Comparative techno-economic analysis of industrial technologies for achieving carbon neutrality in the steel and cement production

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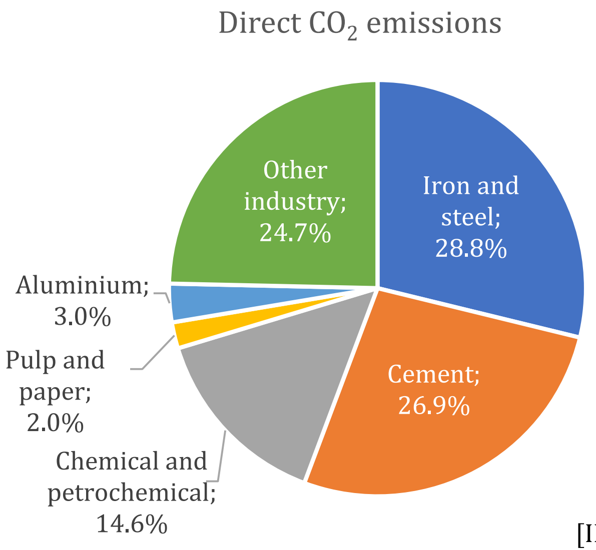
Motivation
Carbon Emissions from the Steel and Cement Industries

- Industries accounted for 23% of the total greenhouse gas emissions in 2021.
  - Steel production generated 2.7 Gt_{CO2} (28.8% of industrial emissions)
  - Cement production generated 2.52 Gt_{CO2} (26.9% of industrial emissions)
- According to the IEA's Sustainable Development Scenario (SDS), in order to achieve climate neutrality by 2050, each CO_2 emissions reduce to
  - 1.18 Gt_{CO2} (reduced by 56%) in steel production
  - 0.9 Gt_{CO2} (reduced by 64%) in cement production



[IEA, 2021]

Research Questions

1. Economic feasibility of Carbon Reduction Technologies

Examining the current economic feasibility and maturity level of **electrification and CCS technologies** with the **levelized costs** of steel and cement.

2. How Energy Costs Affect Production Costs?

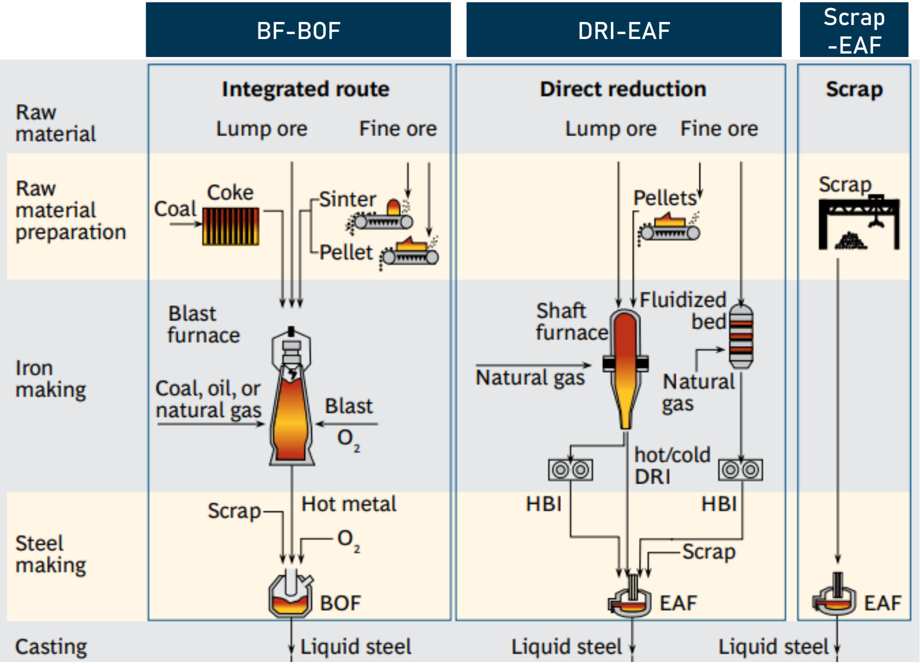
Estimate future scenarios of electricity, natural gas, and coal prices based on current prices, and analyze the impact of energy on production costs.

3. Economic Impacts of EU carbon permits on the Industry

Assessing the financial implications of CO_2 taxes on the steel and cement industries, from a business and policy perspective.

Industry Overview
Carbon Reduction Technology in Steel Production

- **Blast Furnace - Basic Oxygen Furnace (BF-BOF):**
  - the conversion of iron ore into molten iron using a blast furnace, which is then refined into steel using a basic oxygen furnace
  - the most carbon-intensive due to the use of **coking coal** in the blast furnace
- **Direct Reduced Iron - Electric Arc Furnace (DRI-EAF):**
  - reducing iron ore into a sponge iron using **natural gas**, which is then melted down in an electric arc furnace
  - less carbon-intensive than BF-BOF because natural gas emits less CO_2 than coal
- **EAF using Steel Scrap**:
  - melting down **scrap steel** in an electric arc furnace.
  - the least carbon-intensive method because it recycles existing steel instead of producing new steel from iron ore



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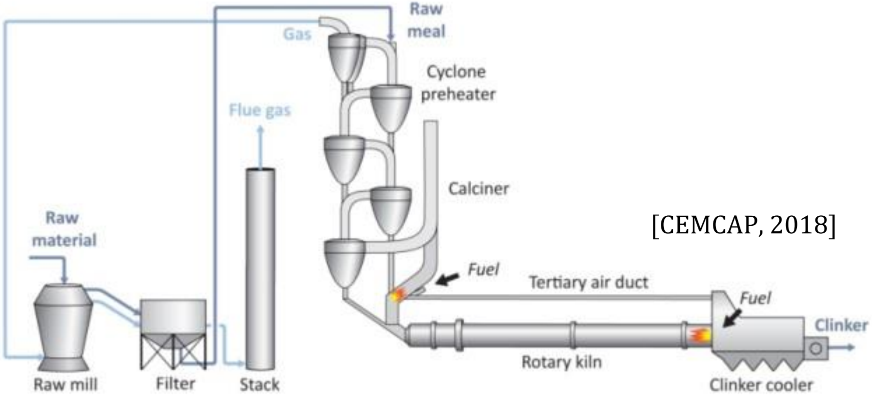
Industry Overview
Carbon Reduction Technology in Cement Production

- **Conventional Cement Production**:
  - heating limestone and other materials in a kiln to produce **clinker**, which is then ground into cement
  - highly carbon-intensive, with most emissions coming from **the calcination process** where limestone (calcium carbonate) is heated to produce lime (calcium oxide), releasing CO_2

- **Cement Production with Carbon Capture and Storage (CCS)**:
  - similar to conventional cement production, but it incorporates CCS technology to capture the CO_2 emitted during the calcination and combustion processes and store it underground.
  - This method reduces CO_2 emissions by more than 90%.

Clinker Production



[CEMCAP, 2018]

In this study, only **the clinker production** process is covered hence it is carbon intensive.

Energy Intensity & Price Assumption

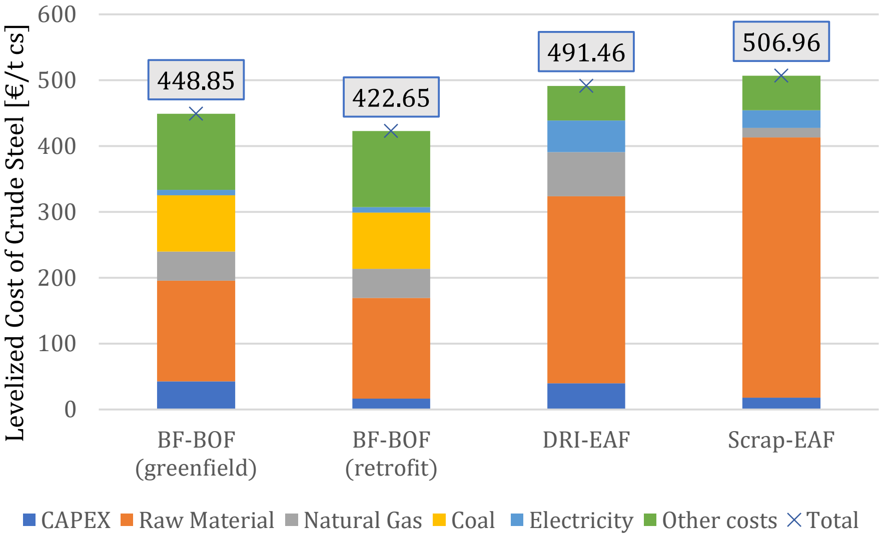
Energy Intensity

	Industrial Process	Natural Gas [GJ/t product]	Coal [t coal/t product]	Electricity [MWh/t product]	Water [m3/t product]
Steel	BF-BOF	6.343	0.855	0.137	-
	DRI-EAF	9.6	-	0.799	-
	Scrap-EAF	2.090	-	0.444	-
Clinker	Reference Plant	-	0.129	0.132	-
	Reference Plant with CCS	-	0.129	0.278	10

Energy Price Assumption

		2022	**2023**	**2030**
Natural Gas	EUR/GJ	9.5	**7**	**6.5**
Coal	EUR/ton	200	**100**	**90**
Electricity	EUR/MWh	120	**60**	**30**

Result
2023 in Steel Production



- **BF-BOF Retrofit**:
  - ✓ 50% of Greenfield investment (BF, BOF)
- **DRI-EAF**: Steel scrap (50%)
- **Scrap-EAF**: Steel scrap (100%)
- **Other cost**: Labour cost and other consumables (Fluxes, Electrodes, Refractories, Oxygen, Inert gases, Industrial water, Bentonite, Cold rolling oil, Pickling acid and Paint)

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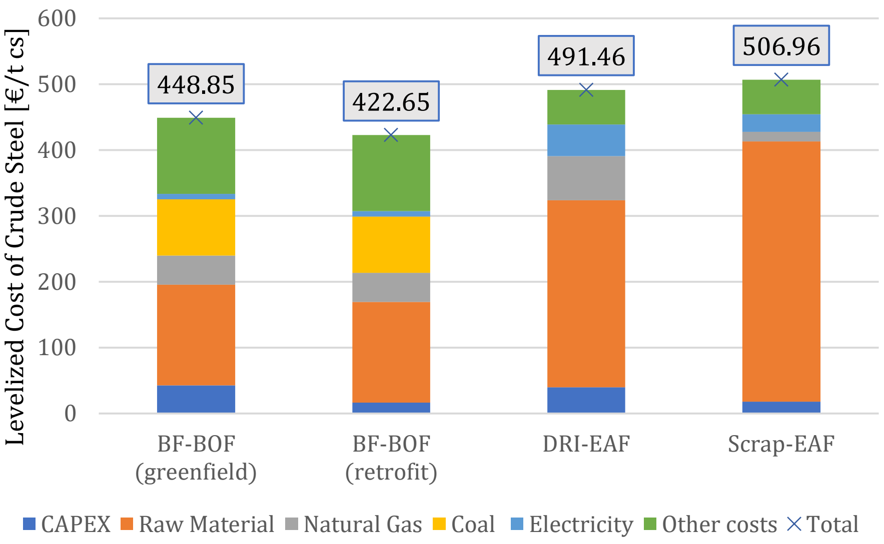
Result
Material Cost in Steel Production



- **Material cost** is the largest component of steel production cost. It accounts for ...
  - **34%** of the total cost in the BF-BOF (greenfield) process,
  - **36.1%** of the total cost in the BF-BOF (retrofit) process,
  - **57.8%** of the total cost in the DRI-EAF,
  - **78%** of the total cost in the Scrap-EAF process.
- The Scrap EAF process has the highest production cost due to the **high price of steel scrap**.
  - Iron Ore: 82.14 €/t
  - Steel Scrap: 219.21 €/t

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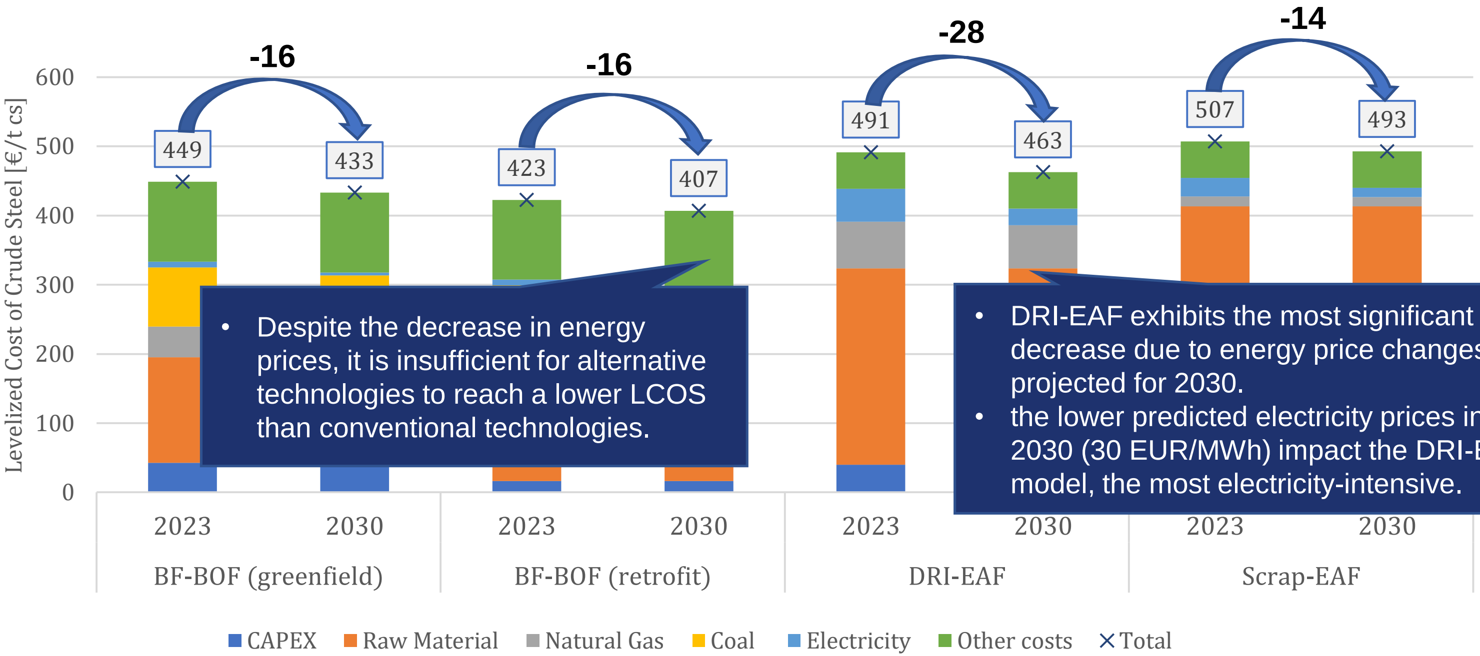
Result
2023 & 2030 in Steel Production



- Despite the decrease in energy prices, it is insufficient for alternative technologies to reach a lower LCOS than conventional technologies.

- DRI-EAF exhibits the most significant decrease due to energy price changes projected for 2030.
- the lower predicted electricity prices in 2030 (30 EUR/MWh) impact the DRI-EAF model, the most electricity-intensive.

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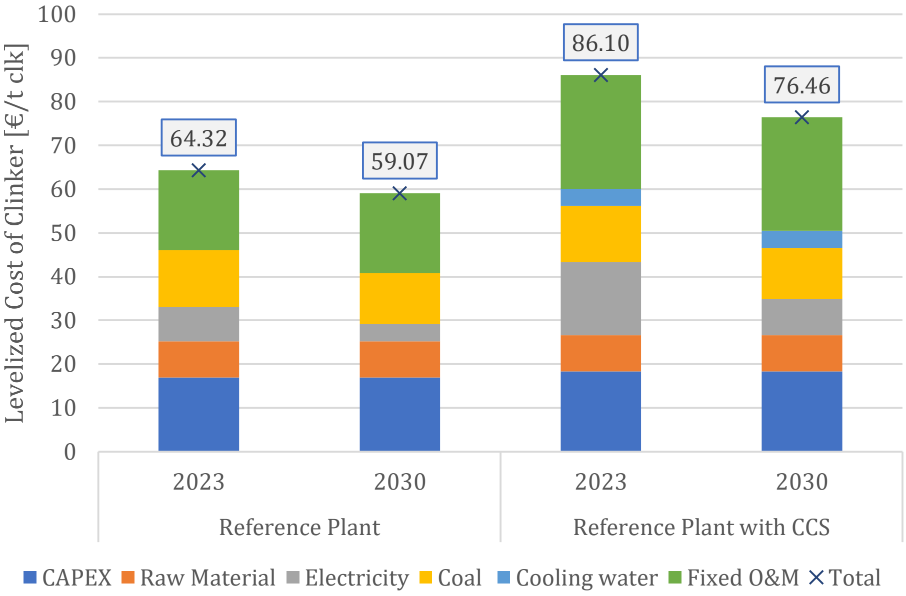
Result
2023 & 2030 in Clinker Production



- CCS technology incurs higher costs than the reference plant as it involves **adding additional processes**.
- Based on 2023, it holds a higher levelized cost of **21.78 €/t_{clk}**, and by 2030, this difference decreases to **17.39 €/t_{clk}**.
- The difference between the costs of the two processes diminishes by **4.39 €/t_{clk}** due to the anticipated decrease in energy prices by 2030.
- However, to find the break-even point between the CCS-inclusive process and the conventional one, **the CO_2 tax must be included** in the scenario.

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Environmental Result
Benchmarks of phase 4 of the EU ETS

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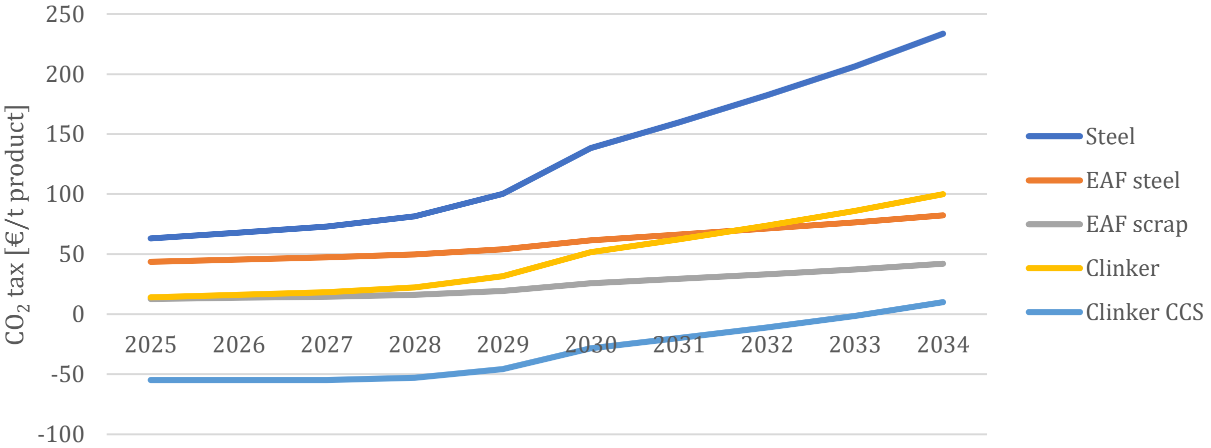
- Benchmarks (2021-2025) and actual carbon intensity [t CO_2 equivalents/t product]

Product	Carbon intensity (t CO2 /t Product)	Benchmark value (allowances/t) for 2021-2025	Average value of the 10 % most efficient installations in 2016 and 2017
Hot metal	-	1.288	1.331
Steel	1.99	-	-
EAF steel	0.7	0.215	0.209
EAF scrap (100% scrap)	0.357	-	-
Grey cement clinker	0.85	0.693	0.722
Clinker CCS	0.085	-	-

ETS = Emissions Trading System

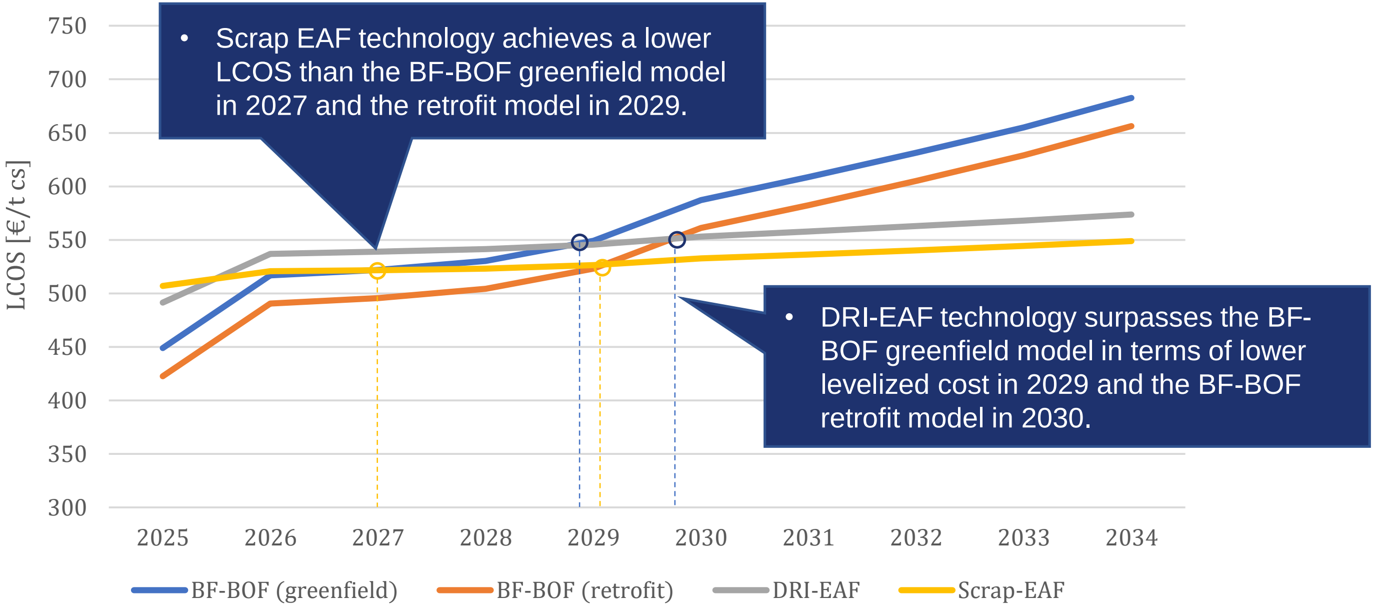
EU Carbon Permits considering free allocation



	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Free allocation reduction rate [%]	-	-	-	2.5%	5%	10%	22.5%	48.5%	61%	73.5%	86%	100%
EU Carbon Permits[1)] [€/t CO_2]	85	87.55	90.18	92.88	95.67	98.54	101.5	104.5	107.7	110.9	114.2	117.7

1) 3% interest rate is assumed

Break-even analysis
in Steel Production



LCOS = Levelized Cost of Crude Steel; CS = Crude Steel

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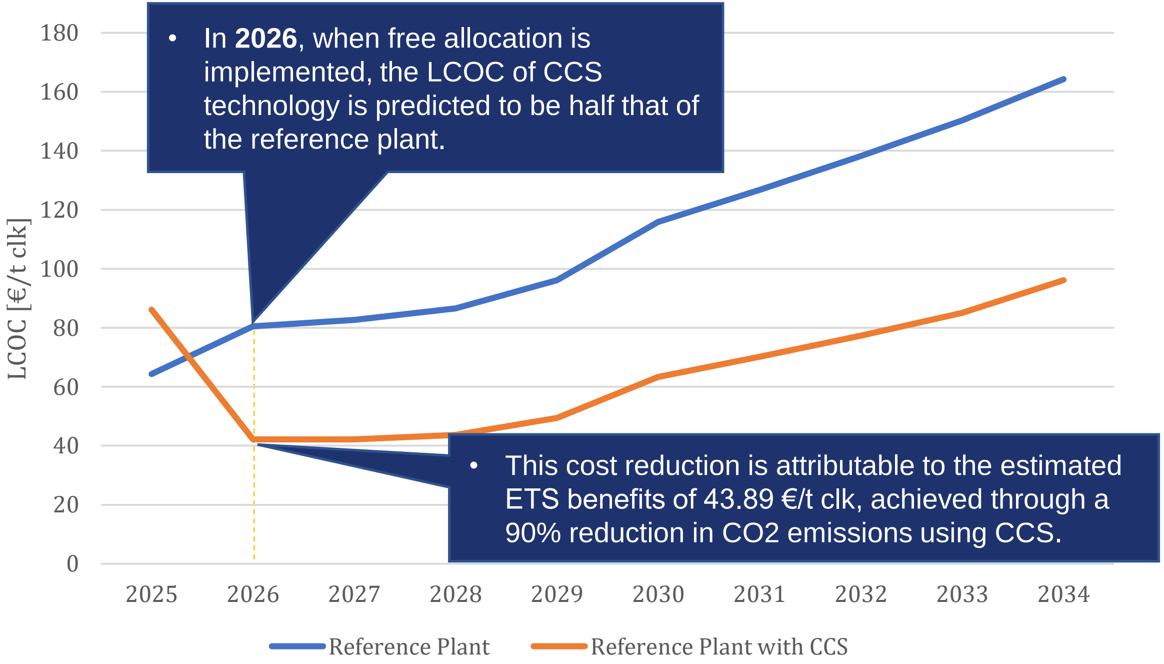
Break-even analysis
in Cement Production



LCOC = Levelized Cost of Clinker; clk = clinker

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Conclusions

- In the steel industry, **material costs are the driving factors**, making it challenging to reach a break-even point without a decrease in material costs (particularly the price of steel scrap) or a carbon tax.
- In the steel and cement industries, the conventional processes are anticipated to experience a significant increase in levelized costs as they are subjected to higher carbon costs due to the **phased withdrawal of free allowances (2026~)**.
- In the steel industry, gradual reduction of free allowances can allow the **Scrap-EAF model to achieve lower LCOS** than BF-BOF (greenfield) **by 2027**.
- In the cement industry, **the carbon emission allowances** are crucial for reaching the break-even point for CCS technology. The reduction in CO_2 emissions resulting from CCS technology leads to a dramatic drop in the Levelized Cost of Clinker via CO_2 emissions trading.

Thanks for your attention!

Any Question?

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