European Commission

Joint Research Centre

SCIENCE FOR POLICY BRIEF

# Mapping the transition of the EU pulp and paper industry to carbon neutrality

2026

## HIGHLIGHTS

- In 2024, direct $CO_2$ emissions from the European Pulp and Paper Industry (PPI) were 22 Mt, down 40% from 1990 levels.
- To meet its 2050 goal of reducing emissions by 80%, the sector must accelerate decarbonisation through energy efficiency, electrification and fuel switching.
- It is estimated that achieving this goal (80% reduction) would require an investment of EUR 24 billion based on a 2017 assessment. This value is expected to be higher, in line with the EU's new 2040 tighter target of a 90% reduction.
- The EU PPI is well positioned to decarbonise thanks to its high biomass use, product diversification potential and secure biomass feedstock access.

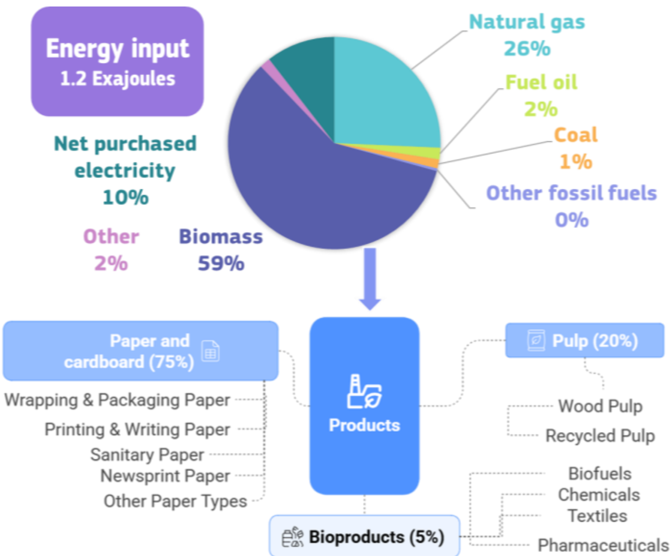
## THE CHALLENGE

### Introduction

The Pulp and Paper Industry (PPI) is heavily dependent on energy and raw materials. In 2024, the sector's annual turnover in the European Union (EU) was EUR 95 billion, contributing EUR 21 billion to the EU's GDP, through the production of pulp and various paper products, including graphic, hygiene, packaging and specialised types (Figure 1) [1].

Europe is the world's second-largest producing region with a share of 20% of global paper and cardboard production in 2023. Within Europe, Sweden and Finland are the largest pulp producers. These two countries, together with Germany and Italy, are also the largest paper producers.

**Figure 1 – Energy inputs and product portfolio of the EU PPI, 2023**




*Source*: JRC, based on reference [1] [1]

[1] CEPI is composed of 19 countries (17 EU, plus Norway and the UK). In terms of production, it covers 90% of the total European production.

In 2024, the European PPI comprised of 662 companies operating 842 mills, including 129 pulp mills, 713 paper and cardboard mills, and 1 157 paper machines. The production of pulp was 33.7 million tonnes, 46% for market pulp and 54% for integrated mills producing both pulp and paper [1]. The overall paper and board production was 78.7 million tonnes (including paper production from recycled paper). Overall, the EU is a net exporter of paper and cardboard products, and recycled paper. Recycling is another cornerstone of the sector's circularity, with 75.1% of paper and board being recycled in 2024 [2].

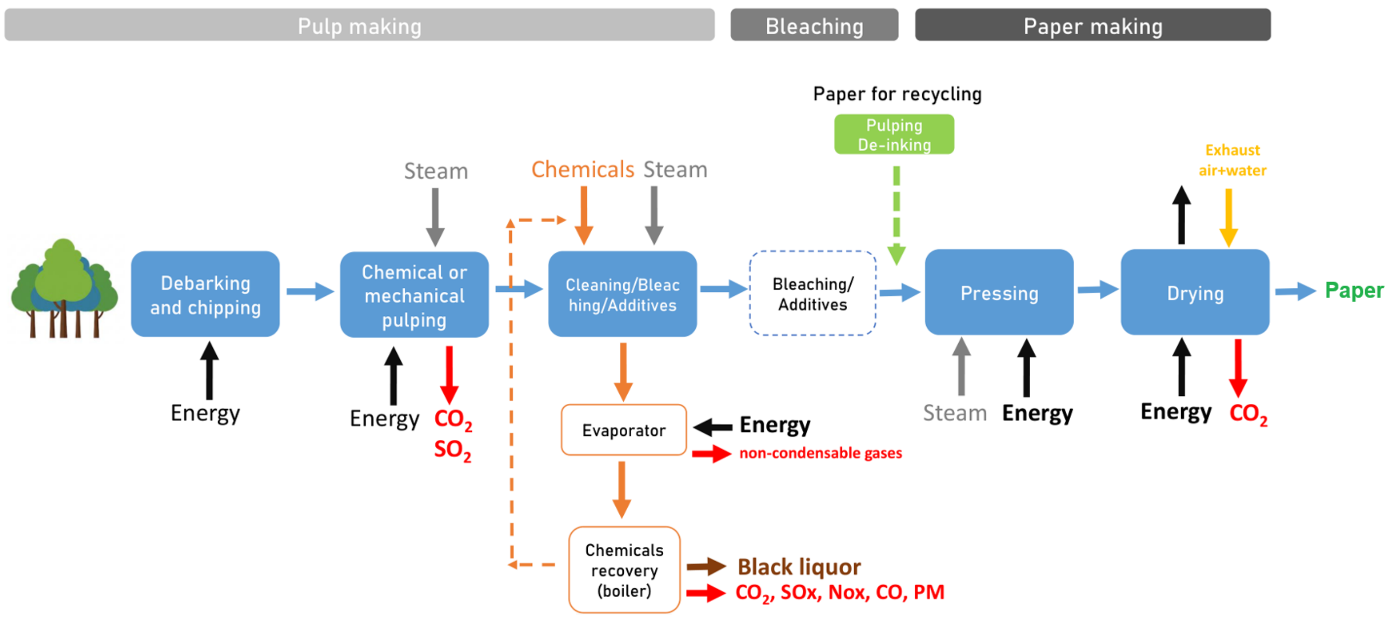
Most of the energy input for the EU's PPI comes from biomass (59%), followed by natural gas (26%) and purchased electricity (10%) (Figure 1). Nevertheless, the energy consumption varies strongly depending on the product type (pulp, paper, and paper products) and raw materials utilised. The final electricity consumption (29%) is higher than the electricity input (10%, referring to external purchased electricity) since the PPI generates a substantial amount of electricity on site through combined heat and power (CHP). As a result, the PPI produces a significant amount of electricity for both self-consumption (77%) and sale on the market (23%). In 2023, the electricity consumption was 76 160 GWh, half of which was produced on site, mostly (95.4%) through CHP [1].

In terms of innovation, the EU's PPI is increasing its share in the production of bio-based products other than pulp and paper, such as biofuels, chemicals, textiles and pharmaceutical products [2]. This shift is driven by feedstock availability, extensive expertise in biomass processing, and the opportunity to broaden the market through an expanded product portfolio. For instance, across the EU, 126 paper mills are producing bio-based products, with 17 additional sites under development. Production spans 18 Member States but is concentrated in Sweden, Finland, Germany, Portugal and Austria. Bio-based products beyond pulp and paper generate an estimated EUR 6 billion in turnover, representing 6.3% of the EU's PPI total.

## Production process

Figure 2 provides a schematic of the integrated pulp- and paper-making process, including sources of energy and water consumption, and emissions as an example. Nevertheless, this process varies depending on the feedstock (wood or recycled paper) and the pulping process applied. Pulp and paper production involves three major processing steps: pulping, bleaching and paper production. Wood is the primary raw material for pulp production, but other non-wood fibrous materials, like grass, straw, hemp, cotton and other cellulose-bearing materials, can be used as feedstock. Pulp is the fundamental raw material from which all types of paper are manufactured, obtained by the separation of cellulose fibres from the lignin in the woody/non-fibrous raw materials. Besides the fibrous material, energy, various chemicals and water are required in the process.

**Figure 2 – Schematic diagram of integrated pulp and paper making process**




*Note:* PM means particulate matter
*Source:* JRC, based on references [3], [4] and [5]

The pulp used for papermaking can be produced either from virgin fibre, by chemical and/or mechanical means, or by the re-pulping of recovered paper, known in the industry as recycled cellulose fibre (RCF). In the pure mechanical pulping process, the wood fibres are separated mechanically, using electricity. Nevertheless, chemical pulping is the most common process and can be divided into three main types: kraft (sulphate) pulping - the most widely used; sulphite pulping; and neutral sulphite semi-chemical (NSSC) pulping.

Most of the energy consumption occurs during the chemical pulping, black liquor[2] evaporation, and drying processes. Energy usage in the PPI varies significantly due to the diverse range of products, raw materials and production techniques utilised. Pulp production primarily requires thermal energy and relatively little electricity (especially for chemical and semi-chemical pulping). In contrast, for paper production, the electricity consumption is higher, even though the heat consumption is still high (70-80% of the total energy).

## Current $CO_2$ emissions

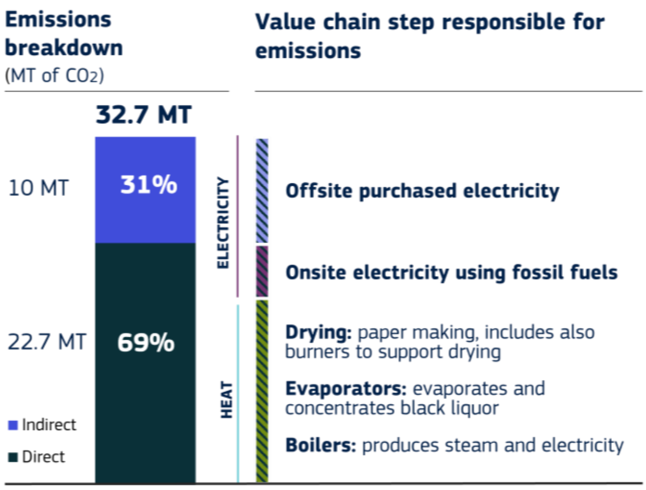
In 2024, CEPI-associated installations reduced their direct $CO_2$ emissions to 22 million tonnes (Mt), a 1.8% decrease from 2022, and 40% lower than 1990 levels. Their indirect emissions from net purchased electricity accounted for 10 Mt of $CO_2$ in 2022, representing a total growth of 2.9% compared to the previous year [1].

Figure 3 shows the estimated emissions breakdown of $CO_2$ emissions in 2023, and the value chain steps responsible for them. It illustrates that total $CO_2$ emissions from the pulp and paper sector reach approximately 32.7 Mt, with heat generation clearly dominating the emissions profile.

The PPI's greenhouse gas (GHG) emissions are divided into direct and indirect emissions and are reported in terms of $CO_2$ equivalent. Direct $CO_2$ emissions refer to fossil fuel combustion (non-biogenic) in pulp and paper plants. Indirect $CO_2$ emissions are associated with purchased electricity from fossil fuels.

This reflects the highly energy-intensive nature of core process steps such as paper drying, evaporation and concentration of black liquor, and steam and power production in boilers. Drying processes alone represent a critical hotspot, as they require sustained high-temperature heat, often supported by auxiliary burners. Electricity emissions arise from a combination of purchased grid electricity and onsite electricity generation using fossil fuels.

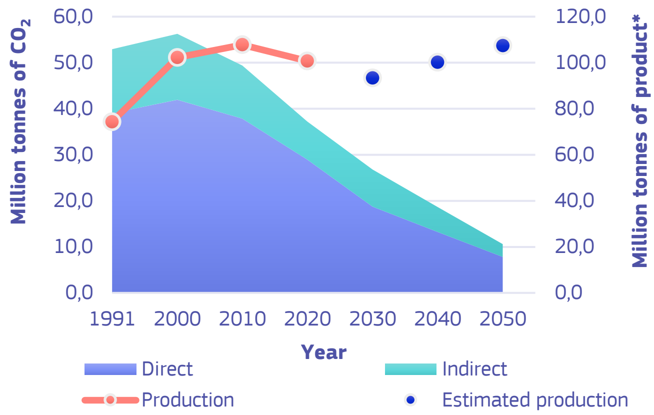
**Figure 3 – Estimated breakdown of $CO_2$ emissions (direct and indirect) in 2023 and the associated value chain steps**




*Source:* JRC, based on references [1], [6], and [7]

Figure 4 shows the evolution of the direct and indirect $CO_2$ emissions and the production of the PPI from 1990 up to 2023. It also includes a forecast for emissions and production up to 2050.

**Figure 4 – Overview of $CO_2$ emissions and production evolution from 1990 to 2050**




*Note:* Production refers to the sum of market pulp, paper and cardboard. Estimated production was calculated based on a yearly production growth rate of 7% [5]. Emissions from 2024 onwards were calculated to decrease linearly to reach the 2050 target of 80% reduction compared to 1990s values [8].
*Source:* JRC, based on references [1] and [5]

Over the years, the PPI was able to partially decouple production and $CO_2$ emissions. This was mainly due to

[2] Black liquor is a dark, viscous by-product of the kraft pulping process in paper mills, composed of dissolved lignin, hemicellulose, and inorganic chemicals.

measures related to energy efficiency and innovations in production processes. Specifically, fuel switching including enhanced utilisation of biofuels, increased use of recycled paper [9] [10] [3], better staff training, and favourable regulations on the use of low-carbon fuels contributed to lower energy consumption and emissions reduction.

### Policy targets and context

The pulp and paper sector is expected to contribute to the goal of emissions reduction by at least 55% by 2030 compared to 1990 levels, following the "Fit-for-55" package, as part of the European Green Deal. Recently, the European Commission has proposed an amendment to the EU Climate Law, setting a 2040 climate target of a 90% reduction in net GHG emissions, compared to 1990 levels.

The PPI is also part of the EU Emissions Trading System (ETS), benefiting from free allowances under the EU ETS. Under the EU ETS system, companies must monitor and report their emissions on a yearly basis and surrender enough allowances to fully account for their annual emissions.

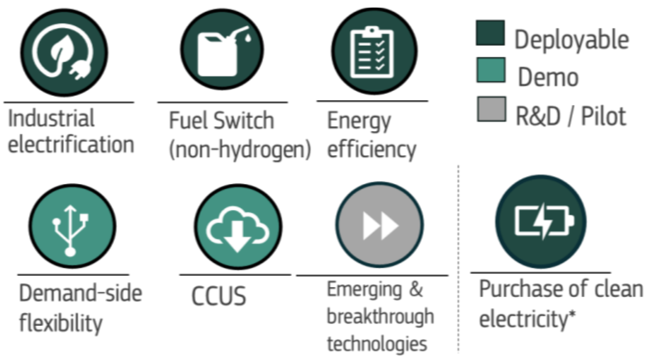
The PPI is not currently covered by the Carbon Border Adjustment Mechanism (CBAM). As long as this remains the case, it will continue to receive free allowances at the benchmark level. Finally, the recent Clean Industrial Deal outlines concrete actions to turn decarbonisation into a driver of growth for European industries, focusing on energy intensive industries.

## THE WAY FORWARD

### Decarbonisation trajectories[4]

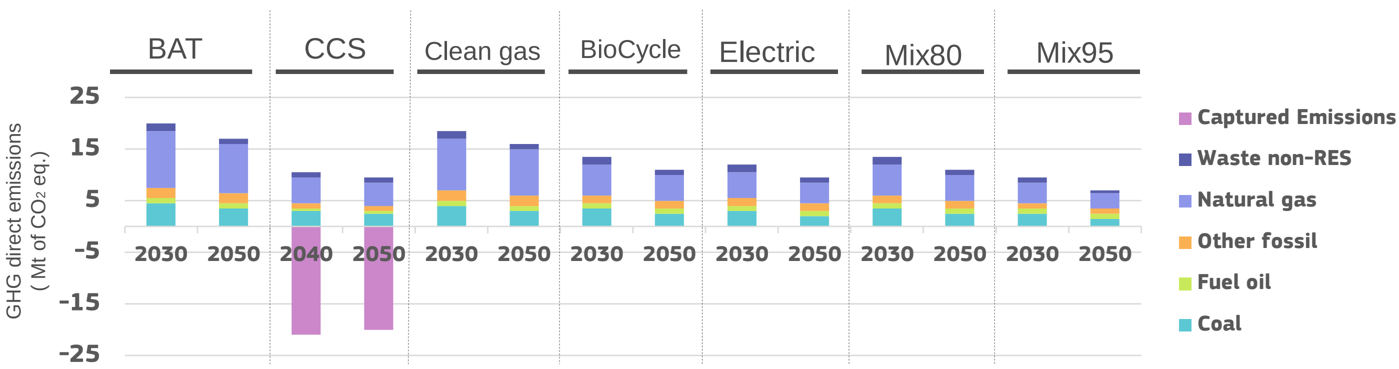
A decarbonisation trajectory is a comprehensive strategy outlining the steps, timelines and goals for reducing carbon emissions to achieve net-zero or climate targets. Decarbonisation levers (Figure 5) are part of decarbonisation trajectories and refer to the key strategies and technological measures that industries, such as the PPI, can implement to reduce their GHG emissions and achieve net-zero or low-carbon targets.

**Figure 5 – Deployment level of decarbonisation levers within the EU's PPI**




*Note:* *Purchase of clean electricity lever is related only to the decarbonisation of indirect emissions
*Source:* JRC, based on references [6], [7] and [8]

**Figure 6 – GHG emissions in the EU PPI by energy carrier and scenario**




*Note:* FORECAST model. Scenarios: BAT: fast deployment of Best Available Techniques (BAT), fuel switch driven by prices; (Carbon Capture and Storage) CCS: energy efficiency innovations TRL>4, fuel switch driven by prices, late CCS by big emitters; Clean gas: Energy efficiency innovations TRL>4, fuel switch driven by prices and clean gas; Biocycle: biomass focus, maximum paper recycling and reuse and replacement of plastics by wood materials; Electric: focus on electric boilers and heat pumps; Mix80: focus on electric boilers and maximum recycling; Mix90: focus on electric clean gas and maximum recycling.
*Source:* JRC, based on reference [12]

[3] From a Life Cycle Assessment (LCA) perspective, using recycled paper emits less GHG than virgin wood [11]
[4] This factsheet avoids using the term 'pathways' to prevent confusion with the sector-specific decarbonisation pathways published by the European Commission in November 2025. Those sector-specific pathways are intended as a voluntary tool to support companies set their individual decarbonisation targets in line with the European Climate Law. See EC, Making finance flows consistent with climate goals – Climate Action, 2025

According to CEPI's 2017 assessment of decarbonisation levers, annual direct $CO_2$ emissions could be reduced by 22 Mt, with an additional 11 Mt reduction possible from indirect emissions associated with purchased electricity. This scenario would set the PPI on a clear path to net-zero emissions by 2050, through the application of the levers illustrated (Figure 5): fuel switching (-8 Mt of $CO_2$, -36%), energy efficiency (-7 Mt of $CO_2$, -32%), followed by the implementation of emerging and breakthrough technologies (-5 Mt of $CO_2$, -23%) and demand-side flexibility (-2 Mt of $CO_2$, -9%)[5]. The reduction of indirect emissions would be mostly due to the purchase of clean electricity and increase in process efficiency (-11 Mt, 100%). Nevertheless, note that the potential emission reductions from CEPI's 2017 is around 10 years old and the cost-effectiveness of the necessary investments to achieve the abovementioned reduction potentials are affected by the variation of energy prices in this timespan. Additionally, grid decarbonisation is essential to ensure that the electrification of fossil-fuel based process results in an effective reduction of emissions.

Figure 6 shows an assessment of different scenarios for the decarbonisation of the EU PPI, with the GHG emissions in $CO_2$ equivalent linked to the energy carrier responsible for emissions [12]. According to it, the top-performing decarbonisation strategies for the EU PPI include the high-renewable fuel mix scenario (Mix95), which achieves the greatest emissions reduction (68%), followed closely by electrification (Electric) and Carbon Capture and Storage (CCS), both reducing emissions by nearly 57%. In contrast, improvements in efficiency alone (e.g. the BAT scenario) yield limited reductions, reinforcing the idea that fuel substitution and systemic technology shifts are essential for achieving climate targets.

Note that, if CCS is applied to capture biogenic emissions, the sector has the potential to achieve negative emissions. These results highlight that transitioning to low-carbon energy sources, such as clean electricity and bio-based fuels, combined with carbon capture technologies, offers the most effective levers to deep decarbonisation, and also corresponds with industry's assessments. Also, as the industry becomes more efficient in using side streams, or to produce new bio-based products (other than pulp and paper) instead of energy, the industry needs to replace this with renewable clean energy, which must be available and affordable.

[5] Demand-side flexibility: this value assumes that the electricity grid decarbonises. Otherwise, there would be only a shift from direct to indirect emissions.

## Decarbonisation technologies

Table 1 shows the technologies associated with the PPI's decarbonisation levers, while Table 2 contains the estimated Technology Readiness Level (TRL), $CO_2$ abatement potential, and costs.

**Table 1 – Summary of associated technologies in the PPI (non-exhaustive) for the decarbonisation levers**

| Levers | Technologies / measures |
|---|---|
| Energy efficiency | - Energy storage; variable speed drivers; turbo blower pumps; radial blowers, mechanical vapour recompression, airless drying, superheated steam drying; biogas production from wastewater treatment<br>- Digitalisation (Industry 4.0) |
| Electrification | - Electrification of heat process and use of renewable electricity, i.e. e-boiler heating<br>- Heat: heat pumps, solar heat<br>- Dryers: air dryers, drying bar, microwave and ultrasound for dewatering and drying |
| Fuel switch (non-hydrogen) | - Switching to using biomass- or gas-based boilers: biogas and biomethane; cogeneration of heat and power (CHP)<br>- Other thermochemical conversion technologies to optimise side streams use: gasification, pyrolysis, torrefaction<br>- Use of waste as fuels, such as bark, sawdust, tall oil |
| Demand-side flexibility | - On-site electricity production and supply of surplus electricity to the grid<br>- Real-time energy management |
| Emerging & breakthrough technologies | - Raw material pre-treatment technologies: chemical with oxalic acid; biological processing<br>- Pulping technologies: Black liquor concentration with membranes; direct green liquor utilisation; DES (Deep Eutectic Solvents) for mild pulping processes<br>- Papermaking technologies: Aq-vane technology; high-consistency papermaking; dry sheet formation<br>- Other innovative and disruptive technologies: use of hydrogen for burners and boilers; water-free paper making; water removal without evaporation |
| Carbon Capture, Utilisation and Storage (CCUS) | - Carbon capture in different parts of the process, e.g., lime kilns, recovery boiler, evaporation process and recausticising. Further storage or use. |

*Source:* JRC, based on references [7], [10], and [13]

**Table 2 – Estimated TRL, $CO_2$ abatement and costs of the de-carbonisation technologies associated with specific levers**

| Levers | TRL | $CO_2$ abatement potential* | $CO_2$ abatement cost (€/t $CO_2$) |
|---|---|---|---|
| Energy efficiency | 8-9 | ≤ 32% | Net positive |
| Fuel switch | 7-9 | ≤ 36% | 10 - 130 |
| Electrification | 8-9 | < 60% | 60 - 170 |
| Demand-side flexibility | 6-9 | ≤ 9% | Net positive |
| Emerging & breakthrough technologies | ≤ 6 | ≤ 23% | Emerging economics |
| CCUS | 6-7 | ≥ 100% | 62 - 120 |

*Note:* *Values based on reference [8]
*Source:* JRC, based on references [7], [8], and [10]

It is important to highlight that Tables 1 and 2 offer only an overview of different decarbonisation technologies for the PPI and the technic-economical specificalities of each needs to be evaluated for further implementation. For instance, $CO_2$ capture in the pulp and paper industry requires process-specific pre-treatment, as flue gas streams vary in volume, $CO_2$ concentration and dust content. CCS can deliver negative emissions when biogenic $CO_2$ is captured and stored, representing a potential advantage of the sector compared to non-biogenic industries, although dedicated transport and storage infrastructure is required. $CO_2$ utilisation for chemical production depends on the availability of hydrogen, with technologies spanning a wide range of TRLs, from low (TRL 2–3, e.g. formic acid) to mature (TRL 9, e.g. ammonia). In the case of emerging and breakthrough technologies, they still have potential for growth and development to achieve higher TRLs.

They are being developed for various stages of the production process, from pulping to papermaking, which could support the decarbonisation of the sector in the future. Additionally, the recovery of by-products for non-energy processes, such as lignin or methanol recovery is emerging at industrial scale and contributes to the decarbonisation of the chemical sector. However, as the production process become more efficient in using by-products, fewer side streams are available for process heat, which must be replaced with renewable energy.

## STATE OF DEVELOPMENT

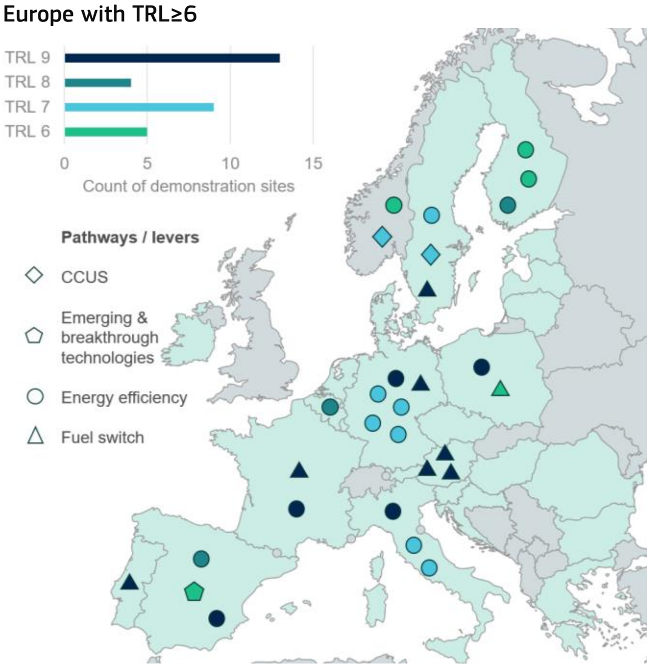
### Industrial pledges

In 2017, CEPI has published a commitment to decrease their GHG emissions by 80% until 2050 compared to 1990's values. Nevertheless, currently CEPI follows the CEO initiative, which reflects the CEPI contributions to the EU 2050 climate neutrality [14]. Based on this, the industry commits to keep a sustainable forest management, and to continue providing a wide range of renewable and recyclable products. Nevertheless, no specific decarbonisation targets are mentioned. In terms of investment, the industry is investing around € 5 billion per annum to be more sustainable, while decreasing their carbon footprint.

### Demonstrators

Figure 7 shows a map of demonstration sites in Europe with TRL≥6, from multiple funding sources, from EU funding - Horizon Europe, Horizon 2020, Innovation Fund (IF), LIFE[6] - to national state aid, and self-industry investments. The majority of demonstrators address energy efficiency (15 sites) and fuel switch (7 sites) levers.

**Figure 7 – Map of demonstration sites (non-exhaustive) in Europe with TRL≥6**




*Note:* countries highlighted in green are part of the EU (February 2026)
*Source*: JRC, based on CINEA and Innovation Fund project dashboards and on reference [15]

[6] Examples of EU-funded projects: for energy efficiency and electrification – SO WHAT, Super Dryer, PUSH2HEAT, STEAMDRY, SPIRIT and Energy1st; for fuel switch, LK2BM and NOVUM; for demand-side flexibility, Bamboo. For emerging & breakthrough technologies, ZEBRA-LIFE and LignEasy. For CCUS, ACCSESS; for circular economy, ReLeaf Paper and PAPERCHAIN.

One example of energy efficiency and electrification is the SPIRIT project (Horizon Europe), which developed one full-scale demonstration system of an industrial heat pump that upgrade waste heat to valuable temperatures (135-160°C) in a corrugated packaging industry to optimise the steam use in the drying process. Also, the LK2BM project (IF) is an example of fuel switch. A pilot-scale rotary kiln burner and its wood fuel feeding lines and equipment was designed and built, in order to allow a fuel shift to 100% hardwood residues (eucalyptus sawdust and pellets), replacing the current natural gas fired in the existing pulp mill's lime kiln.

Additionally, several companies already apply decarbonisation levers in practice. For instance, the Metsä Group (Finland) operates a fossil-free bioproduct mill producing pulp, textiles, fibre products, biofuels and renewable electricity (bio-based products, circularity) Lecta Group (Spain) integrates solar thermal energy, cutting around 1000 tonnes of $CO_2$ equivalent per year (energy efficiency). Other examples are Arctic Paper Grycksbo (Sweden), which offers 30 MW of reserve capacity (demand-side flexibility); and VPK Packaging (Belgium) uses biogas from waste water to power operations (fuel switch, circularity) [15].

### Evaluation of progress and alignment with policy and industry targets

With the EC's recent proposal for a 90% emissions reduction by 2040, the sector is expected to accelerate its decarbonisation efforts. By 2023, direct emissions dropped 40% compared to 1990. To meet the EU's 2030 climate target of a 55% reduction, the PPI must cut annual direct emissions by an additional 23%, about 5 million tonnes (Mt) of $CO_2$. If emissions remain stable until the end of 2025, this implies a yearly reduction of 1 Mt from 2025 to 2030. This is achievable using ready-to-deploy decarbonisation levers outlined in Figure 5, including fuel switching, electrification, energy efficiency, and green electricity.

However, meeting the 2040 target would require faster action, with annual emissions needing to be 1.3 Mt per year. The selection of a suitable lever depends on plant-specific factors such as location, size, product portfolio and access to clean electricity and biomass. While CCUS shows potential to decarbonise the sector, it is less attractive for the industry, since biogenic $CO_2$, is excluded from the EU ETS. Additionally, infrastructure for $CO_2$ transport, storage, and utilisation remains a key barrier. The economic viability of each option will also depend on policy and market conditions, including subsidies, energy prices, and carbon pricing mechanisms like the EU ETS and CBAM. These instruments will strongly influence which decarbonisation levers are ultimately adopted.

## CONCLUSIONS

Since 1990, the EU pulp and paper industry has achieved a substantial reduction in $CO_2$ emissions (40%) [1]. However, to align with both the EU's climate targets and its own long-term ambitions, the sector will need to deliver further and deeper $CO_2$ cuts in the coming decades, expecting a yearly reduction of 1.3 Mt of $CO_2$ per year to decrease emissions by 90% in 2050.

To stay on track, the sector should focus on proven solutions such as fuel switching, energy efficiency, electrification, and demand-side flexibility. From the 2030s onwards, emerging options like CCUS and other breakthrough technologies will be needed to deliver deeper reductions and enable net zero.

With access to bio-based feedstock, compared to other energy-intensive industries, the PPI is well positioned to decarbonise. Achieving negative emissions, however, will require combining bioenergy with large-scale CCUS, which still needs further development. Progress depends on the current implementation of available solutions, better financing for energy-efficient investments, stronger support for renewable integration, carbon storage infrastructure, and continued research into emerging technologies.

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