Substitution potential and climate impact in the EU forest value chain

EXTERNAL REPORT

AFRY MANAGEMENT CONSULTING 2024

INTRODUCTION

The objective of this study is to estimate the material substitution potential in the EU forest industry.

FAM

Future of Forestry

AFRY

AFRY Management Consulting has carried out the study for FAM in close collaboration with them.

Increasing the substitution from fossil to fibre-based raw materials is crucial for the EU to reduce emissions

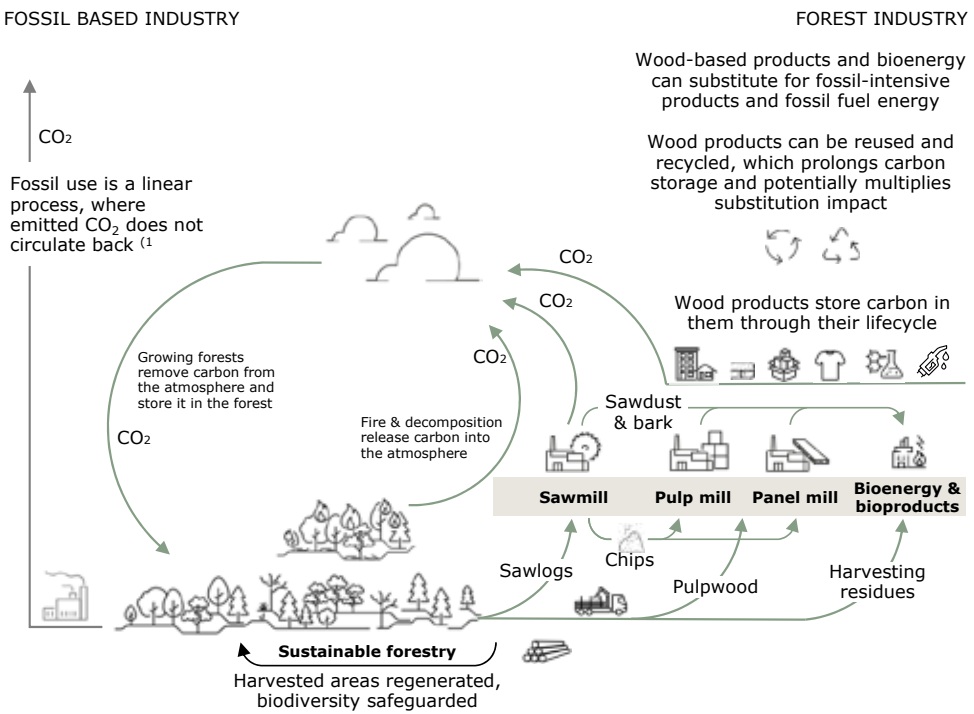
Growing and actively managed forests remove more carbon from the atmosphere

Bioenergy can support the transition to more sustainable energy systems at the whole EU level

Forest-based innovation will continue to deliver new solutions to the climate challenge

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Active sustainable forest management could offer most climate benefits through increased carbon sinks and reduced emissions



Forests and the forestry sector contribute to climate change mitigation in multiple ways:

- Growing forests remove carbon from the atmosphere and store it in the forest
- Wood products store carbon in them throughout their life-cycle
- Wood products and bioenergy can substitute fossil-based materials, which reduces emissions

Active sustainable forest management ensures that more trees are grown and regenerated than are harvested, i.e., forests are a carbon sink. Wood-based products are considered renewable as forests remove more carbon from the atmosphere than what is released through forest use.

(1) It takes millions of years for released CO2 to transform through biomass back into coal, oil and gas

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Material substitution potential in the EU in 2050 was analysed for sectors where clear substitution potential exists

Low High

PRODUCT AREA	SUBSTITUTION POTENTIAL	DESCRIPTION AND DEMAND VOLUMES IN 2021
WOOD PRODUCTS [1]		**130** Mm^3
New wooden buildings		High substitution potential to replace fossil-dependent building materials such as concrete in new buildings
Other construction		Raw material choices are often limited by original materials; substitution potential is limited (e.g. renovation)
Pallets and packaging		Wood already plays an important role in these applications (e.g. pallets); substitution potential is limited
Joinery and furniture		Wood already holds a significant market share in these applications; some potential to replace plastic/metals
PAPER AND BOARD		**45** Mt
Packaging boards and papers		High substitution potential to replace plastics
Graphic papers		Declining market, no clear material substitution exists
Tissue paper		No clear material substitution exists
Other paper and board		Multiple applications; substitution potential is limited
TEXTILES		**1** Mt
Cellulosic textiles		High substitution potential to replace synthetic textiles such as polyester
BIOFUELS AND CHEMICALS		**1** Mt
Pulp mill side streams, biomass-based biorefineries, e-fuels		High substitution potential to replace liquid fossil fuels and fossil-based chemicals

[1] Wood products include sawnwood and wood-based panels (including wood insulation board)
The definition for material substitution is provided at the end of the document for further information.

All product categories were considered in the baseline volumes in 2021 & 2050, but detailed analysis was made for applications demonstrating the greatest potential for additional substitution.

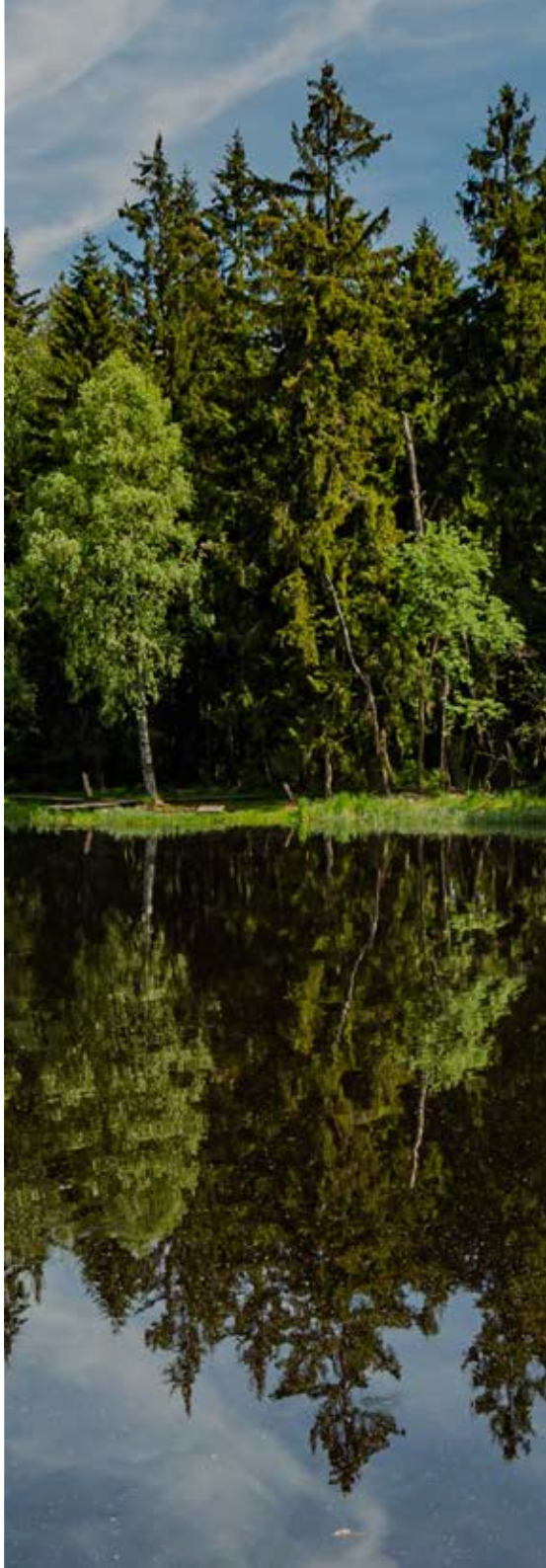
FOCUS OF THIS STUDY

ADDITIONAL SUBSTITUTION:

New wooden buildings
Packaging boards and papers
Cellulosic textiles
Biofuels and chemicals

OTHER PRODUCTS:

Wood products: other construction
Wood products: pallets and packaging
Wood products: joinery and furniture
Graphic papers
Tissue paper
Other paper and board



INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Assuming that all material use of fibre was substitution, 390 Mt CO2eq emission savings was achieved in 2021

FIBRE-BASED MATERIALS		IF THIS VOLUME WOULD BE FOSSIL-BASED	
Wood products	**130** Mm^3	Equivalent volume in concrete/plastic	**80** Mm^3
Paper and Board excl. tissue and graphic papers	**20** Mt	Equivalent volume in plastic	**10** Mt
Cellulosic textiles	**1** Mt	Equivalent volume in synthetic textiles	**1** Mt
Biofuels and chemicals	**1** Mt	Equivalent volume in fossil fuels and chemicals	**1** Mt

-310 Mt CO_2eq	
-80 Mt CO_2eq	
-1 Mt CO_2eq	
-2 Mt CO_2eq	

Material substitution impact 2021

-390 Mt CO_2eq equals to…

Annual emission of

50 million people in the EU

Note: numbers rounded

This calculation assumes that all fibre used in these product categories is considered substitution. However, there are also other drivers for using fibre-based materials than the substitution of fossil counterparts only; e.g., when fibre is a more cost-efficient raw material, when it is a tradition to use fibre, or when it is better material compared to other options. These factors will also continue to favour the increasing demand for fibre-based products in the future. Methodology and references are provided at the end of the document for further information.

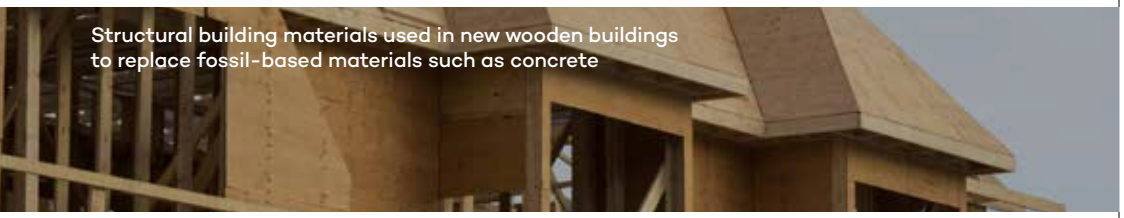
Fossil-based volumes were assessed using various conversion factors for all the product areas, as the fibre and fossil-based demand volumes were assumed to be equal in this analysis. Fibre-based materials can substitute only part of the fossil-based products. For example, the cement consumption in the EU was 420 Mm^3 in 2021 and 67 Mt of plastics were consumed in the EU in the same year.

The climate impact of wood products is high for several reasons. Firstly, it's assumed that they are incinerated at the end-of-life, replacing the average European electricity mix. Moreover, wood products are expected to substitute for both concrete and plastics, which increases the climate impact, particularly considering the substantial emission factors associated with plastics. The assumed split between plastic and concrete is approximately 40/60 due to multiple end-use areas of wood products such as construction, packaging, furniture and joinery. Most of the climate impact of material substitution within this category comes from plastic substitution.

Average generated emissions per EU citizen was 7.8 t CO2eq in 2021. It is assumed that all wood products, paper and packaging products and plastics are incinerated at the end-of-life, replacing the average European electricity mix. Plastic is assumed to be single-used and fibre-based packaging is recycled and reused before incineration.
Out of a total -390 Mt CO2eq impact in 2021, 9% comes from recycling packaging materials, 27% from end-of-life incineration, and 64% from actual material substitution. For example, regarding wood products (-310 Mt CO2eq), 33% of the climate impact comes from end-of-life incineration and 67% from actual material substitution.

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Additional substitution can be achieved when the use of materials with high substitution potential is promoted



Additionally, there are other wood and fibre-based product applications, where further climate benefits could be realised. However, the potential for additional substitution in these product areas is limited, and therefore, these products were not in the focus of the main analysis. The focus product segments offer the largest future potential for additional substitution and detailed climate impact calculations were made for these applications.

Favouring substitution-friendly environment will support existing fibre-based products and innovations to deliver new solutions to the climate challenge

AFRY SUBSTITUTION SCENARIOS IN THE EU IN 2050

LOW SCENARIO

Low additional substitution potential in selected product areas in 2050.

MEDIUM SCENARIO

Additional realistic substitution potential in selected product areas in 2050.

HIGH SCENARIO

High additional substitution potential in selected product areas in 2050.

KEY DRIVERS & INHIBITORS
Factors significantly impacting the realisation of material substitution potential in the future

- (+) Growing building sector
- (+) Regulations: Increasing share of wood in new buildings
- (+) Sustainable choices enforced
- (?) Availability of sawnwood

- (+) Novel solutions development (e.g., barriers)
- (+) Packaging recyclability targets driven by circular economy principles; favour fibre
- (?) Regulations: The exact impact of PPWR on fibre-based packaging is still uncertain

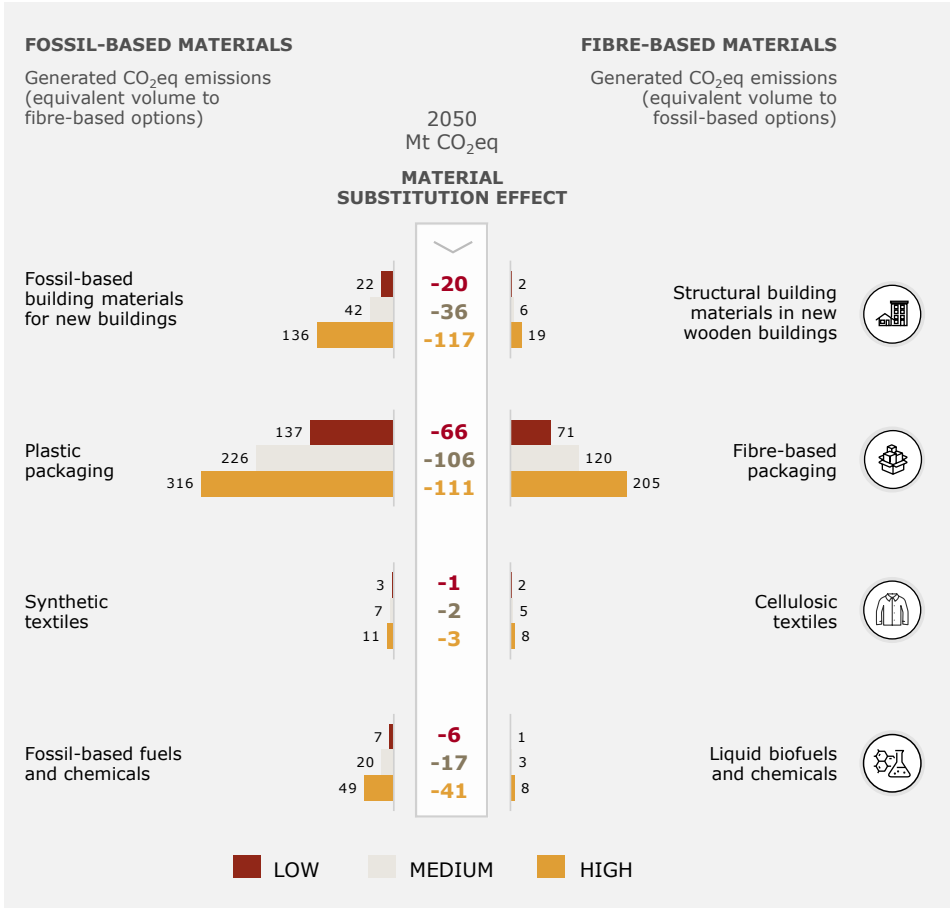
- (+) Growing consumer awareness and brand owners' sustainability targets
- (+) Novel wood-based solutions development
- (−) Increasing competition against textile and agricultural residue materials

- (+) Supportive policy landscape is needed with clear regulatory incentives
- (+) Technical development and commercialisation of R&D efforts
- (−) High price of biobased options compared to fossil-based alternatives currently

Additional information regarding the demand scenarios is provided at the end of the document.

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

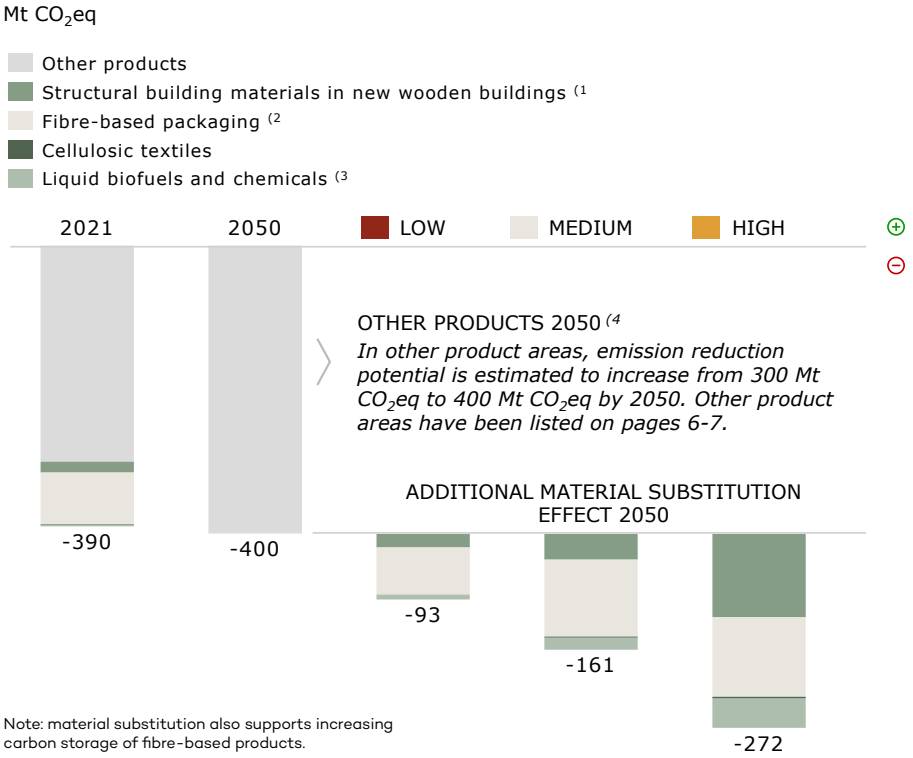
Replacing fossil-based materials with fibre-based alternatives brings considerable climate benefits



Note: numbers rounded

Material substitution effect: Fibre-based products replace fossil-based alternatives. Equivalent volumes used in the calculations. It is assumed that all wood products, paper and packaging products and plastics are incinerated at the end-of-life, replacing the average European electricity mix. Plastic is assumed to be single-used and fibre-based packaging is recycled and reused before incineration. Bioenergy is excluded from the material substitution effect but would also bring considerable climate benefits.

EMISSION REDUCTION POTENTIAL 2021-2050



Note: material substitution also supports increasing carbon storage of fibre-based products.

(1 Sawnwood, wood-based panels and wood insulation board. It is assumed that all wood-based building material will be incinerated at the end-of-life, replacing average European electricity mix.

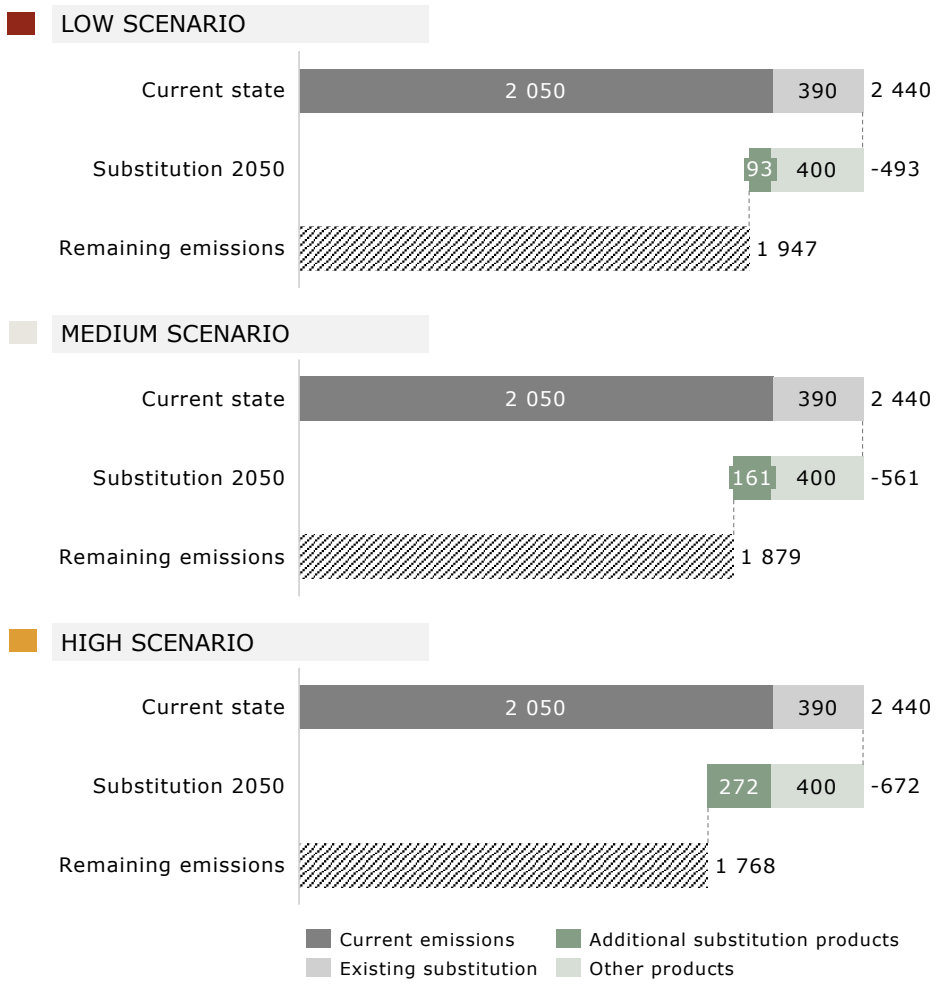
(2 Containerboard, cartonboard, kraft paper, sack paper and moulded fibre (type III). Optimal situation where fibre-based packaging and plastics are incinerated at the end-of-life, replacing the average European electricity mix. Plastic is assumed to be single-used and fibre-based packaging is recycled and reused before incineration.

(3 Pulp production side streams, stand-alone biorefineries and e-fuels.

(4 Other product areas include various end-use sectors where fibre is already extensively utilised, such as in different wood products. While there is limited potential for additional substitution in these products, the utilisation of fibre-based products helps to avoid reliance on fossil-based materials. As wood fibre continues to play a significant role in these applications in the future and demand for these products is also estimated to increase, the potential for emission reduction is expected to grow by 2050.

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Forest products can take us a substantial part of the way to net zero in 2050



The source for the current EU emissions data is Eurostat (2022). It's important to note that the total number includes only specific sectors relevant to the study products, including manufacturing, energy, and transportation. Without considering the existing substitution effect, current emissions would be 2 440 Mt CO2eq.

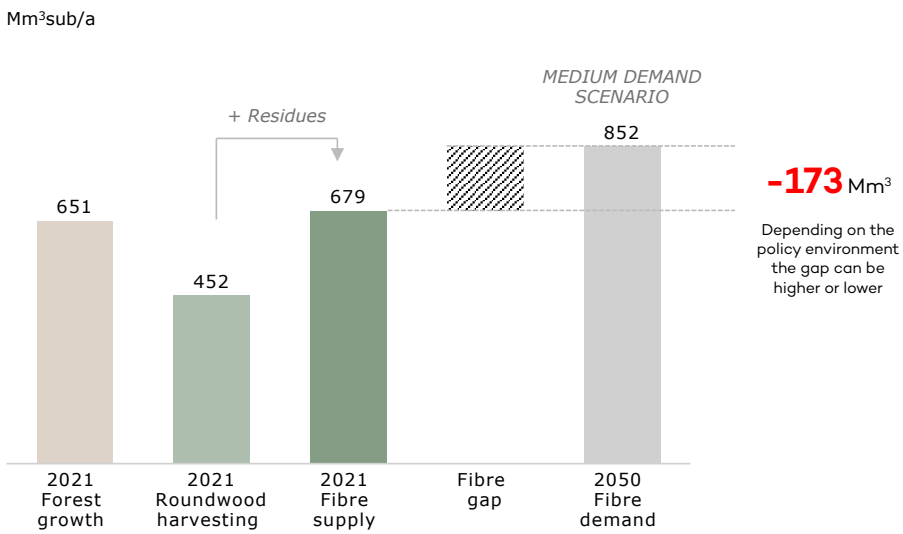
Material substitution with fibre contributes to emission reduction, but it is only a part of the solution. Other industry sectors have also initiatives contributing to the emission reductions, such as:

- Carbon-neutral steel and concrete production
- Improved plastic recycling practices
- Development of bio-based and biodegradable plastics

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Active sustainable forest management would help reduce emissions through substitution and ensure the EU's self-sufficiency in fibre supply

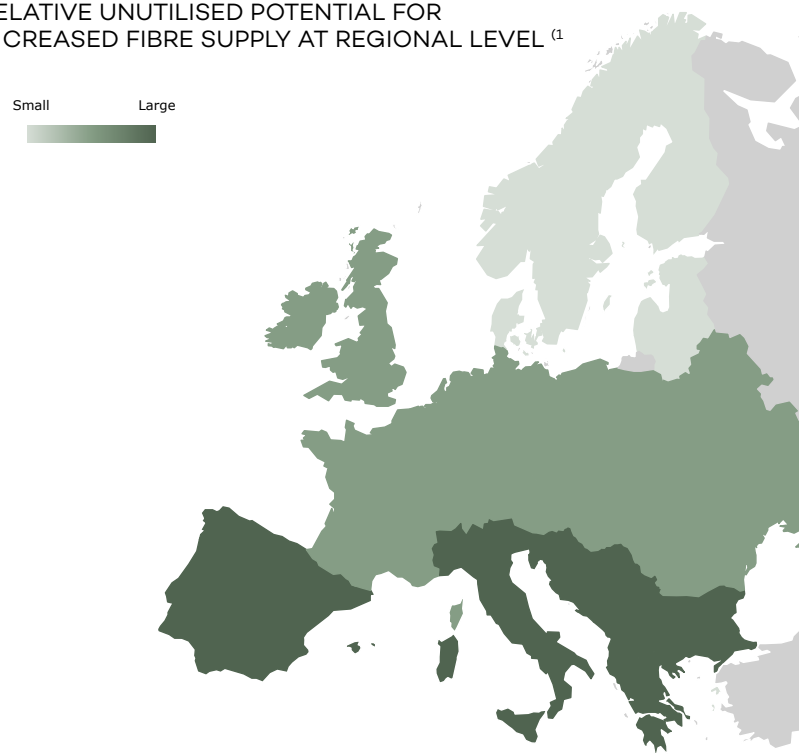
FIBRE SUPPLY GAP IN THE EU IN 2050



Forests act as carbon sinks when forest growth exceeds harvesting. Limited fibre supply e.g. due to policy decisions, compromises the climate benefits of substitution and may result to increased use of fossils. The EU has a theoretical potential to both increase harvesting levels and remove CO_2 from atmosphere as forest growth is currently higher than harvesting. This would increase fibre supply for substitution in the EU by 2050. If there is a preference for locally produced products when the demand for fibre-based materials increases in the future, product exports outside the EU could be reduced. This could potentially increase the supply within the EU while supporting the increasing demand for fibre.

The current forest growth in the EU allows an increase in roundwood harvesting to support the increased fibre demand for substitution and to meet the wood demand gap consisting of roundwood and processing residues. Harvesting some 90% of current forest growth would result in a 130 Mm³ increase in roundwood supply and some 50 Mm³ of additional residue volume. Active sustainable forest management across Europe would further promote forest growth, which in turn would increase forest carbon sink, provide raw material for fossil substitution and support biodiversity targets. Hence, the forest resource in Europe provides an excellent basis for realising the climate benefits of substitution.

RELATIVE UNUTILISED POTENTIAL FOR INCREASED FIBRE SUPPLY AT REGIONAL LEVEL [1]



Additional substitution requires additional fibre from the EU forests. Current harvesting level is not sufficient to meet fibre demand from additional substitution. While active sustainable forest management is a common practice in some large European forest industry countries, it should be introduced more widely across Europe. This would increase the growth of the forest resource in the region and allow an increase in wood supply to fill the gap, while ensuring sustainable use of forests.

Active sustainable forest management adapted to local forest conditions, forest types and practices supports healthy and resilient forests through ensured regeneration and forest monitoring.

[1] Source: State of Europe's Forests 2020, Faostat and AFRY. A full list of references is provided at the end of the document for further information.

INCREASING THE SUBSTITUTION FROM FOSSIL TO FIBRE-BASED RAW MATERIALS IS CRUCIAL FOR THE EU TO REDUCE EMISSIONS

Full climate impact of forests has not been fully recognised in the EU, as policies focus on carbon sinks and disregard the role of wood products

CURRENT EU POLICIES

	CARBON SINK/STOCK		
	FORESTS	WOOD PRODUCTS	SUBSTITUTION
Biodiversity Strategy	⊕	⊗	⊗
Forest Strategy	⊕	?	?
Nature Restoration Proposal	⊕	⊗	⊗
EU Regulation on Deforestation-free Products	⊕	?	?
Land Use, Land Use Change and Forestry (LULUCF)	⊕	⊕	?
European Union Emissions Trading System (EU ETS)	⊕	?	?
Renewable Energy Directive III (RED III)	⊕	?	?
EU Taxonomy	⊕	?	?
Carbon Removal Framework Regulation Proposal	⊕	?	?

⊕ Supports ⊗ Has conflict with ? Does not support

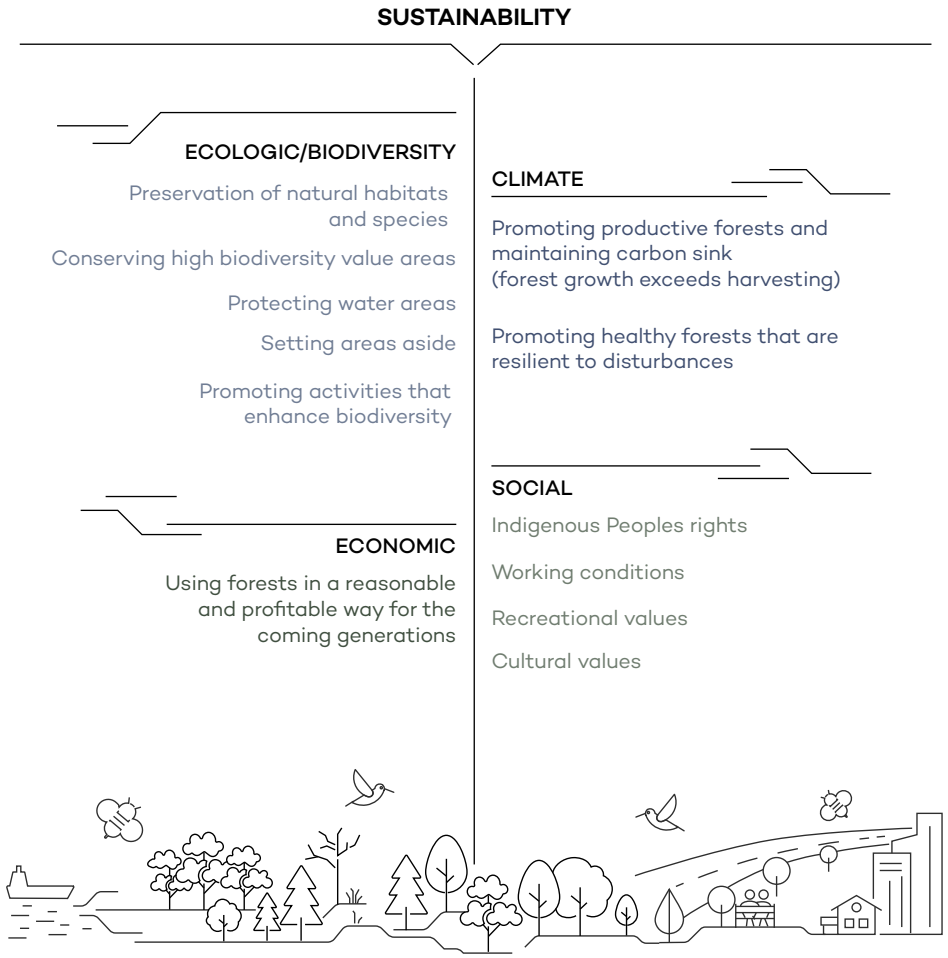
A balanced and holistic approach, where ecological, climate, economical and social impacts of forests have been considered, is required to achieve the most sustainable use of forests and forestry products.

Substitution needs to be recognised and supported as a climate change mitigation tool.

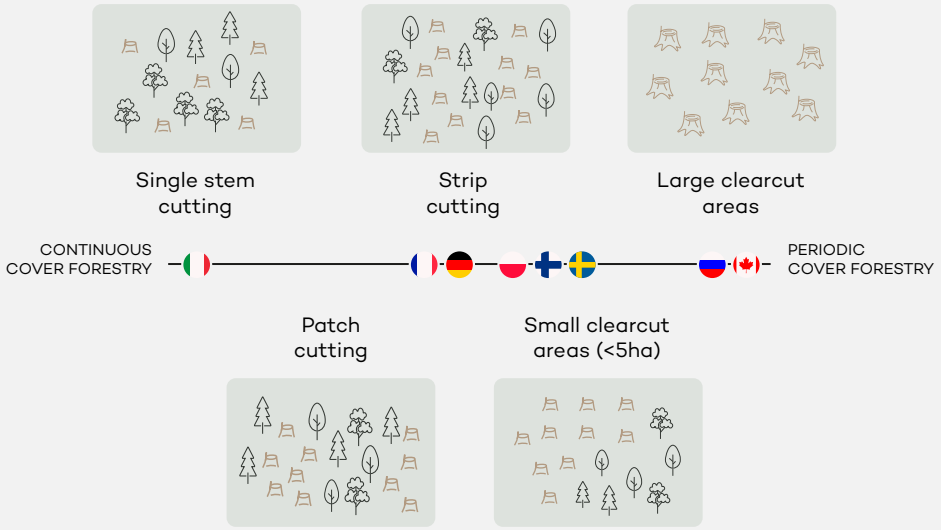
GROWING AND ACTIVELY MANAGED FORESTS REMOVE MORE CARBON FROM THE ATMOSPHERE

A balanced approach to sustainability should be considered while taking into account all aspects of the different ways to manage forests in the EU

ACTIVE SUSTAINABLE FOREST MANAGEMENT



ONE MANAGEMENT MODEL DOES NOT FIT FOR ALL:
WIDE SPECTRUM OF FOREST MANAGEMENT TYPES



Europe has several forest types, structures and operating environments, impacting the suitable management models and methods.

SAFEGUARDING AND IMPROVING BIODIVERSITY WITH INCREASED WOOD PRODUCTION

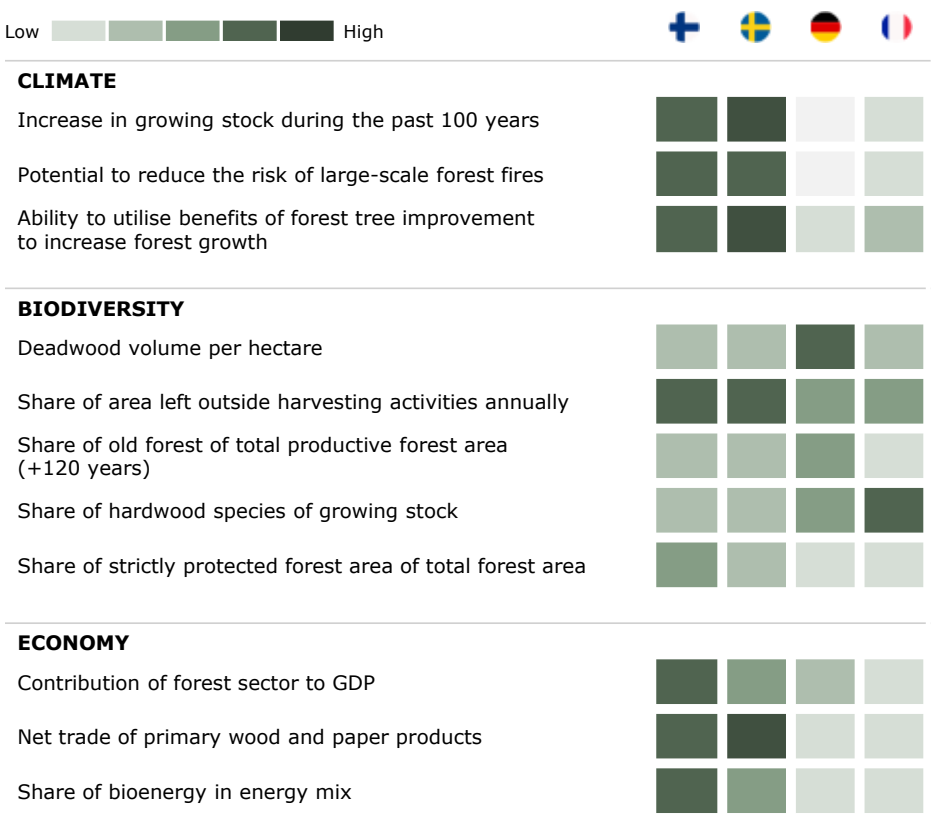
- Increasing share of deadwood
- Increasing variety of species (e.g. share of broadleaves)
- Setting aside areas of high biodiversity values
- Fit for purpose forestry (e.g. harvesting methods)
- Investing into forests and forestry [1]

〉 Maintained and improved productivity in European forests in combination with biodiversity measures will offer most benefits

[1] Investing into forests and forestry e.g., by monitoring, planting, improved silviculture, optimised thinnings, etc.
A list of references is provided at the end of the document for further information.

GROWING AND ACTIVELY MANAGED FORESTS REMOVE MORE CARBON FROM THE ATMOSPHERE

Forests are a strategic resource for Europe in many aspects, and therefore, well-balanced forest management is essential



The scale indicates the extent to which various factors have been considered in the forest management of different countries (climate and biodiversity topics). It also reflects the role of a specific factor in each country's economy.
A list of references is provided at the end of the document for further information.

RESILIENCE

In today´s geopolitically volatile world, the supply chains of the European bioeconomy will remain stable. Bio-based products are largely sourced, manufactured, used, recycled as well as reused in Europe. Growing the market for bio-based products therefore enhances Europe's resilience.

CLIMATE

Increasing growing stock means that forest carbon stock has also increased, providing significant climate benefits. Active sustainable forest management results in higher growth, which allows higher harvesting levels, while increasing or maintaining carbon stock. Through active sustainable forest management, risks are easier to mitigate, which reduces large-scale forest damages, which again reduces unwanted release of carbon to the atmosphere.

BIODIVERSITY

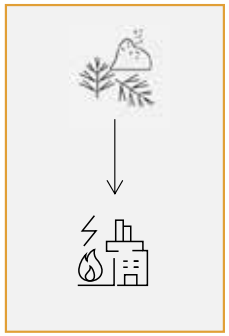
While biodiversity is naturally higher in unmanaged forests, biodiversity can be improved through various methods in managed forests as well. Methods that increase biodiversity include leaving dead wood in the forest, leaving high biodiversity value areas and old growth forests outside of harvesting activities, increasing the share of hardwood species in growing stock, etc.

ECONOMY

Forest industry has a major economical role in many European countries, particularly in the Nordics. The forest industry contributes significantly to GDP, wood and wood products are highly traded commodities, forest sector provides work, forest industry enables the use of residues for bioenergy replacing fossil-based energy, etc.

BIOENERGY CAN SUPPORT THE TRANSITION TO MORE SUSTAINABLE ENERGY SYSTEMS AT THE WHOLE EU LEVEL

Energy use of residues has the same CO2 impact when decomposed but it substitutes fossil fuel demand; this efficient model is already utilised in the Nordics



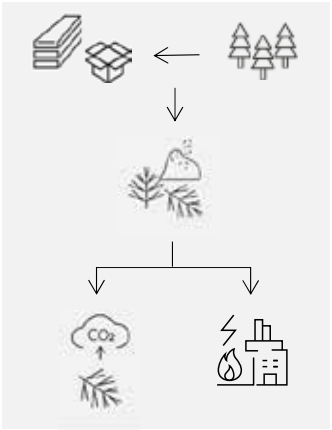
The Nordic energy model utilises residues that currently have no material use

WOOD DEMAND
Wood is harvested for products

RESIDUES
Forestry produces residues: branches, bark, sawdust, …

UTILISATION
If residues are not utilised, they decompose and release CO_2

ENERGY DEMAND
Energy use of residues has the same CO_2 impact when decomposed [2] but it substitutes fossil fuel demand

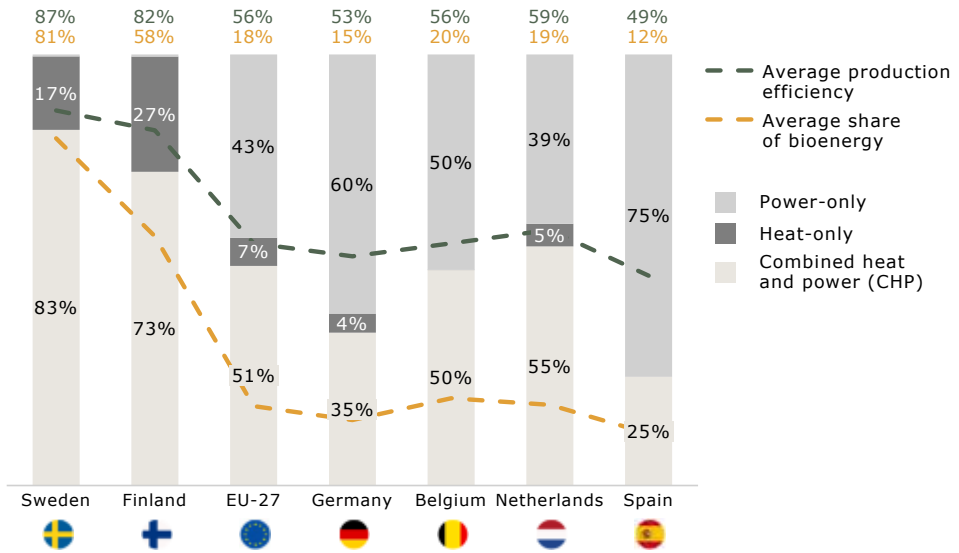


Decomposition	Energy use
Energy demand met by fossil fuels	Displaces fossil demand

-74 [1] Mt CO_2eq

Technologies used in the Nordics produce 2-3 times more energy compared to conventional power-only production with the same fuel

Division of fuel use (biomass and fossil) in combustion-based heat and power production



[1] Current utilisation of bioenergy avoids 74 Mt CO2eq in Finland and Sweden, (compared to natural gas and coal)
[2] Decay will take longer time compared to burning but volume wise the impact is similar

BIOENERGY CAN SUPPORT THE TRANSITION TO MORE SUSTAINABLE ENERGY SYSTEMS AT THE WHOLE EU LEVEL

Efficient use of biomass in material use and CHP production in power generation has a valuable contribution to the whole EU-level energy system

CURRENT ENERGY SYSTEMS IN THE EU	FUTURE CHANGES	
	High level capacity development trend in Europe	
Increasing amount of weather dependent renewable production (wind and solar) in whole Europe leads to a mismatch between supply and demand profiles.	WIND AND SOLAR ↑	Variable
Nuclear production provides stable base load, but flexible production is still required.	NUCLEAR ?	Constant
Nordic dispatchable hydro production could balance the production in the Nordics, but the potential is also utilised to balance other parts of Europe through interconnectors.	HYDRO →	Dispatchable
The remaining balancing of electricity production in Continental Europe is often carried out with electricity-only production by fossil fuels.	FOSSIL-BASED ↓	
Utilising bioenergy in efficient CHP plants in the Nordics leaves more hydro capacity for Continental Europe, and hence reduces fossil fuel demand in European electricity production.	BIOENERGY ?	

Production becomes more variable and flexibility decreases; mismatch between supply and demand.

POTENTIAL SOLUTIONS PROVIDING FLEXIBILITY:

- Bioenergy (with BECCS [1])
- Hydrogen economy
- Small modular reactor (nuclear)
- Fossil carbon capture and storage
- Energy storage
- Demand flexibility
- Strengthening interconnection

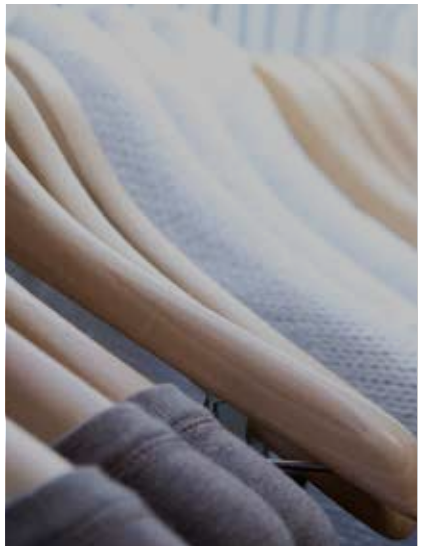
[1] Bioenergy with carbon capture and storage (BECCS) provides potential for carbon removals, necessary in all IPCC 1.5C pathways.

FOREST-BASED INNOVATION WILL CONTINUE TO DELIVER NEW SOLUTIONS TO THE CLIMATE CHALLENGE

Continued focus on world-leading innovation in Europe will enable forest raw materials to be used for an even wider range of applications in the future

- Wood fibre insulation
- Bio-based glues/resins
- Demanding/taller wooden buildings

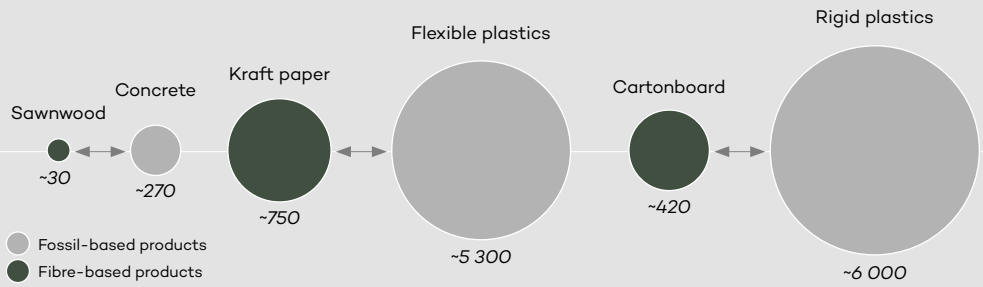
- Novel barrier solutions
- Moulded fibre products

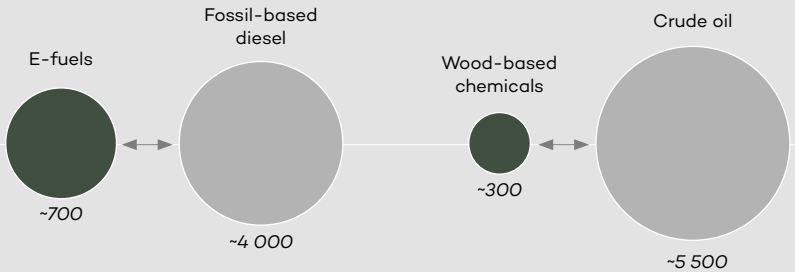


- Novel wood-based textile fibres under development

- Bio-based chemicals
- Sustainable aviation fuels
- Side stream products from pulp mill
- E-fuels

GENERATED EMISSIONS FROM FOSSIL-BASED PRODUCTS VS. FIBRE-BASED





Bubble size reflects specific emission factors (kg CO_2/m^3 or t). Emission factors are based on EPDs, LCA databases (e.g., Ecoinvent) or developed using LCA expertise and dedicated software (SimaPro and GaBi).

KEY CONCLUSIONS

Increasing the substitution from fossil to fibre-based raw materials is crucial for the EU to reduce emissions

Highest climate benefits can be achieved in wooden buildings and packaging materials.

Regulations and political decisions have a major impact on the extent of benefit. Substitution effect should be recognised and supported by policy packages on the EU-level.

Growing and actively managed forests remove more carbon from the atmosphere

Multifunctional and balanced use of the forest is critical in order to meet the increasing demand for additional substitution.

The role of actively managed forests should be recognised in the EU policies as it enables growth.

Bioenergy can support the transition to more sustainable energy systems at the whole EU level

Efficient combined heat and power production based on forest residues enables an increased uptake of intermittent electricity generation without risking the security of supply.

Furthermore, BECCS provides further opportunity for negative emissions.

Forest-based innovation will continue to deliver new solutions to address the climate challenge

Continued focus on world-leading innovation in Europe will enable forest raw materials to be used for an even wider range of applications in the future, from textiles to batteries to jet fuel.

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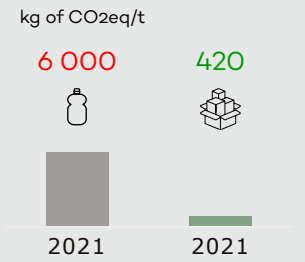
MATERIAL SUBSTITUTION

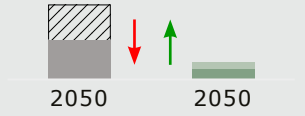
Substitution in this study refers to the use of fibre-based materials to reduce consumption of fossil-based products

SUBSTITUTION



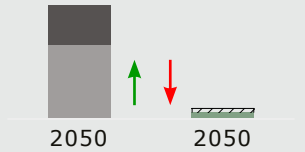
The use of fibre-based packaging already provides climate benefits as emissions are lower than in plastic packaging.

ADDITIONAL SUBSTITUTION



Increasing fibre-based material use with high substitution potential reduces fossil emissions significantly.

REVERSE SUBSTITUTION



Reducing fibre-based material use increases overall emissions significantly.

SUBSTITUTION

Fibre-based products can replace fossil-based products, e.g., fibre-based packaging replacing plastic packaging. In addition, there are also other drivers for using fibre-based materials than the substitution of fossil counterparts; e.g., when fibre is a more cost-efficient raw material, when it is a tradition to use fibre, or when it is better material compared to other options. These factors will continue to favour the increasing demand for fibre-based products in the future. [1]

ADDITIONAL SUBSTITUTION

Additional substitution can be achieved when the use of materials with high substitution potential is promoted:

- Consumer behavior changes towards preferring sustainable options
- EU or country-level incentives or legislation change towards restricting fossil-based material consumption and/or preferring more sustainable materials
- Technical innovations of sustainable materials are developed further.

This decreases the future demand for fossil-based materials, which also reduces overall emissions. Some product groups provide significant potential for additional substitution in 2050 via organic demand growth and high emission reduction potential:

- Wood products used in new buildings instead of concrete
- Fibre-based packaging used instead of plastic packaging
- Cellulosic textiles used instead of synthetic textiles
- Liquid biofuels and chemicals used instead of fossil fuels and chemicals

REVERSE SUBSTITUTION

If fibre availability or other essential drivers are restricted, a risk exists that emissions increase because products will be made of fossil-based materials instead of fibre.

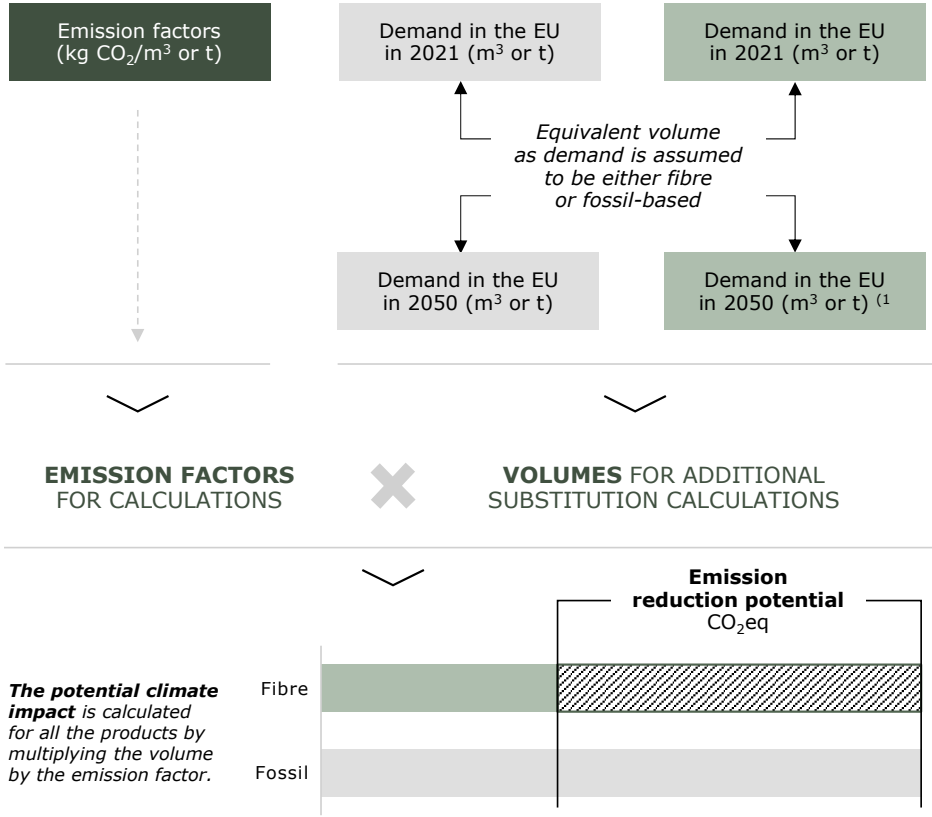
[1] Material substitution also supports increasing carbon storage of fibre-based products. Please note that not all fibre-based products substitute fossil-based products, e.g., tissue and graphic papers.

APPROACH FOR CLIMATE IMPACT CALCULATIONS

Specific emission factors used for each product area. Emission factors are based on EPDs, LCA databases (e.g., Ecoinvent) or developed using LCA expertise and dedicated software (SimaPro and GaBi).

Fossil-based counterparts for fibre-based products such as concrete, rigid or flexible plastics, etc.

Fibre-based products:
- Wood products
- Packaging
- Textiles
- Biofuels & chemicals



[1] Three demand scenarios in the EU in 2050:
Low substitution impact
Medium substitution impact
High substitution impact

APPENDIX MATERIAL

PRODUCT VOLUMES

For fibre-based products, numerous public sources, AFRY in-house databases and knowledge were utilised. Fossil-based volumes were assessed by using various conversion factors for all the main product areas as the fibre and fossil-based demand volumes were assumed to be equal in this analysis. Main sources for the product demand analysis included:

Wood products: AFRY in-house databases and models, IHS, European Union, Eurostat (2021-2022), Euroconstruct, United Nations, IMF, EPF, Statista, IAL, Freedonia

Packaging: AFRY in-house databases and models, Eurostat (2021-2022), Smithers Pira, European Union, European Environment Agency, Statista, country-specific paper/board associations, CEPI, Concensus

Textiles: AFRY in-house databases and models, Textile Exchange, European Union, The Fibre Year reports

Biofuels and biochemicals: AFRY in-house databases and models. Industry expert interviews were also a source of input. Pulp mill sidestream product volumes were estimated based on AFRY's pulp production forecasts, where the base data comes from country-specific data sources. Only Finnish and Swedish pulp mills were considered in the low and medium scenarios, while the whole EU27 was the scope in the high scenario (only specific pulp grades relevant for sidestream products were considered).

EMISSION FACTORS

Specific emission factors were used for each product area. Emission factors are based on EPDs, LCA databases (e.g., Ecoinvent) or developed using LCA expertise and dedicated software (SimaPro and GaBi).

POTENTIAL CLIMATE IMPACT

The potential climate impact was calculated for all the products by multiplying the volume by the emission factor. Please note that not all bio-based solutions are inherently more sustainable. Whether emissions reductions occur will only be evident after a thorough calculation.

AFRY developed multiple demand scenarios for additional substitution products to capture broader and more extreme developments affecting substitution potential and climate impact, considering the uncertainty due to the long time horizon up to 2050. Key factors impacting the scenarios included shifts in consumer thinking and preferences, changes in policy and regulatory frameworks, development of technical innovations, cost dynamics and improvements in recycling and material efficiency.

KEY DEMAND DRIVERS

- Consumer thinking
- Policy and regulations
- Technical innovations
- Costs
- Recycling & material efficiency

A LIST OF REFERENCES FOR THE BALANCED SUSTAINABLE FOREST MANAGEMENT:

European Forest Institute (2022), Forest Biodiversity in Europe

International Boreal Forest Research Association & Swedish Forestry Agency (2021), Sustainable forest management – challenges and opportunities for climate change mitigation

Korosuo A. et al. (2023), The role of forests in the EU climate policy: are we on the right track?. Carbon Balance Manage 18, 15

Mason, W.L. et al. (2022), Continuous forestry in Europe: usage and the knowledge gaps and challenges to wider adoption, Forestry: An International Journal of Forest Research

Nabuurs, G-J. et al. (2018), Climate-Smart Forestry: mitigation impacts in three European regions. From Science to Policy 6. European Forest Institute.

FOR FOREST AND SUPPLY ANALYSIS, NUMEROUS PUBLIC SOURCES AND SCIENTIFIC PUBLICATIONS WERE USED, INCLUDING:

Kändler & Cullman, (2015), Regionale Auswertung der Bundeswaldsinventur 3 – Land Baden-Württemberg

National Forest Inventory of France

National Forest Inventory Sweden

Natural Resources Institute Finland (LUKE)

Second and Third National Forest Inventory of Germany

State of Europe's Forests 2020

Swedish Forestry Agency

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