CLIMACT | Empowering **you** to act on **climate change**

FEFCO Climate Neutrality Roadmap

Final presentation

30th of November 2022

FEFCO Corrugated Packaging

Overall introduction to this document

- In H1 of 2022, Climact developed a climate neutrality roadmap for the European* corrugated sector (represented by FEFCO).

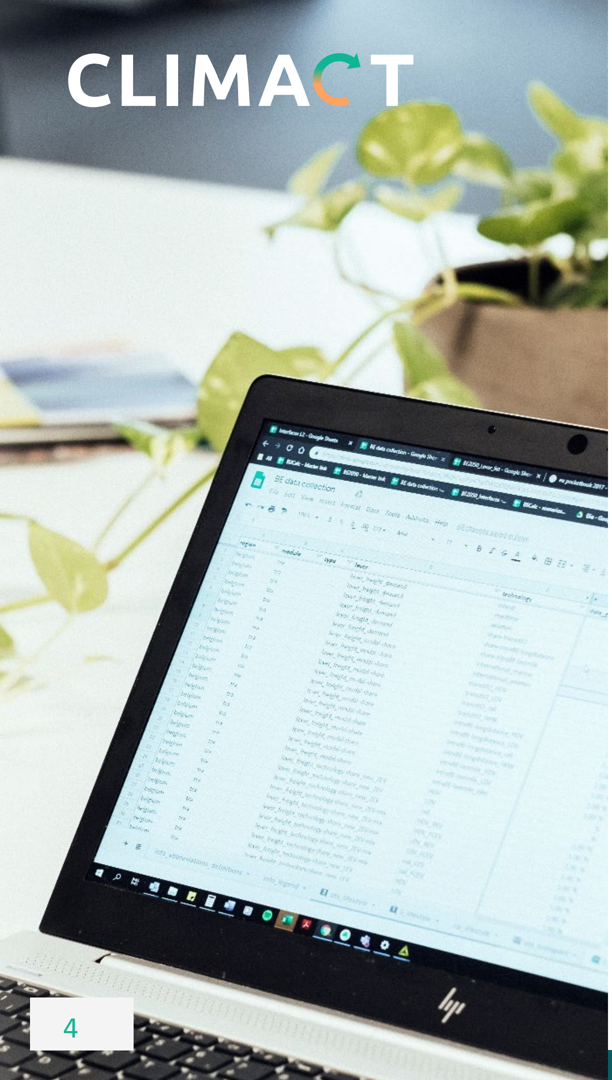
- The roadmap was developed in close cooperation and consultation with sector representatives. During the course of the project, the sector's input and feedback was obtained through:

  - Five steering committees with overall sector representatives
  - Four expert meetings with energy experts from the sector
  - Multiple bilateral interviews with key experts within the sector

- This slide deck contains all results of the climate neutrality roadmap that was developed for FEFCO

- The slide deck starts with main messages and results. Back-up slides with background information or the underlying methodology are included in the technical annex at the end.

* Scope includes corrugated plants in the EU27 + UK + EEA countries. Turkey is not included.



The corrugated sector today

- **The corrugated sector in a nutshell**
- Importance of sustainability within the sector
- Current carbon footprint and energy/material use

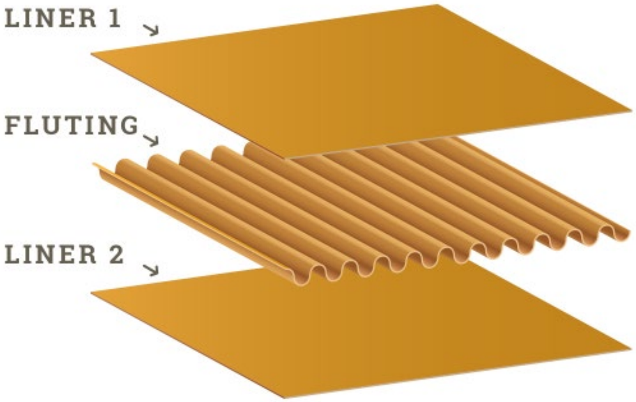
The vision: climate neutrality by 2050

The roadmap to implement the vision

Technical Annex

Corrugated board is a fibre-based packaging product, combining 2 or more layers of paper.

The outside layers (liners) are attached to an inner, corrugated medium (fluting) using a starch-glue



There is a wide variety of applications. 75% of goods transported today are packed in corrugated

Standard boxes

Food & beverages

FMCG's

Point-of-purchase displays

Source: www.fefco.org

Countless variations of corrugated board are possible, based on:

Containerboard used

	Recycled	Virgin
Liner	Testliner	Kraftliner
Fluting	Recycled fluting	Semi-chemical fluting

+ variations in terms of base weight (g/m²) and finishing (colouring, coating, …)

Construction types

SINGLE FACE CORRUGATED | SINGLE WALL (DOUBLE WALL) CORRUGATED | DOUBLE WALL CORRUGATED | TRIPLE WALL CORRUGATED

Fluting heights

Table 2: Flute types

Flute	Flute height* mm	Number of flutes per m length of the corrugated board	Take-up factor	Glue consumption g/m² glue layer
A	4.8	110	1.50-1.55	4.5-5.0
B	2.4	150	1.30-1.35	5.5-6.0
C	3.6	130	1.40-1.45	5.0-5.5
E	1.2	290	1.20-1.35	6.0-6.5
F,G,N	0.5-0.8	400-550	1.15-1.25	9.0-11.0

Source: www.fefco.org

Some key figures about the corrugated sector in Europe:

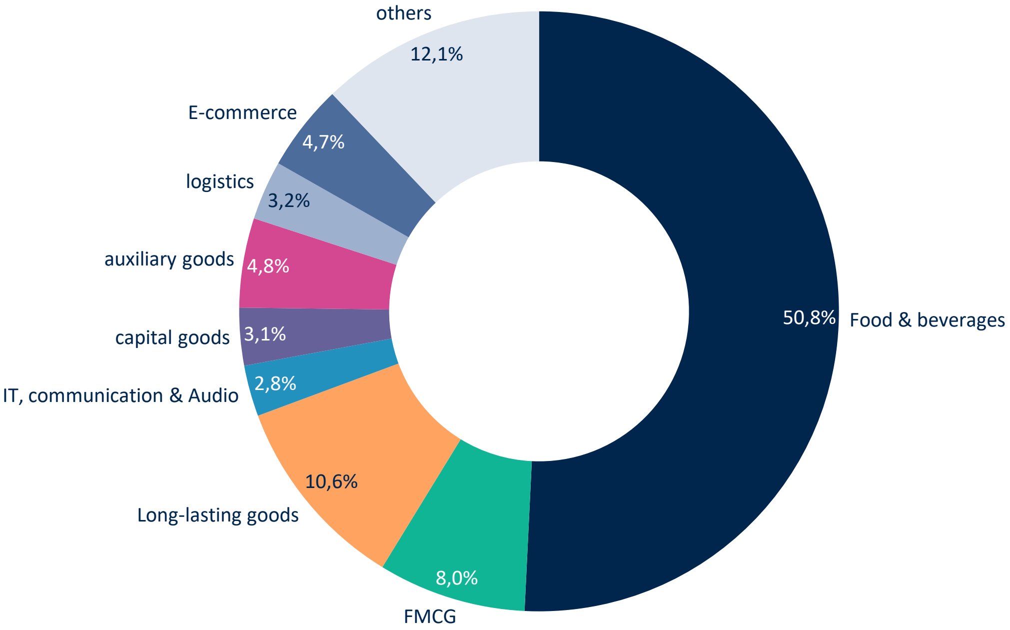
Annual production of +- 50 billion m² of corrugated boards

360 companies, counting 660 plants, and 100 000 direct employees

Over the last 20 years, improvements have led to 9% weight decrease and an increased recycling rate (from 75% (1996) to 88% (2020))

Source: FEFCO industry statistics for 2020, excluding Turkey

Key markets for corrugated products.



Source: FEFCO industry statistics for 2020, weighted average

Corrugated packaging has multiple benefits on sustainability dimensions.

Bio-based and renewable

Corrugated packaging paper is made almost entirely from natural resources with any new fibers used, the wood is harvested from sustainably managed forests.

Easy to recycle

Continuous increase of the use of recycled fibres, which now make up 88% of the raw material for new corrugated packaging.

Prevents food waste

Production processes that kill microbes give corrugated packaging unique hygiene levels that prevent the cross-contamination and spoilage of fresh produce.

Adding value after use

Today's market for recycled paper as a secondary raw material provides value to every stakeholder across the supply chain

Eco-design built in

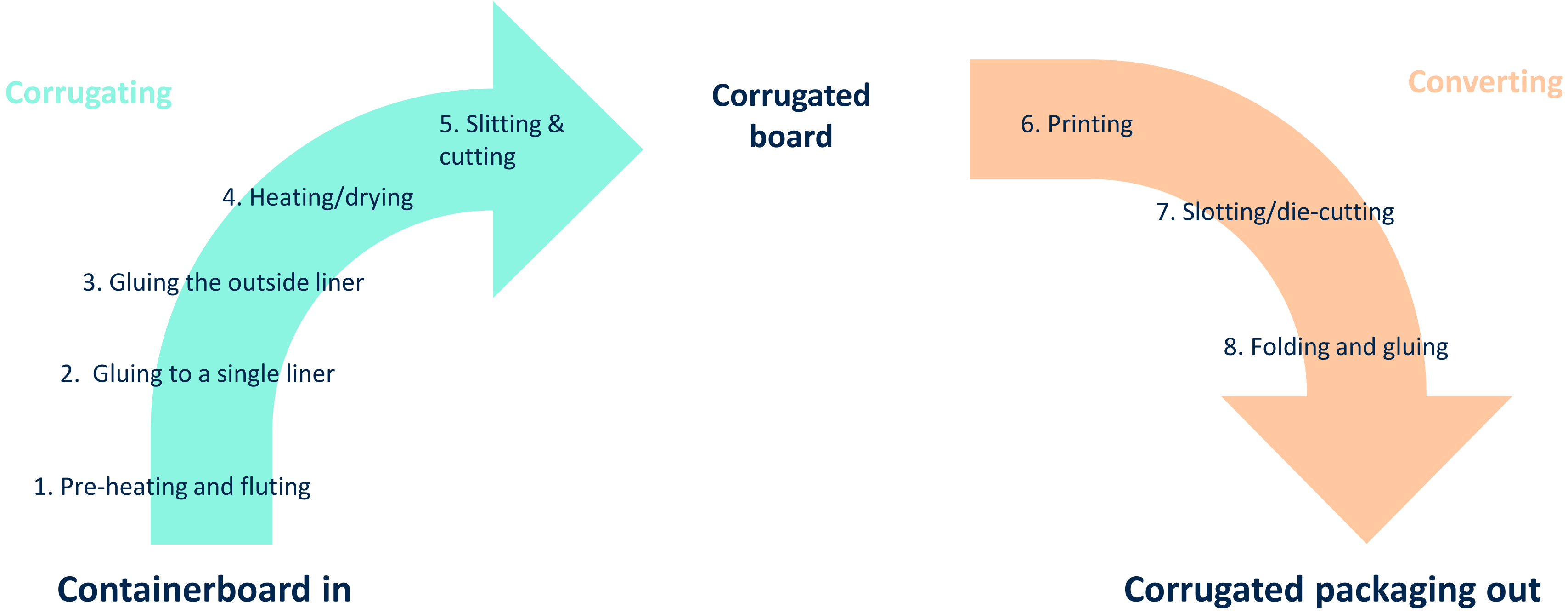
Corrugated packaging can be easily shaped for cost efficient logistics, storage handling and recycling – saving time, energy and money while preserving the environment.

The real Circular Economy champion

Recyclable, based on renewable sources and bio-degradable, corrugated packaging is circular by nature.

Source: www.fefco.org

The production of corrugated packaging can be divided in two main steps: corrugating and converting.



Source: www.fefco.org

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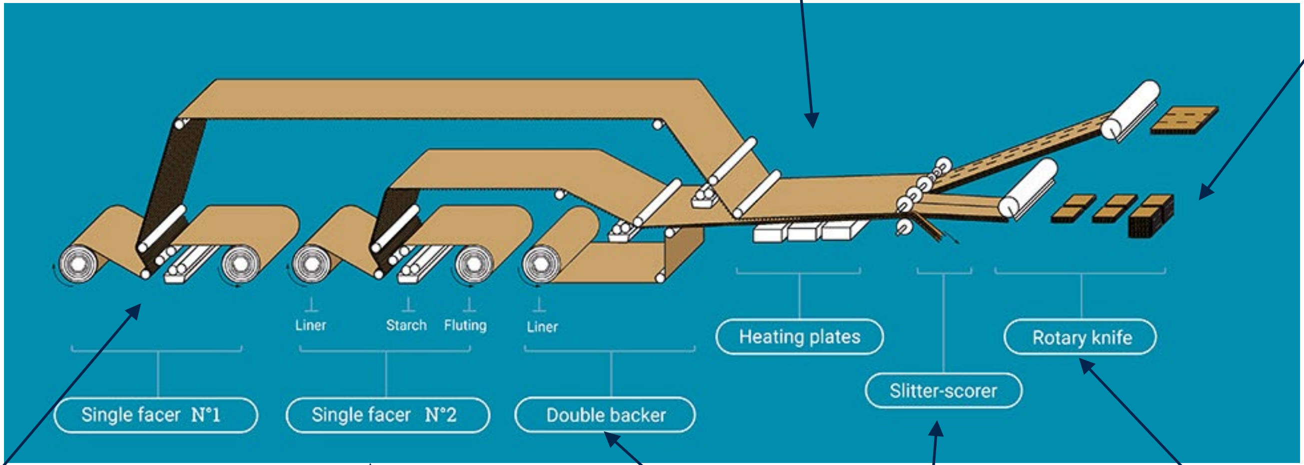
The corrugating process in detail.

4. Heat is applied to ensure a strong bond by gelling the glue and removing moisture

7. The sheets are then stacked and transported to the converting line



1. The liner and recycled medium are fed into the corrugator and pre-heated. Starch is applied to the tips of the fluting and then fluting and liner are glued together.

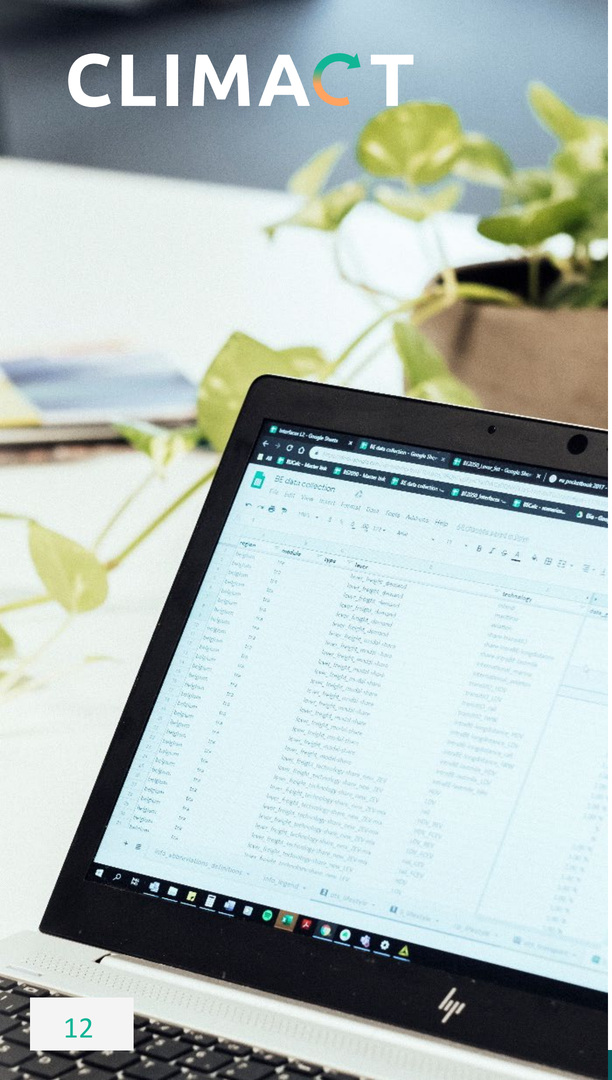
2. The process can be repeated to make double-wall corrugated board

3. The bottom outside liner is glued via the double backer.

5. The slitter/scorer cuts the board to the desired widths

6. The rotary knife cuts the board in lengths to obtain corrugated sheets of the desired length

Source: www.fefco.org



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The sector is under increasing pressure to further improve its sustainability and climate performance.

- Increased **awareness** and **demands** from key stakeholders (customers, consumers, investors & employees)
- Dramatic **price increases** in energy and carbon, affecting materials and logistics supplies as well as our own operations

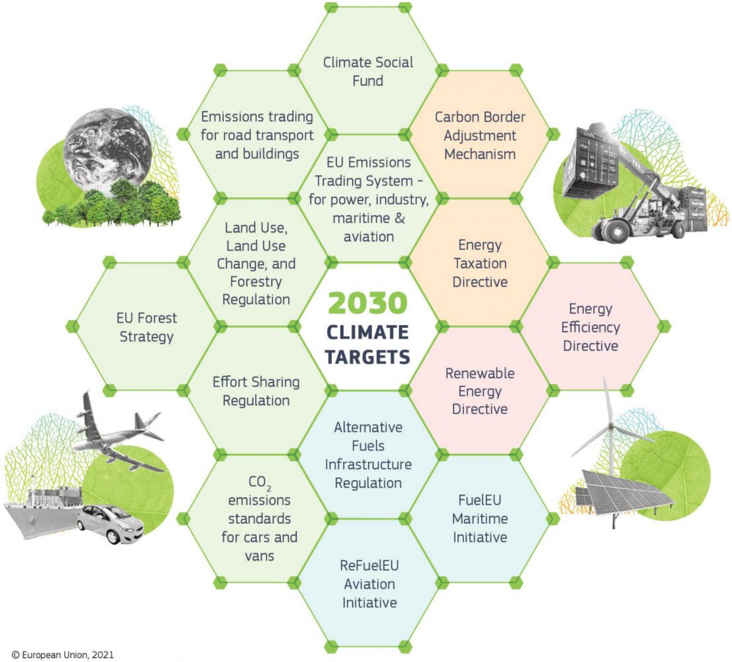
MARKET & SOCIETAL PRESSURE

REGULATORY PRESSURE

FEFCO
Corrugated Packaging

- **EU climate objectives and policies** (climate neutrality, Fit for 55)
- **Corporate Social Responsibility Directive** with mandatory reporting obligations
- **Packaging & waste policies** at EU and national level, including strong pressure for re-use

Fit for 55 package foresees a comprehensive framework for reducing the EU's GHG emissions, which will also impact the corrugated sector.



- Increased ambition for GHG emission reductions, renewable energy and energy efficiency, which will trigger **more ambitious national policies**
- Increased carbon price signal under the **EU ETS**, with impacts on **electricity prices** and **paper production costs**
- **Extension of the ETS** to buildings, road transport, and the maritime sector, with **impacts on logistic costs**
- Specific strategy (EU Forest Strategy) and legislation (LULUCF regulation) to further drive **sustainable forest management and afforestation**

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Increased consumer awareness of packaging brings both risks and opportunities…

80%	**85%**	**32%**	**64%**	**25%**
say climate change is an important issue to them	Would like to use as little packaging as possible	Consider packaging as one of the top 3 priorities for the environment	Are willing to pay more for sustainable packaging	Are actively anti-plastic

Source: DS Smith (based on IPSOS) (2022)

Many customers already have targets for sustainable packaging, and increasingly will expect suppliers to align with SBTi principles.

TESCO

- By 2025, all packaging fully recyclable
- SBTi (climate neutral validated, net-zero committed)

LIDL

- By 2025, 100% of its own-label and branded packaging to be recyclable, reusable, refillable or renewable
- By 2025, reduce own-label plastic packaging with 40%
- SBTi (1.5° validated)

Carrefour

- By 2025, 100% recyclable, reusable or compostable packaging for the Group's own brands
- SBTi (well-below 2° validated, net-zero committed)

Apple

- By 2025, remove all plastic in packaging
- By 2030, become entirely carbon-neutral
- SBTi (1.5° validated)

PEPSICO

- Use 25% recycled content in plastic packaging by 2025 (and 50% by 2030)
- SBTi (climate neutral validated, net-zero committed)

Unilever

- By 2025, reduce use of virgin plastic by 50% + collect/process more plastic than it sells
- By 2025, ensure that 100% of plastic packaging is designed to be fully reusable, recyclable or compostable
- SBTi (climate neutral validated, net-zero committed)

Nestlé

- By 2030, reduce use of virgin petroleum plastic by 50%
- By 2030, make 100% of packaging recyclable or reusable
- SBTi (climate neutral validated, net-zero committed)

P&G

- By 2025, 100% recyclable or reusable
- By 2025, reduce the use of virgin plastics by 1/3
- SBTi (climate neutral validated, net-zero committed)

Both the physical impacts of climate change as the climate & energy transition hold risks (and some opportunities) for the corrugated sector.

Physical
Impact of climate change

ACUTE
Increased probability and severity of natural disasters

- Supply chain disruptions (impact of forest fires on fibre supply)
- Threatened assets (flooding, heatwaves…)
- Insurance liabilities

CHRONIC
Long term changes in weather patterns

- Availability of raw materials
- Logistics changes
- Cooling costs

Transition
Impact of transition policies & behaviours

POLICIES & LEGAL

- Disclosure & compliance obligations
- Specific targets/norms for the corrugated sector and/or its supply chain
- Carbon price (direct + indirect via price of electricity and transport)

ECONOMICAL

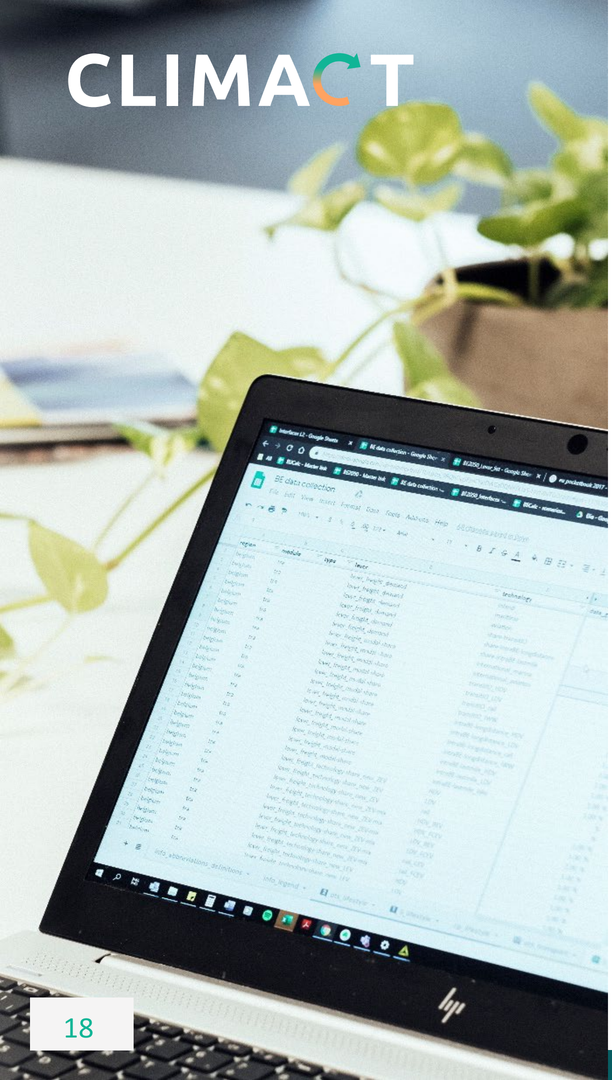
- energy and material expenditures
- Write-off investments / early retirement
- CAPEX + OPEX for technology shift

MARKET

- Increased sustainability demands for customers (and suppliers)
- Client fees & discounts based on sustainability
- Motivation of employees/recruitment of young talents

SOCIETAL

- Increased consumer awareness and sustainability preferences
- Shift to circular and functional economy
- Profound behavioural changes
- Climate-related business processes and data management



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Overall, the sector's carbon footprint is determined by four categories.

Fossil emissions	All emissions related to the combustion of fossil energy sources. No fossil process emissions are generated throughout the value chain.
Biogenic emissions	All emissions related to the combustion of biomass.
Emission removals	All removals of CO_2 from the atmosphere due to the cultivation of biomass, which is related to the activities of the sector[1].
Avoided emissions	Avoidance of emissions (fossil or biogenic) elsewhere in the economy due to the valorization of waste (energy) streams created by the sector.

[1] For the corrugated sector, emission removals mainly relate to CO2 that is taken out of the atmosphere by trees and plants, which are then harvested for paper and starch production. Part of the carbon that is taken out of the atmosphere is re-emitted again at a later stage, e.g. due to the combustion of biogenic waste streams (black liquor) or the incineration of corrugated products at end-of-life. These emissions are accounted under 'biogenic emissions'. However, the overall balance between removals and biogenic emissions for the corrugated sector is negative, due to two dynamics:

- Most of corrugated products are recycled at end-of-life. As the production of corrugated packaging continues to increase, and to the high recycling rate in the sector, the carbon stock in corrugated products increases each year;
- The carbon content of ;corrugated products which are recycled for other products than containerboard (e.g. sanitary paper, insulation material, …) fall beyond the accounting boundaries.

The analysis covers all four categories for all major sources in the value chain (cradle-to-grave).

	Paper Production			Corrugated production			Product use	
	Feedstock production	Transport to mills	Paper production	Transport to CB plant	Corrugator + converting	Transport to client	Packaging	EOL
Fossil	Fossil fuel combustion Electricity consumption	Fossil fuel combustion	Fossil fuel combustion Electricity consumption	Fossil fuel combustion	Fossil fuel combustion Electricity consumption	Excluded*	Excluded	Fossil fuel combustion Electricity consumption
Biogenic	Land Use Change Biomass combustion	Biofuel combustion	Biofuel combustion Electricity consumption	Biofuel combustion	Biofuel combustion Electricity consumption	Excluded*	Excluded	Biomass incineration
Removals	Carbon sequestration related to paper and starch production	Carbon sequestration related to any biofuels used in the value chain						
Avoided								Energy recovery from incineration

* Emissions from downstream transport are not included due to lack of data. However, the corrugated sector is a local sector, with plants within a 250km range of their customers (due to high transport costs, as corrugated packaging has a high volume/weight rate). A conservative estimation shows that the footprint of downstream transport is therefore relatively low (15 to 20 kg $CO_{2eq.}$ per tonne product)

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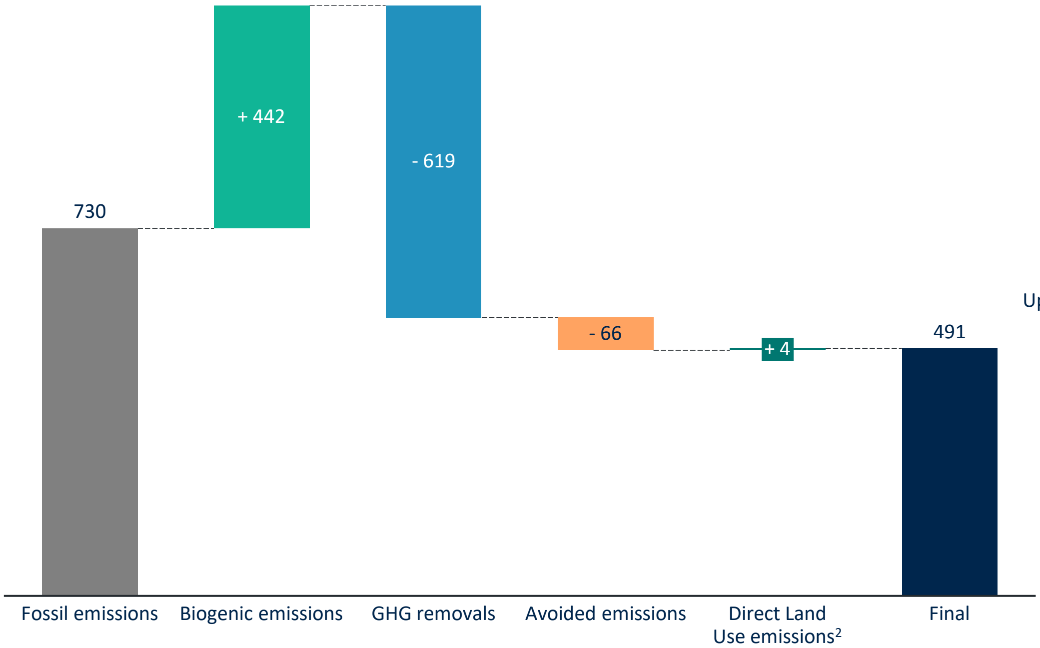
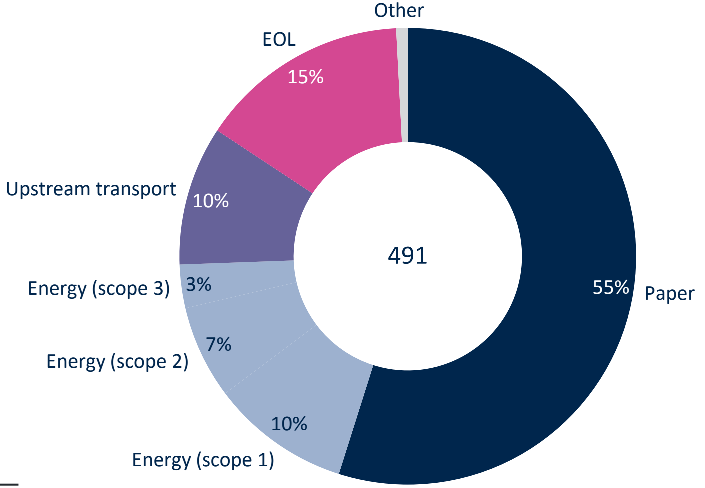
In 2020, the total carbon footprint of 1 tonne of corrugated board was 492,5 kg CO_2eq.

GHG footprint based on 2020 data[1]
[in kg $CO_{2eq.}$/t nsp]



Main emissions sources are[1]:

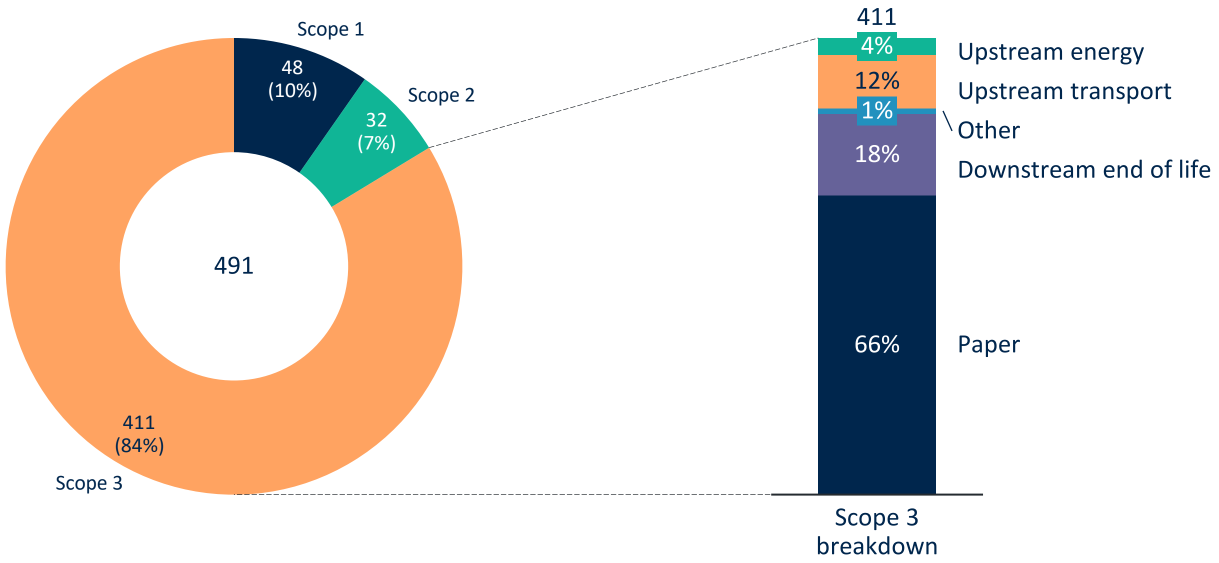
1) Upstream emissions from paper production (55%)
2) Own energy consumption (20%)
3) Upstream transport (10%)
4) Incineration at end-of-life (EOL) (15%, mainly biogenic emissions)



1. Source: Based on LCA studies performed for FEFCO. See https://www.fefco.org/lca/ Including fossil emissions, biogenic emissions, emission removals, and avoided emissions.
2. The LCA study also includes some very limited Direct Land Use emissions (4kg $CO_{2eq.}$/t nsp), but these are not considered in the roadmap for simplification purposes.

Scope 3 emissions account for +- 85% of the total footprint, and are dominated by upstream paper production.

GHG footprint based on 2020 data
[in kg $CO_{2eq.}$/t nsp]



Source: Based on LCA studies performed for FEFCO. See https://www.fefco.org/lca/ Including fossil emissions, biogenic emissions, emission removals, and avoided emissions

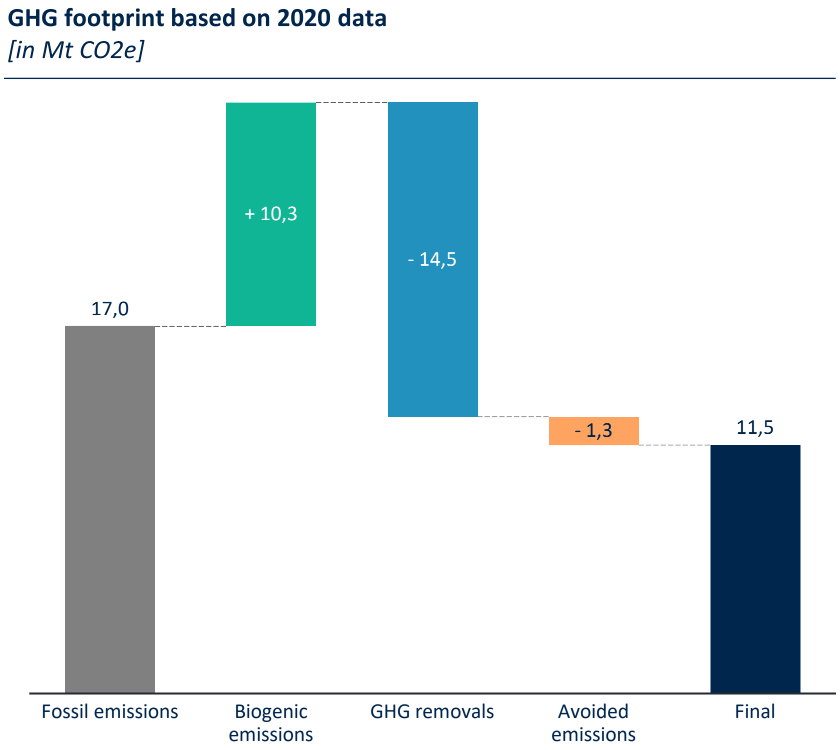
Detailed breakdown of current footprint, per category, source and scope.

GHG footprint based on 2020 data
[in kg $CO_{2eq.}$/t nsp]

	Scope 3 (upstream)				Scope 1	Scope 2		Scope 3 (downstream)	Total
	Paper production	Other inputs	Upstream energy	Upstream transport	Fuel use	Electricity use	Steam imports	End-of-Life	
Fossil	562,4	20,6	15,4	48,4	48,4	29,9	2,6	4,8	733
Biogenic	303,8	0,9	0,1	0	0,8	3,6	0	134,1	443
Removals	-596,9	-21,6	-0,3	0	-0,8	-3,7	0	0	-623
Avoided	0	0	0	0	0	0	0	-65,9	-66
Direct Land Use[1]	*2,2*	*2,1*	*0*	*0*	*0*	*0*	*0*	*0*	*4,3*
Total[1]	**271,5**	**1,9**	**15,0**	**48,4**	**47,7**	**29,8**	**2,6**	**73,2**	**491,3**

1. The LCA study also includes some very limited Direct Land Use emissions (~4kg $CO_{2eq.}$/t nsp), but these are not considered in the roadmap for simplification purposes.

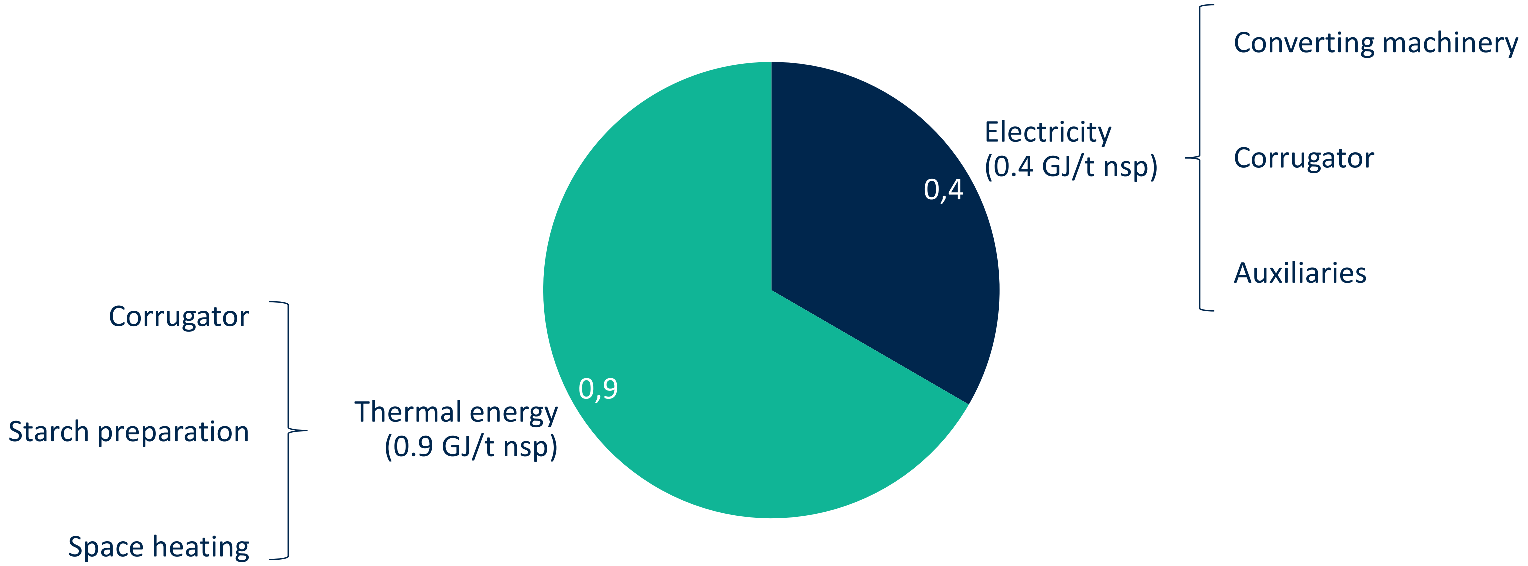
The sector-wide footprint was 11,5 Mt of $CO_{2eq.}$



Source: Based on LCA studies performed for FEFCO. See https://www.fefco.org/lca/ Including fossil emissions, biogenic emissions, emission removals, and avoided emissions

Energy consumption for corrugated production is +- 1,3 GJ per tonne nsp*.

Of which 1/3 electricity and 2/3 thermal energy

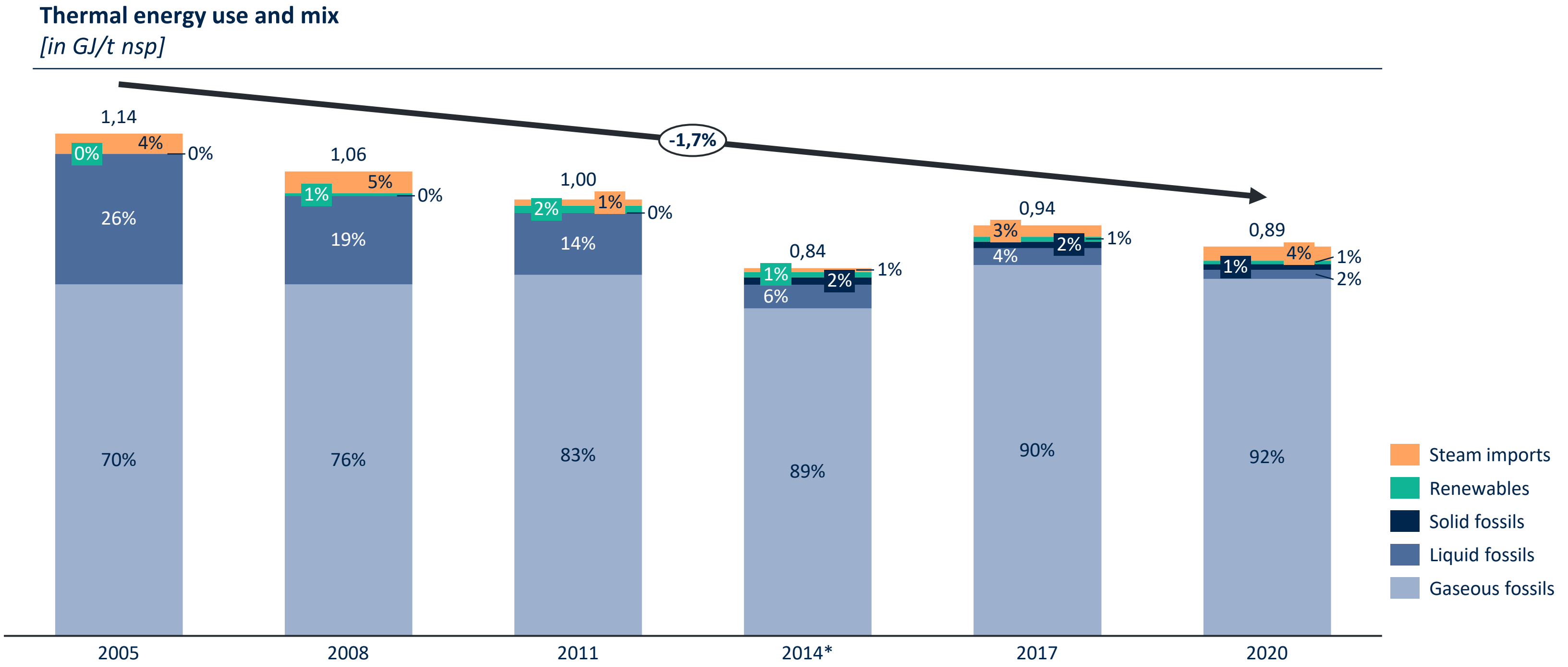


* This refers to the energy consumption within corrugated production process: that is to make corrugated board and to convert it to packaging products. The value represents a sector average, with energy demand varying strongly depending highly on type of packaging produced, the plant efficiency and size (larger plants are typically more efficient)

Source: FEFCO 2021 LCA study

Thermal energy efficiency has been improving on average 1,7% per year since 2005.

Liquid and solid fossils have been almost completely phased out, with natural gas the predominant current fuel used.



* The energy consumption was relatively low in 2014 compared to other years. This might be related to the very mild winter in Europe that year (59 Heating Degrees Days that compared to a 90 HDD average for the EU27), as a certain share of the energy use is related to building heating.

Source: FEFCO LCA studies (2021), CLIMACT analysis

On the other hand, the electricity intensity has been (slightly) increasing.

Mainly driven by new converting machinery which consumes more electricity for IT, automation, infrared drying, etc. …

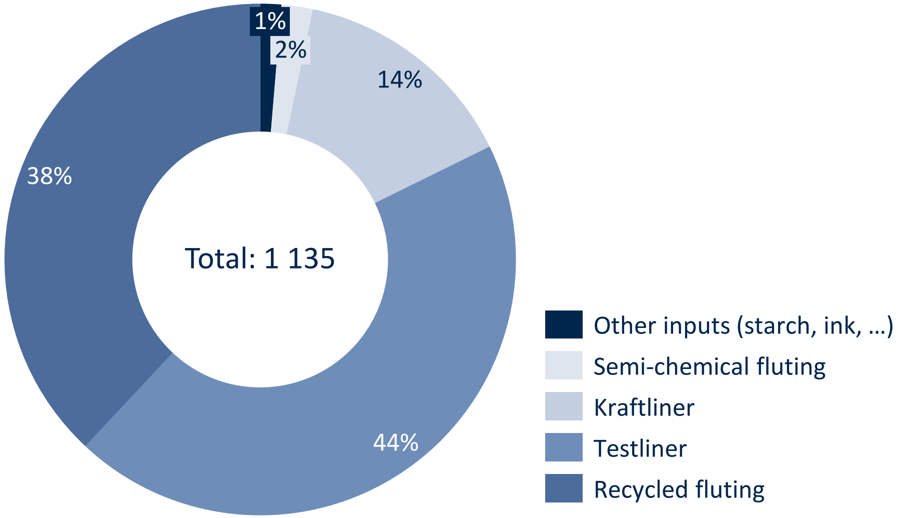
Grid electricity consumption
[in GJ/t nsp]

Source: FEFCO LCA studies (2021), CLIMACT analysis

Paper/containerboard is the predominant material input (99%) of total.

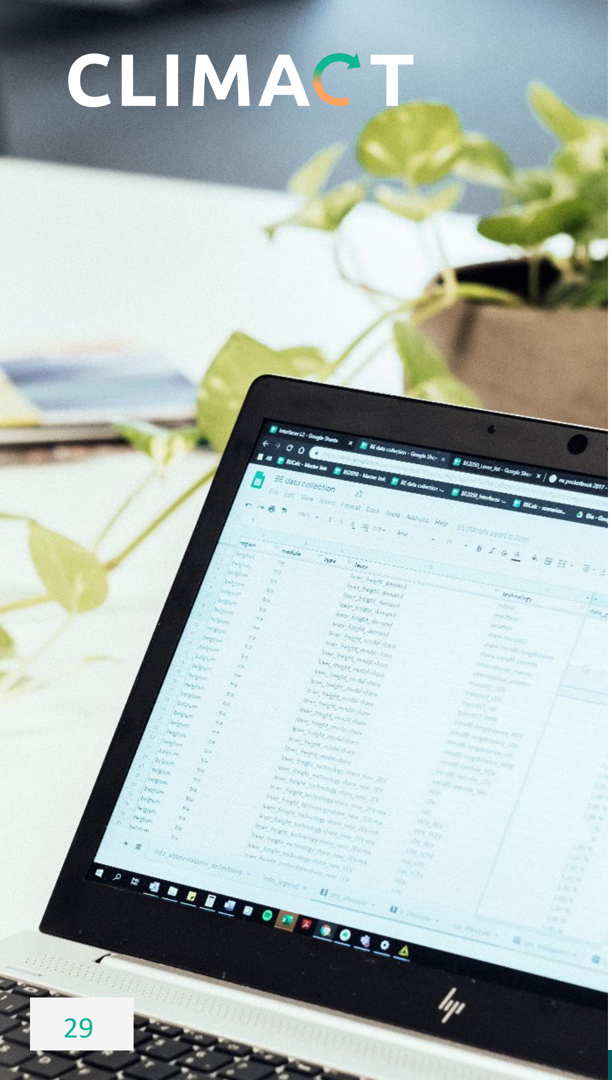
88% of which is recycled content

Material input
[in kg/t nsp]



* The % of recycled fibre is slightly higher as even ‘virgin’ paper grades (kraft, semi-chemical) contain a certain % of recycled fibres

Source: FEFCO LCA studies (2021)



The corrugated sector today

The vision: climate neutrality by 2050

- GHG emission under the different scenarios
- Energy use under the different scenarios
- Cost assessment

The roadmap to implement the vision

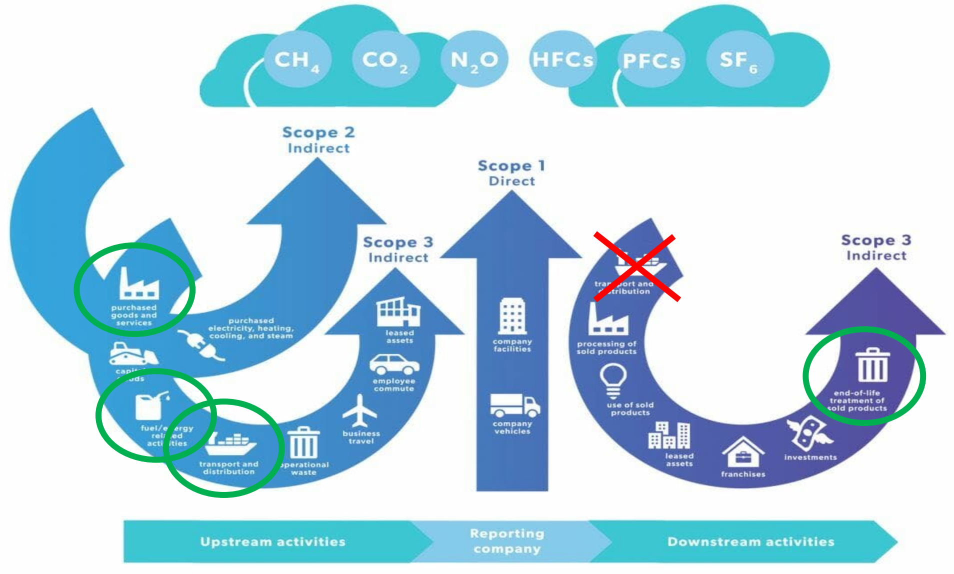
Technical Annex

The EU corrugated sector has the ambition to achieve climate neutrality by 2050.

This target englobes all major emission sources from scope 1 to scope 3

Upstream scope 3 emissions include:

- Purchased goods (paper, glues, ink, varnish, NaOH…)
- Upstream transportation
- Upstream energy emissions



Downstream scope 3 emissions include

- End of life treatment (incineration)
- Downstream transport is excluded due to lack of data, but estimated to be limited (< 5% of total) as corrugated plants are generally within a 250km radius of their clients.

Scope 1 and 2 emissions include all fuel, electricity and imported steam use within corrugated plants

To successfully achieve the Climate Neutrality Scenario, actions need to be taken across three complementary dimensions:

Climate neutral corrugated sector

Material efficiency and circularity

Key objectives

- Reduce required amount (m^2) and average weight (g/m^2) of corrugated packaging
- Increase recyclability and recycling of corrugated packaging
- Minimize material losses during the production process
- Improve product design

Energy measures

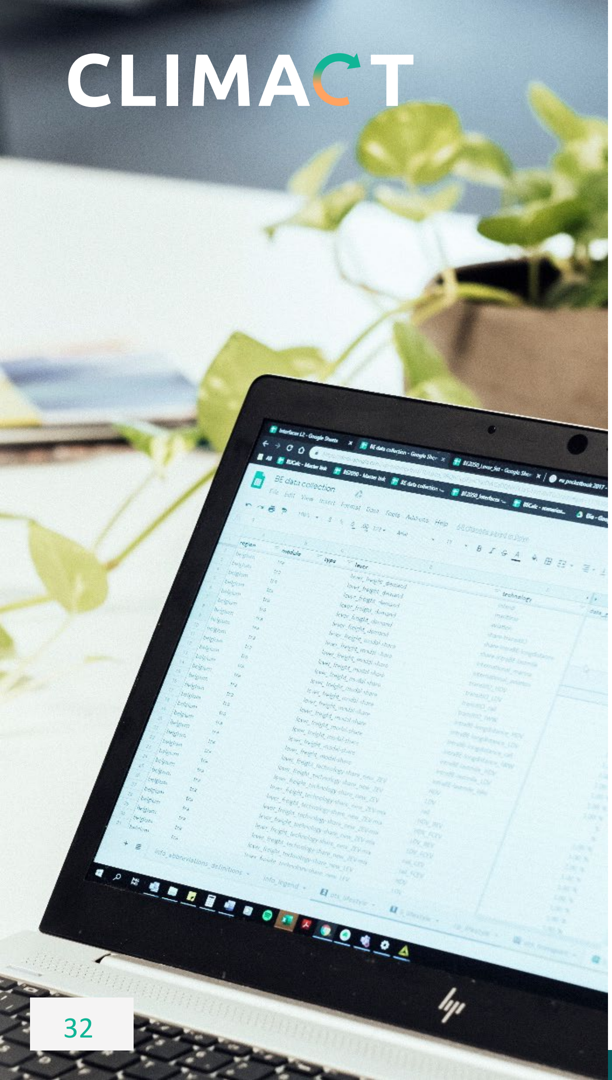
Key objectives

- Improve energy efficiency and reduce the amount of energy input required per unit of production
- Decarbonize the energy supply of the sector

Supplier engagement

Key objectives

- Decarbonize the main material inputs for the corrugated sector (mainly paper)
- Decarbonize the logistical chain
- Improve the (energy) efficiency of corrugating and converting machinery



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The vision: climate neutrality by 2050

- **GHG emission under the different scenarios**
- Energy use under the different scenarios
- Cost assessment

The roadmap to implement the vision

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To underpin the climate neutrality roadmap, four different scenarios were developed.

These scenarios cover the EU27 + UK + EEA countries. Turkey is not included in the roadmap.

Business as usual	This scenario simulates how the sector would evolve would no measures be implemented
Electrification	A climate neutral scenario with a heavy focus on electrification
Balanced	A climate neutral scenario with a balanced focus between electrification and the use of sustainable biofuels
Biofuel	A climate neutral scenario with a heavy focus on biofuel use

Main assumptions under the Business-as-Usual Scenario:

Production levels and material intensity

Production continues to increase by on average +1.3% p.a., reaching an annual production of 68 billion m² (or 34 Mt) in 2050.

The material intensity is assumed to remain constant.

Energy consumption and production

No further energy efficiency improvements beyond 2020.

The energy mix remains stable compared to 2020.

No further reduction of the electricity grid emission's intensity.

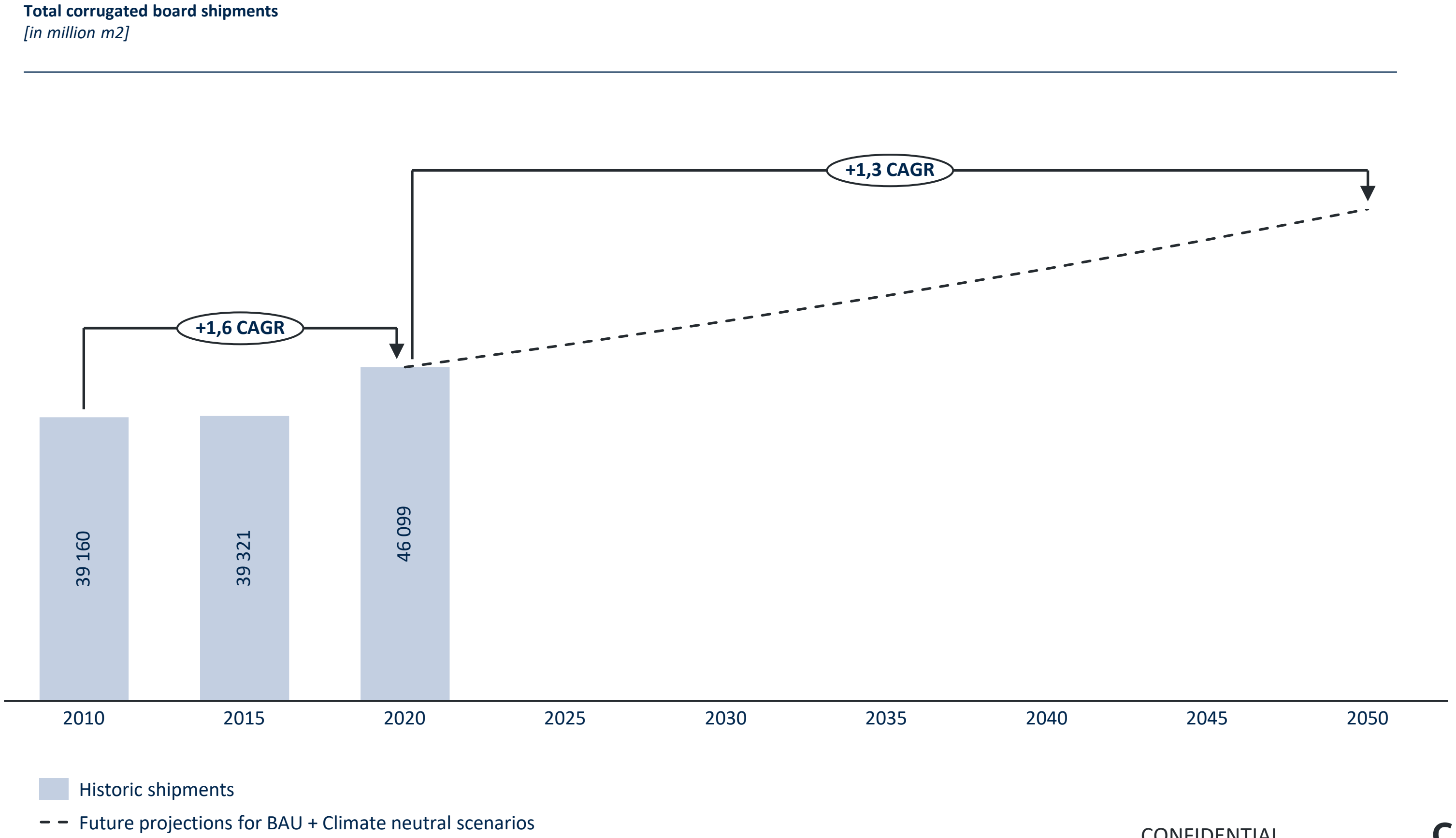
Paper emission intensity

No further reduction in the emission intensity of paper production beyond 2020.

Transport

Both covered distance, the modal split between transportation modes, and their specific emission factors remain unchanged until 2050.

Production growth is assumed to continue, but is expected to slow down over time as the market matures



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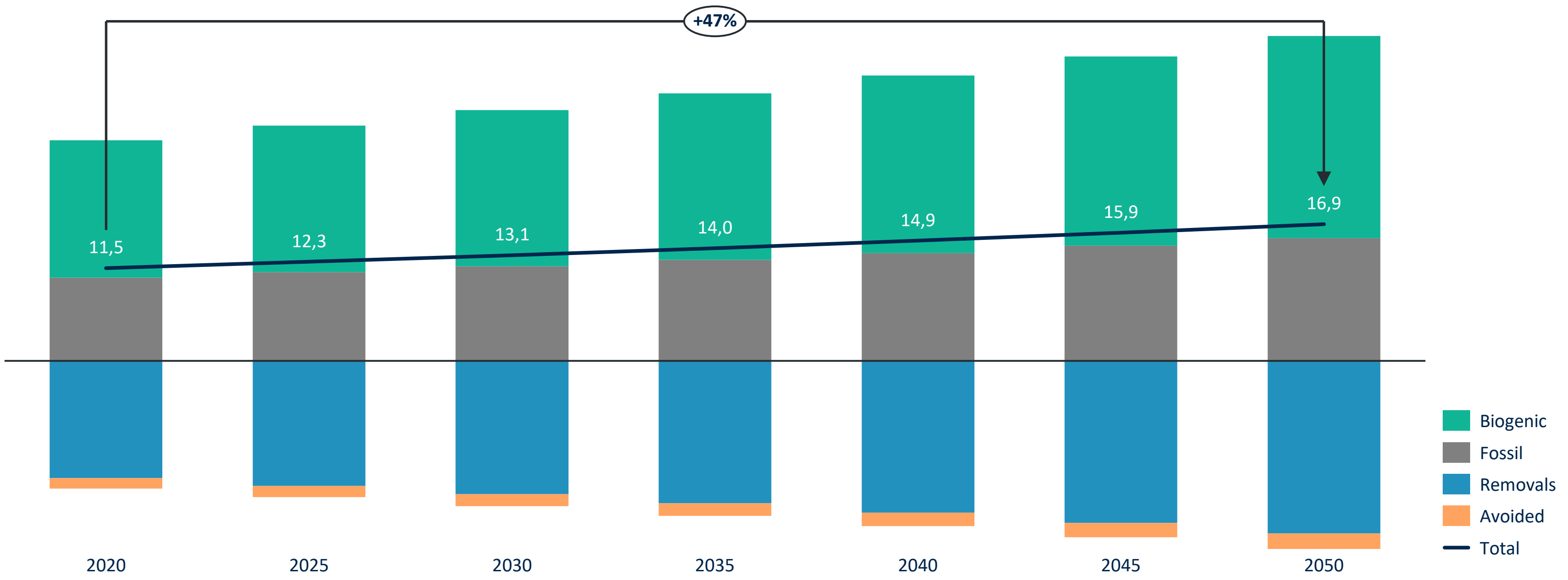
Under the Business-as-Usual scenario, emissions are projected to increase by +47% by 2050. This would be incompatible with the EU's climate neutrality objective

Projected GHG footprint of the corrugated sector – BAU

[in Mt $CO_{2eq.}$]



Three climate neutrality scenarios were explored. They differ mainly on the energy mix used.

Production levels and material intensity

Production volumes evolve as under the BAU scenario

However, the footprint is reduced by improvements in material efficiency:

- The average weight of corrugated board is reduced by 16,5% (-0,6% p.a.) by 2050. As a result, the total production volume decreases from 34,4 Mt under BAU to 28,7 Mt under the climate neutral scenarios
- Slight reduction of material losses during the production process (from 1.12 to 1.1 tonne of paper input per tonne output)

Paper emission intensity

The paper sector is assumed to reduce its (fossil) emission intensity by 80% by 2050 compared to 2050.

This corresponds to a reduction of 73,5% compared to 2020.

Energy production and consumption

The thermal energy required per tonne product reduces by 1.75% p.a.

The grid electricy required per tonne product reduces by 1.3% p.a. (including through renewable on site production)

The thermal energy mix is completely decarbonized by 2050, based on different energy mixes (see next slide)

The EU electricity grid assumed to be fully decarbonized by 2050.

Transport

Upstream transport is assumed to be fully decarbonized by 2050, through the switch to zero-emission vehicles and carbon-neutral fuels.

Reductions in transport distances and modal shifts could also contribute, but are not considered in the quantified scenarios.

Different pathways exist to decarbonize the sector's heat supply.

With electrification and sustainable biofuels as the most probable solutions

	Direct electrification	Biofuels	Hydrogen-based fuels	External (waste) heat
Pro's	• Suitable for the relatively low temperatures needed (< 200°C) • Flexible supply (easy ramp-up/ramp-off) • EU electricity grid could be fully decarbonized by 2050	• Can deliver both low- and high temperature heat • Could be considered climate-neutral (in case of sustainable biomass) • Biomethane could be used with existing infrastructure	• can deliver both low- and high temperature heat • Flexible • Can (partially) work through existing infrastructure (in case of blending) • Availability less susceptible to seasonality (compared to electricity)	• Valorisation of waste heat (e.g. from paper mill)
Con's	• Current heat pump technology not mature for higher temperatures. New high-temp heat pump types are under development, but require source of waste heat which is not common for the corrugated sector • Therefore mainly direct electrification via electric boilers, which are less efficient compared to heat pumps (but still more efficient compared to fuel boilers) • Economic viability ~ electricity prices • Feasibility ~grid capacity	• Solid biomass boilers are less flexible • Solid biomass requires local availability • Biomethane is currently a rare and expensive energy source	• Expected high costs, low availability vs. high demand from energy-intensive sectors (steel, chemicals, …) • Significant energy losses compared to direct electrification	• Local source of (waste) heat needed → not common as corrugated sector is dispersed • Carbon footprint depends on local heat source
Final	**High potential**	**Medium- to high potential**	**Low potential,** only for plants where direct electrification and/or biofuels are not an option	**Low potential,** only for some specific plants (e.g. nearby paper mills)

[1] The energy demand in a corrugating plant is very dynamic, and changes in function of shifts and production planning. Therefore, the chosen heating technology should allow for a flexible and dynamic supply.

CLIMACT

Which low-carbon energy source will be most available/affordable is uncertain. Therefore, three different climate-neutral scenarios are considered.

Focus on electrification

Electrification scenario:
- Heavy focus on electrification (75% of total demand)
- Remaining heat is supplied through combination of hydrogen (40%) and biofuels (60%)

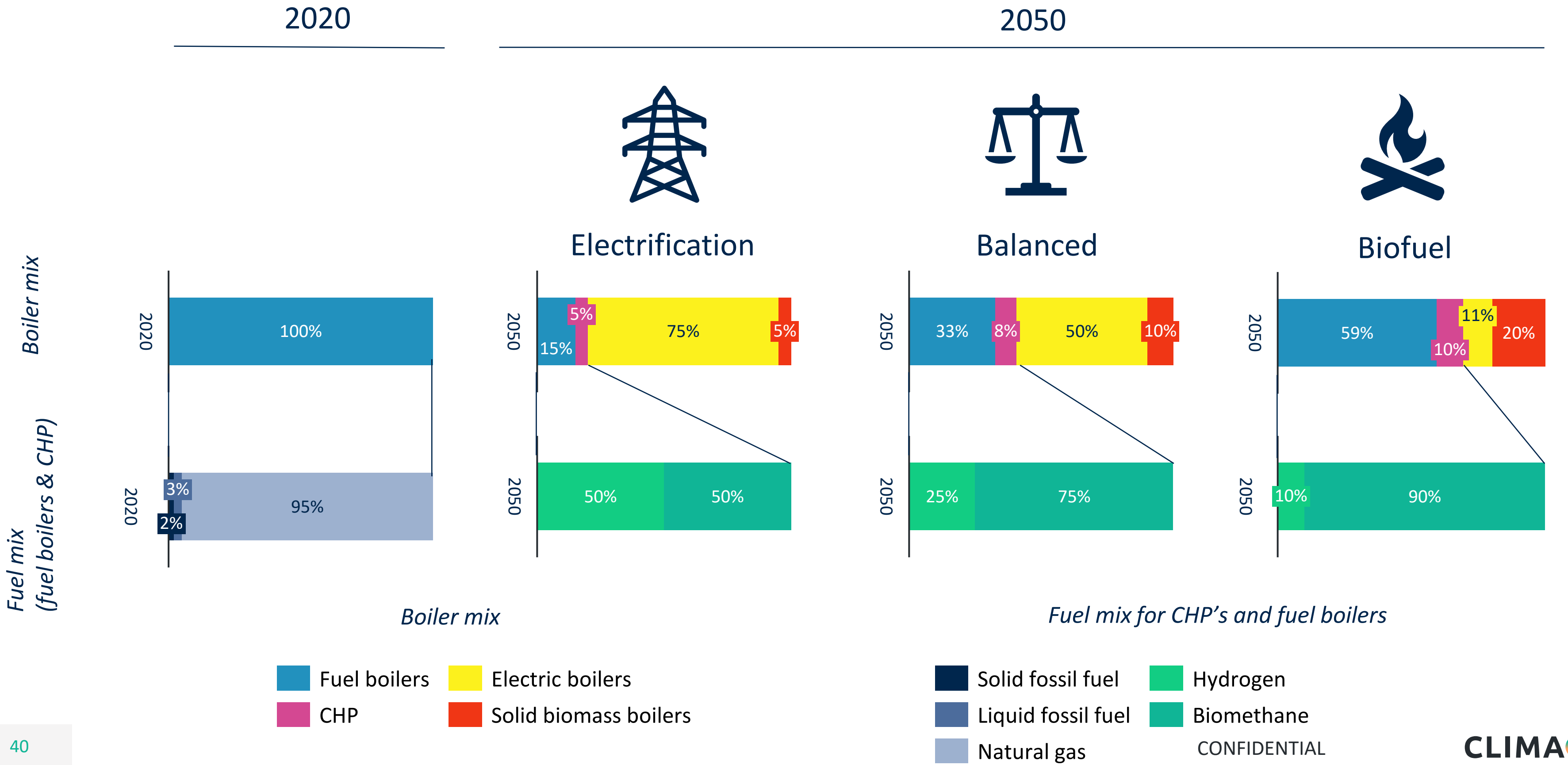
Balanced scenario
- Half of the heat (50%) is supplied by electric boilers
- 40% is supplied by biofuels (solid biomass and biomethane)
- 10% is supplied by hydrogen

Biofuel scenario
- Heavy focus on use of biofuels (82,5% of total supply)
- Remaining heat is supplied through combination of direct electrification (10%) and hydrogen (7,5%)

Focus on biomass

*Given the low current use and future potential, the use of external steam was not considered for the analysis.

The (thermal) energy mix in the three climate neutral scenarios differ in terms of boiler technologies and the fuel mix for CHP's and fuel boilers.



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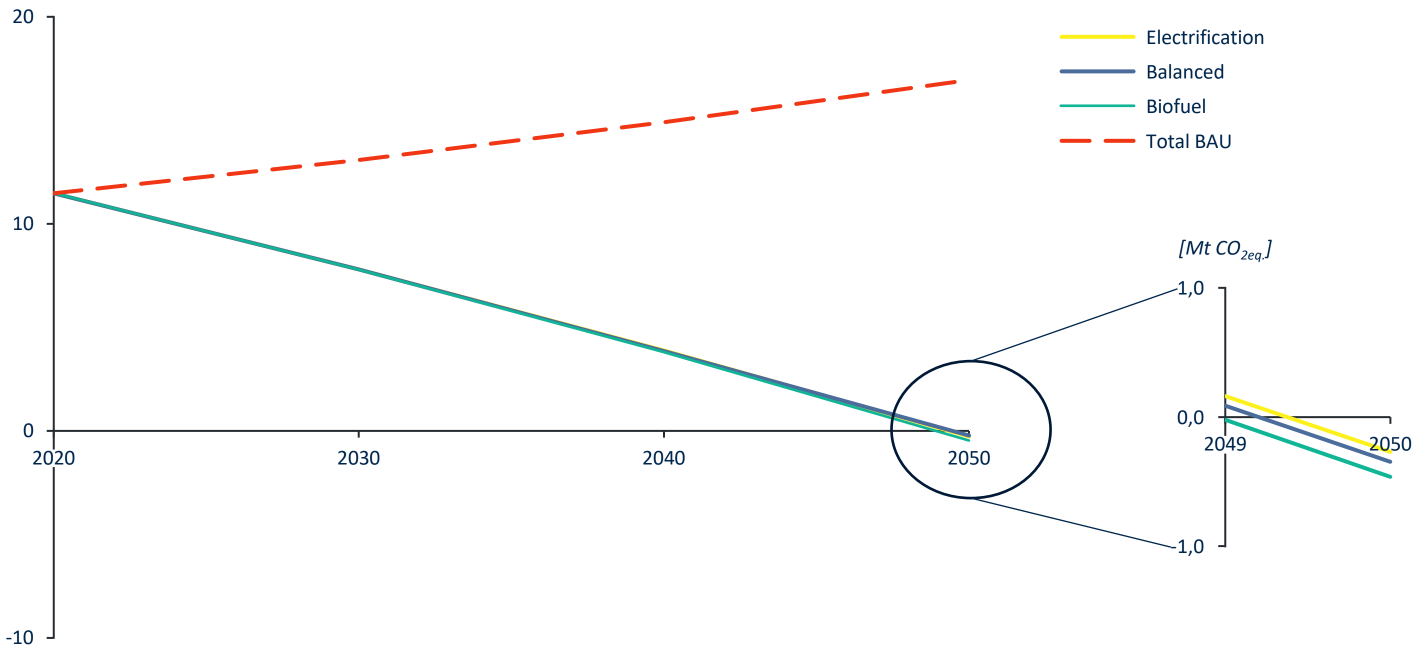
All Climate Neutral scenarios reach climate neutrality by 2050.

and -32% by 2030 compared to 2020

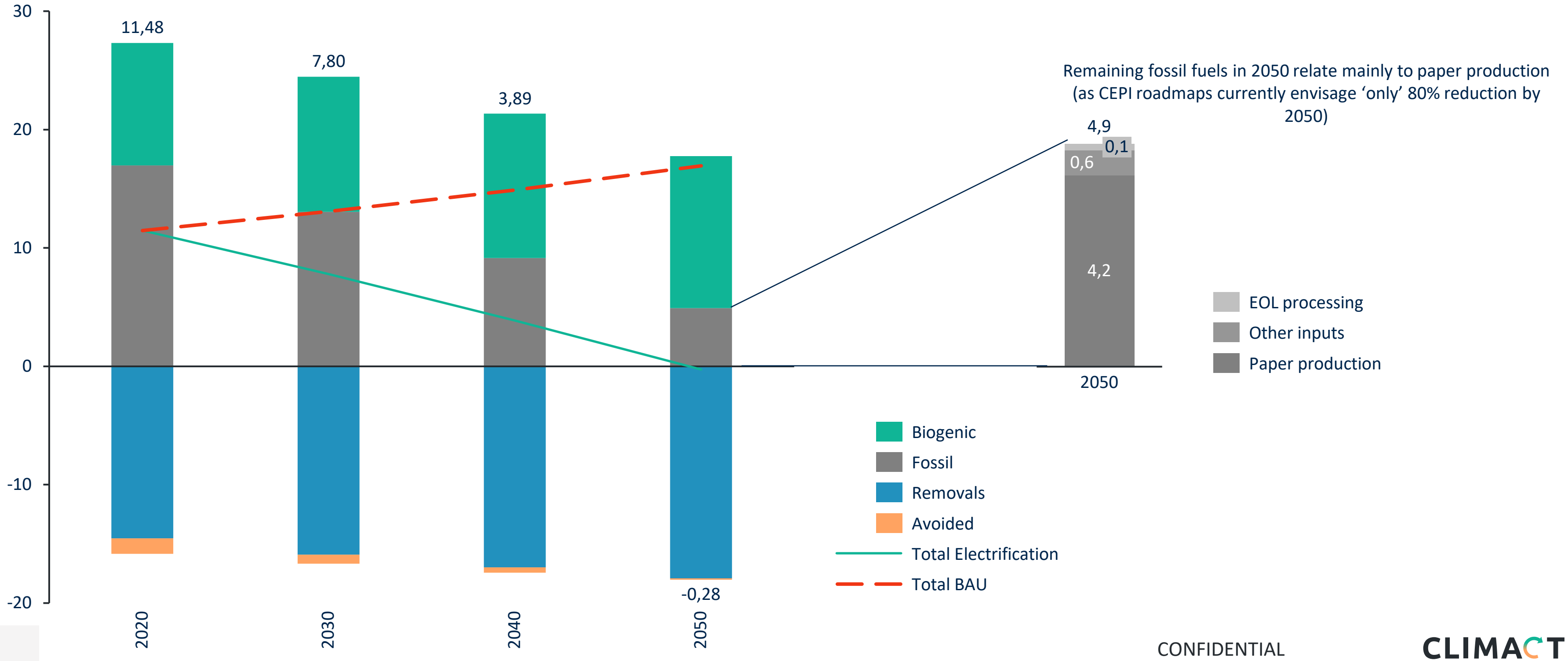
Projected GHG footprint of the corrugated sector in the different scenarios vs BAU
[in Mt $CO_{2eq.}$]



All Climate Neutral scenarios reach climate neutrality by 2050: electrification scenario.

and -32% by 2030 compared to 2020

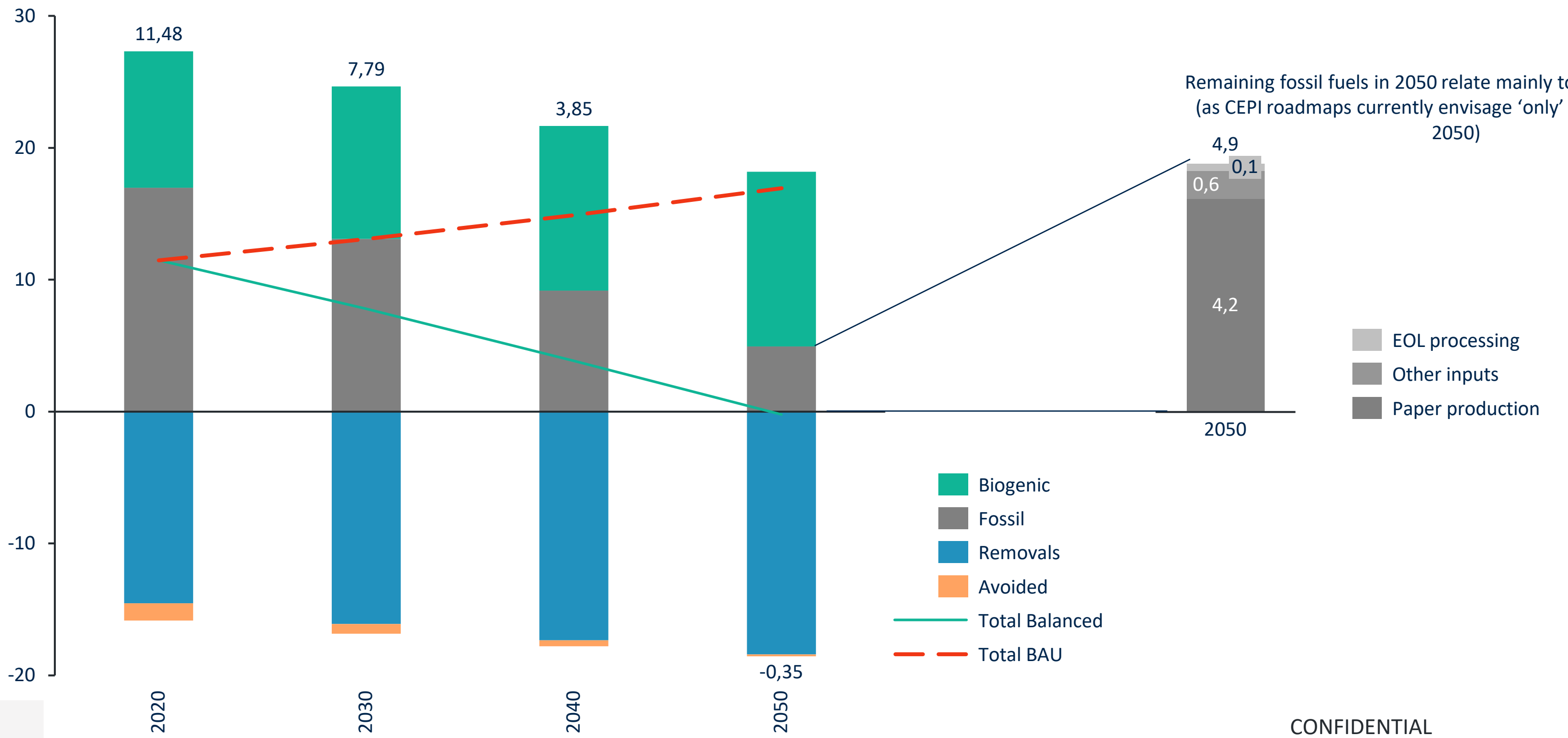
Projected GHG footprint of the corrugated sector in the "electrification" scenario vs BAU
[in Mt $CO_{2eq.}$]



All Climate Neutral scenarios reach climate neutrality by 2050: balanced scenario.

and -32% by 2030 compared to 2020

Projected GHG footprint of the corrugated sector in the "balanced" scenario vs BAU
[in Mt $CO_{2eq.}$]

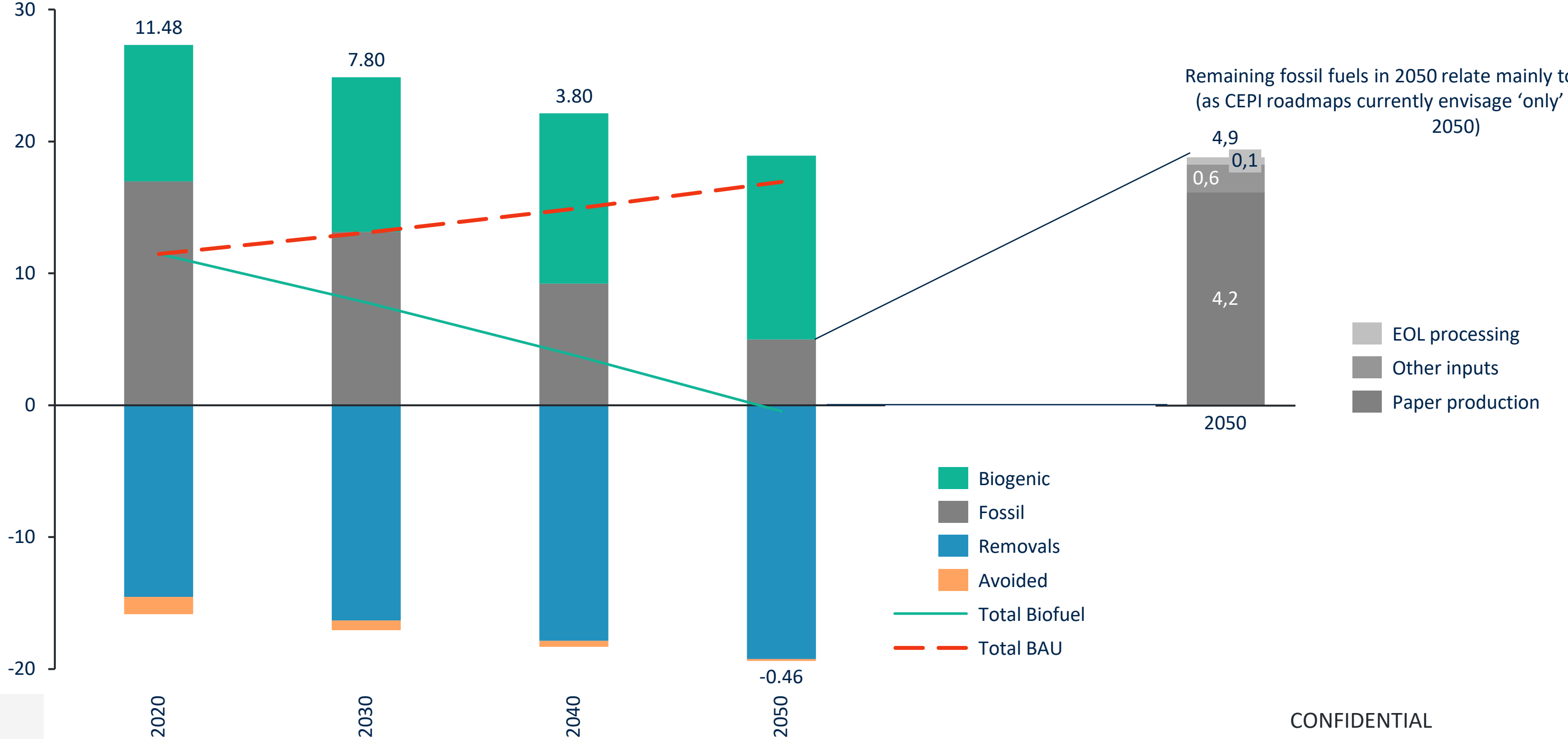


CLIMACT

All Climate Neutral scenarios reach climate neutrality by 2050: biofuel scenario.

and -32% by 2030 compared to 2020

Projected GHG footprint of the corrugated sector in the "biofuel" scenario vs BAU
[in Mt $CO_{2eq.}$]



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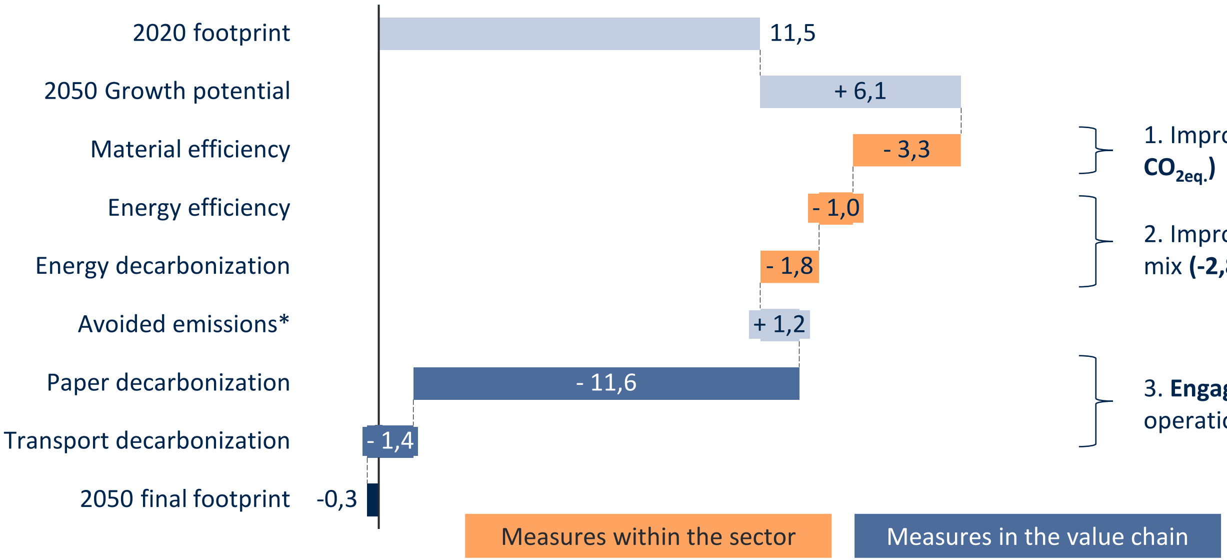
Three key types of actions will be required to achieve the climate neutrality objective.

Bulk of reductions need to be realized in the (upstream) value chain: paper and transport

Contribution of each type of measure towards climate neutrality
[in Mt $CO_{2eq.}$]

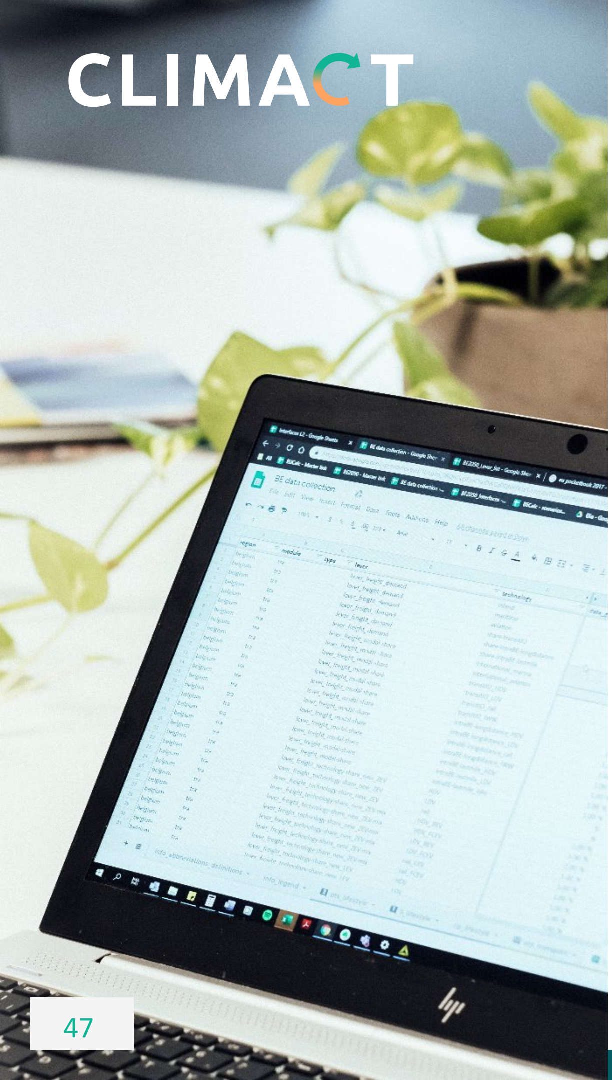


1. Improve **material efficiency and circularity (-3,3 Mt $CO_{2eq.}$)**

2. Improve **energy efficiency** and **decarbonize** the energy mix **(-2,8 Mt $CO_{2eq.}$)**

3. **Engage with (upstream) suppliers** to make their own operations climate-neutral **(-13 Mt $CO_{2eq.}$)**

* Avoided emissions refer to the emissions related to fossil-based power generation which is avoided elsewhere in the economy due to energy recovery at the EOL stage (incineration). Because under the climate neutrality scenario it is assumed that the EU electricity grid is fully decarbonized by 2050, these avoided emissions drop to 0, resulting in a 'loss' of avoided emission compared to the BAU scenario.



The corrugated sector today

The vision: climate neutrality by 2050

- GHG emission under the different scenarios
- **Energy use under the different scenarios**
- Cost assessment

The roadmap to implement the vision

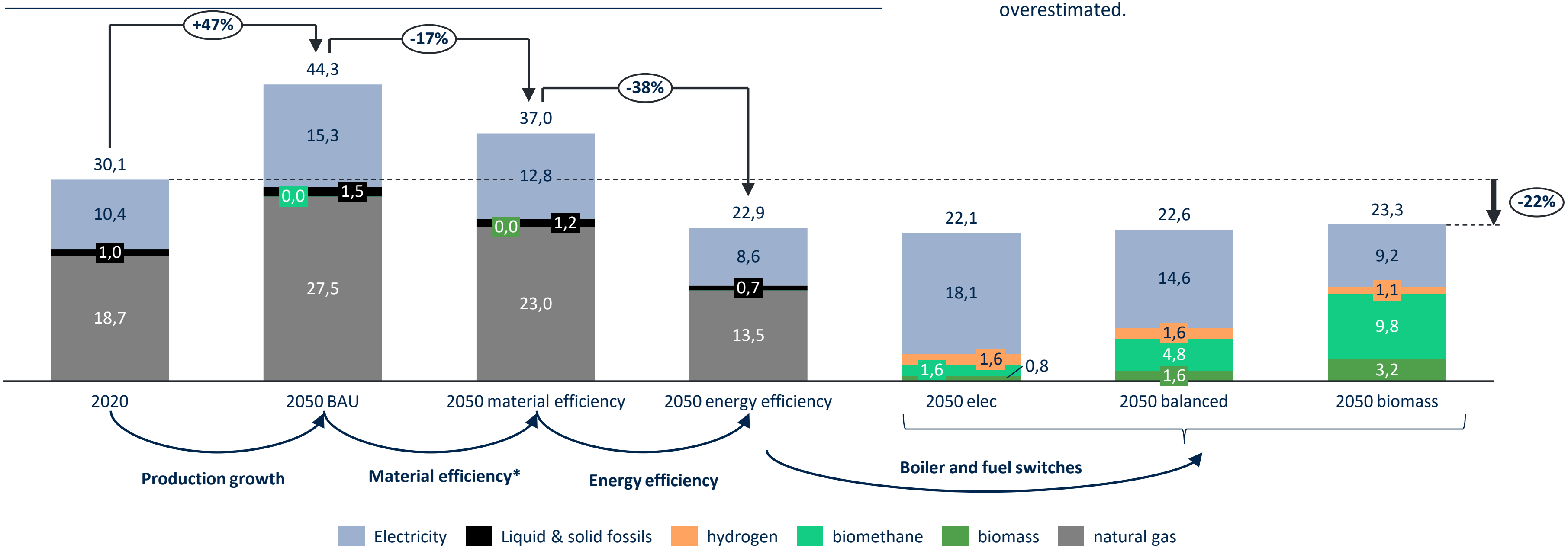
Technical Annex

Ambitious efficiency improvements allow to reduce total energy consumption while increasing production…

Required measures are described in more detail in the next chapter

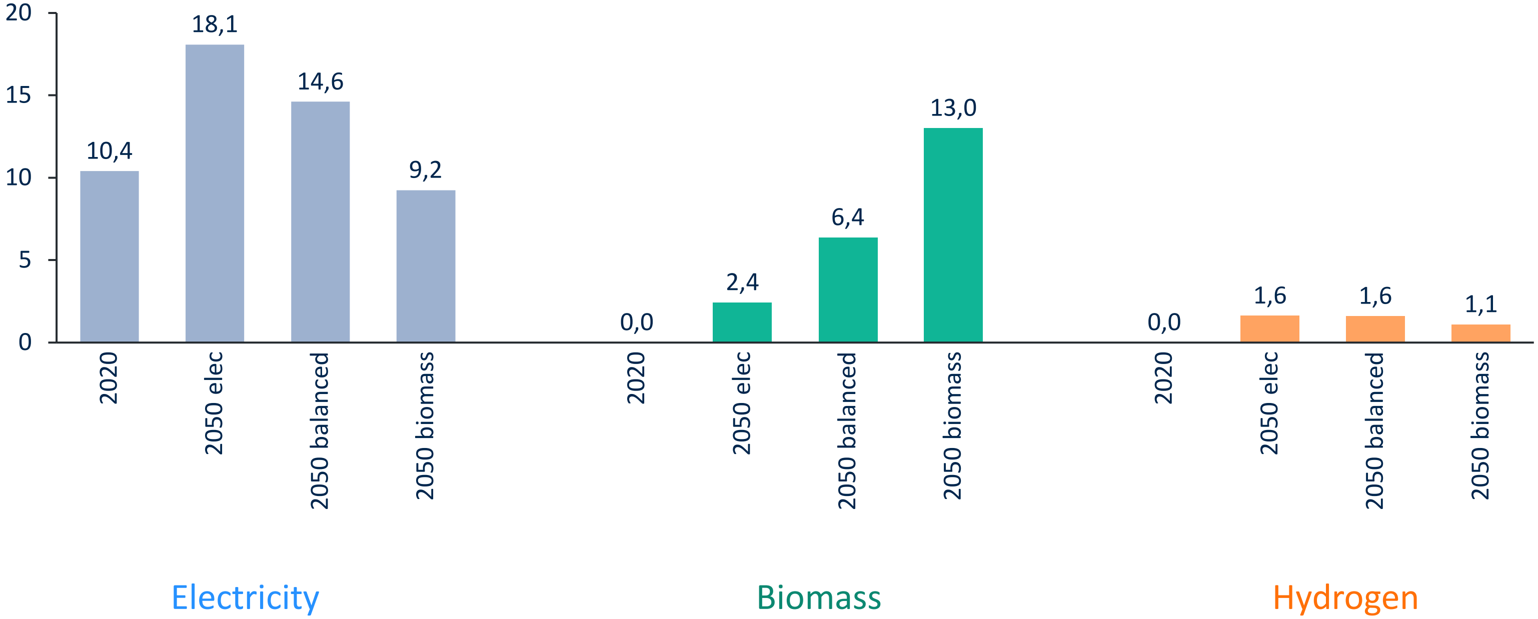
Projected energy consumption in the corrugated sector
[in PJ]

* Material efficiency decreases energy consumption as specific energy consumption is defined in GJ/t product. In reality, energy consumption is partly linked to the tons of packaging produced, but also partially to the volume (m^2) of packaging produced. Therefore, the impact of material efficiency on energy consumption might be overestimated.



… but demand for climate-neutral energy carriers would increase significantly.

Projected energy consumption in the corrugated sector
[in PJ]



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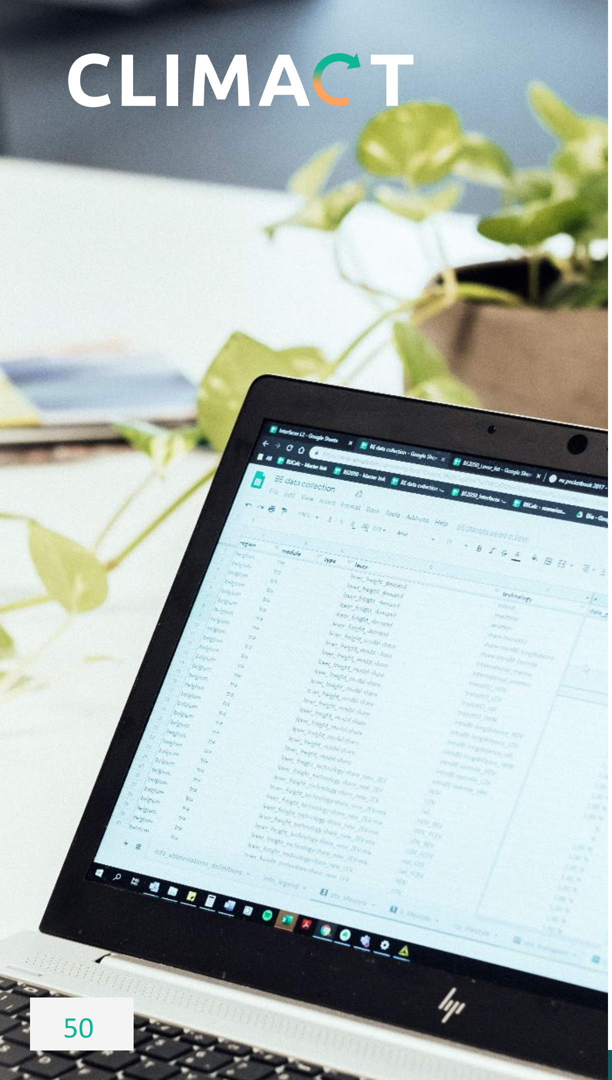


The corrugated sector today

The vision: climate neutrality by 2050

- GHG emission under the different scenarios
- Energy use under the different scenarios
- **Cost assessment**

The roadmap to implement the vision

Technical Annex

<u>Disclaimer</u>: cost projections were calculated prior to the war in Ukraine, and before the high increase in prices for natural gas, fossil fuel, etc.

Different price trajectories were used for the different scenarios

Cost projections are highly uncertain. In this cost assessment, this uncertainty is taken into account by providing for each cost factor a lower and higher range for the expected price increase (or decrease) by 2050.

Scenario	Description
Higher range decarbonization	This cost scenario projects the highest expected costs, in the case of a decarbonization scenario
Lower range decarbonization	This cost scenario projects the lowest expected costs, in the case of a decarbonization scenario
Business as usual	This cost scenario simulates how the total costs would evolve with no decarbonization measures implemented

Used for estimating the upper and lower range for the three **decarbonization scenarios**

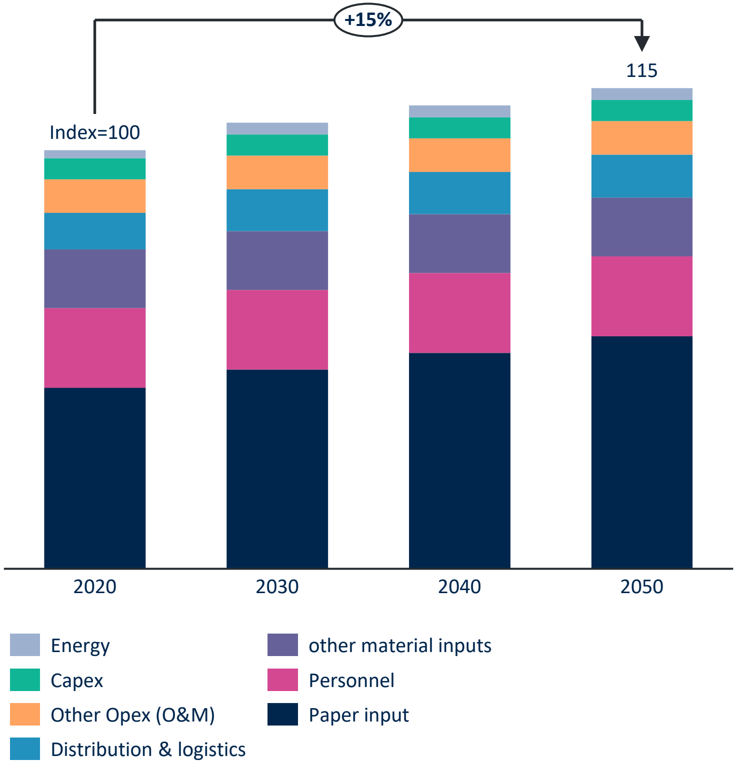
Detailed assumptions in the appendix[1]

1. Refer to the technical annex (slides 106-126 of the present presentation)

Under business as usual, production costs to increase by 15% by 2050 (in €/t nsp, excluding inflation).

Production costs corrugated packaging

[in €/t nsp]



Main cost components	Impact on €/t nsp	Underlying trend
Paper purchases	+12.3%	*Higher paper prices, mainly driven by higher carbon prices and lower allocations under the EU ETS*
Transport costs	+1.6%	*Driven by higher diesel prices in accordance with the IEA Stated Policies scenario. No carbon price assumed*
Energy costs	+0.9%	*Stabilization of natural gas prices at €70/MWh after 2025, and increasing carbon price on electricity production towards 2050*

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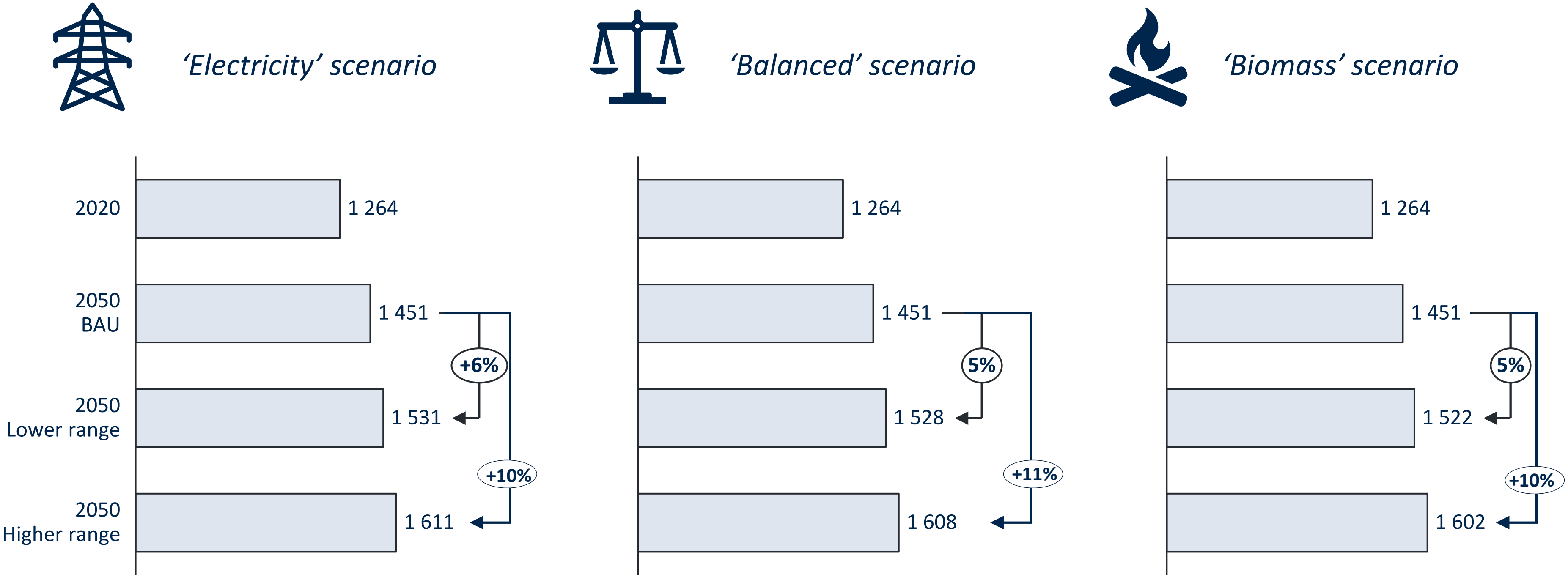
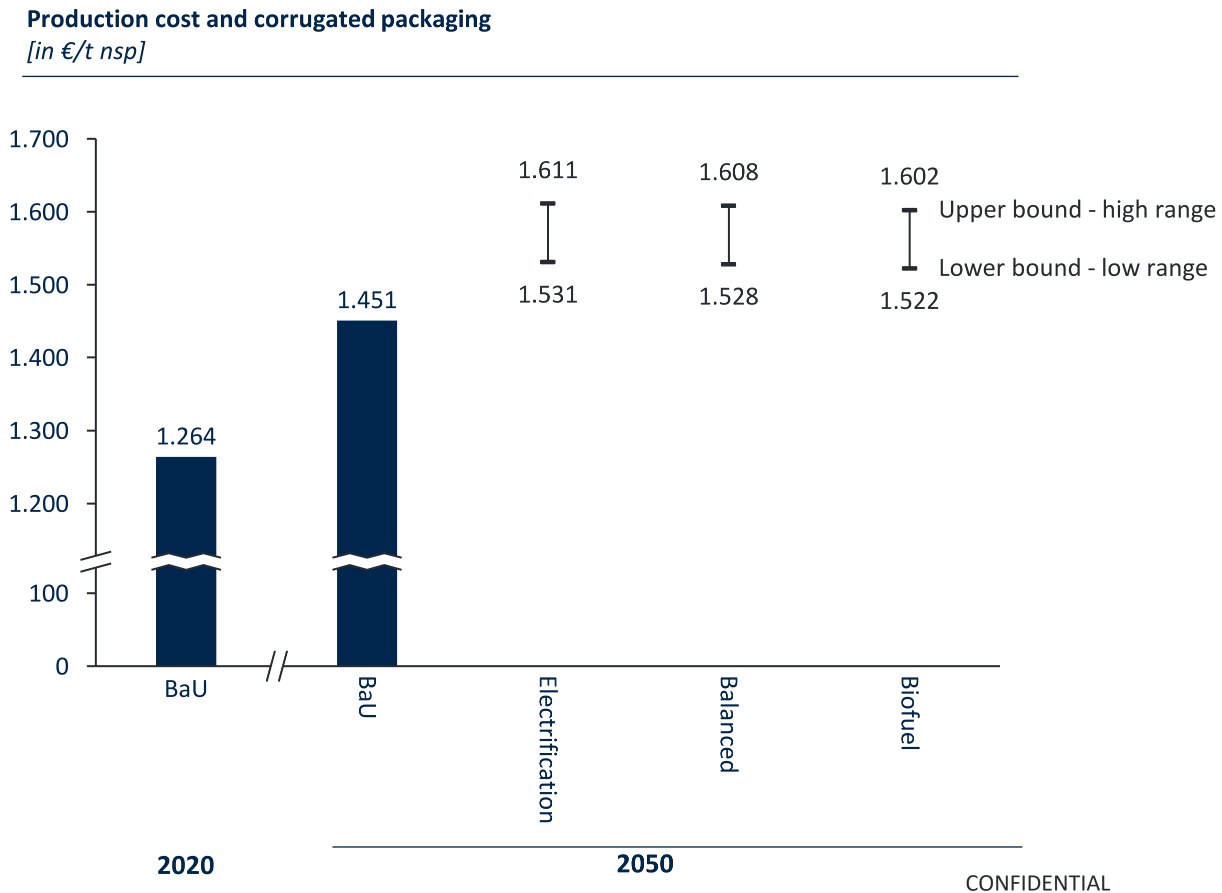
Production costs increase further under the different Climate Neutrality scenario (+5% to +11% compared to BAU in 2050).

Production costs corrugated packaging
[in €/t nsp]



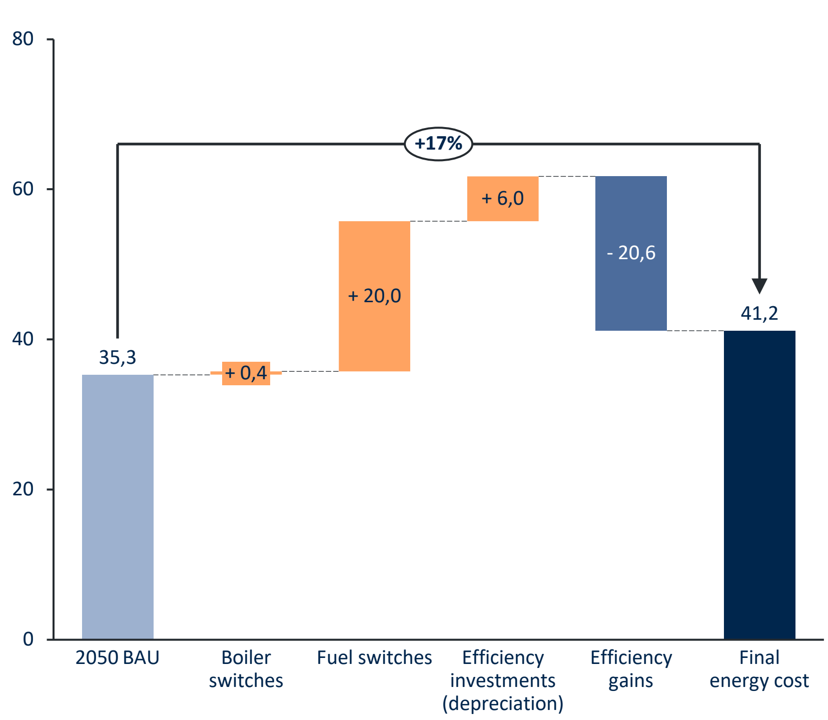
CLIMACT

Production costs increase further under the different Climate Neutrality scenario.

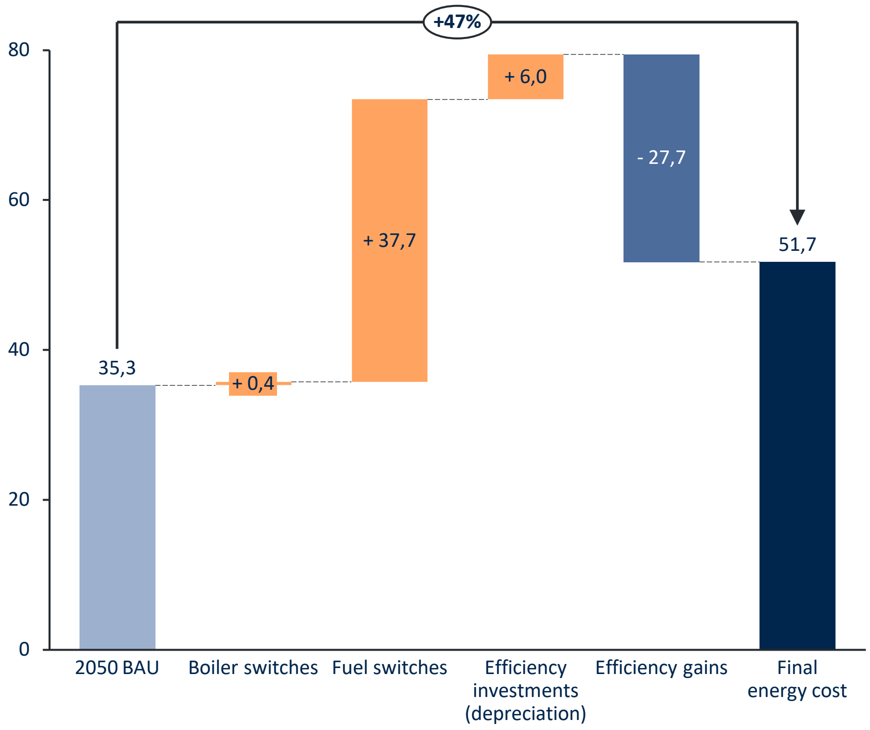


Energy costs would overall increase compared to BAU, although most of the increase can be compensated by efficiency improvements.

Energy cost - Lower range (balanced scenario)
[€/t nsp]

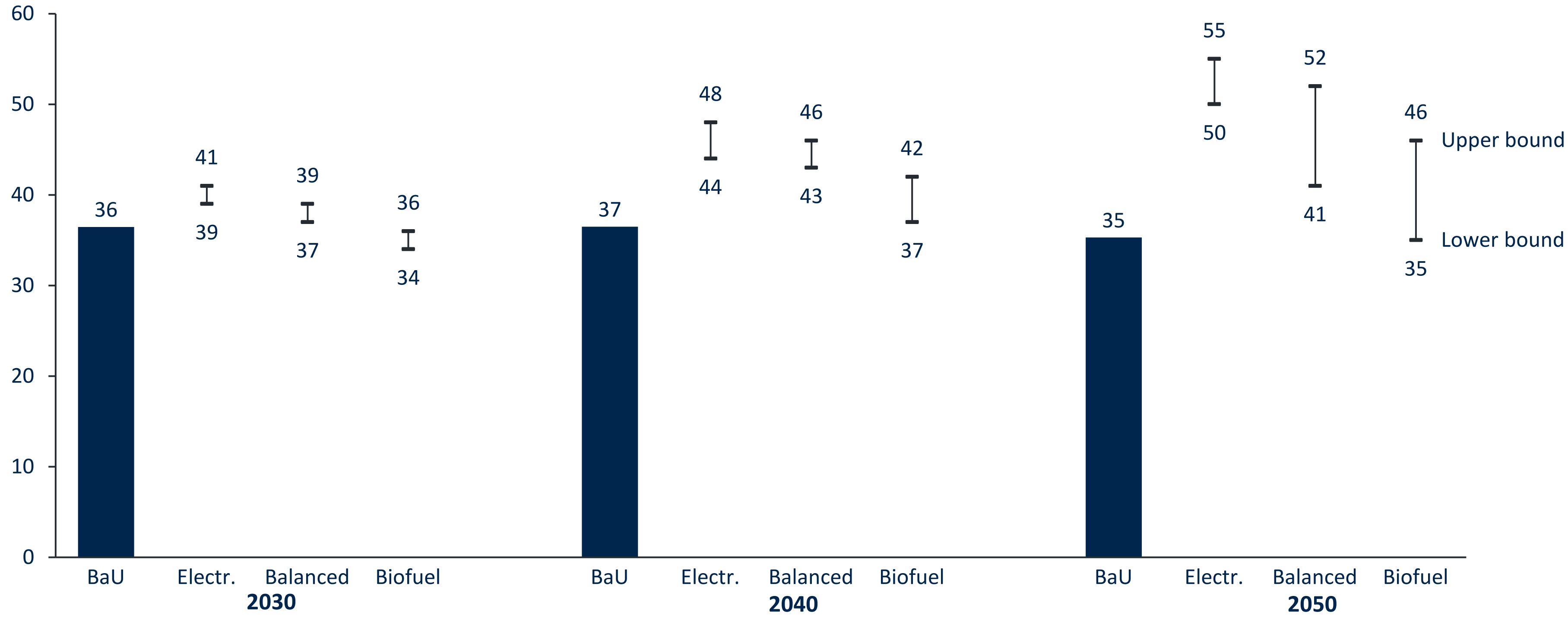


Energy cost - Higher range (balanced scenario)
[€/t nsp]



The cost for energy use are projected to be higher in all climate neutral scenarios. Effective energy costs are highly dependent on (uncertain) availability and prices.

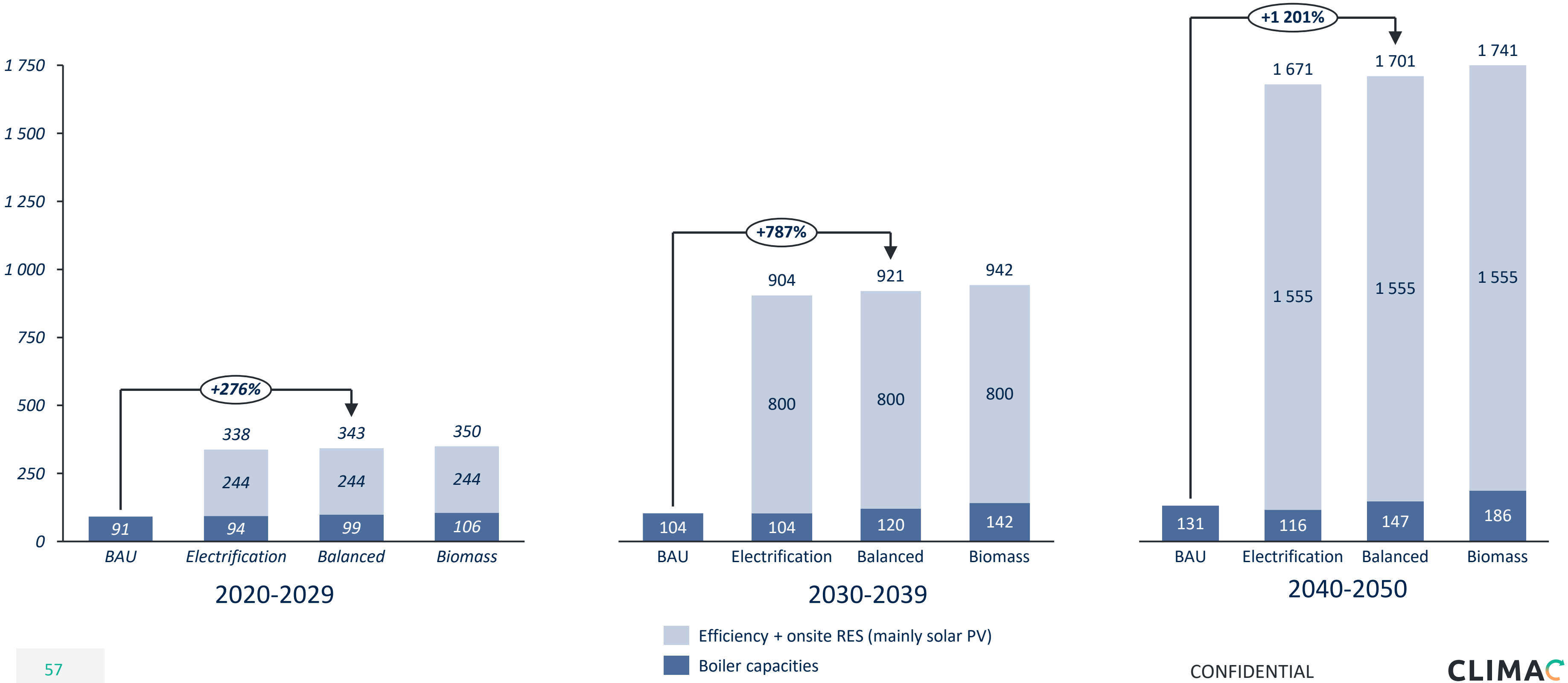
Energy costs
[in €/t nsp]



Energy-related CAPEX needs to be increased significantly compared to BAU.

Mainly investments in efficiency improvements, which help to reduce boiler-related CAPEX

Cumulative energy-related CAPEX requirements
[in € million, annualized, excluding inflation]



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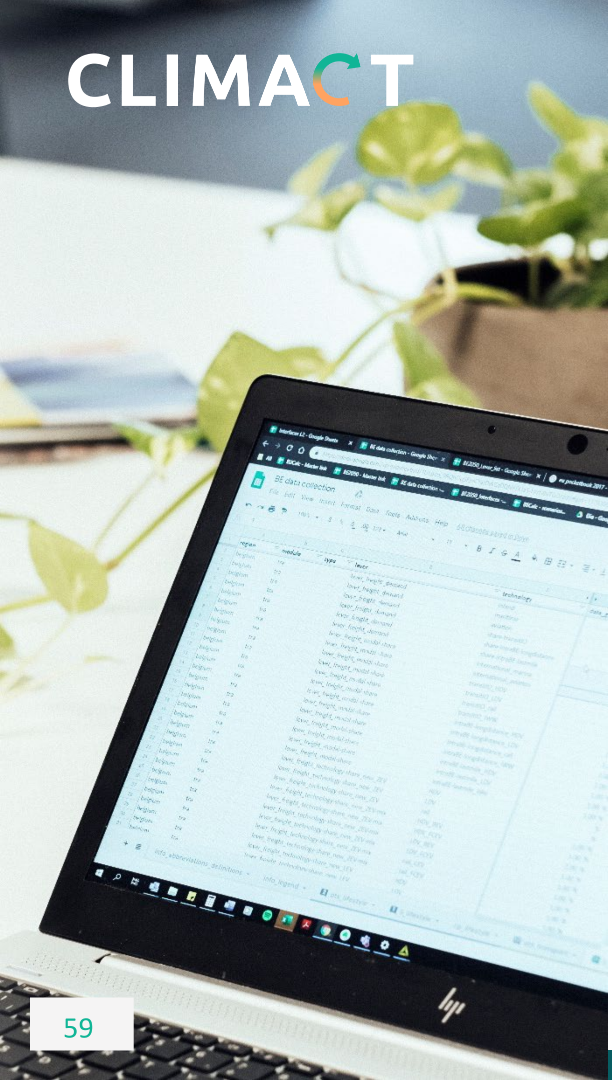

The corrugated sector today

The vision: climate neutrality by 2050

The roadmap to implement the vision

- **Main actions to take by the corrugated sector**
- Main actions to take by other stakeholders

Technical Annex

To successfully achieve the Climate Neutrality Scenario, actions need to be taken across three complementary dimensions:

Climate neutral corrugated sector

Material efficiency and circularity

Key objectives

- Reduce required amount (m^2) and average weight (g/m^2) of corrugated packaging
- Increase recyclability and recycling of corrugated packaging
- Minimize material losses during the production process
- Improve product design

Energy measures

Key objectives

- Improve energy efficiency and reduce the amount of energy input required per unit of production
- Decarbonize the energy supply of the sector

Supplier engagement

Key objectives

- Decarbonize the main material inputs for the corrugated sector (mainly paper)
- Decarbonize the logistical chain
- Improve the (energy) efficiency of corrugating and converting machinery

A five-pronged approach to improve material efficiency and circularity in the sector.

1. An integrated approach
2. A focussed approach
3. Optimized design in an optimized supply chain
4. Optimized operations
5. Supporting broader sustainable trends

A five-pronged approach to improve material efficiency and circularity in the sector.

1. An integrated approach
2. A focussed approach
3. Optimized design in an optimized supply chain
4. Optimize operations

The **sustainability of packaging** can be assessed and measured against **several criteria,** such as the carbon footprint, the share of recycled and renewable content, the degree of recyclability, reusability and/or biodegradability, the material efficiency, etc. …

Solutions for one dimension can have a **positive (creating synergies**) or **negative (creating trade-offs**) impact on other dimensions. Therefore, the corrugated sector has the ambition to apply an **integrated approach towards sustainable design,** rather than looking at each dimension in isolation.

To implement such an integrated approach, the following steps can be applied:

1) Identify and select **key criteria/sustainability dimensions** against which the performance of packaging solutions is assessed.
2) For each criterium, develop **clear metrics** which **allow to measure and report** the sustainability performance of different design options on different dimensions in a transparent and comparable way.

Such an approach allows to easily assess and compare different design options, identify synergies, trade-offs and room for improvement, and to engage with clients to find optimized solutions.

A five-pronged approach to improve material efficiency and circularity in the sector.

1. An integrated sustainability approach
2. **A focussed approach**
3. Optimized design in an optimized supply chain
4. Optimize operations

The corrugated sector produces a **wide variety of packaging solutions** for a **wide variety of clients and product groups**. Revising and optimizing designs for a whole range of packaging solutions at once is not always practical or efficient. A common approach is to focus on the largest runners first (Pareto Principle 80/20 rule – 20% of the specs provide 80% of the volume). This is particularly the case for smaller companies with small design teams and limited capacities[1]. It should also be noted that the customer also needs people and time internally top plan, test and implement any changes.

The sector will therefore **focus its design optimization efforts** on those market segments with **highest improvement potential**. This includes market segments which require **large volumes** of packaging material, with a **large margin of improvement**, and whose requirements are expected to remain **relatively stable over a longer time period**.

Priority market segments to target are FMCG's (Fast Moving Consumer Goods), e-commerce and produce (fresh foods that are transported in large quantities, such as fruits, vegetables, …)

[1] almost 400 different corrugated companies are currently active in the EU, ranging from small local companies to large international groups.

A five-pronged approach to improve material efficiency and circularity in the sector.

1. An integrated sustainability approach
2. A focussed approach
3. Optimized design in an optimized supply chain
4. Optimize operations

The main goal of **packaging design** is to ensure that **the minimum requirements** as asked by the client (strengths, humidity resistance, …) are met. Within this boundary condition, design can be further **optimized to improve the material efficiency and circularity** of corrugated packaging.

The minimum requirements for packaging solutions are determined by **the downstream supply chain**. Therefore, **optimized design needs to be embedded in an optimized supply chain**. To this end, the sector will (continue to) apply the following approach:

1) First step is to **fully map and understand** the client's supply chain end-to-end
2) Second step is to **optimize the supply chain to reduce the minimum requirements** where possible. Often, small changes within the supply chain can significantly reduce those requirements (and therefore, improve the sustainability of packaging solutions)
3) Third step is to **explore multiple design options**, and to select that option which meets the minimum requirements at the **best possible sustainability performance**.

The approach described above requires the sector to **actively engage with its clients** to jointly explore bottlenecks and possible solutions. Clear metrics (as described under point 1) can **support discussions** with clients to identify areas of improvement, synergies and trade-offs.

One particular priority in the design of corrugated packaging is to further **increase the recyclability** of packaging products (**see next slide**).

A five-pronged approach to improve material efficiency and circularity in the sector.

1. An integrated sustainability approach
2. A focussed approach
3. Optimized design in an optimized supply chain
4. Optimize operations

Designing for recyclability

One of the major advantages of corrugated packaging is that it can be **easily recycled** and is already **recycled at a very high rate**. Between 86% and 96% of all corrugated packaging products are recycled at their end-of-life.

Further improvements to both the recycling rate as the recycling quality (reusing fibres for purposes with highest added value) can be gained by **efforts of the industry, clients, end-consumers and policy makers**. To this end, FEFCO and its members aim for the following solutions:

1) The **use of non-recyclable materials** in packaging needs to be **avoided** wherever possible. This can be done by using new, innovative, fibre-based solutions and/or revising client needs
2) In case the use of non-fibre material is unavoidable, **the separation of different materials** at end-of-life needs to be **facilitated through design**. This can be done by making those materials **easily separatable** + by **printing guidance on packaging** products on how to separate and sort the different components
3) Finally, end-consumers need to be further promoted to properly recycle packaging products at end-of-life. This would require **information and awareness campaigns**, as well as **sufficient infrastructure** to facilitate sorting.

A five-pronged approach to improve material efficiency and circularity in the sector.

1. An integrated sustainability approach
2. A focussed approach
3. Optimized design in an optimized supply chain
4. Optimized operations

Once the design has been finalized, a final step is the optimization of operations to avoid quality losses and/or material losses during the production process. Specific measures that are already common in the sector include:

- **Quality assurance procedures:** quality checks are performed at different stages of the production process: on the main input materials (containerboard, starch), on the corrugated board leaving the corrugator and on the final packaging product leaving the convertor line. This enables the sector to guarantee the performance of the final packaging product (reducing the need for over dimensioning)
- **Optimized planning:** both corrugators and paper rolls have a fixed width, leading to a cutting stock problem (standard-sized inputs need to be cut to specified sized, resulting in trim losses). The sector has a decades-long experience with planning optimization to reduce such trim losses, including by combining different production orders (= “deckling”). Further improvements could be achieved by integrating this dimension already in the design phase, that is by designing products as such that they facilitate optimal deckling.

A five-pronged approach to improve material efficiency and circularity in the sector.

Trade-off between standardization and tailor-made design

One of the key trade-offs that need to be made by the corrugated sector is how to balance between standardization and tailor-made solutions:

- **Standardization** has the advantage that it can facilitate **optimized processes and planning**. For example, the least variation in products a plant produces, the better it can optimize the design and operations to minimize trim losses during the production process. It would also allow faster corrugator speed which reduces the average energy consumption. On the other hand, standardization inevitably results in some **overdimensioning**, both in volume as in strength, which increases the material and energy required.
- **Tailor-made solutions** are the **other side of the same coin**: they allow to avoid overdimensioning and therefore reduce the required material and energy. However, they also make production processes more complicated and therefore harder to optimize. This in turn leads to higher energy needs and increased material losses during the production process.

One approach is not necessarily preferable over the other. Each plant needs to make a **continuous trade-off** between both options to provide the most sustainable and cost-effective solutions to its customers.

A five-pronged approach to improve material efficiency and circularity in the sector.

5. Supporting broader sustainable trends

In parallel to the 4 steps described so far, there are some **broader societal trends** which allow the corrugated sector to further reduce its climate footprint. These include the increased **use of reusable (e.g. refillable) or bulk packaging**. These trends could accelerate in the future driven by policies and/or customer preferences.

The sector has the ambition to **support these trends** by developing sustainable, corrugated solutions for reusable and bulk packaging. However, it is important to assess the benefits of reusable packaging **a case-by-case** basis, as **trade-offs or unintended consequences** might occur:

- reuse could **increase the energy intensity** due to additional transport and processes for control/cleaning
- Reuse could also **increase the material intensity**: to allow reuse, packaging would need to be stronger + more standardised (which inevitably leads to some over dimensioning)
- Reusability might also require the **increased use of non-fibrous materials,** which would reduce the recyclability of the packaging product.

Therefore, a case-by-case assessment is recommended. Using metrics as described in step 1 would allow to transparently compare different packaging solutions along different criteria, and therefore identify synergies and trade-offs.

Eight groups of actions need to be activated to reduce the sector's energy-related carbon footprint.

Dimension	Lever	Action group	Examples of steps to take
Energy efficiency	Thermal efficiency	1. Heat system (boilers + piping)	Use of condensate return, valorisation of flue gas heat, steam pipe insulation, air pressure controls, …
		2. Corrugator	Better control of heat and starch application. Develop standards + benchmarks for corrugator efficiency
		3. Breakthrough techs	Support research into alternatives to starch which require lower temperature and water use
	Electric efficiency	4. Convertor line	Develop standards + benchmarks for converting machinery
		5. Auxilaries	LED lighting, compressed air leak detection & prevention, conveyor belt transport, …
Energy decarbonization	Heat decarbonization	6. Boiler switches	Switch from natural gas to electric boilers, heat pumps, solid biomass boilers or CHP's, and/or use external steam imports
		7. Fuel switches	Within fuel boilers and CHP's, switch from natural gas to biomethane or (green) hydrogen
	Electricity decarbonization	8. Onsite PV production	Produce onsite renewable electricity via PV installation

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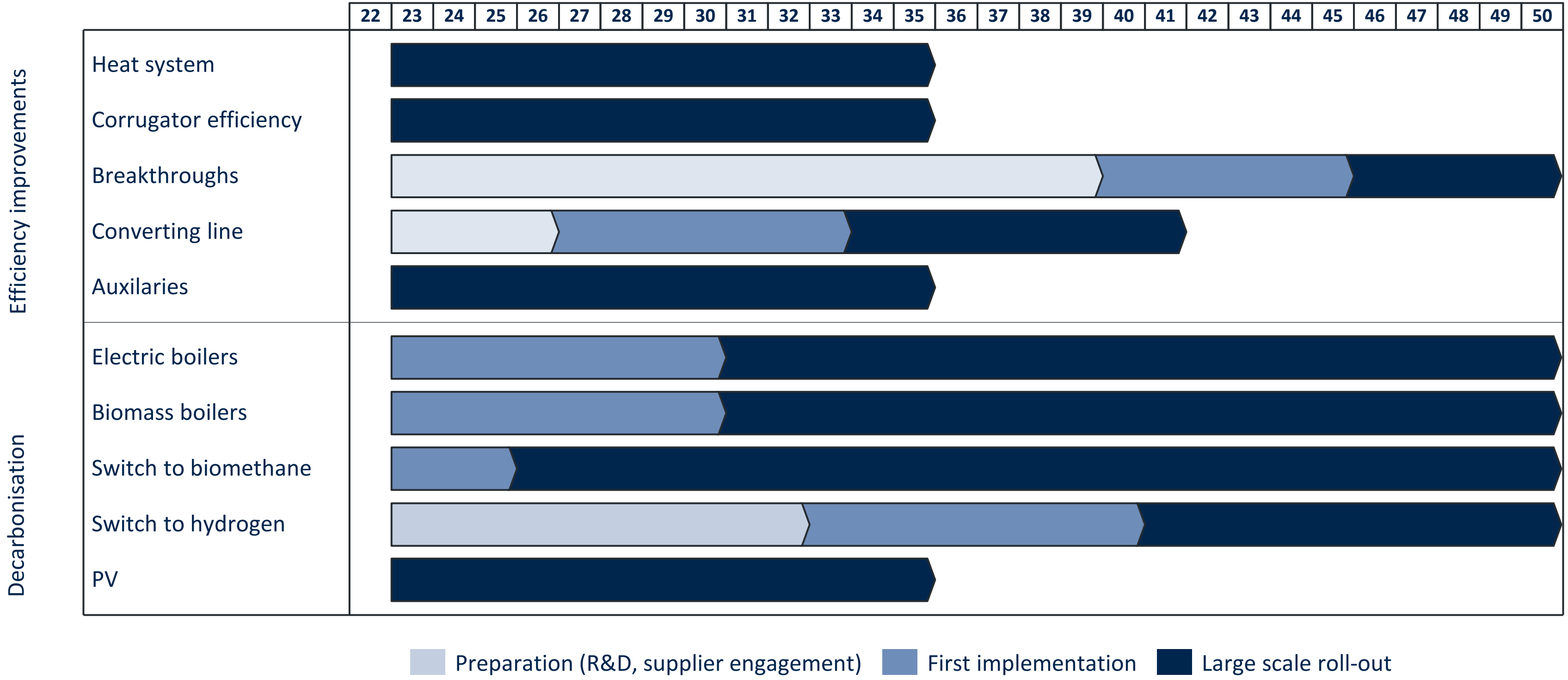
Potential and feasibility of energy efficiency measures.

Action group	Examples of actions to take	Potential	Feasibility
1. Heat system	• Insulate steam pipe network + leak prevention and detection • Valorise condensate return and flue gas heat • Better control of boiler operations (O_2/CO concentration, inlet air) • Better air balance management (e.g. automated doors etc.),	Already common practice Some further improvements possible	Measures can be easily implemented, also on existing equipment, with short payback periods No limitations in terms of resource availability
2. Corrugator efficiency	Main aim is to improve heat and starch application control (apply exactly the amount necessary, not more) • Develop standard for measuring corrugator efficiency • Set benchmarks • Push/engage suppliers to retrofit corrugators	Potential to be confirmed but could allow significant improvements. Many corrugators don't have a precise steam control yet	Requires several steps to be taken + supplier involvement. Since several corrugator manufacturers already provide retrofitting solutions, the feasibility is considered medium to high
3. Breakthrough technologies	The industry should continue to look for breakthrough technologies, through investments in R&D, e.g. development of alternative glues	The developments of glues with lower gel points could significantly reduce energy demand.	Still in low TRL, needs to be developed further + implemented
4. Converting line efficiency	Energy efficiency can be enhanced through developing more efficient machinery Need to develop standards for measuring and benchmarking efficiency, both for separate converting machines as throughout the whole converting line.	Potential to be confirmed but could allow significant improvements.	Need to develop standards first. Need to replace or retrofit existing/functioning machinery. Need for the purchase department to be on board
5. Auxiliary efficiency	Increase efficiency of auxiliaries used across the production plants • LED lightning • Compressed air leak detection and prevention • Efficient ventilation system • Conveyer belts instead of vacuum transport	Auxiliaries make up a non-negligible part of the plants electricity consumption (up to 20%). Since some of these measures have already been implemented, the remaining potential is estimated to be between 5 and 10 %	Technology exists and is not very capital intensive. Short payback periods

Potential and feasibility of decarbonization measures.

Action group	Examples of actions to take	Potential	Feasibility
6.a CHP's	Replace fuel boilers with CHP's	Could lead to efficiency improvements. Carbon impact depends on fuel used.	High investment costs Only feasible in 5-shift plants
6.b Electric boilers	Replace fuel boilers with electric boilers, which provide a carbon neutral alternative once the European grid will be fully decarbonized	Could enable full decarbonization (in case of decarbonized grid)	High TRL Main conditions are availability and affordability of electricity + grid capacity
6.c Heat Pumps	Replace fuel boilers with heat pumps for auxiliaries at lower temperatures (e.g. space heating), or with High Temperature Heat Pumps for the corrugation process	Current technologies only generate low-temperature heat which is used for auxiliaries,. New types are being developed to provide high-temperature heat (150-200 °C), but these require waste heat as a source.	Technology is already available for lower temperatures, feasibility depends on availability and affordability of electricity + grid capacity For higher temperature, a source of waste heat is needed, which is not common in the corrugated sector
6.d Solid biomass boilers	Replace fuel boilers with solid biomass boilers, would provide a carbon neutral altrernative	Depends on the Commission's decision regarding biomass as a carbon neutral solution	Depends on local, sustainable solid biomass availability, and space availability for these bigger boilers + biomass storage. Also less flexible. Higher CAPEX and OPEX.
7.a External heat	The main aim would be to valorize excess heat from nearby plants for plant operations	Decarbonization potential depends on emission intensity of local heat source.	Only for plants with local heat source available (uncommon)
7.b Biomethane	Replace natural gas with biomethane	Depends on the commission's decision regarding biomass as a carbon neutral solution	Depends mainly on future availability. Commission aims to increase the production of biomethane tenfold by 2030
7.c Hydrogen	Replace natural gas with green hydrogen	Zero-emission energy source (in case of green H_2)	High cost, and high expected demand from major industries. Requires adapted boilers and grid infrastructure.
8. Onsite PV	Sector decarbonization can be achieved by producing on-site its own energy, mainly through rooftop PV	Depending on the location of the plant, rooftop PV could supply between 10% - 55% of the local electricity demand	Rooftop PV is well-developed, and cost-competitive. Feasibility depends on space availability, roof orientation and strength, and location

Timing of energy measures.



Three key suppliers to engage with in the decarbonization efforts.

Paper suppliers | Machine suppliers | Logistics suppliers

Upstream emissions from paper production currently account for **55%** of the corrugated sector's carbon footprint. Achieving **deep emission reductions in the paper sector is therefore crucial** to achieve a climate neutral corrugated sector.

The FEFCO Climate Neutral Roadmap builds on the **expectation that the paper sector will reduce its (fossil) GHG emissions by 80% by 2050** (75% compared to 2015) in line with the CEPI 2050 Roadmap. On average, this would require the (fossil) emission intensities of the different containerboard grades to decrease in line following milestones:

Milestones for containerboard emission intensities (kg fossil $CO_{2eq.}$/t paper, measured cradle-to-gate)

	2020	2030	2040	2050
Testliner + recycled fluting	535	400	275	140
Semi-chemical fluting	365	275	185	100
Kraftliner	330	250	170	85

Three key suppliers to engage in the decarbonization efforts.

Paper suppliers (cont.) | Machine suppliers | Logistics suppliers

Corrugated companies should **track the carbon performance** of their paper suppliers and **encourage** them to reduce their (fossil) emission intensity in line with the CEPI roadmap. To this end, they should check:

- The **current carbon footprint** of their paper suppliers, both the footprint value as the scope. By preference, the footprint should be measured and reported in line with the **GHG Protocol (or equivalent) and cover scopes 1 to 3 or – if available – an LCA**
- Whether the supplier has committed to a **reduction trajectory**, for example under the **Science Based Targets initiative**
- To what extent the supplier has a **concrete action plan** to achieve its reduction trajectory, and what its track-record has been so far

To this end, **different information sources** can be used, depending on the available resources and possibilities of each corrugated company:

1. **Public reports by paper producers at company level** (e.g. reported under existing initiatives such as the **SBTi, Ecovadis** and/or the **Carbon Disclosre Project**). The Corporate Sustainable Reporting Directive will (expectedly) require most companies to report on their climate commitments and carbon performance as of 2024;
2. **Specific reports by paper producers at installation/product level.** Corrugated companies with the capacity to do so are encouraged to ask their suppliers to report site- or product-specific carbon footprints and action plans.

Three key suppliers to engage in the decarbonization efforts.

Paper suppliers | **Machine suppliers** | Logistics suppliers

The **energy efficiency** of a corrugated and converting plant is to a large extent determined by the **efficiency of the machinery** which is used in the plant. To achieve the ambitions of the climate neutral roadmap, the machine efficiency needs to be improved significantly:

1) The heat consumption of corrugators should be on average reduced by 40% by 2050
2) The electricity consumption of the converting machinery should be on average reduced by 33% by 2050

To this end, the following steps will need to be implemented:

1) The first step is to **measure the specific energy efficiency** of the different machines which are present in a typical box plant (corrugator, die-cutter, inliner, printer + driers, …). To ensure comparability, **sector-specific KPI's and measuring methodologies** will need to be developed
2) Based on step 1, specific **benchmarks/standards** can be set. These should be strengthened over time to ensure continuous improvements;
3) Corrugators and converting machinery have long lifetimes (> 20 years). To reach climate neutrality already by 2050, these benchmarks should not only apply to new machinery, but also to existing infrastructure. This implies that machine manufacturers will have to provide (and where not yet available, develop) options to **retrofit existing machinery**

Three key suppliers to engage in the decarbonization efforts.

Paper suppliers | Machine suppliers | **Logistics suppliers**

Upstream logistics (transport between the paper mill and the corrugated plant) currently account for **+- 10%** of the corrugated sector's carbon footprint, making it the third biggest source of emissions. The emissions of **downstream logistics** (transport between the corrugated plant and the client) have so far not been quantified due to lack of data, but a conservative estimate would add 15 to 20 kg $CO_{2eq.}$ per tonne of product, increasing the share of logistics in the total footprint from **10 to 15%**. **Decarbonizing the logistical chain is therefore a third priority** for reducing the corrugated sector's footprint beyond its own operations.

Within the logistical chain, diesel-powered trucks are the main source of emissions: they account for 1/3 of the transport activity (tkm's) but 60% of the transport-related emissions. Corrugated companies should therefore ask their logistical partners what they are planning in the future to reduce the (fossil) carbon intensity of their services. Possible solutions include:

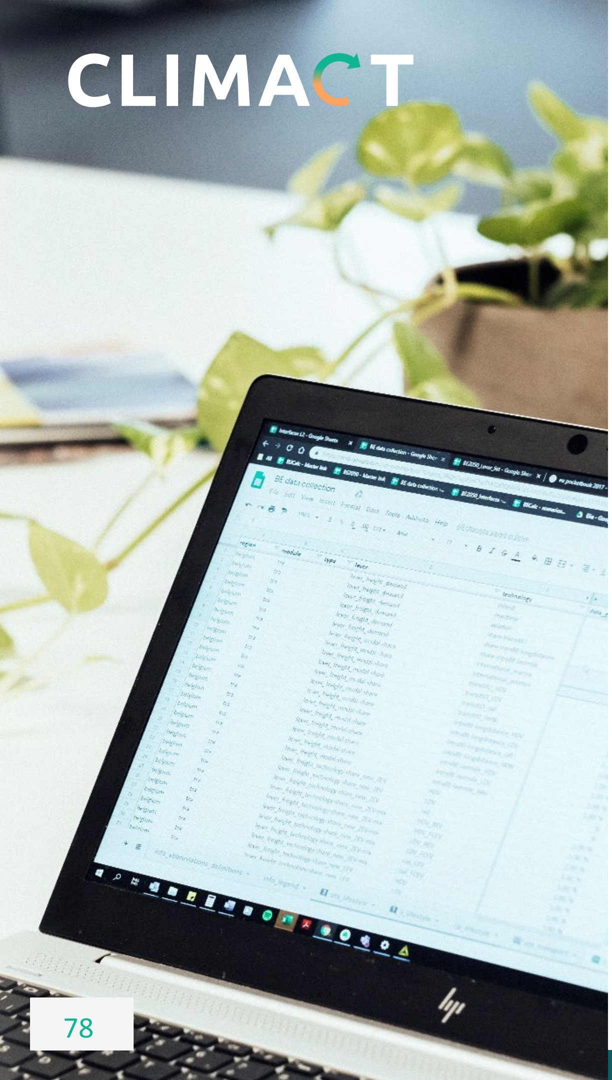
1) **Optimizing logistics**, e.g. by increasing load factors and avoiding 'empty' kilometers (short term, but already a common practice)
2) Switching to **alternative transport modes** such as rail or waterways (short term, but highly dependent on available infrastructure)
3) The use of more **efficient vehicles/tractors** (short term) , including megatrucks
4) The use of **sustainable, advanced biofuels** such as HVO's (short to medium term)
5) The switch **to new, low- or zero-emission vehicle types** (LNG or PHEV on the short term, BEV's or FCEV's on the medium- to long-term).
6) The switch to **other, carbon neutral-fuels** in the future (long-term) such as synthetic fuels

Three key suppliers to engage in the decarbonization efforts.

Paper suppliers (cont.) | Machine suppliers | Logistics suppliers

Corrugated companies can apply different engagement strategies towards these three key supplier groups, ranging from a strictly voluntary (facilitation/support) to more forceful (strict requirements) strategies. To achieve the objectives of the FEFCO Climate Neutrality Roadmap, it is recommended to start with voluntary/supportive approach, but to increase incentives for suppliers over time:

1. **Short term – information/facilitation**: invite/encourage suppliers to commit to report on their performance, commit to specific objectives and disclose progress. By preference, suppliers commit to objectives under the SBTi, to ensure sufficient ambition, and robust and transparent reporting. Corrugated companies could support their suppliers through trainings, templates, sharing of best practices, etc. ...
2. **Medium term –competition**: based on reported data, a scoring/benchmarking system can be developed and included in future tenders. The performance of suppliers along these scoring frameworks/benchmarks can be included as one of the criteria to award purchasing orders.
3. **Long term – enforcement**: in the longer run – provided that the majority of suppliers is moving forward – the approach could become more stringent, with supplier commitments or achievements on the different criteria as a condition to continue working together. This is similar to the policy many corrugated companies today apply with regard to FSC/PEFC certification.



The corrugated sector today

The vision: climate neutrality by 2050

The roadmap to implement the vision

- Main actions to take by the corrugated sector
- **Main actions to take by other stakeholders**

Technical Annex

Achieving climate neutrality requires actions through the entire value chain.

Role of material suppliers

- Decarbonize their own processes
- Paper suppliers: align their reduction strategies (at least) to the level of the CEPI roadmaps

Role of machinery suppliers

- Develop energy efficient machinery
- Provide retrofit solutions to increase the efficiency of existing machinery

Changes within the industry

Role of customers and end-users

Customers:
- Work together with corrugated sector to optimize supply chain and design
- Prioritize sustainable packaging options

End-user:
- Prioritize sustainable products in sustainable packaging
- Facilitate recycling by sorting correctly

Role of logistical partners

- Switch to more energy-efficient and low/zero-emission vehicles
- Further optimize logistical flows where possible

Enabling policies and regulatory framework

Enabling policies and regulatory framework

1

Policy recommendation 1:

Provide a **predictable** and **stable regulatory framework** to steer investments.

- the corrugated sector is capital-intensive with long life-span investments (> 15-20 years). A predictable and stable regulatory framework is essential to boost investor confidence and steer investments towards low-carbon solutions.
- Key areas where regulatory predictability and stability is required is 1) the sustainability criteria and carbon accounting for biomass fuels and feedstocks, 2) taxation and pricing policies and 3) waste-related policies.

Enabling policies and regulatory framework

2

Policy recommendation 2:

Ensure sufficient **availability and affordability** of climate-neutral energy carriers

- Despite ambitious efficiency improvements, the **sector's demand for climate neutral energy carriers is projected to grow**. By 2050, the sector could require up to 5 TWh of (zero-carbon) electricity; 2,7 TWh of biomethane; 0,9 TWh of solid biomass and 0,5 TWh of green hydrogen.

- All of these carriers are today less available and (significantly) more expensive than fossil fuels. To enable achievement of the 2050 climate-neutrality objective, policy makers need to ensure a **sufficient and secure supply** of these carriers, and that they are **affordable/competitive** compared to fossil fuels. The electricity grid should be fully decarbonized by 2050 the latest, and preferably sooner.

- To this end, policy makers need to:
  - **Fully decarbonize the electricity grid**, by 2050 the latest and preferably sooner.
  - Ensure a **further integration of the EU energy market,** and consider market reforms which allow consumers to benefit from low-cost renewable electricity production
  - Reform the **energy taxation system**, which in many EU countries today puts high taxes and levies on electricity and low to no taxes and levies on fossil (heating) fuels
  - Supportive and simplified **permitting rules** to facilitate large-scale deployment of renewable energy sources
  - R&D and **investment support** for technologies which have not yet reached full maturity (e.g. green hydrogen, biomethane production, batteries, …)

3

Policy recommendation 3:

Ensure an adequate and robust **energy grid infrastructure**

- Shifting to climate-neutral energy carriers will also require **changes and extensions** to the **energy grid infrastructure**:
  - The electricity grid needs to be reinforced to allow for higher volumes, and adapted to cope with high shares of intermittent renewable energy sources. Strong, EU-wide interconnectivity is required to ensure sufficient security of supply;
  - The gas grid needs to be adapted or extended to allow the transport of green, gaseous molecules such as biogas or hydrogen

- Corrugated production facilities are **widely dispersed**, and are often located outside large, industrial clusters. When strengthening energy infrastructures, policy makers and grid operators **should not only focus on large, energy-intensive industries** but also on industrial sectors with lower energy-intensity but high added value.

Enabling policies and regulatory framework

4

Policy recommendation 4:

Facilitate the **decarbonization of the paper sector**

Achieving a climate-neutral corrugated sector largely **depends on the ability of their upstream paper suppliers to decarbonize the paper-making process**. Emissions from the paper production accounts for 55% of the sector's emissions. FEFCO and its members are in line with the policy recommendations put forward in the CEPI climate roadmaps, including:

- Integrating the objective of obtaining **a vibrant bioeconomy** in all relevant EU strategies
- Support **research and innovation**, in particular for demonstration plants and breakthrough technologies
- Apply the **cascading principle for biomass,** prioritizing use with highest added-value
- **Reform the electricity market** to allow the most cost-effective decarbonisation of the electricity system,
- Facilitate the development of a **decarbonized, well-performing transport sector** (see also next slide)
- Ensure the availability of a **skilled workforce**
- Facilitate access to existing **support mechanisms**.

Enabling policies and regulatory framework

5

Policy recommendation 5:

Facilitate the **decarbonization of the transport sector**

- Upstream transport currently accounts for +- 10% of the corrugated sector's footprint.

- Ambitious policies will be required to facilitate the shift towards a climate-neutral transport system, including:
    - setting ambitious emission norms for Heavy-Duty Vehicles
    - ensuring sufficient (charging) infrastructure to switch to zero- and low-emission vehicles
    - investing in low-carbon transport modes (rail, maritime)
    - Address bottlenecks for transboundary transport, such as non-harmonized standards and regulations
    - supporting the development of climate-neutral fuels for hard-to-electrify transport segments (e.g. maritime).

6

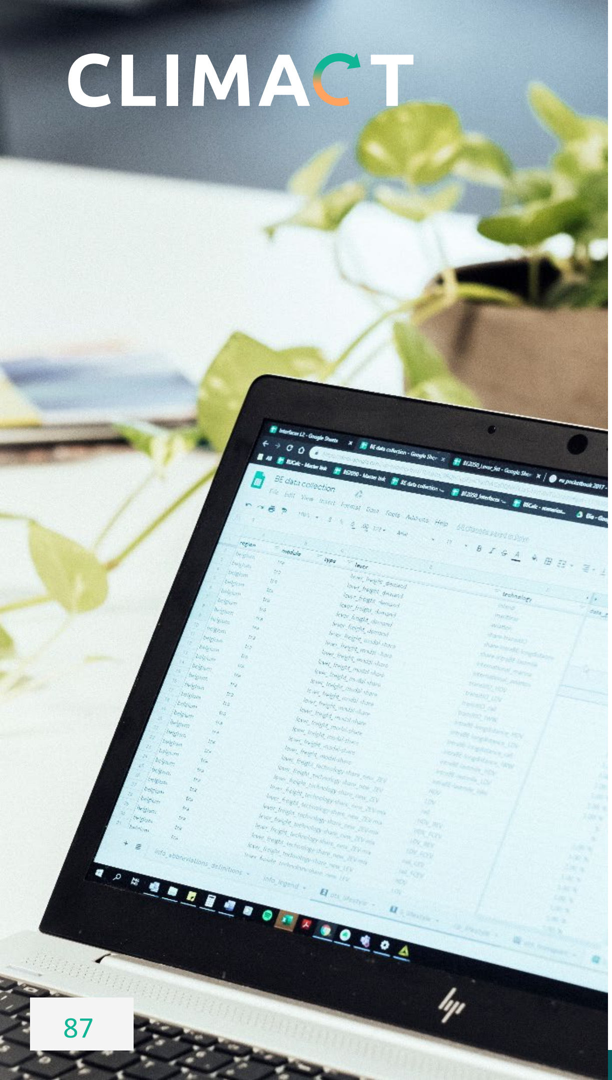
Policy recommendation 6:

The European packaging & packaging Waste policies including recycling and reuse should be **aligned with the EU Green Deal** and **Climate neutrality objectives**

- The corrugated sector has already achieved a high recycling rate, with +- 83% of paper & board packaging products being recycled at end of life.

However, the **quality of the recycling can be further improved**, mainly by avoiding contamination of waste streams with non-recyclable materials. Separate collection and clean source of packaging materials for recycling are essential for high quality (or optimised) recycling. Municipalities and national governments could support this by:

- **Awareness and educational campaigns** that promote the proper sorting of waste materials. These should focus i.a. on the negative impact of mixing board waste with other materials (e.g. plastic components, food waste, …)
- Ensure the required **infrastructure** (e.g. separate waste bins in the public domain) to enhance the correct sorting of waste streams



The corrugated sector today

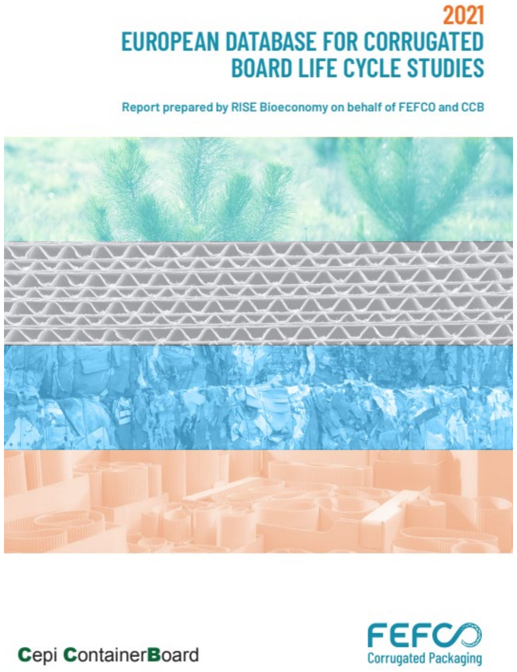
The vision: climate neutrality by 2050

The roadmap to implement the vision

Technical Annex

- **Current carbon footprint**
- Modelled decarbonization pathways
- Cost assessment
- Detailed assessment of energy measures

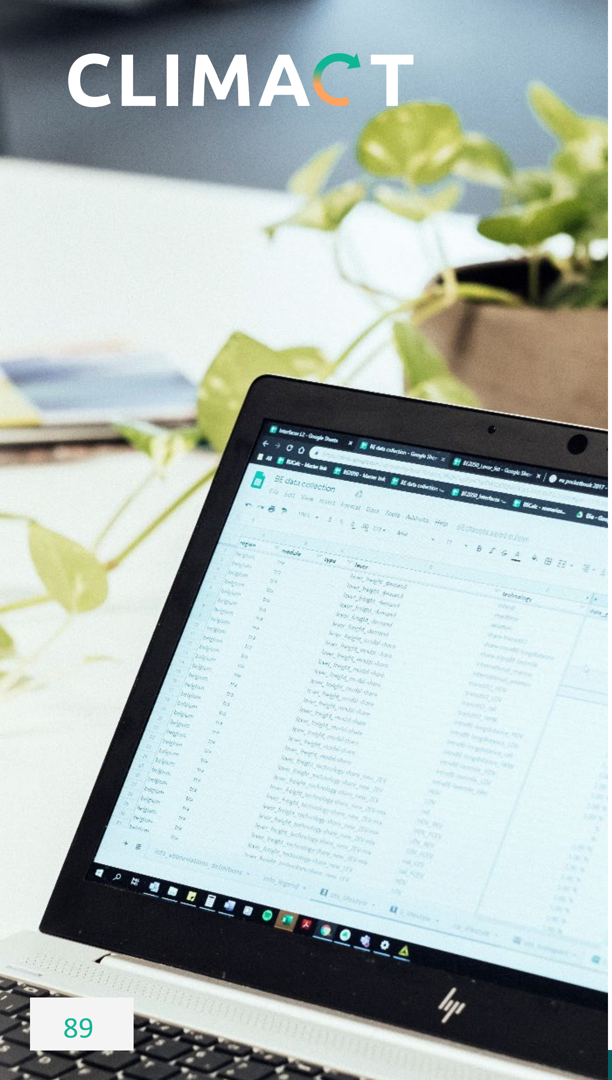
The carbon footprint calculations is based on the 2021 LCA assessment which is published by FEFCO



- It is based on a methodology and tool developed by CITPA (the International Confederation of Paper and Board Convertors in Europe),
- The CITPA methodology is closely aligned with the EU Product Environmental Footprint methodology, and is the reference methodology for paper and board convertors in Europe
- It uses a closed-loop approach to account for the fibres in corrugated board products which are recycled at end-of-life to become a feedstock for new corrugated products
- All data and calculations are included in the Excel below.

Microsoft Excel Worksheet

https://www.fefco.org/technical-documents/documents-overview



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The corrugated sector today

The vision: climate neutrality by 2050

The roadmap to implement the vision

Technical Annex

- Current carbon footprint
- **Modelled decarbonization pathways**
- Cost assessment
- Detailed assessment of energy measures

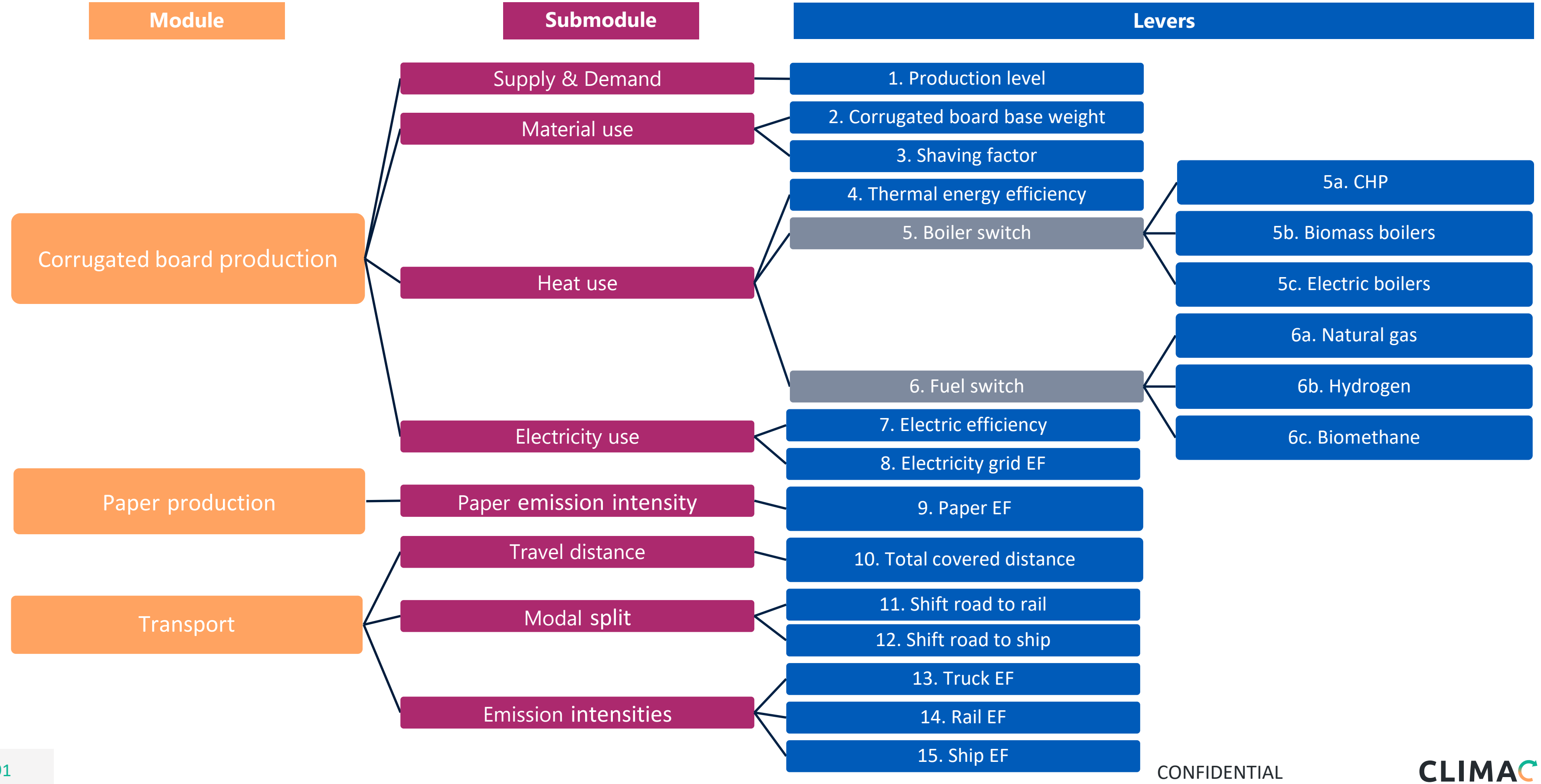
Climate neutral scenarios are constructed by using levers, with different levels of ambition

For each lever (= variable), the model allows the user to make a choice between 4 potential ambition levels. Scenarios are then constructed by setting different ambition levels for different levers.

Level 1	Level 2	Level 3	Level 4
Business as usual	**Intermediate** level, more ambitious than a projection of historical trends but not reaching the full potential of available solutions	**Very ambitious** level, given the current technology evolutions and the best practices observed in some geographical areas	**Transformational** and requires some additional breakthrough or efforts such as important costs reduction for some technologies, very fast and extended deployment of infrastructures, major technological advances, strong societal changes, etc.

A total of 19 different levers are modelled, that allow to visualize changes in terms of corrugated board **demand**, corrugated board **production** (*material*, *heat* and *electricity* demand), **paper production**, and **transport**

A total of 19 levers are used, covering 3 main topics: production of corrugated, paper production and transport



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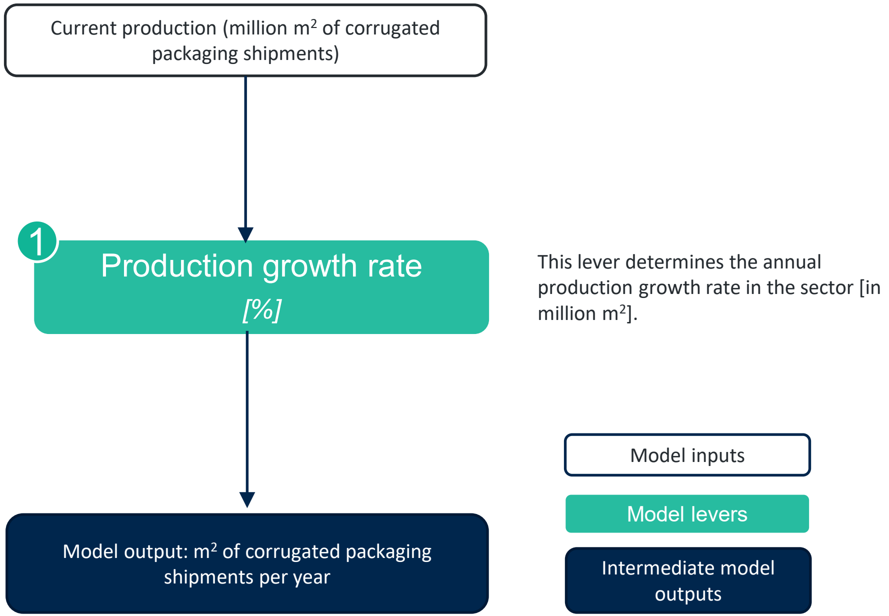
1. Packaging demand/production level modelling appoach

A simple approach is applied to estimate future production levels, by applying an average annual growth rate on current production levels (in m²)



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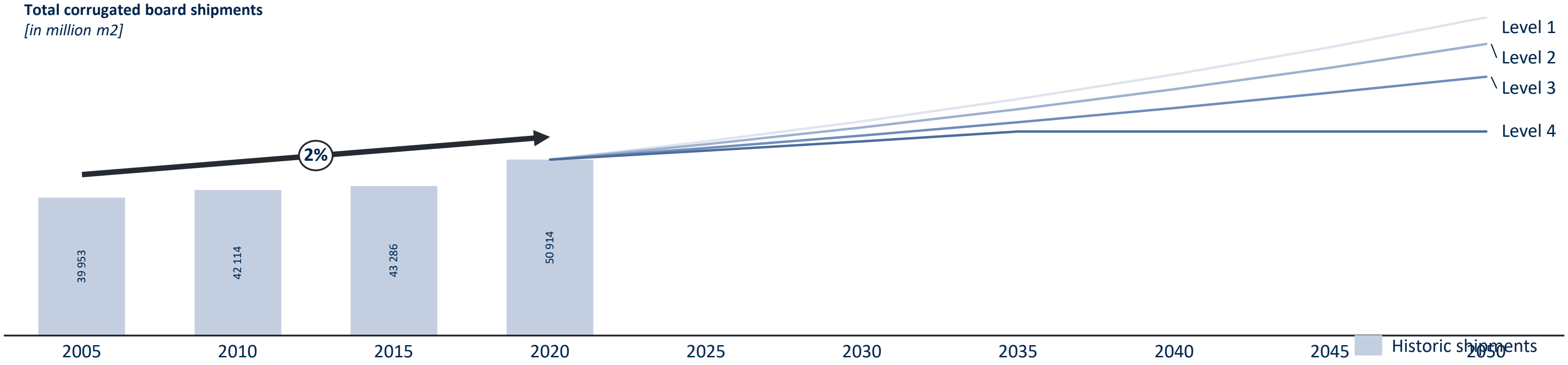
This lever determines how the production level for corrugated board is going to evolve

Historical values



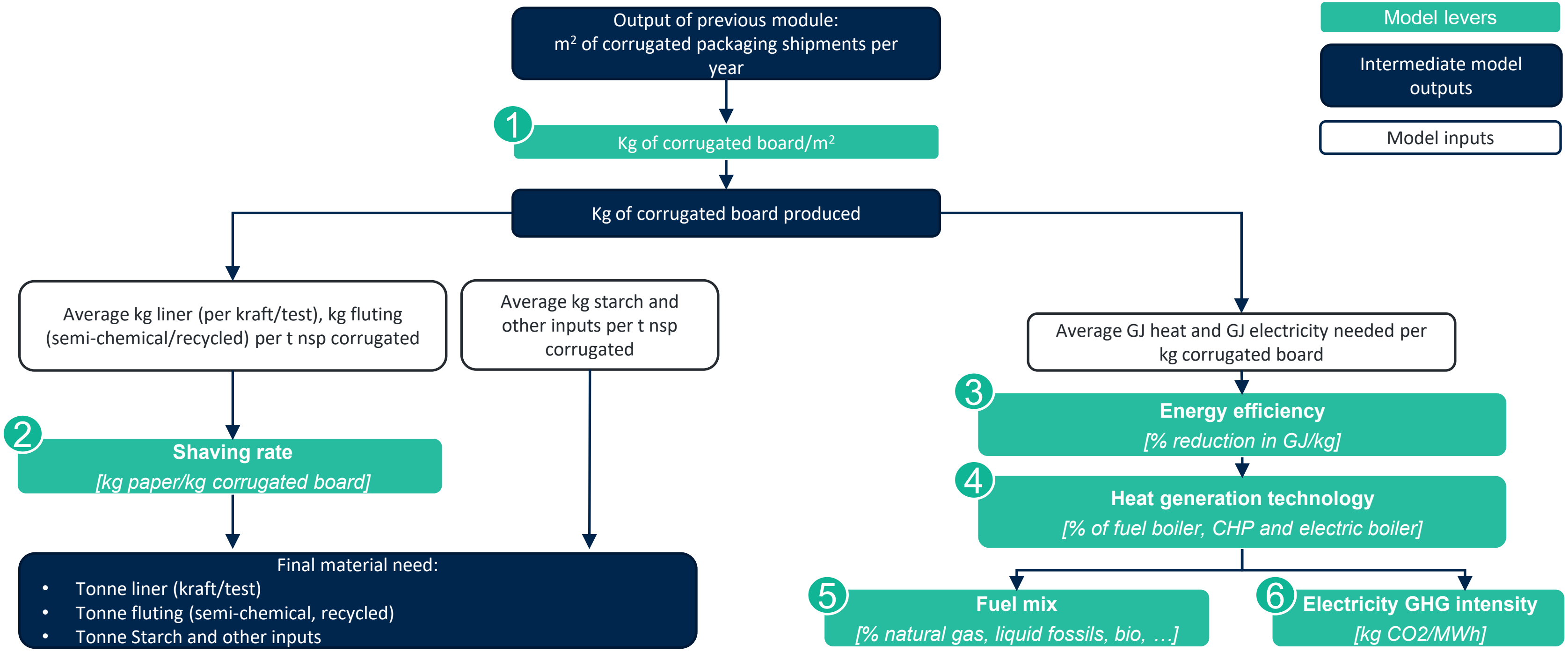
Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Underlying values (CAGR 2020-2050)	**+2%**	**+1,7%**	**+1,3%**	**+1% until 2030, stable thereafter**
Narrative	Trend 2010-2020 assumed to continue until 2050	Based on McKinzie trend projection for 2030. Growth rates are strong in Eastern Europe, but more moderate in Western Europe. The resulting growth rate is similar to the one observed between 2005 and 2020 (+1,9%). Trend continues after 2030.	= average annual growth rate until 2050 if we assume a CAGR of 2% until 2030, then slowing down to 1,5% in 2030-2035, 1% in 2035-2045 and 0,5% in 2045-2050.	Most ambitious assumption: production growth slows down until 2035, and then stabilized. Consumers become very sensitive for packaging and waste, reducing the growth in market demand.

Level 3 is used for both the BAU as the climate neutral scenarios

2. Packaging design and production modelling approach

Approach for thermal energy is elaborated further on in this slide deck



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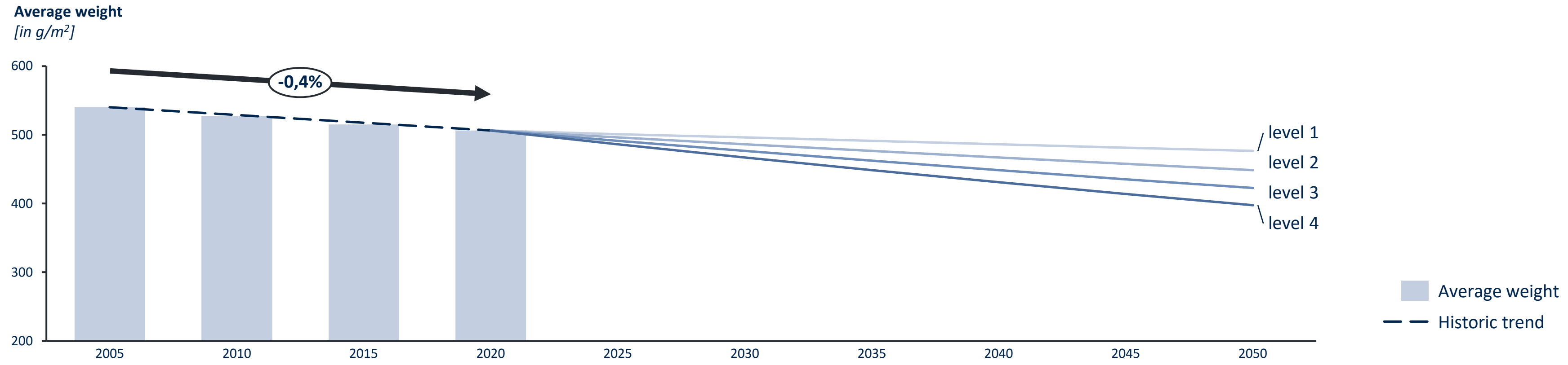
This lever determines how the base weight of corrugated boards will evolve

Historical values



Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value (CAGR until 2050)	**-0,2% 2030: 496 g/m² 2050: 477 g/m²**	**-0,4% 2030: 486 g/m² 2050: 449 g/m²**	**-0,6% 2030: 476 g/m² 2050: 422 g/m²**	**-0,8% 2030: 467 g/m² 2050: 398 g/m²**
Narrative	The historic trend slows down as the potential for further reductions becomes scarcer.	The historic trend is assumed to continue due to continuous improvement until 2050.	The historic trend is assumed to increase due to innovation and technological breakthroughs.	The historic trend is assumed to double due to innovation and technological breakthroughs.

Level 3 is used for the climate neutral scenarios (under BAU, the base weight is assumed to remain constant until 2050)

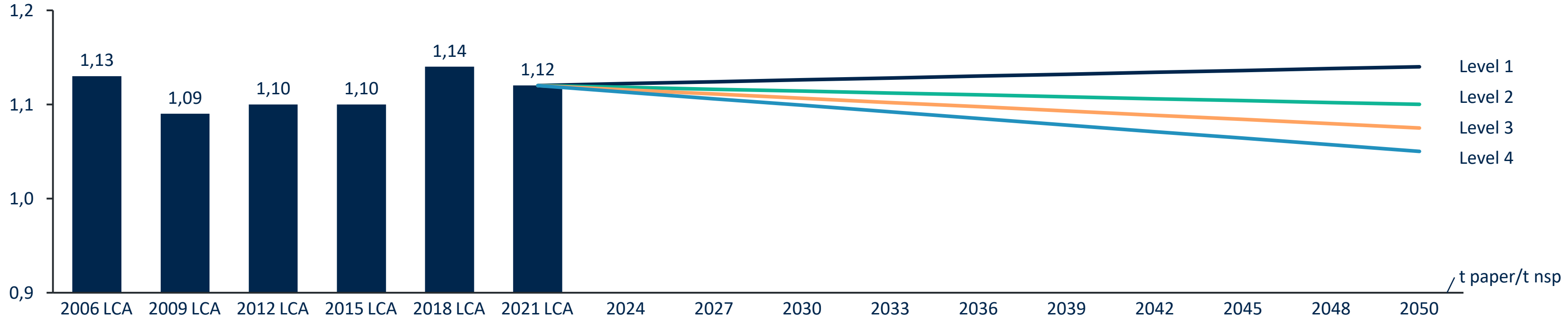
Demand/production levels | Design and production | Paper production | Transport

Material use → Shaving rate

This lever determines the required tonnage of paper input per ton of net saleable product produced

Paper input/packaging output ratio
[in t paper/t nsp]

Historical values

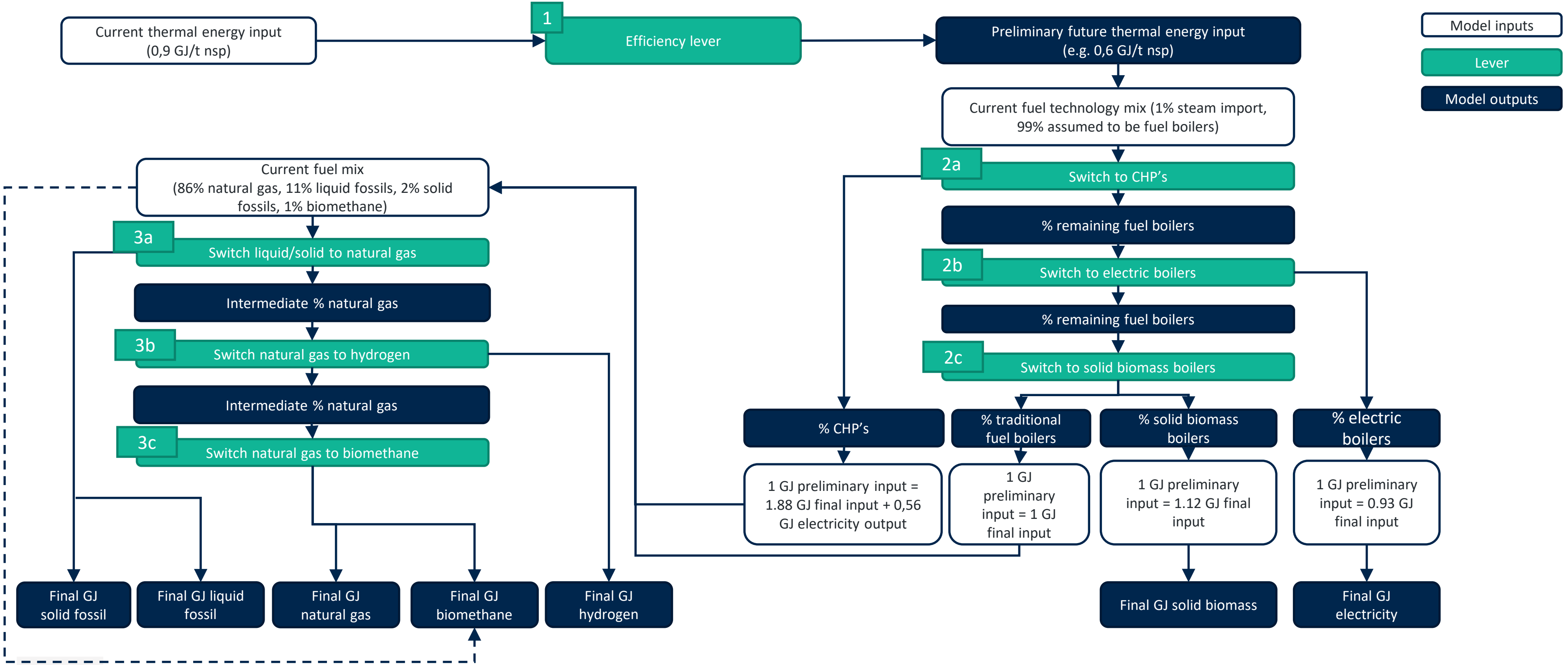


Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value	**Shaving rate remains at 14%** *(114 t paper input/t nsp)*	**Shaving rate drops to 10% by 2050** *(110 t paper input/t nsp by 2030)*	**Shaving rate drops to 7,5% by 2050** *(107,5 t paper input/t nsp by 2030)*	**Shaving rate drops to 5% by 2050** *(105 t paper input/t nsp by 2030)*
Narrative	Status quo from latest LCA value.	Lower range of the LCA values since 2006	Halfway between level 2 and 4	Based on lower range values of industry statistics data

Level 2 is used in the climate neutral scenarios. Avoiding paper losses is a continuous effort in the sector, and potential for further improvements is considered limited.

A detailed approach was used to model the sectors energy demand and mix



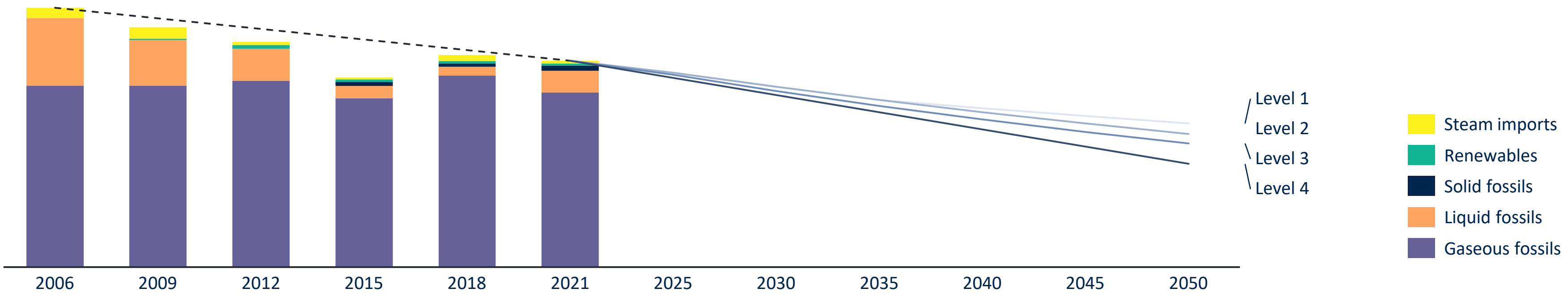
Demand/production levels | Design and production | Paper production | Transport

Thermal energy use and supply → Efficiency lever

This lever determines the preliminary required quantity of thermal energy input per ton of net saleable product corrugated board (without considering improved boiler efficiencies)

Historical values

Preliminary* thermal energy demand
[in GJ/t nsp]



Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value	**CAGR of -1,5% until 2035, reduced to 1% further improvements thereafter**	**CAGR of -1,5% until 2050**	**CAGR of -1,75% until 2050**	**-50% by 2050 (compared to 2021)**
Narrative	The sector continues to improve its heat efficiency at historic rates until 2035. After that, the improvement rate slows down as easy potential is exhausted.	The sector continues to improve its heat efficiency at historic rates until 2050	The sector manages to accelerate its heat efficiency compared to historic rates, and maintains this effort until 2050.	Breakthrough technologies and/or innovative practices (e.g. use of cold glues) reduces the required heat by 50% by 2050 compared to 2021.

Level 3 is used for the climate neutral scenarios. Further reductions could be possible but would require breakthrough technologies

* Before taking into account boiler efficiencies

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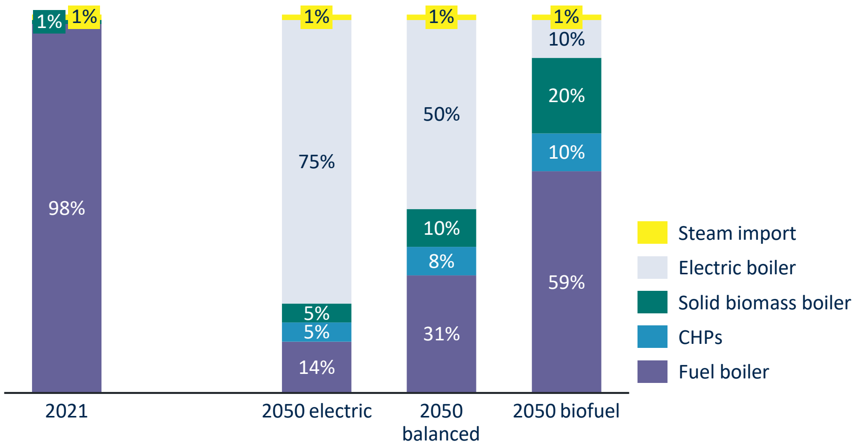
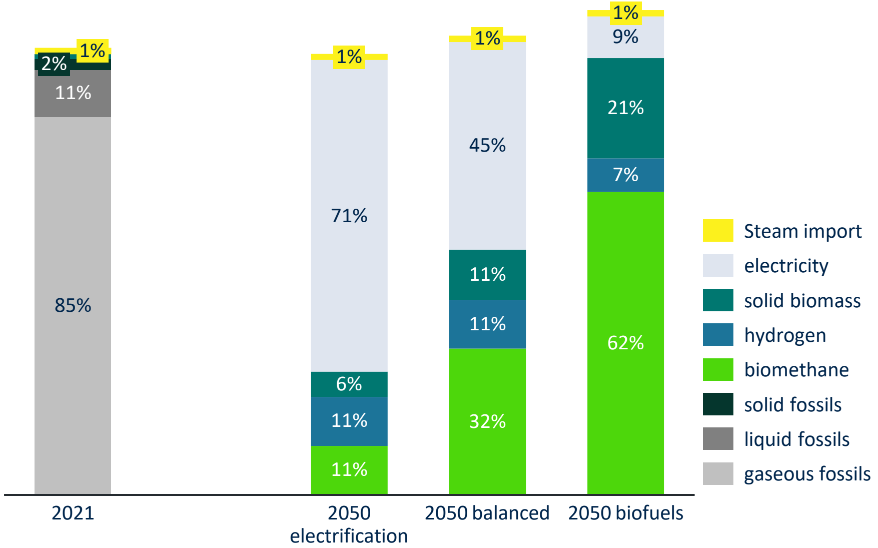
For the energy mix, the model levers were set as such to achieve the following boiler and fuel mixes in the different scenarios

Boiler mix



Energy mix



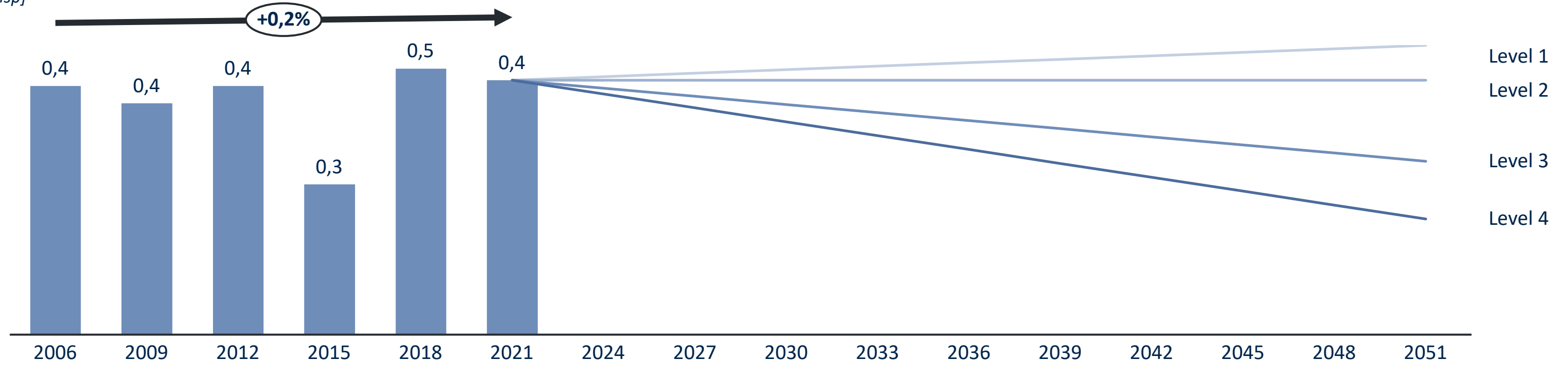
The energy mix takes into account boiler efficiencies. The total energy input increases in function of the switch to CHP's, as these require more energy input per heat output (but also lower the required 'grid electricity)

This lever determines the required (grid) electricity input per ton of net saleable product corrugated board. This excludes electricity required for heat production if a switch to electric boilers is considered

Note: this relates to electricity purchased from the grid. It excludes autoproduced electricity

Historical values

Electric efficiency of corrugated board production
[GJ/t nsp]



Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value	**Increases to 0,5 GJ by 2050**	**Constant at 0,44 GJ**	**Decreases to 0,30 GJ by 2050**	**Decreases to 0,2 GJ by 2050**
Narrative	Increased high-quality printing gradually increases the amount of electricity needed per t nsp.	Efficiency improvements offset increased demand from high quality printing, keeping the electricity need stable until 2050.	Increased efficiency, reduced printing and own renewable production (4,4 GJ/t, 10% of current demand) reduces the required electricity to 0.30 GJ per t nsp.	Increased efficiency, reduced printing and own renewable production (11 GJ/t, 25% of current demand) reduces the required electricity to 0,2 GJ per t nsp.

Level 3 is used for the climate neutral scenarios. It includes auto production through renewable sources

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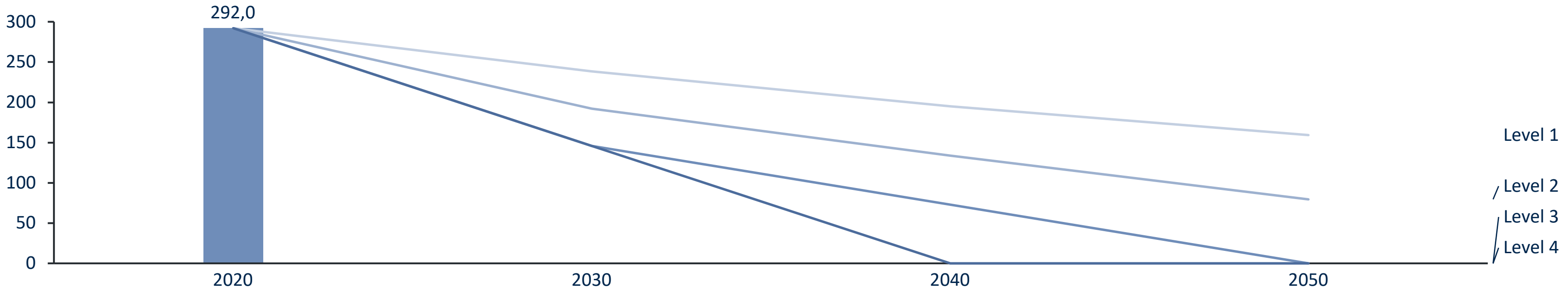
Demand/production levels | Design and production | Paper production | Transport

Electricity use → Electricity emission intensity

This lever determines to what extent the average emission intensity of the grid electricity consumed is decreased

Historical values

Emission factor of electricity grid
[g CO2/kWh]



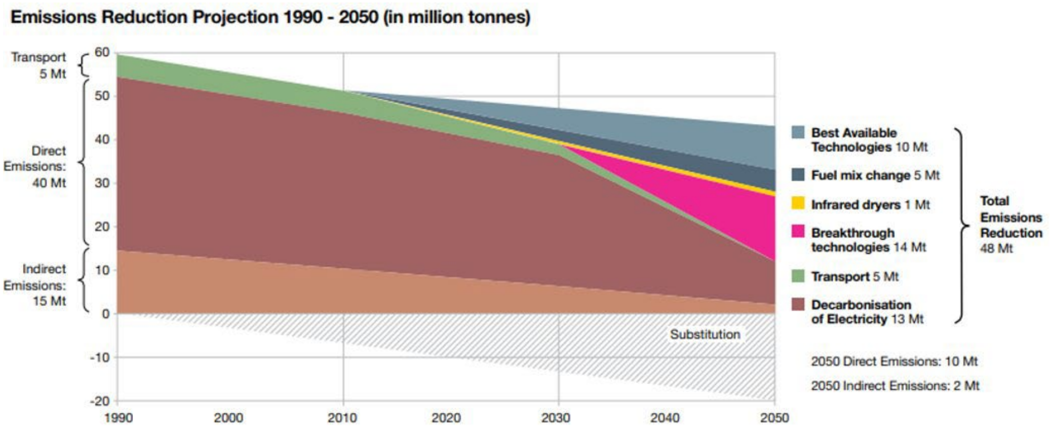
Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value	**Slowing reduction at CAGR of -2% per year (= average 2005-2016)**	**2030: decrease of -25% to 220 g 2050: decrease of -50% to 146 g**	**2030: decrease of -50% to 146g 2050: full decarbonization**	**2030: decrease of -50% to 146g Full decarbonization already by 2040**
Narrative	The decreasing trend observed since 2016 is slowed down, i.a. due to stronger growth of CB sector in countries with high emission intensities.	[halfway 1 and 3] The decarbonization of the EU electricity grid is only partially realized. Fossil fuels continue to be used until 2050.	The CB sector can make of the successful decarbonization of the EU electricity grid. The EU power grid's emission intensity is reduced with 50% by 2030 as envisaged in the EU Green Deal	The EU power grid is fully decarbonized. The CB sector leads by example, and ensures a fully decarbonized power supply by 2040 by purchasing 100% renewable electricity.

The climate neutral scenarios assume a full decarbonization of the EU electricity grid by 2050 the latest

This lever determines the decrease in the fossil emission intensity (cradle-to-gate) for the production of the paper consumed within the corrugated sector. The same decrease rate will be applied to all different paper types (kraftliner, testliner, flutings).

Historical values



The CEPI roadmap estimates a projected decrease in emissions of 73.5% in 2050 compared to 2015, considering the emergence of breakthrough technologies. Otherwise, a reduction in emissions of 63% should be achieved

Projection

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value across all papers	**-26% in 2050 compared to 2015**	**-63% in 2050 compared to 2015**	**-73.5% in 2050 compared to 2015**	**-100% in 2050 compared to 2015**
Narrative	CAGR of -1%, a slowing of the historical trend as low-hanging fruit becomes exhausted.	Aligned with the CEPI roadmap, without emerging & breakthrough technologies. (-60% compared to 1990)	Aligned with the CEPI roadmap, with emerging & breakthrough technologies.	Aligned with the CEPI roadmap, with emerging & breakthrough technologies.

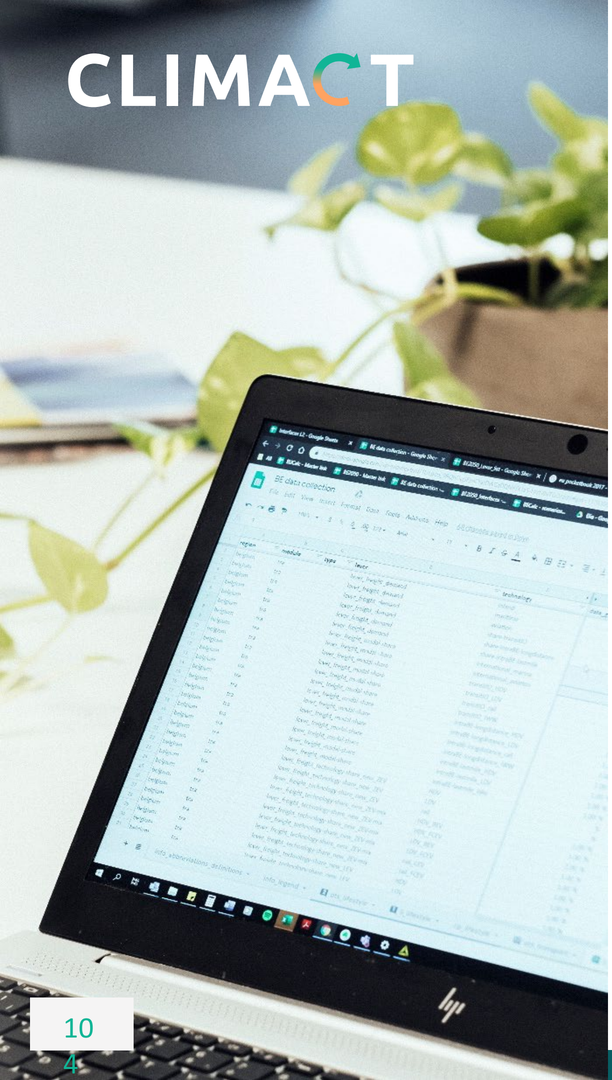
The climate neutral scenarios assume that the paper sector can reduce its (fossil) GHG emissions by 80% by 2050 compared to 1990 (73,5% compared to 2015)

These 3 levers determine how the emission intensities of trucks, trains and ships will evolve

	Level 1 (BAU)	Level 2 (Intermediate)	Level 3 (ambitious)	Level 4 (transformational)
Proposed value	**Truck:** -15% by 2050 **Rail:** -18 % by 2050 **Boat:** -3% by 2050	**Truck:** -68% by 2050 **Rail:** -52% by 2050 **Boat:** -73% by 2050	**Truck:** -90% by 2050 **Rail:** -87 % by 2050 **Boat:** -95% by 2050	**Truck:** -100% by 2050 **Rail:** -100 % by 2050 **Boat:** -100% by 2050
Narrative	Minor efficiency improvements and limited uptake of Low- and Zero Emission vehicles. Biofuel share remains at today's levels (7%)	Medium efficiency improvements and increased uptake of Low- and Zero Emission vehicles. Biofuel share in remaining combustion engines increases to 38% by 2050.	Ambitious efficiency improvements and uptake of Low- and Zero Emission vehicles. Biofuel share in remaining combustion engines increases to 69% by 2050.	*Carbon neutral transport (aligned with the CEPI roadmap)* Breakthrough improvements in energy efficiency By 2050, all new truck sales are either LEV's or ZEV's Biofuel share in remaining combustion engines increases to 100% by 2050.

The climate neutral scenarios assume a zero-emission transport system to be achieved by 2050

Transport emission intensities are based on Climact's EU net-zero 2050 calculator, available here. Values were derived by applying the trend observed in this calculator under the different ambition levels, on the 2020 emission intensity values used for the FEFCO roadmap. All underlying assumptions (load factors, technology mix, fuel mix, …) can be consulted in the net-zero 2050 calculator.



The corrugated sector today

The vision: climate neutrality by 2050

The roadmap to implement the vision

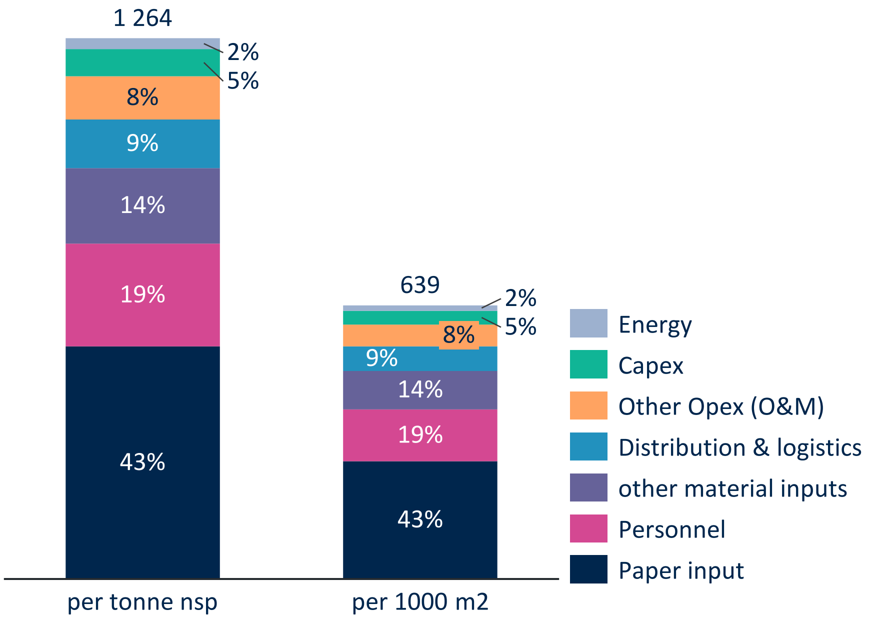
Technical Annex

- Current carbon footprint
- Modelled decarbonization pathways
- **Cost assessment**
- Detailed assessment of energy measures

In 2020, the production cost for 1 tonne of corrugated product was assumed to be +- € 1265

* estimation, order of magnitude confirmed/validated by several sector representatives

Production costs corrugated packaging
[€]



- **Over half of production costs are related to material inputs: paper (43%) and other inputs (14%)**
- Personnel costs are another important factor (19%)
- Distribution and logistics com in third place (at 9%)
- **Energy costs only account for 2%** of the total production cost (based on prices before the current energy crisis). This suggests that increased energy costs (e.g. by switching to low-carbon energy carriers) would not significantly increase the production cost of corrugated board. This has to be confirmed by the analysis

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Overview of different production cost components and how they are included in the cost assessment

Cost component	Scope of the assessment
Energy costs	**Future costs evolve in function of:** 1) Energy prices 2) CAPEX for different boiler types 3) Energy efficiency investments 4) Carbon prices
Distribution and logistic costs	**Future costs evolve in function of:** 1) Energy prices 2) Carbon costs 3) Degree of decarbonization
Paper costs	**Future costs evolve in function of:** 1) Energy prices 2) (shadow*) carbon costs. * *shadow costs to reflect the added costs for decarbonization)*
Other costs: • CAPEX • OPEX O&M • OPEX Personnel • OPEX other material inputs	**Future cost are assumed to be stable** throughout time (fixed cost per 1000m^2 corrugated board)

Costs are calculated based on best available data, but uncertainty remains high (in particular for paper costs, which have a high impact on total production costs)

	Data source used	Level of uncertainty	Impact on total production cost
Energy costs	1) IEA/European Commission for energy prices 2) Literature for boiler CAPEX 3) Industry averages for energy efficiency improvements 4) Climact assumptions for (future) carbon prices	◑	◔
Distribution and logistic costs	1) Literature for CAPEX and average energy consumption 2) IEA for fuel prices 3) European Commission for carbon prices	◑	◑
Paper costs	1) Climact calculation based on (shadow) carbon price and energy prices	●	◕

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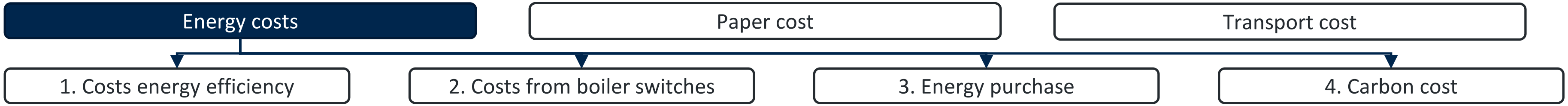
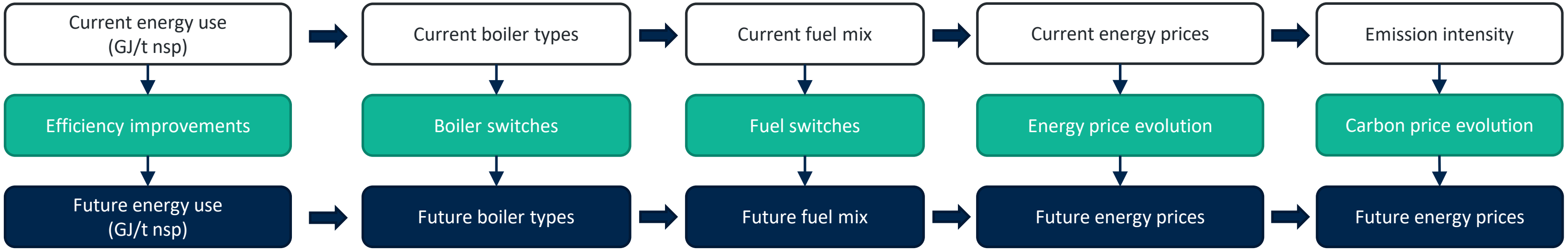


Overview of cost elements that will be included to assess the future (thermal) energy costs for corrugated board production



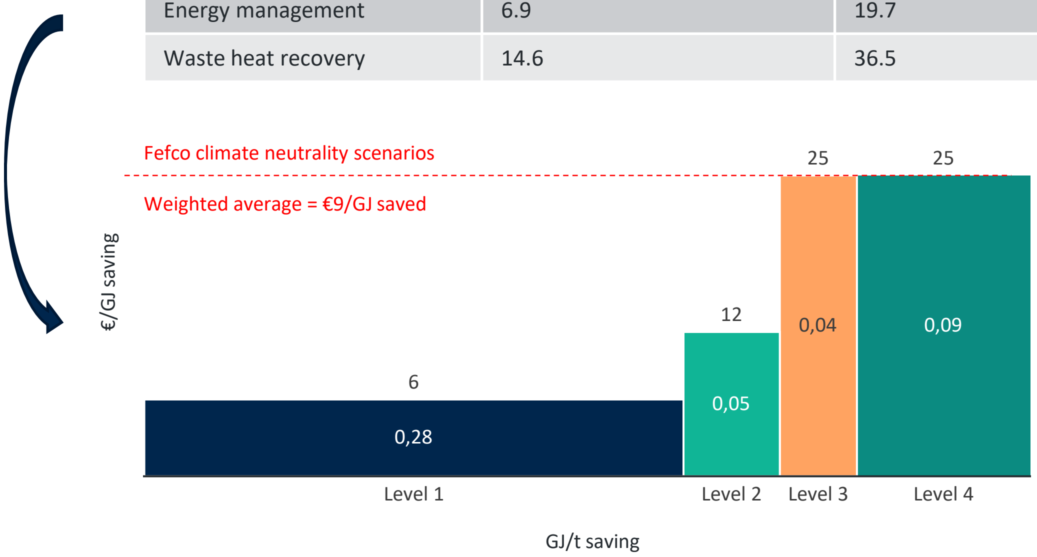
Overview of costs that will be estimated for each step

	Costs related to efficiency improvements	Costs related to boiler switches	Costs related to energy consumption		Carbon costs
CAPEX	✓ The total costs related to reducing energy consumption will be taken into account (mainly CaPEX)	✓ CAPEX of different boiler types	X included upstream (in boiler switches)	X not relevant	X not relevant
OPEX		✓ OPEX O&M included X energy expenditures included downstream	X included downstream (in energy expenditures)	✓ Energy expenditures (final $use_{carrier\ X}$ * $price_{carrier\ X}$)	✓ Carbon costs[1] (final use $_{carrier\ X}$ * $EF_{carrier\ X}$ * carbon price)

[1] currently, the corrugated board sector is not yet covered by a carbon price. However, in the future, this might change. See e.g. the current proposal to extend the EU ETS to buildings and road transport. In the future, this might be extended further to smaller industrial sectors

Methodology to determine costs related to (thermal) energy efficiency improvements

Measure	Avoidance cost (€/MWh energy saving)			
	25th percentile	median	75th percentile	90th percentile
Heating efficiency	4.3	12.5	27.7	60.4
Energy management	6.9	19.7	37.8	122.1
Waste heat recovery	14.6	36.5	68.5	92.5



reasoning

- A 0.28 GJ/t nsp efficiency improvement is achieved using the above-mentioned measures at an average of their median costs (i.e. 22,9 €/MWh)
- A further 0.05 GJ/t nsp efficiency improvement is achieved using the above-mentioned measures at an average of their 75th percentile costs (i.e. 44 €/MWh)
- A further 0.04 GJ/t nsp efficiency improvement is achieved using the above-mentioned measures at their 90th percentile costs (i.e. 91,67 €/MWh)
- The costs for the further 0.09 GJ/t nsp efficiency improvements is the same as for level 3, due to the lack of information regarding costs of breakthrough technologies

Source: https://deep.eefig.eu/

Methodology to determine costs related to electric efficiency improvements

	Avoidance cost (€/MWh energy saving)			
	25th percentile	median	75th percentile	90th percentile
Energy management	6.9	19.7	37.8	122.1
Lighting	41.7	75	106.4	140.8
PV (connected to grid)	45.11	45.11	45.11	45.11
Compressed air	27.8	53.6	91.6	139.2

reasoning

- No electric efficiency improvement was achieved at this level, therefore no avoidance costs are associated to it
- A 0.02 GJ/t nsp electric efficiency improvement is achieved using the above-mentioned technologies at an average of their median costs (i.e. 48.35 €/MWh)
- A further 0.14 GJ/t nsp efficiency improvement is achieved using the above-mentioned technologies at an average of their 75th percentile costs (i.e. 70,23 €/MWh)
- The costs for the further 0.1 GJ/t nsp efficiency improvements is the same as for level 3 (i.e. €70,23/MWh)

Source: https://deep.eefig.eu/

CAPEX and OPEX (O&M) for different boiler types (after adjustments to €2021)

	Unit	Fuel boiler (natural gas)	CHP/gas turbine	Electric boiler	Solid biomass boiler[3]
Capacity	(MWth)	1-30	1-50	1-30	20-250
Nominal investment	(€k/MW capacity)	120.39	1082.96 (per MW_{el})	131.27	328.17
Fixed O&M	(€k/MW capacity/year)	3.28	9.8 (per MW_{el})	0.55	5.47
Variable O&M	(€/MWh)	0.55	8.8 (per MW_{el})	0.22	0.22
Efficiency	MWth/MW	92%	32% electricity 55% heat	98%	84%
Technical lifetime	(year)	25	35	20	25
Capacity factor	%	65%	77%	65%	65%
Annual production	(MWh per MW capacity)	5238	2158 (electricity) 3710 (heat)	558	4783
CaPEX[1]	**(€/MWh heat) (€/GJ heat)**	**0.92 0.26**	**7.6 2.1**	**1.18 0.33**	**2.74 0.76**
OpEX O&M[2]	**(€/MWh heat) (€/GJ heat)**	**0.63 0.17**	**7.8 2.2**	**0.10 0.03**	**1.14 0.32**
Source	https://publications.jrc.ec.europa.eu/repository/handle/JRC109006				
		Table 2	Table 26	Table 8	Table 6

Final values to be used for the roadmap

[1] = nominal investment/(annual production * technical lifetime)
[2] = Fixed O&M/annual production + variable 0&M
[3] source used does not provide data for smaller solid biomass units

Energy costs | Paper cost | Transport cost

1. Costs energy efficiency | 2. Costs from boiler switches | 3. Energy purchase | 4. Carbon cost

Different price trajectories were used for the different scenarios

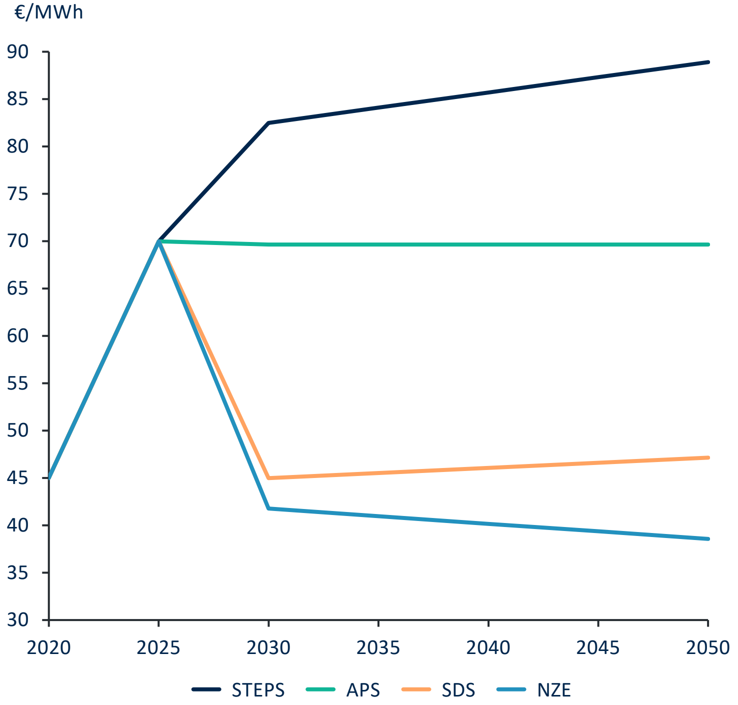
Scenario	Description	Use
Business as usual	This cost scenario simulates how the costs would evolve would no measures be implemented	Used for the **business-as-usual scenario**
Higher range decarbonization	This cost scenario projects the highest expected costs, in the case of a decarbonization scenario	Used to give the upper and lower range for the three **decarbonization scenarios**
Lower range decarbonization	This cost scenario projects the lowest expected costs, in the case of a decarbonization scenario	

Energy costs | Paper cost | Transport cost

1. Costs energy efficiency | 2. Costs from boiler switches | 3. Energy purchase | 4. Carbon cost

Possible evolution of future energy prices – natural gas

current energy crisis is expected to have an impact until 2025, with prices increasing to €70/MWh in 2025. No impact of the current crisis assumed thereafter.



Level 1 – aligned with Stated Policies Scenario

- Further increase to €85/MWh by 2030, and to €89 /MWh in 2050
- Consider where the energy system might go without additional policy implementation

Level 2 – aligned with Announced Pledges Scenario

- Increase up to €70/MWh by 2025/2030, then remains constant.
- Consider all climate commitments by governments

Level 3 – aligned with Sustainable Development Scenario

- Increase to €70/MWh until 2025, then drops back to pre-crisis levels unti 2050
- "Well below 2°C" pathway to achieve Paris agreement

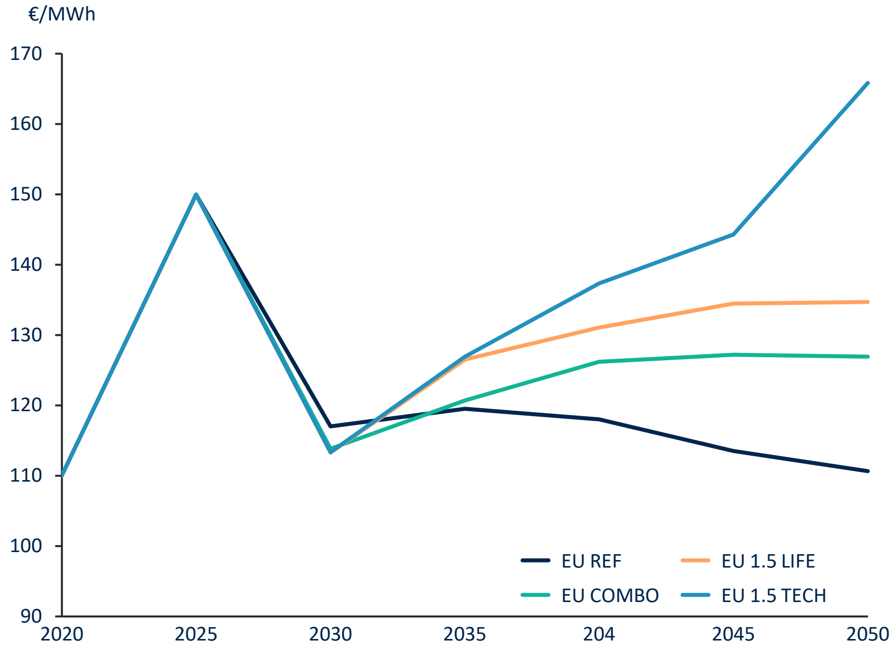
Level 4 – aligned with Net Zero Emission

- Increase to €70/MWh until 2025, then drops back to pre-crisis level by 2030 and declines further to €39/MWh in 2050
- Narrow, but achievable, pathway to achieve net zero by 2050

Source: Based on price evolution in IEA 2021, *World Energy Outlook 2021*, applied to an initial price of €45/MWh
2025 price based on TTF gas futures for 2025

Possible evolution of future energy prices – electricity

current energy crisis is expected to have an impact until 2025, with prices increasing to €150/MWh in 2025. No impact of the current crisis assumed thereafter.



Level 4 – aligned with EU 1.5 TECH
- € 117 by 2030, then increase to €166/MWh in 2050
- Include CCS on top of level 2 scenario to reach economy-wide net-zero emissions at EU level

Level 3 – aligned with EU 1.5 LIFE
- €114 by 2030, then decline to €135/MWh in 2050
- Include lifestyle changes and a stronger circular economy on top of level 2 scenario to reach economy-wide net-zero emissions at EU level

Level 2 – aligned with EU COMBO
- € 113 by 2030, then further increase to €127/MWh in 2050
- Combine main available technology option on the basis of cost-efficiency to reach economy-wide 90% GHG reduction at EU level

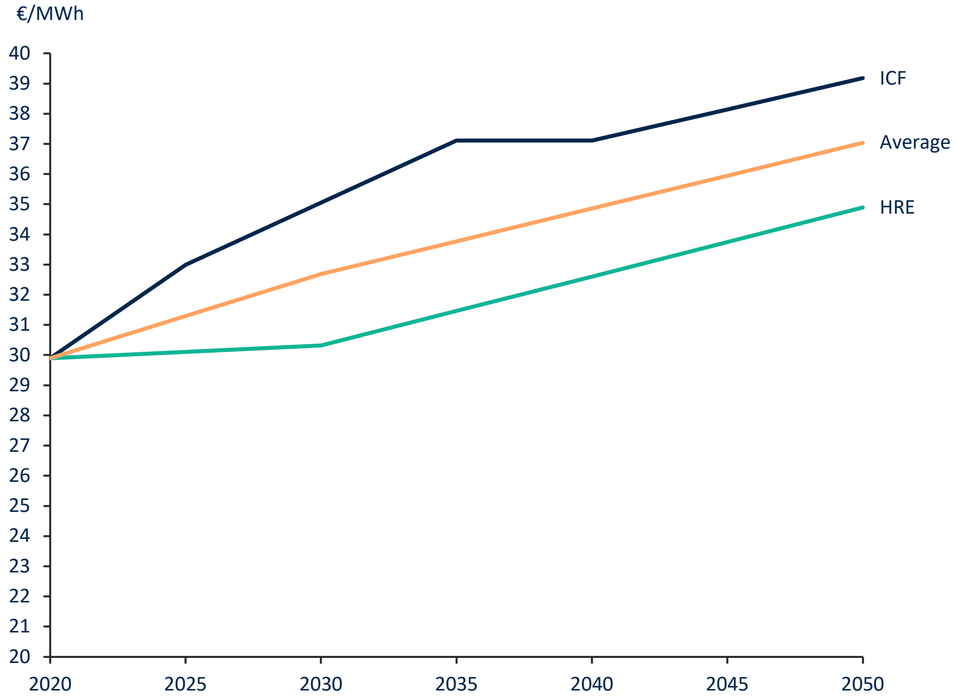
Level 1 – aligned with EU REF
- € 113 by 2030, then decline to €110,5/MWh in 2050
- Baseline scenario on which policy scenarios are evaluated by the Commission

Source: Based on price evolution from European Commission, *A clean Planet for All, In-depth analysis,* applied to an initial price of €110/MWh
2025 price based on German power futures for 2025

Energy costs | Paper cost | Transport cost

1. Costs energy efficiency | 2. Costs from boiler switches | 3. Energy purchase | 4. Carbon cost

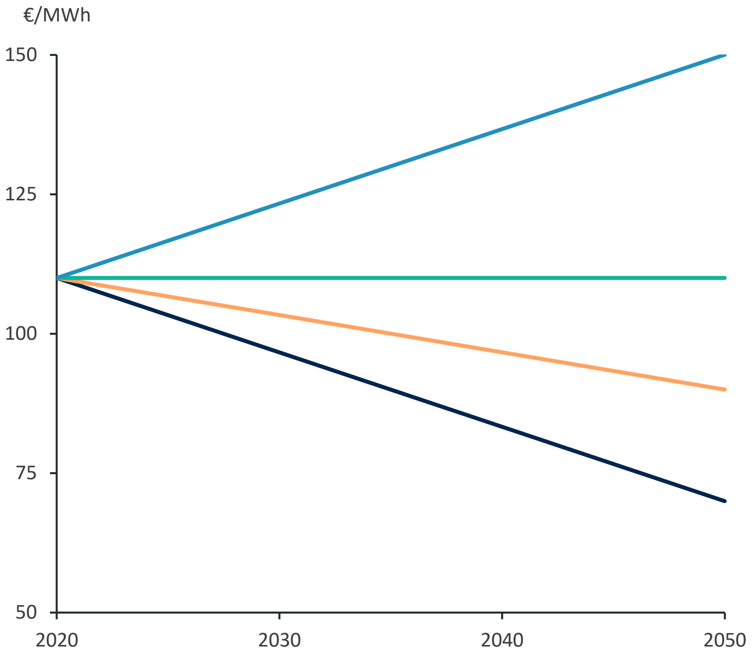
Possible evolution of future energy prices – biomass



Price projections are consistent throughout the different sources found. An average value was used for all scenarios

Sources:
Heat Roadmap Europe (2017), *EU28 fuel prices for 2015, 2030 and 2050*
ICF & Fraunhöfer (2019), *Industrial Innovation: Pathways to deep decarbonisation of Industry. Part 2: Scenario analysis and pathways to deep decarbonisation*

Possible evolution of future energy prices – biomethane



Level 4 – based on high biomethane demand
- Meeting high demand would require tapping into high-cost production potential (up to €150/MWh in 2050)

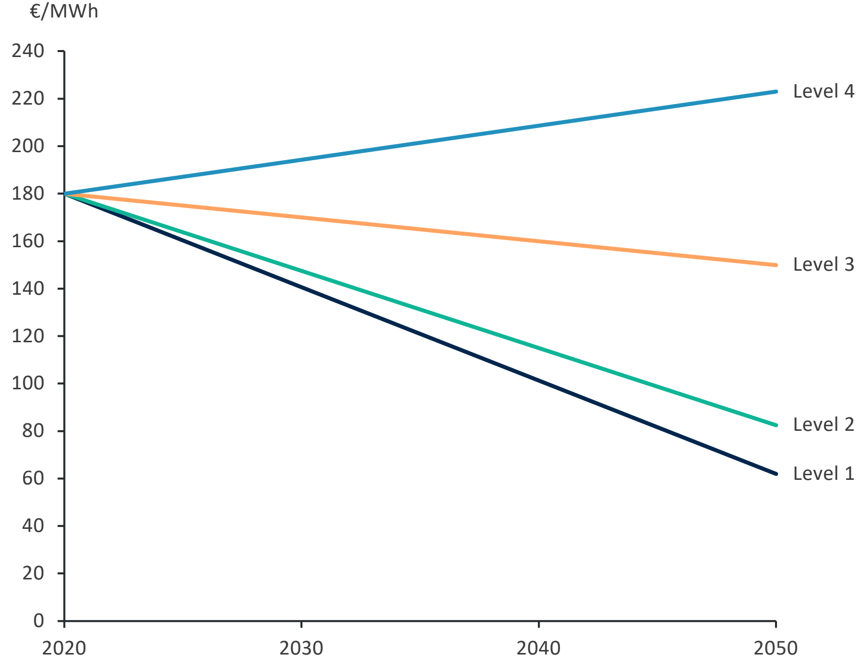
Level 3 – based on medium biomethane demand
- Constant price level compared to today

Level 2 – based on moderate biomethane demand
- Price decreases due to economies of scale/technological improvements, until €90/MWh in 2050

Level 1 – based on limited biomethane demand
- Up to half of the full biomethane potential in the EU materializes by 2050
- Prices decrease compared to today based on economies of scale/technological improvements

Source: Engie 2021, *Biomethane: potential and costs in 2050*

Possible evolution of future energy prices – hydrogen



Level 4 – increase by 31% in 2050 (vs 2015)

- Following electricity evolution according to EU 1.5 TECH scenario

Level 3 – decrease by 13%

- Intermediate between level 4 and 1

Level 2 – decrease by 31%

- Hydrogen price from the Hydrogen Import Coalition Final Report

Level 1 – decrease by 64%

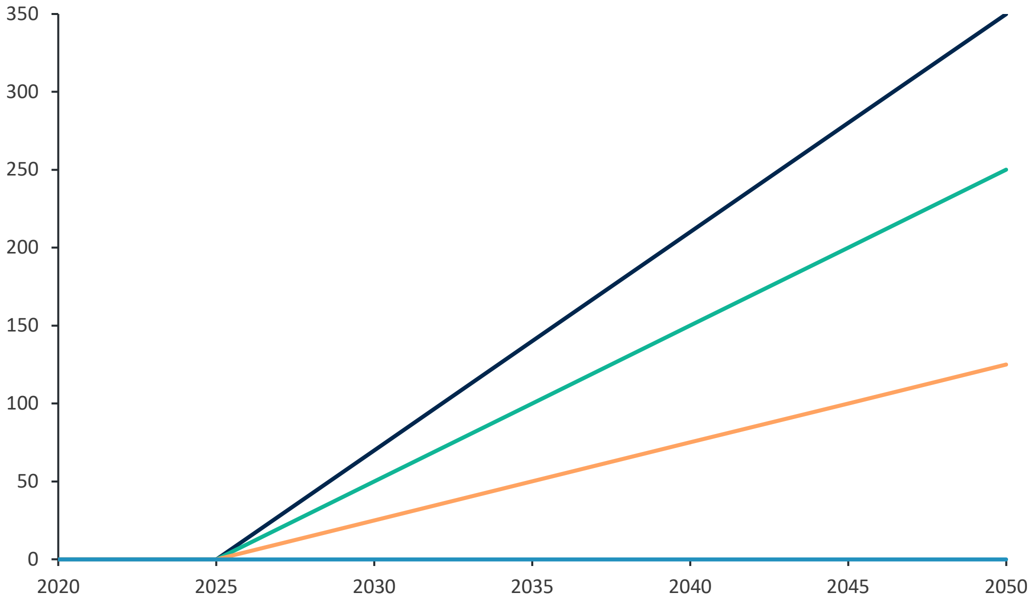
- Idem level 2, assuming even further hydrogen price reduction

Source:
Hydrogen council 2019, *Path to Hydrogen*
The hydrogen import coalition (2020), *Hydrogen Import Coalition Final Report*

Energy costs | Paper cost | Transport cost

1. Costs energy efficiency | 2. Costs from boiler switches | 3. Energy purchase | 4. Carbon cost

- The corrugated board sector is currently not (yet) covered by a (EU-wide) carbon price
- however, this might change in the future (see e.g. current plans to extent the ETS to buildings and road transport)
- The climate neutral scenarios assume that a carbon price (or equivalent) would be applied to the sector after 2025



Level 4

- Carbon price of €70/t by 2030 and €350 t by 2050
- Consistent with upper end of Commission's projections for the ETS for buildings and road transport

Level 3

- Carbon price of €50/t by 2030 and €250 t by 2050
- Consistent with the lower end of Commission's projections for the ETS for buildings and road transport

Level 2

- Carbon price of €25/t by 2030 and €125 t by 2050
- Halfway L1 and L3

Level 1

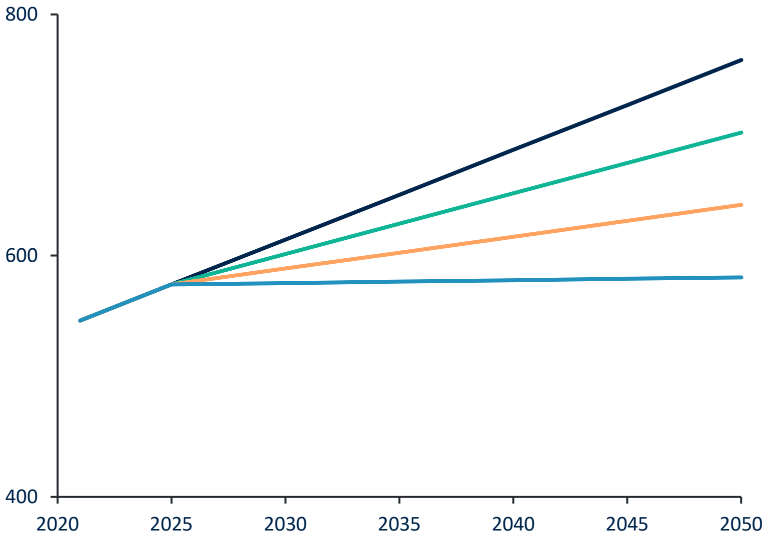
No carbon price (Business as Usual)

Energy costs | **Paper cost** | Transport cost

To assess the potential cost impacts of decarbonized paper a simplified approach was used based on a (shadow) carbon price

The (shadow) carbon price reflects either the additional cost of low-carbon technologies to reduce 1 tonne of $CO_{2eq.}$, or the carbon cost carried under the EU ETS in case of no decarbonization

Paper cost
(in €/tonne nsp)



Level 4 – shadow price of €150/t CO_2 in 2030 and €400/t CO_2 in 2050

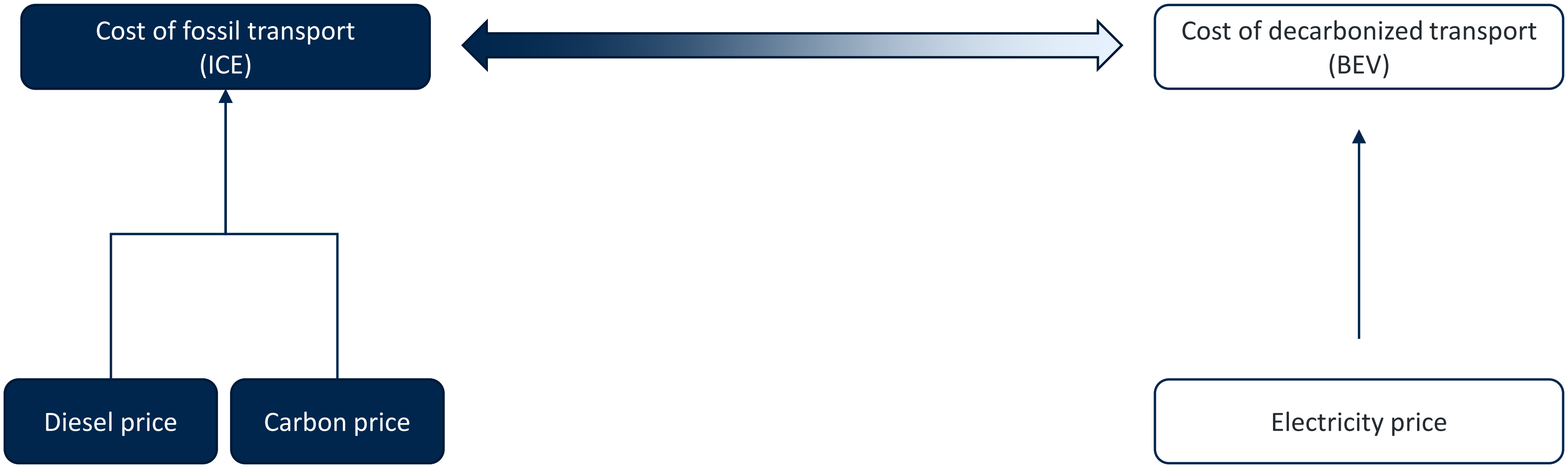
Level 3 – shadow price of €130/t CO_2 in 2030 and €300/t CO_2 in 2050

Level 2 – shadow price of €110/t CO_2 in 2030 and €200/t CO2 in 2050

Level 1 – shadow price of €90/t CO_2 in 2030 and €100/t CO2 in 2050

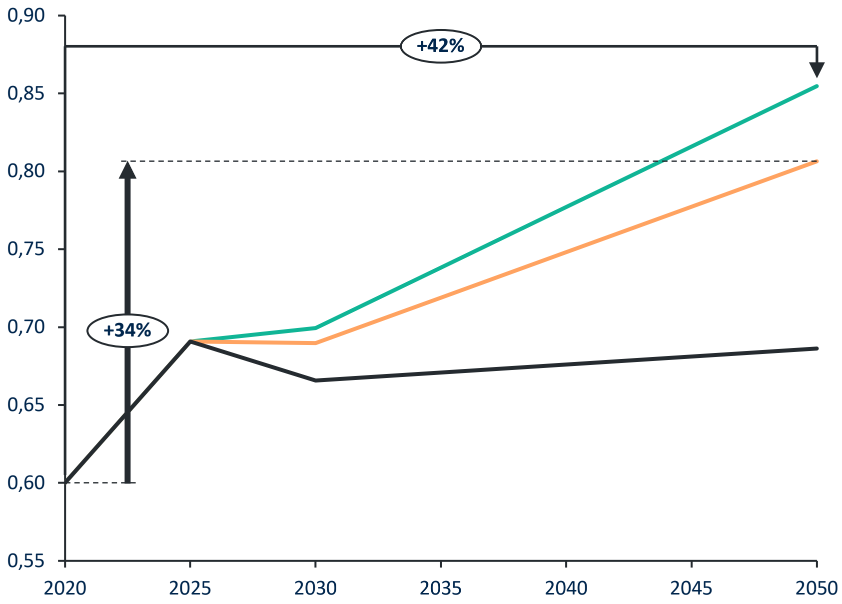
Transport costs will be based on the degree of decarbonization in each scenario

Transport costs will be determined in function of level of decarbonization assumed (based on weighted average)



Costs of fossil-based transport increase slightly under BAU (due to higher oil prices), and more significantly (due to a carbon price) under the climate neutrality scenarios

Cost of fossil-based transport
(in €/vkm)



Climate neutrality scenario – higher range
- Diesel price evolves in line with the IEA STEPS*
- Carbon price starts in 2026, reaches €350/t in 2050

Climate neutrality scenario – lower range
- Diesel price evolves in line with the IEA STEPS
- Carbon price starts in 2026, reaches €250/t in 2050

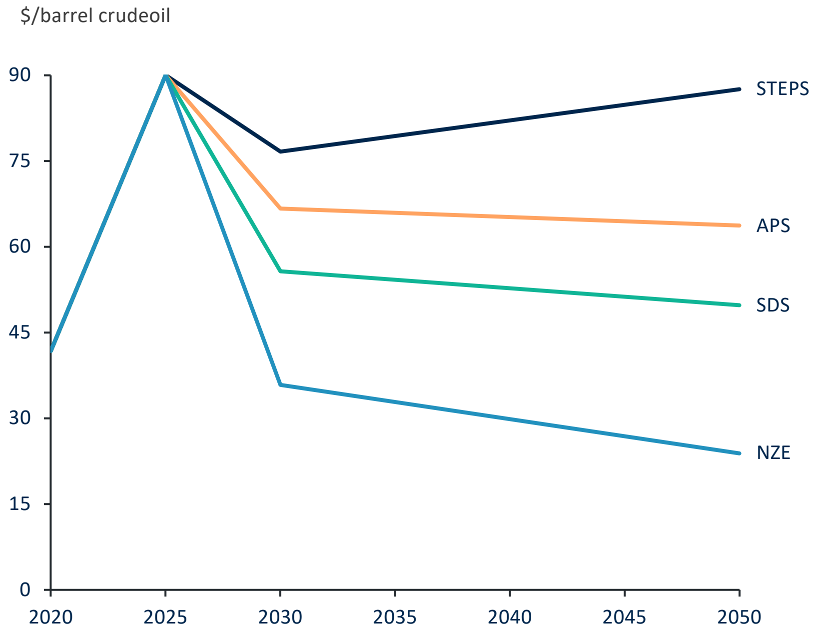
BAU
- Diesel price evolves in line with the IEA STEPS
- No carbon price

Fossil transport – background info

	Per vehicle	Per vehicle-km
Vehicle cost (CAPEX)	k€ 115	€0.164
Vehicle travel distance	700,000 vkm	
O&M	€18.5/100km	€0.185
Diesel consumption	25 l/100km	0,25 l
Emission factor	2,6 kg CO_2/l diesel	798 g CO_2

Source: ICCT 2021, TOTAL COST OF OWNERSHIP FOR TRACTOR-TRAILERS IN EUROPE: BATTERY ELECTRIC VERSUS DIESEL

Except for average consumption, where an assumption was made based on average consumption of new models

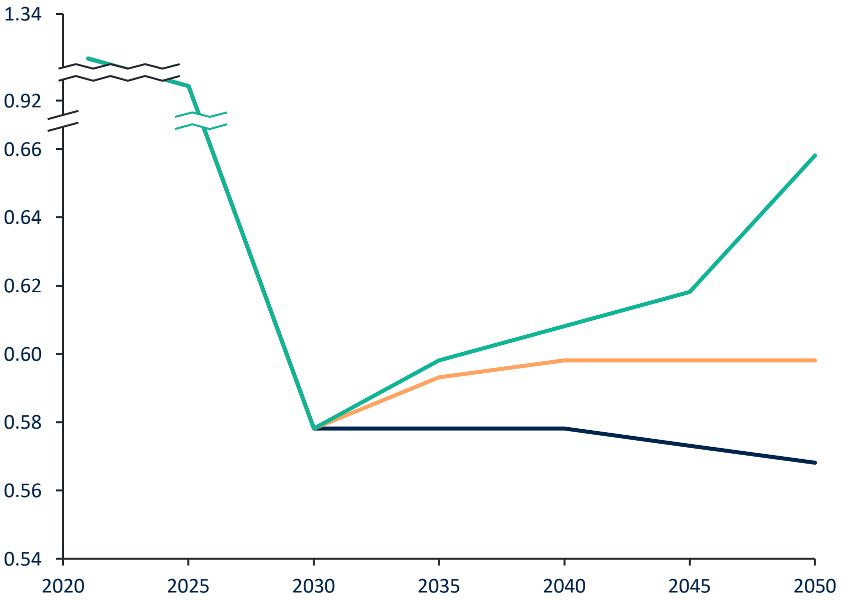


Source: IEA, World Energy Outlook 2021

Energy costs | Paper cost | **Transport cost**

Costs of electrified transport would decrease between now and 2030 due to technological developments, and would then evolve in function of electricity prices.

Cost of electrified transport
(in €/vkm)



Climate neutrality scenario – higher range
- Prices drop between 2020 and 2035 due to economies of scale
- After 2035, price increases due to increasing electricity prices (e-prices aligned with the EU 1.5TECH scenario)

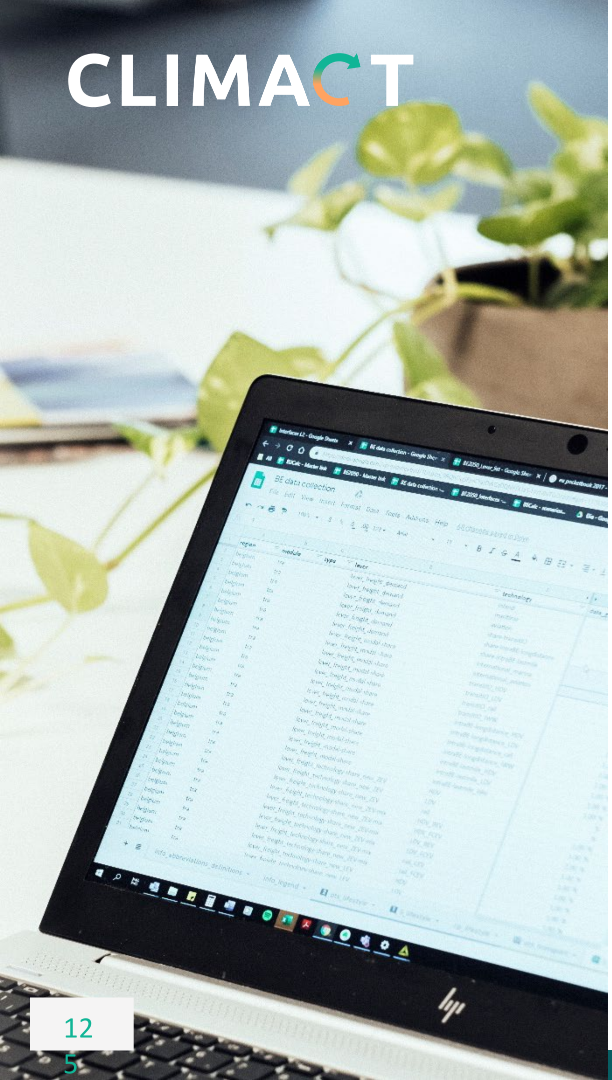
Climate neutrality scenario – lower range
- Prices drop between 2020 and 2035 due to economies of scale
- After 2035, price increases slightly due to increasing electricity prices (e-prices aligned with the EU 1.5LIFE scenario)

BAU
- Prices drop between 2020 and 2035 due to economies of scale
- After 2035, price continues to (slightly) decline due to decreasing electricity prices (e-prices aligned with the EU REF scenario)

Electrified transport – background info

	2020		2030 (assumed constant beyond 2030)	
	Per vehicle	Per vehicle-km	Per vehicle	Per vehicle-km
Vehicle cost (CAPEX)	k€ 450	€0,64	k€ 200	€0,29
Vehicle travel distance	700,000 vkm		700,000 vkm	
O&M	€13.24/100km	€0,132	€13.24/100km	€0,132
Diesel consumption	140 kWh/100 km	1,4 kWh	100 kWh/100 km	1 kWh
Electricy price for charging	€394/MWh		€152/MWh in 2030 Evolves with EU scenarios beyond 2030 (see slide 17)	

Source: ICCT 2021, TOTAL COST OF OWNERSHIP FOR TRACTOR-TRAILERS IN EUROPE: BATTERY ELECTRIC VERSUS DIESEL
https://theicct.org/sites/default/files/publications/TCO-BETs-Europe-white-paper-v4-nov21.pdf



The corrugated sector today

The vision: climate neutrality by 2050

The roadmap to implement the vision

Technical Annex

- Current carbon footprint
- Modelled decarbonization pathways
- Cost assessment
- **Detailed assessment of energy measures**

1. Heat system (boiler house, steam pipe network, …)

Examples of actions to take

- Closed loop condesate systems and economiser to pre-heat feed water
- Steam pipe insulation, steam leak detection and regular inspection of the condensate traps
- Energy management systems, including better air pressure balance (manage under- and overpressure in the factory halls)
- Further valorisation of condensate return and dlue gas heat (e.g. pre-heat inlet air and/or building heating)
- Better control of boiler operations (online measurement of O_2/CO concentration)

Potential

Cummulatively, these measures can reduce the required fuel input in a corrugated plant between 20% and 30% (and even more, if waste heat is fully recovered). However, many of the actions described above are already a common practice in the sector, although some potential remains. The remaining potential is therefore estimated to be between 5% and 10%.

Feasability & timing

Technology for these measures is mature and applied at a large scale.
Most measures have a low cost/short payback period.
These measures can also be applied on existing equipment (retrofitting)
No limitations in terms of resource availability.

Feasibility is therefore considered to be high, these measures can be implemented as of today.

2. Corrugators

Examples of actions to take

The efficiency of corrugators can be improved by improving heat, moisture and starch application control. This requires the following steps:

- Use advanced control systems (these already exist on new corrugators, but existing ones could also be retrofitted)
- Ongoing training of the operating staff
- Regular and thorough maintenance of corrugators to guarantee minimum starch application
- Develop standard for measuring corrugator efficiency and set benchmarks
- Further development of the control systems, especially moisture and humidity along the whole process chain.

Potential

New, more efficient corrugators have been reported to +- 20% (and in some cases, even up to 50%) more efficient than old models. As many corrugators in the sector are not yet equipped with advanced control system, the improvement potential is therefore estimated to be +- 15%

Feasability & timing

As corrugators are capital intensive and have long lifetimes, the feasibility of these actions depends on the ability of corrugator manufacturers to supply retrofit solutions, and the willingness of the corrugated sector to invest in retrofitting and ongoing training.

As several corrugator manufacturers already provide retrofitting solutions, the feasibility is considered to be medium to high.

3. Breakthrough technologies

Examples of actions to take

Some breakthrough technologies could allow the sector to significantly lower its energy consumption.
One particular area is the development of alternative glues which require significantly lower temperatures compared to existing starches.
RISE (Research Institutes of Sweden) are currently already doing research on this topic, but the technology is still in an early development phase [TRL 1-2]

Potential

Breakthrough technologies such as alternative glues could significantly lower the required heat to produce corrugated board.
As the corrugator is the main heat consumer within the sector, the potential is therefore estimated to be high.

Feasability & timing

As the technology is still in a very early development phase, the feasibility is considered to be low.

Roll-out of the technology – if proven feasible – would only be possible as of 2030-2040.

4. Converting line efficiency

Examples of actions to take

Converting machinery accounts for a significant share (> 40%) of the electricity consumption in an integrated corrugated plant. Up till now, energy efficiency has not been a prime focus of machinery suppliers. Furthermore, new machinery consume significantly more electricity (up to x10!) compared to older models, due to high performance control systems, infrared dryers, increased IT systems, etc. … To improve the energy efficiency of the converting process, following steps would need to be taken:

1) Measure the energy consumption of current machinery throughout the sector based on harmonized standards (to ensure comparibility)
2) Based on the measurements under step 1, define benchmarks
3) Engage with suppliers and incentivize them to increase efficiency of both new as existing (via retrofitting) solutions.

When considering the efficiency of converting machinery, both the efficiency of individual machines as well as of the entire converting line should be considered.

In parallel to improving energy efficiency, manufacturers should also aim to reduce the loss of the board strength during the converting process.

Potential

Energy efficieny has not been a prime focus of machinery suppliers so far. It is expected that significant improvements can be made regarding the energy efficiency of converting machinery.

Feasability & timing

This measure requires the engagement of manufacturers of converting machinery to develop solutions with higher energy efficiency.
The feasibility is therefore considered to be medium to high.
Taking into account the time required to measure efficiency, develop benchmarks and develop optimized machinery,
large-scale roll-out could start by 2030.

5. Auxilary efficiency

Examples of actions to take

In addition to the corrugator and coverting machinery, auxiliary services are another major source of electricity consumption (up to 30% of total). Within this group, internal vacuum transport systems (for waste disposal), ventilation systems, compressed air and lighting are the most important sources of electricity consumption.

Several measures can be taken to improve the energy efficiency, including:

- Switching from vacuum to conveyer belt transport systems (-5% electricity demand at plant level)
- Compressed air leak detection and prevention (-5% electricity demand at plant level)
- LED lighting (-3% electricity demand at plant level)
- More efficient ventilation systems
- Replace fuel-based with electric fork lifts

Potential

Cummulatively, these measures can reduce the required electricity consumption in a corrugated plant up to 20%

As some of these measures have already been implemented within the sector, the remaining potential is estimate to be between 5 and 10%

Feasability & timing

Technology for these measures is mature and applied at a large scale.

Most measures have a low cost/short payback period.

These measures can also be applied in existing plants (except conveyer belt transport, which might be more difficult)

No limitations in terms of resource availability.

Feasibility is therefore considered to be high, these measures can be implemented as of today.

Thank you.

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