compared with 2022, but falls by 15% in the Mass-scale reuse and limited fuelwood scenario. The more than 25% drop in production of graphic papers is partly mitigated in the innovation scenario by the 25% rise in packaging paper production, despite the fact that the process is much less human resources-intensive.

Estimated indirect jobs are slightly up in the innovation scenario (+7%) to 6 910 FTEs, despite a fallow period in 2030. In the reuse scenario, they track direct jobs and fall by 10% in 2050. The divergence is due to differences in the amounts of energy and materials used for production in each scenario.

Expectations of lower production could also see production capacities closed down. However, this does not necessarily signal the end of industrial activity. There are two ways for industry to recover. One involves refocusing on paper and board market segments with greater potential, from graphic paper to sanitary and packaging paper for example.

However, in our scenarios, job numbers in the packaging segment continue to rise steadily as plastic packaging is phased out in favour of paper and board alternatives. The decline in production – and ultimately jobs – in the graphic paper segment is more drastic, compelling paper mills to act with greater urgency in making the switch to other segments.

[42] Esane 2019

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Acronyms and abbreviations

ADEME - French Agency for Ecological Transition
CITEPA - Interprofessional Technical Centre for Atmospheric Pollution Studies
COPACEL - French Union of Paper, Board, and Cellulose Industries
RCP - Recovered paper
GHG - Greenhouse gases
SNBC2 - French National Low-Carbon Strategy, 2nd Version
COP 21 - 21st Conference of the Parties
UNFCCC - United Nations Framework Convention on Climate Change
STP - Sectoral Transition Plan
LHV - Lower Heating Value
AGEC - French anti-waste law for a circular economy
PPWR - Packaging and Packaging Waste Regulation
LCA - Life Cycle Analysis
EU - European Union
CCUS - Carbon Capture, Utilisation, and Storage
SMR - Small Modular Reactor
ASN - French Nuclear Safety Authority
SIG - Scientific Interest Group
EPR - Extended Producer Responsibility
BCIAT - Biomass Heat for Industry, Agriculture, and Tertiary
IGN - National Institute for Geographic and Forestry Information
FCBA - Technological Institute for Forest Cellulose, Construction Wood and Furniture
INRAE - French National Research Institute for Agriculture, Food, and Environment
HTHP - High-temperature heat pump
MVR - Mechanical vapour recompression
CBP - Corrugated base paper
SRF - Solid recovered fuel
R&D - Research and development
CapEx - Capital expenditure
OpEx - Operating expenditure
WEM - With existing measures
ETS - Emissions Trading System
CPB - French Biogas production certificate
COP - Coefficient of performance
URSSAF - French body responsible for collecting social security contributions
FTE - Full-time equivalent

ADEME AT A GLANCE

At ADEME – the Agency for Ecological Transition – we are firmly committed to fighting climate change and the depletion of resources.

On all fronts, we mobilise citizens, economic actors, and local and regional authorities, giving them the tools they need to move towards a more resource-efficient, low-carbon economy that is fairer and more harmonious.

In every field – energy, circular economy, food, mobility, air quality, climate change adaptation, soil, etc. – we advise, facilitate, and help to fund numerous projects, from the research stage through to sharing solutions.

At every level, we put our expertise and forward-looking capabilities at the service of public policies.

ADEME is a public body under the supervision of the Ministry for an Ecological Transition and Territorial Cohesion, Ministry for the Energy Transition and the Ministry for Higher Education and Research.

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FAITS ET CHIFFRES
ADEME is a reference: It provides objective analysis on the basis of regularly updated statistical indicators.

CLÉS POUR AGIR
ADEME is a facilitator: It draws up practical guides to help stakeholders implement their projects in a methodical manner and/or in compliance with regulations.

ILS L'ONT FAITS
ADEME is a catalyst: Stakeholders talk about their experiences and share their know-how.

EXPERTISES
ADEME provides expertise: It reports on the results of research, studies and collective work conducted under its supervision.

HORIZONS
ADEME looks to the future: It proposes a prospective and realistic vision of the challenges of the energy and ecological transition, for a desirable future to be built together.

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EXPERTISES

PAPER AND BOARD

Summary Report

The current National Low-Carbon Strategy (SNBC 2) defines the path that France intends to take to achieve carbon neutrality by 2050. For industry, this trajectory translates into an 81% reduction in emissions compared to 2015. Of the nine most energy-intensive industries, the paper and board sector, which represents 3% of French industrial emissions and includes production of packaging, sanitary, graphic, and other papers, faces major technological, financial, economic, and regulatory challenges as it looks to navigate the energy transition.

Two scenarios are considered for achieving the greenhouse gas emissions reductions targets of 60% by 2030 and over 95% by 2050, compared with 2015 levels. Though different, both of these scenarios are based on the use of mostly proven technologies. They show that the sector can significantly decarbonise by 2030, particularly by gradually replacing the use of natural gas with biomass and deploying energy efficiency measures. After 2030, two scenarios are examined, reflecting different levels of tightness in the supply of biomass. The first scenario assumes that the deployment of new biomass boilers will be scaled down vastly in favour of high-temperature heat pumps (HTHPs) and electric boilers. The second assumes that biomass boilers will continue to be deployed at the same rate, and that HTHPs will also be used in conjunction with technological innovations to improve energy efficiency.

These far-reaching changes take place against a backdrop of market transformation, with falling demand for graphic papers, rising demand for packaging papers, and tightness in the supply of recovered paper and wood. Opportunities are also opening up with the potential development of carbon capture, utilisation and storage (CCUS) technologies and newly-won market share in pulp production. In the right conditions, the French paper industry could potentially have a key role to play in rebuilding the country's industrial sovereignty and decarbonising its economy.

The Finance ClimAct project contributes to the implementation of France's National Low-Carbon Strategy and European policy on sustainable finance. It aims to develop new tools, methods and knowledge that will enable (1) energy-intensive industries to promote investment in energy efficiency and the low-carbon economy, (2) financial institutions and their supervisors to integrate climate issues into their decision-making processes and align financial flows with energy-climate objectives, and (3) savers to integrate environmental objectives into their investment choices.

The consortium, coordinated by the French Agency for Ecological Transition, also includes the French Ministry for Ecological Transition, the Autorité des marchés financiers (French Financial Markets Authority), the Autorité de contrôle prudentiel et de résolution (French Prudential Supervision and Resolution Authority), the 2° Investing Initiative, the Institut de l'économie pour le climat (Institute for Climate Economics), the Institut de la Finance Durable (Paris Sustainable Finance Institute) and the Rocky Mountain Institute.

Finance ClimAct is an innovative programme with a total budget of €18 million and €10 million in funding from the European Commission.

Duration: 2019-2024

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