A climate and socio-economic study of a multi-member state carbon price floor for the power sector

Final report

20 December 2018

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Content of the report

ES Executive Summary

Content

Study context and FTI-CL Energy mandate

- **The European Commission has reaffirmed and increased its commitment to decarbonise its economy** with the ratification of the Paris agreement on 5 October 2016
- **The power sector has a key role to play in the decarbonisation of the European economy**:
  - An efficient and sustainable transition would avoid lock-in in thermal plants, …
  - and facilitate investment in capital intensive low carbon technologies.
- **With this background in mind, FTI-CL Energy has been mandated by a group of sponsor companies to:**
  - Assess the EU ETS price outlook and resulting progress against EU objectives; and
  - Identify the possible contribution of a CPF to an accelerated decarbonisation of the power sector.
  - Using fact-based modelling, and assumptions based on third parties recognized independent studies.

Study committee members

Eneco
SIEMENS Gamesa
EDF
Ørsted
edp
IBERDROLA
Vestas
Shell
ENGIE
EnBW

Strong and credible economic signals are needed to support a rapid decarbonisation in line with the Paris Agreement

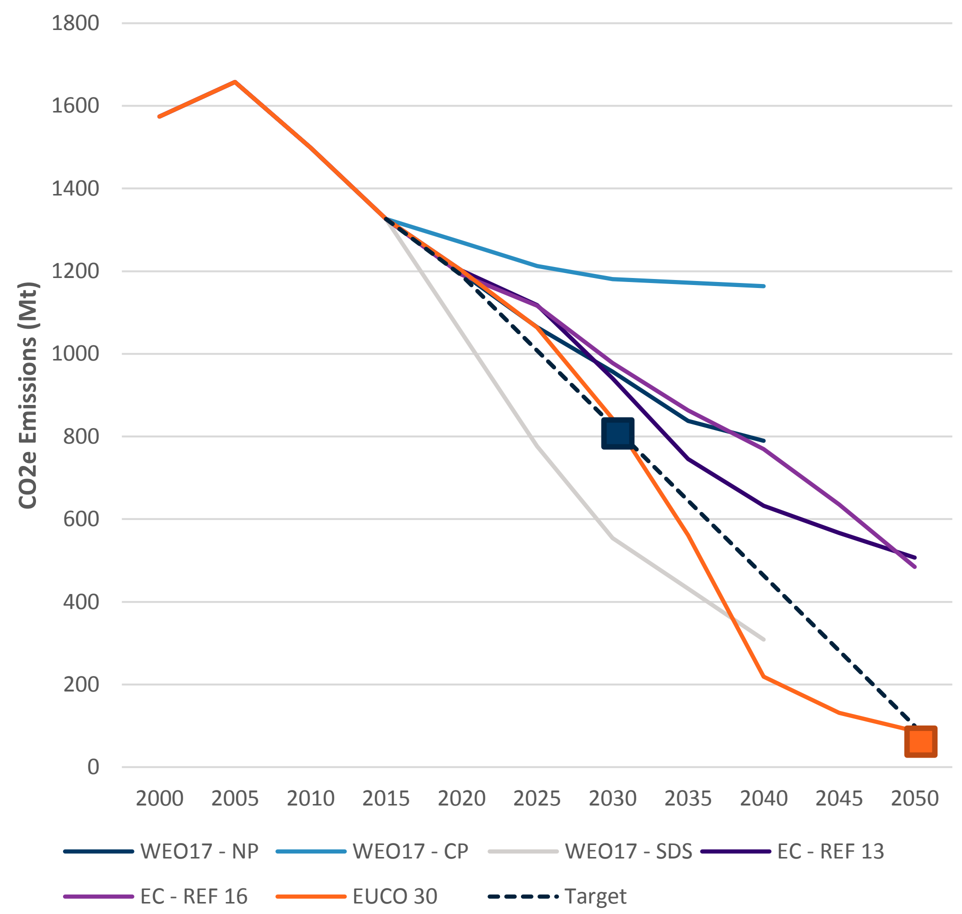
Challenges for policymakers and investors

- Global action consistent with the **Paris Agreement and 2C** may require more than 40% emissions reduction from the EU by 2030, and net zero emissions or more by 2050
- The **power sector** is central to the decarbonisation of the European economy

An efficient energy transition requires clearer and more predictable price signals

- Major **investment and retirement** decisions in clean technologies are required to decarbonize the power sector
- The EU ETS price is **insufficient in the short term**, and does not provide a **strong and credible enough signal** for decarbonisation in the medium to long term

EU CO2e Emissions and targets to 2050



2030 Targets: GHG 40% (826Mt), RE 32% of energy and RE in Power 57%(modelled)

2050 Targets: GHG 80-95% (100Mt)

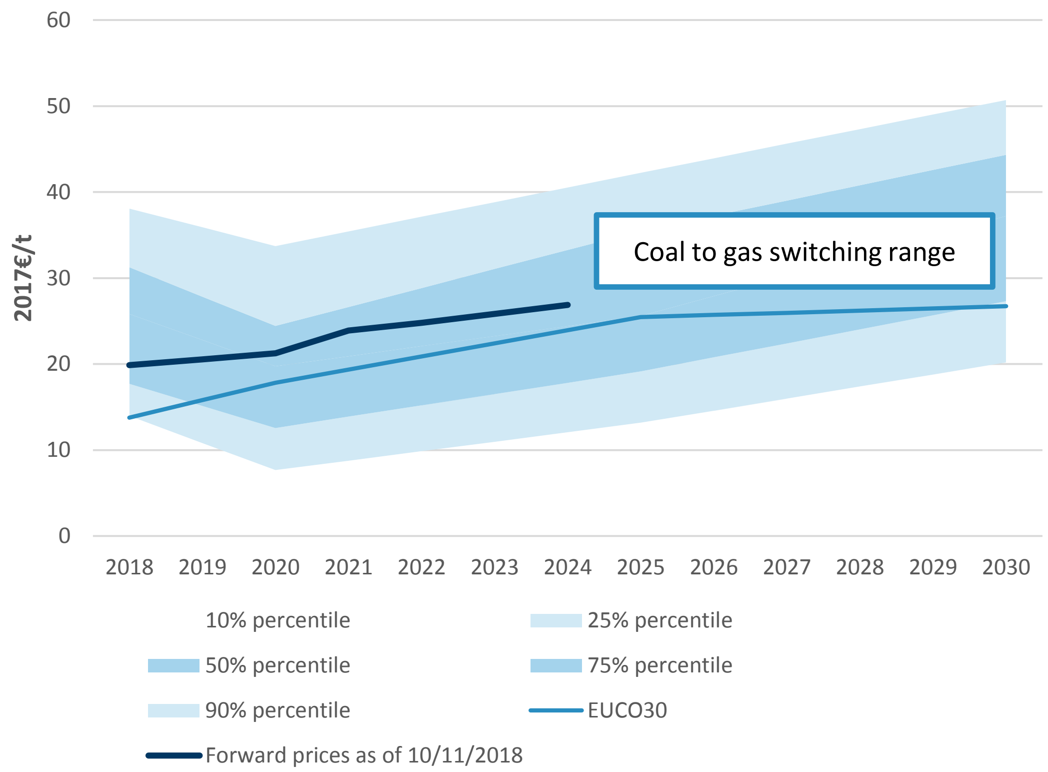
Source: International Energy Agency, European Commission

ETS prices are insufficient in the short term to drive the decarbonisation of the EU power sector

ETS reform is helping but not enough

- Current prices around €20/t are due to the **ETS reforms**, market fundamentals, and hedging behaviour.
- However **parallel policies** such as energy efficiency, RES support, nuclear support, coal phase outs reduce the prospects for a sufficient carbon price.
- **Sustained coal and lignite to gas switching** across Europe would require prices around €15-35/t in the near term, but in the 2020s would require around €20-50/t according to our analysis.
- Current **forward prices are too low** to:
  - Drive a full switching between coal and gas units
  - Incentivize large scale renewables to be developed on a merchant basis

EU ETS carbon price pathways (real 2017)



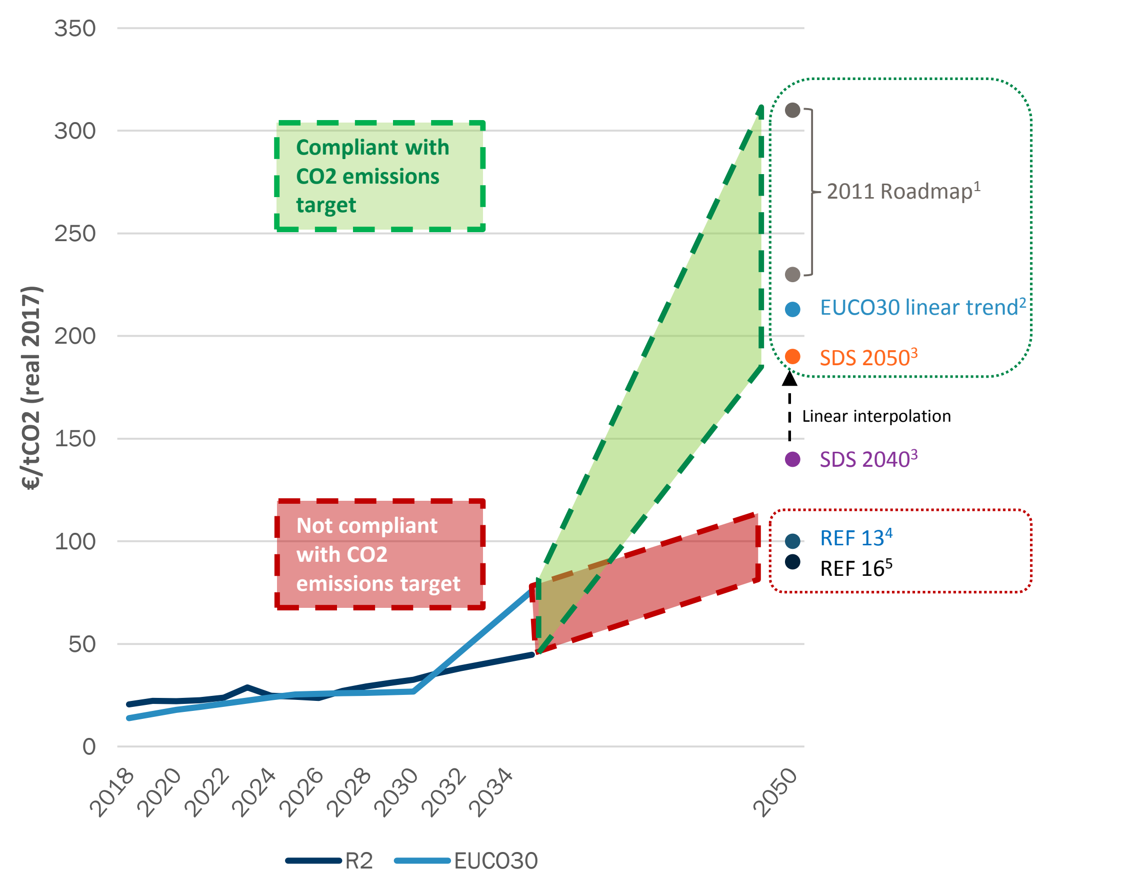
Source: EEX, European Commission

Long term carbon prices may need to rise significantly to complete decarbonisation of some sectors

ETS prices are not intertemporally efficient

- In the long run, **carbon prices may need to reach between 130-150 €/t from 2040** based on Commission and IEA modelling to drive a full decarbonisation of the EU economy
- Such estimates raise the issue of the ETS's ability to send **long term predictable and credible price signals** to investors.
- Too low and unclear price signals in the medium term could lead to:
  - **Technology lock-in for fossil fuel technologies** and the risk of stranded assets
  - **Inefficient investment signals in renewables and low carbon technologies**

Long term EU carbon price (real 2017)



Source: FTI CL Energy modelling, European Commission (EC), International Energy Agency (IEA)

[1] 2011 EC Roadmap to 2050

[2] EC scenario to achieve the 2030 energy and climate targets, interpolated from 2030-2035

[3] IEA Sustainable Development Scenario, 2050 figure interpolated from 2040 figure

[4] 2013 EC Reference scenario

[5] 2016 EC Reference scenario

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Carbon price risks affect investment decisions

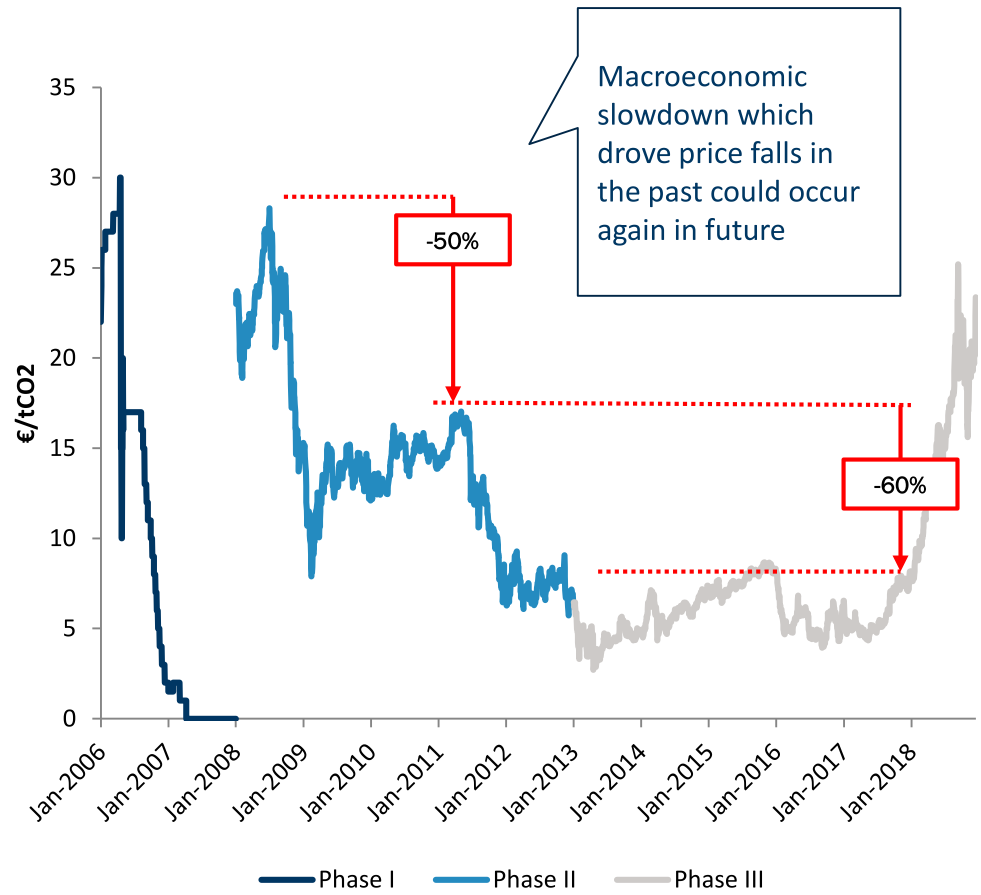
Investors in clean technologies see falling technology costs, but increasing market risk

- **Technology costs** are coming down, improving the business case for renewables investment
- But **revenues are increasingly uncertain as** greater reliance on power prices (and carbon prices as they affect power prices) **increases investor risk**

Investors focus on the *expected* carbon price and the risk that the price in the future may be lower than anticipated

- **Anticipated carbon prices** included in investors' business plans include a significant discount compared to base case projections reflecting the risk of a future price shock / decrease
- It is efficient for Governments to **protect investors against policy risk** which markets cannot accurately price

ETS prices 2006-2018, a history of price falls (downside risk)



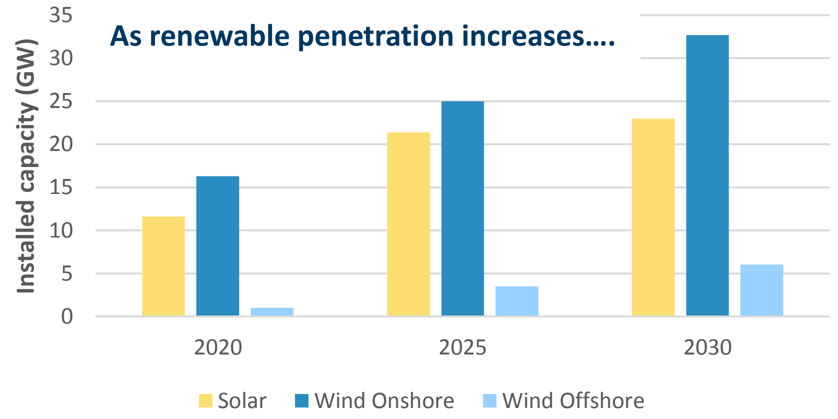
… at a time when most competitive renewables are increasingly bearing market risk

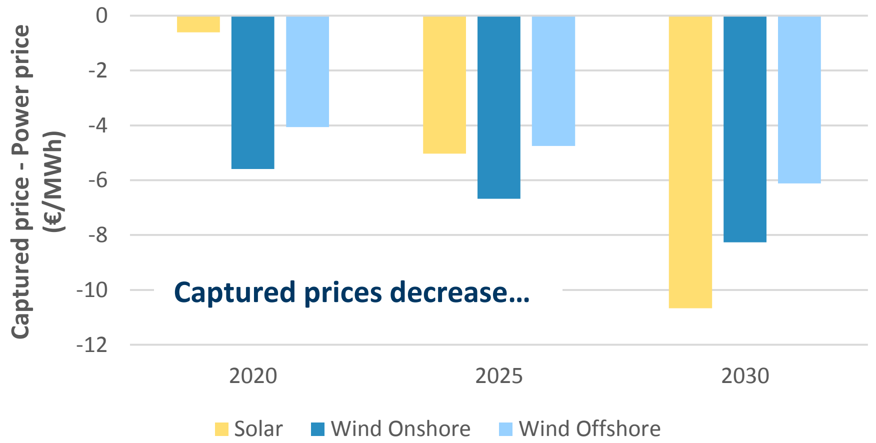
Renewable projects and the "merit order effect"

- Renewables are **low marginal cost** – they push out fossil generation from the merit order
  - **Wholesale prices fall** as a results of increased renewables penetration
- But investors see a **correlated revenue risk** (referred to as 'cannibalisation of revenues')
  - The **captured prices** by wind and solar projects refers to the price achieved during half-hours when wind and solar are generating
- **Carbon price risk** amplifies power price risk and is driven by hard to predict policy decisions
  - The effect on wind and solar revenues will **become worse over time** as renewables penetration increases
  - Additional **storage and other forms of flexibility** on the system would act to smooth out prices

Merit order effect and RES Captured prices

(France to 2030)





High carbon and electricity price risks lead to higher cost of capital and financing constraints

Higher risk increases cost of capital, and constrains access to finance

- Renewable energy projects currently enjoy low cost of capital and access to a wide range of investors due to being considered quasi regulated assets with low risk profiles
- **Greater exposure to power price risk** would
  - Increase the risk premium
  - Reduce debt levels
  - Reduce the pool of investors

We have gathered evidence on the size of the impact

- **Literature review/benchmarking** suggests that power price risk could add around **3-5% points at least onto the WACC for power plant investments**.
- **Financial sector interviews** have broadly supported this range, and further stressed the diversity of financial investors, with very **different tolerance for risk**.
- Our analysis, literature review and interviews suggested that a **CPF could reduce the risk premium** by around 1% point

Price risk (power, carbon) increases financing costs

Literature review/benchmarking

The impact of risks in renewable energy investments and the role of smart policies
Diacore (2016)

Changes in hurdle rates for low carbon generation technologies [...]
NERA (2013)

Can German renewables become competitive within 5 years
Aurora (2013)

Towards triple A policies: more renewable energy at lower cost
EU research project Re-Shaping (2011)

Note on impacts of the CfD [...] on costs and availability of capital and discount on PPAs
CEPA (2011)

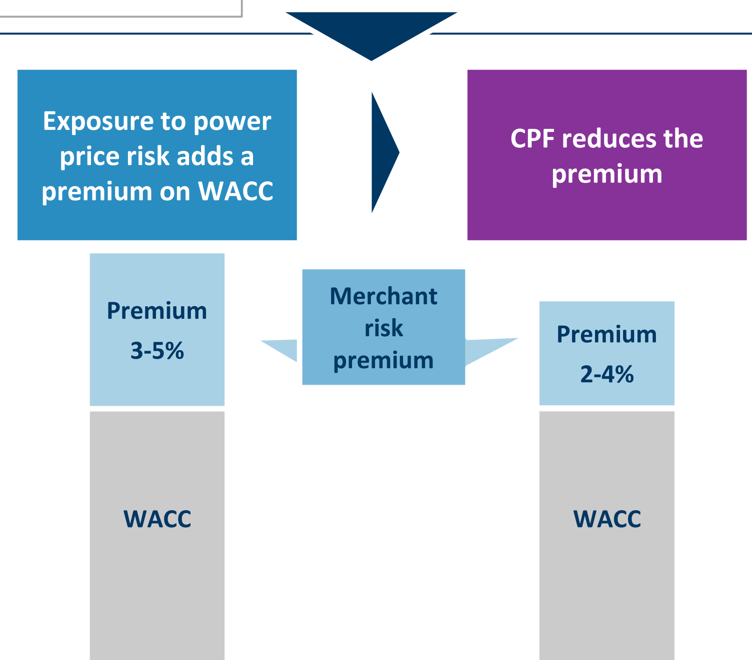
Financial Sector interviews

BNP PARIBAS

CRÉDIT AGRICOLE

HSBC

MUFG



What could be the impact of a Carbon Price Floor (CPF)?

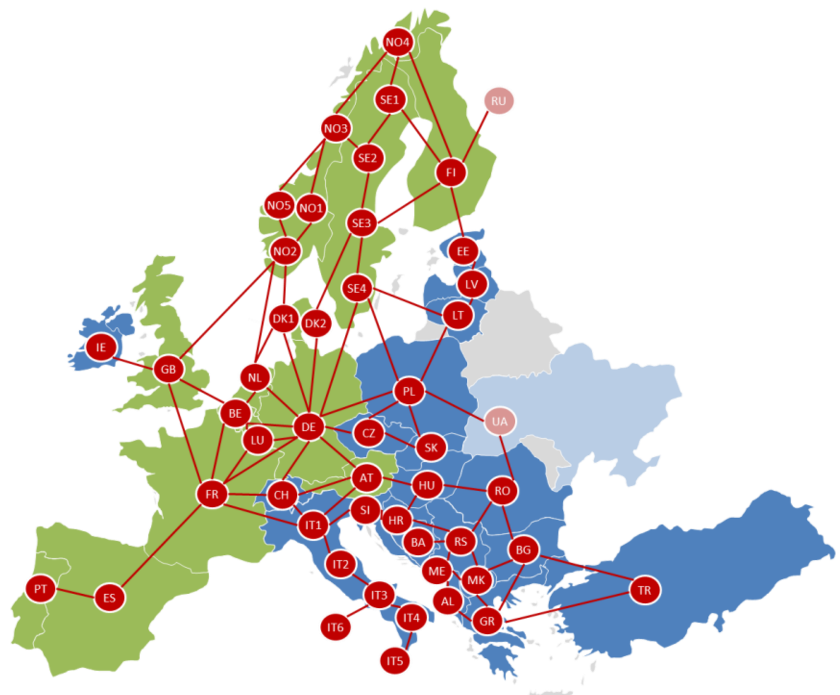
- A **Carbon Price Floor (CPF)** is a mechanism that Governments can use to create a minimum carbon price in their countries.

- **Different implementation models could be used :***
  - As a **top up tax** on the power sector above the EU ETS price (the UK model)
  - **Permit buy backs** – the Government or a market operator could commit to buying EUAs at a minimum price
  - As an **auction reserve price** – e.g. the Government could hold back permits from auction if the price went below a certain level

- In this study **we have not considered implementation questions**, but have assumed that the CPF is implemented in a way which is credible to the market and investors in a '**coalition of the willing' grouping 12 EU member states – in order to minimise unintended consequences such as carbon leakage**.

- In this study, we assume that:
  - The CPF is implemented in **12 Member States as a top up tax**
  - The CPF only impacts the **power sector**
  - **The MSR** will absorb some of the surplus allowances generated by the CPF - **Complementary policies** (such as EUA cancellations) are introduced and absorb the rest in order to maintain the effectiveness of the ETS and minimise leakage to the non-CPF Zone.

We have modelled a CPF introduced in 12 EU member states (the UK is assumed to keep its CPF)



CPF Countries: Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden, Norway and Finland.

- *Newbery et al (2018): When is a carbon price floor desirable? , EPRG Working Paper – Note permit buy backs would only work at EU level*
- *There is also another option whereby regulation would require companies within the CPF zone to surrender additional allowances*

Modelling Approach: Combination of ETS and EU Power Sector Models, based on authoritative and public assumptions

FTI-CL's modelling approach is based on:

- FTI-CL Energy's in-house European power market model and EU ETS model , grounded in reputable modelling platform; and
- Background assumptions based on third party studies compatible with EU objective of (i) energy consumption reduction and (ii) decarbonisation of the EU wide economy.

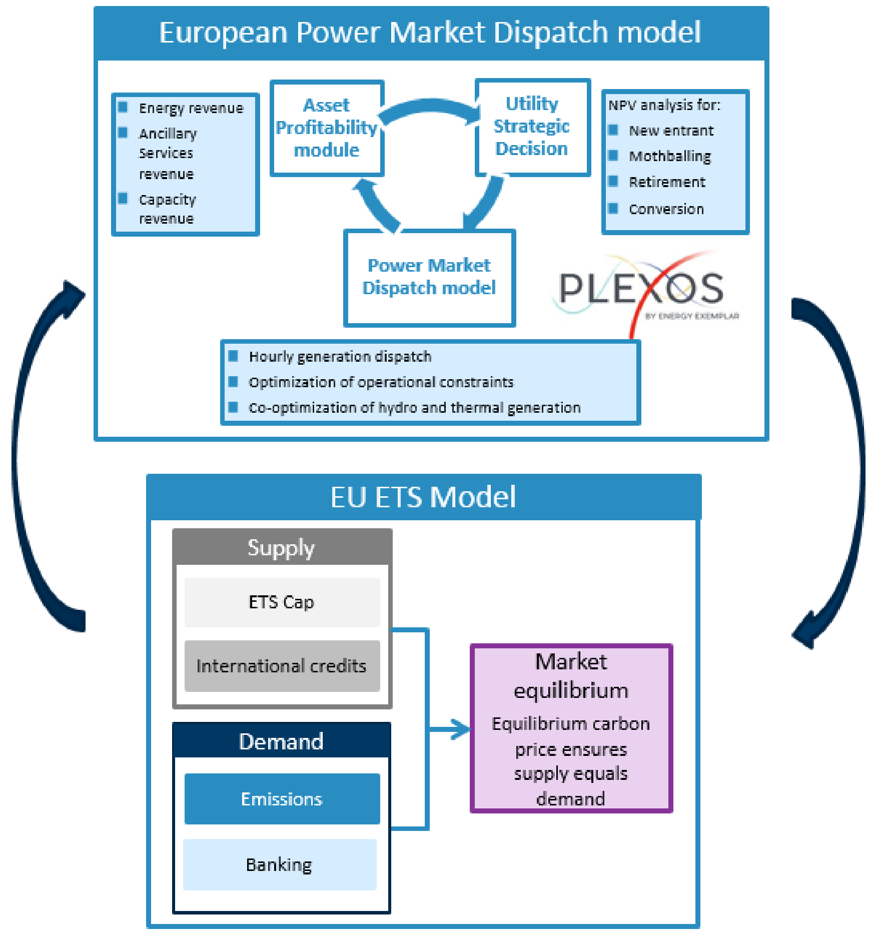
A two-step optimisation process is performed by our power market model:

- **Dynamic optimisation of the generation mix** based on the economics of RES, thermal plants and storage, to ensure security of supply and meet EC objectives at the least cost; and
- **Short term optimisation of dispatch** of the different units on a hourly basis.

This study has used our proprietary models to investigate:

- The ETS price outlook and resulting progress against EU objectives
- The possible contribution of a CPF to an efficient decarbonisation of the power sector

We have used our EU power market model and our EU ETS model



To assess the potential role of a CPF, we have modelled a range of scenarios

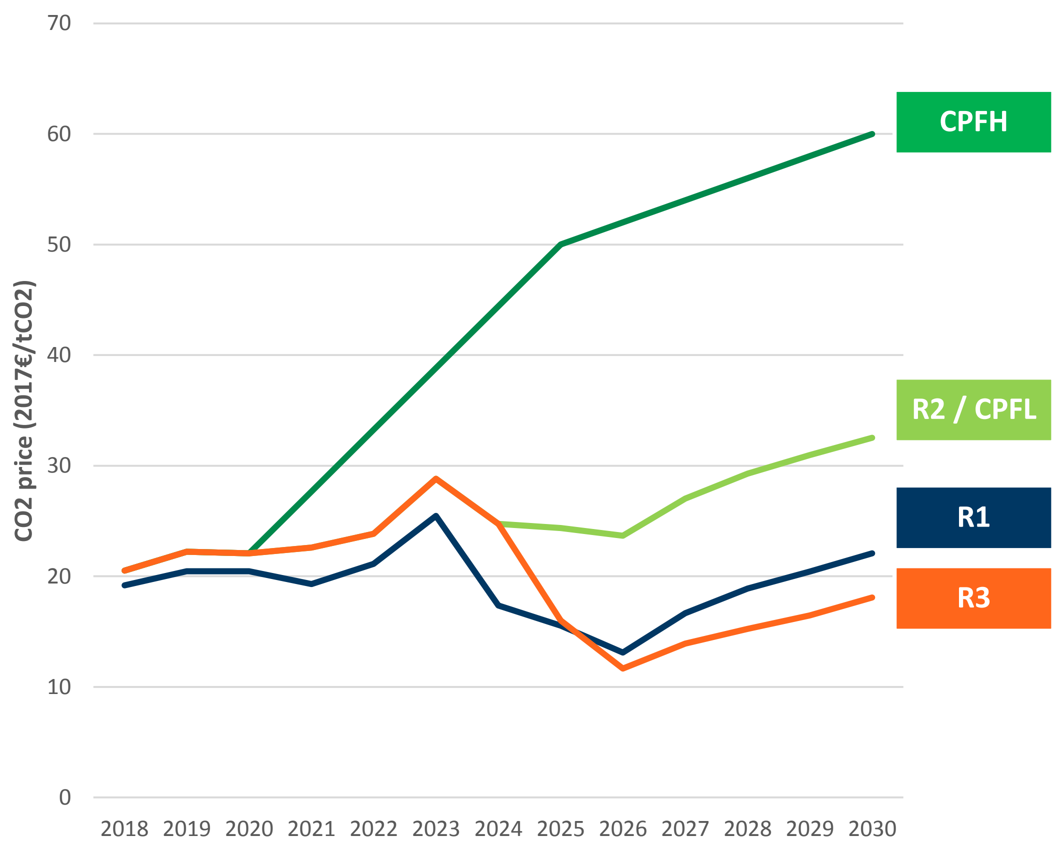
Contrast Scenarios

- **R1 scenario (ETS Low):** ETS prices remain low on the basis of current parallel national RES policies
- **R2 scenario (ETS High):** ETS prices are higher as a result of phasing out parallel RES policies and RES being more exposed to merchant price risk
- **R3 scenario (ETS Price Fall)** illustrates the plausible impact of a demand reduction on ETS prices (based on analysis of historical precedent)

Carbon Price Floor Scenarios

- **Carbon Price Floor High (CPFH)** sets the **CPF at €20/t in 2020 rising to €60/t in 2030.** This scenario illustrates a higher ambition world in which policymakers want to put a major policy emphasis on the carbon price instrument to meet their national RES objectives. The ETS price in the Non-CPF zone is assumed to be kept at the R2 level
- **Carbon Price Floor Low (CPFL)** sets the **CPF at €20/t rising to €30/t in 2030.** This illustrates the role the CPF can play even when set at a similar level to the expected ETS price, as an **insurance policy** against sudden ETS price falls. The ETS price in the Non-CPF Zone is assumed also to be kept at the R2 level

Carbon Price Scenarios to 2030



Note: (1) CPFH RES new capacities are set at R1 RES new capacities to meet national RES objective in CPF countries. (2) R2, R3 and CPFL RES new capacities are built based on a least cost capacity mix expansion optimization.

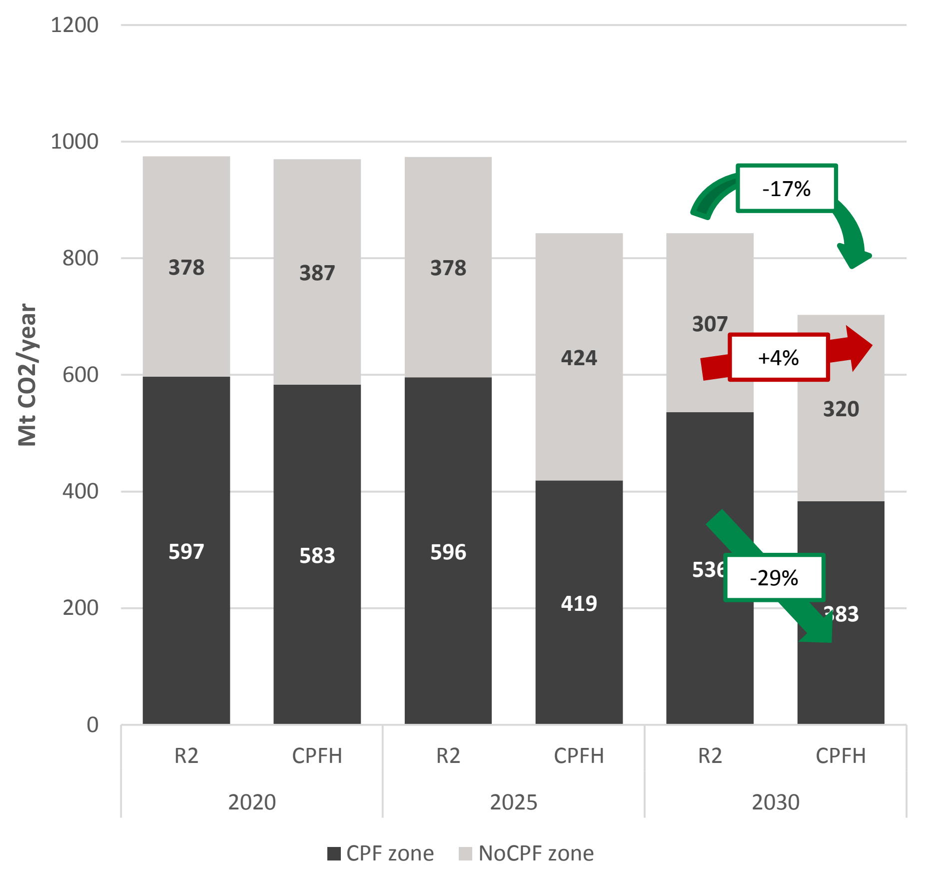
A Carbon Price Floor (CPF) could reduce emissions at the EU Level

Power sector decarbonisation could be accelerated

- A CPF would **reduce emissions overall across Europe**
  - In the CPF High scenario **power sector emissions in the CPF Zone are 29% lower, and 22% lower cumulatively** between 2020-2030 compared to the R2 scenario
  - **ETS emissions in 2030 are 17% lower** and 11% lower in cumulative terms
  - The CPF Low scenario shows that emissions reductions are possible without a higher carbon price – if investors believe in a credible carbon price, more investment in renewables will replace fossil generation faster and reduce emissions compared to R2

- **Emissions leakage** through cross-border flows can occur to the extent that CPF abatement leads to surplus ETS allowances and price falls in the ETS.
  - The MSR will however absorb some of the surplus.
  - The leakage can be further **minimised by ETS complementary policy** to cancel excess allowances (reducing the price differential between CPF and non-CPF zones), and through ensuring that the **CPF zone is of a minimum acceptable size**

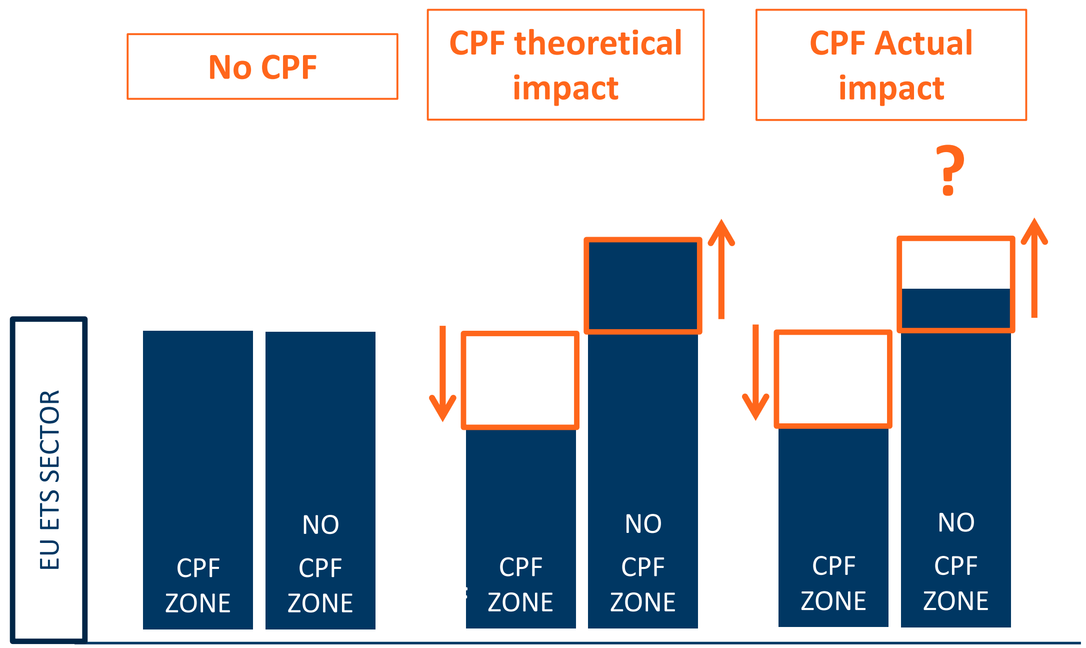
EU ETS Power Sector Emissions (MtCO2e/year)



The CPF and the ETS: current reforms may not be sufficient, but cancellations or continued reform can preserve emissions reductions

- The **introduction of a CPF** would need to be managed carefully to protect the EU wide carbon (ETS) price
- The **theoretical impact** of a CPF would be to reduce demand for EUAs as CPF induced abatement in the CPF zone. Within the overall EU wide cap this could lead to a surplus of EUAs and falling ETS prices.
- **In theory the MSR could absorb the surplus supply relative to demand, but is unlikely to do so in its current definition**
- **In practice** demand and prices especially in the industrial sectors (33% of total EUA demand) may be "sticky"
- We have taken a **conservative approach** in our modelling assuming that the theoretical impact prevails and therefore complementary policies would be required to underpin the EU wide ETS price (e.g. cancellation of allowances or continued ETS reform such as the MSR intake rate increased to 48% of surplus, or linear reduction factor increased).
- However, the adjustment of industrial output may be lower or slower meaning that the **complementary policies may not be needed as quickly or to the same extent**

Emissions in 2030 with CPF implementation



A Carbon Price Floor (CPF) could accelerate coal to gas switching and coal retirements

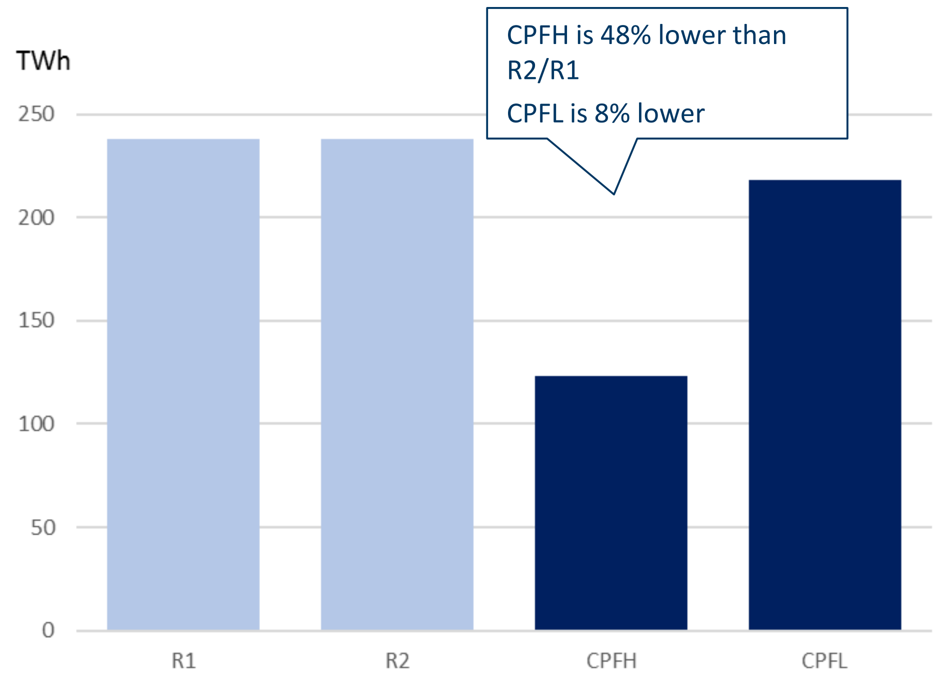
Coal is phased out faster

- A CPF would **reduce the amount of coal generation** as well as the installed coal capacity **significantly faster** than existing ETS price projections

- The **CPF makes coal less competitive** compared to gas and other lower carbon technologies, leading to lower coal plant load factors, and lower coal-fired generation
  - In 2030 in the **CPFH scenario** coal-fired electricity generation across the EU as a whole **is 48% lower** than in the R1 and R2 scenarios
  - In the **CPFL scenario** coal-fired electricity generation across the EU is **8% lower**

- This provides a clearer signal to coal plants to retire so installed capacity in 2030 is 8% lower in the CPFH scenario

EU 28 Coal Fired Generation – 2030*



*Notes: Coal and lignite generation

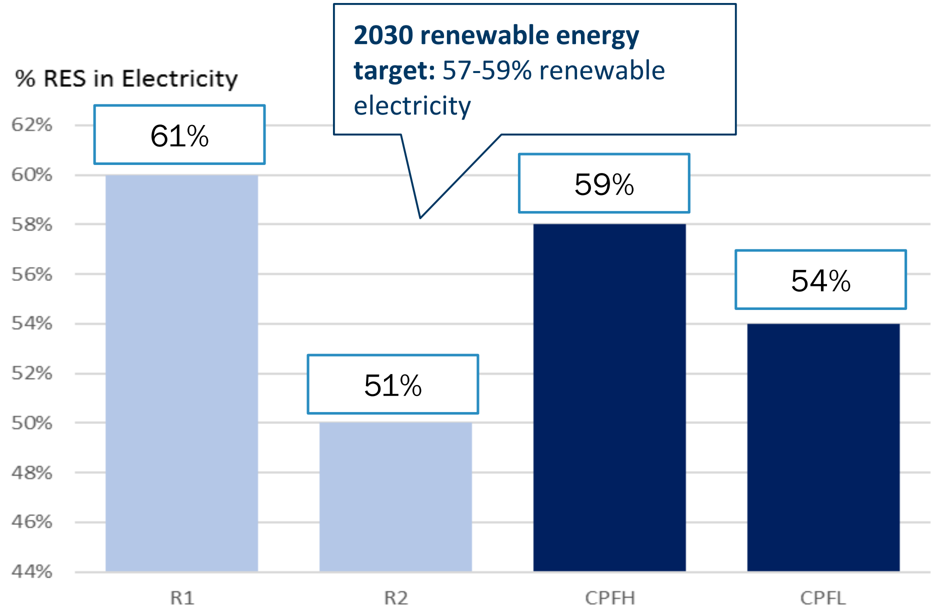
A Carbon Price Floor (CPF) could support renewables investment, in a more competitive merchant environment

Supporting renewable investment, by reducing risk and cost of capital

- The **R2 scenario** shows that the move to 'merchant RES' could reduce renewable investment considerably – without RES support schemes and exposed to power and carbon price risk, RES generation only reaches 51% of total electricity in 2030

- A **CPF would reduce carbon and power price risk**, and therefore **revenue risk** to renewable projects

Renewable energy* as % of Electricity production - 2030



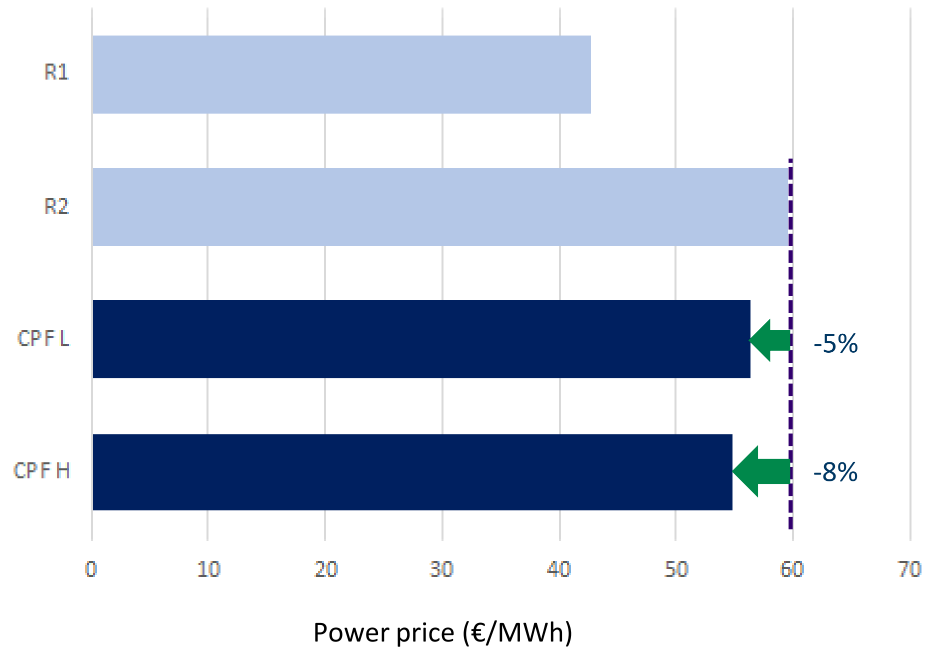
* Notes: Renewable generation takes into account Wind, Solar, Hydro excluding PS and Other Res

The power price impacts depend on the fossil-fuel mix and merit order effects

A tale of two effects

- A CPF would **increase wholesale power prices** (to 2025) to the extent that fossil fuel generators are setting the power price
  - In the medium to long term this effect will diminish as more low variable cost RES are added to the mix
  - As fossil fuel generators are taken off the system, the power price will be less influenced by the CO2 price
- A CPF would **decrease wholesale power prices** in the long term (post 2030) to the extent that it enables greater investment in renewable capacity and reduces the cost of capital
  - Our modelling suggests that by 2030 the overall impact of a CPF on power prices can be moderate and slightly reducing power prices when compared to the R2 scenario
- In the R1 scenario the power price is lower because part of the decarbonisation costs are paid through RES support schemes

EU Wholesale Power Price* - 2030



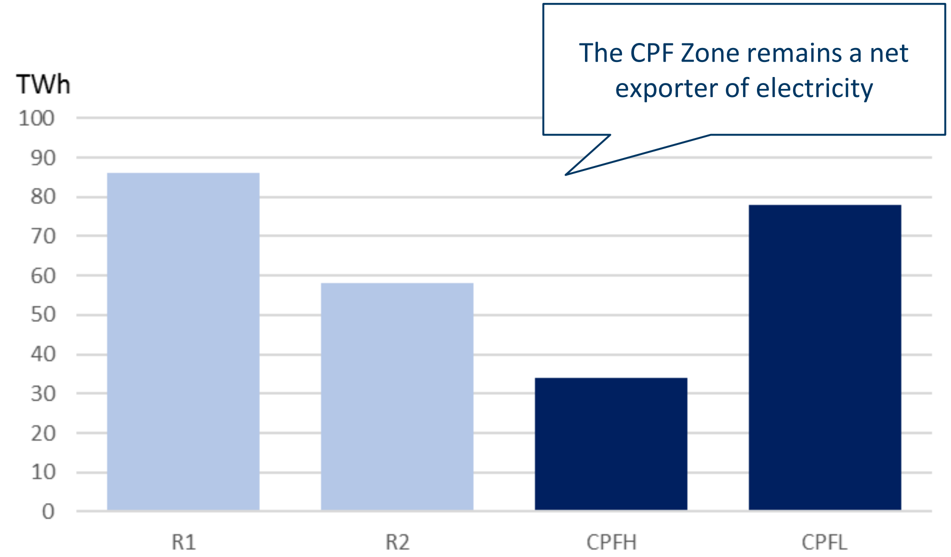
Notes: *Load weighted average power prices for all European countries

A CPF would affect net exports from the zone – a wider CPF zone would minimise these

Net exports will depend on power price differentials

- Cross border flows will in general be driven by price differentials
- Overall the **CPF Zone would continue to be a net exporter** of electricity to the non-CPF Zone
  - With a higher CPF the price differentials at key borders lead to a significant reduction in net exports
  - With a lower CPF the power prices at key borders lead to net exports virtually the same as in R1
- With **the higher CPF some countries can start to become net importers of power.**
  - However, this effect diminishes over time as greater renewables investment drives down prices through the merit order effect
- A **wider CPF Zone would minimise the impact on net exports**.
  - Conversely, a smaller zone (such as excluding Germany) would increase electricity and emissions leakage.

Net Electricity Exports from CPF Zone - 2030

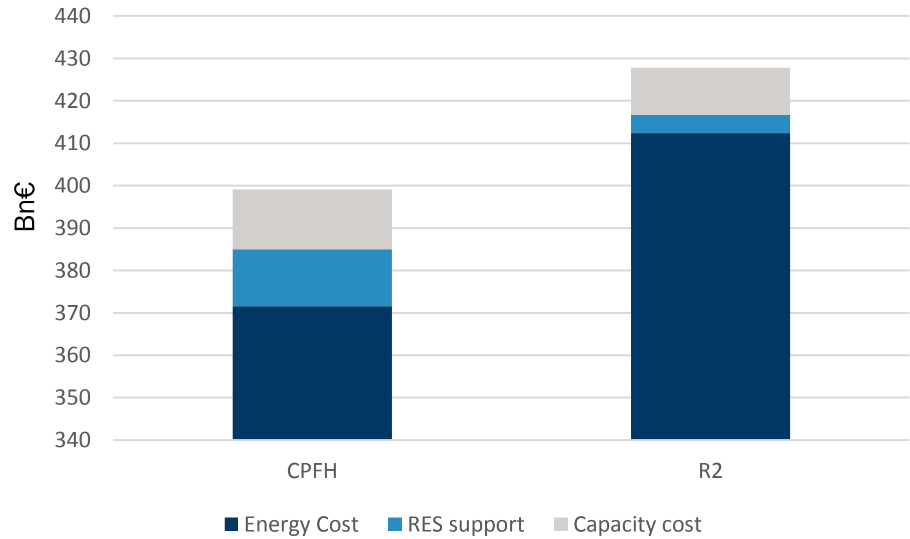


Socio-economic impacts from a CPF depend on power prices - lower investment costs and power prices would benefit consumers

Impacts on consumers

- The impact on consumers would **depend on wholesale power prices** – but **also on the effect on renewables support costs and additional capacity costs** to maintain security of supply.
- Lower power prices via the merit order effect could lead to lower consumer energy bills by 2030.
    - **In 2030 consumer costs are almost €30bn (6%) lower in CPFH than in R2**, wholesale energy costs are lower though partially offset by somewhat higher renewables support costs (under CfD/variable premium regimes the support cost goes up if power prices go down and vice versa). The increase in RE support costs is €9bn.
- Compared to **the R1 scenario** total energy system costs are €5bn higher (the CPF scenario has higher energy costs, but lower renewables support and capacity costs)

Net Impact on Consumer Costs in 2030 – CPFH versus R2



Source: FTI Power Price and ETS models; Technical report on Member State results of the EUCO policy scenarios, E3MLab & IIASA, December 2016

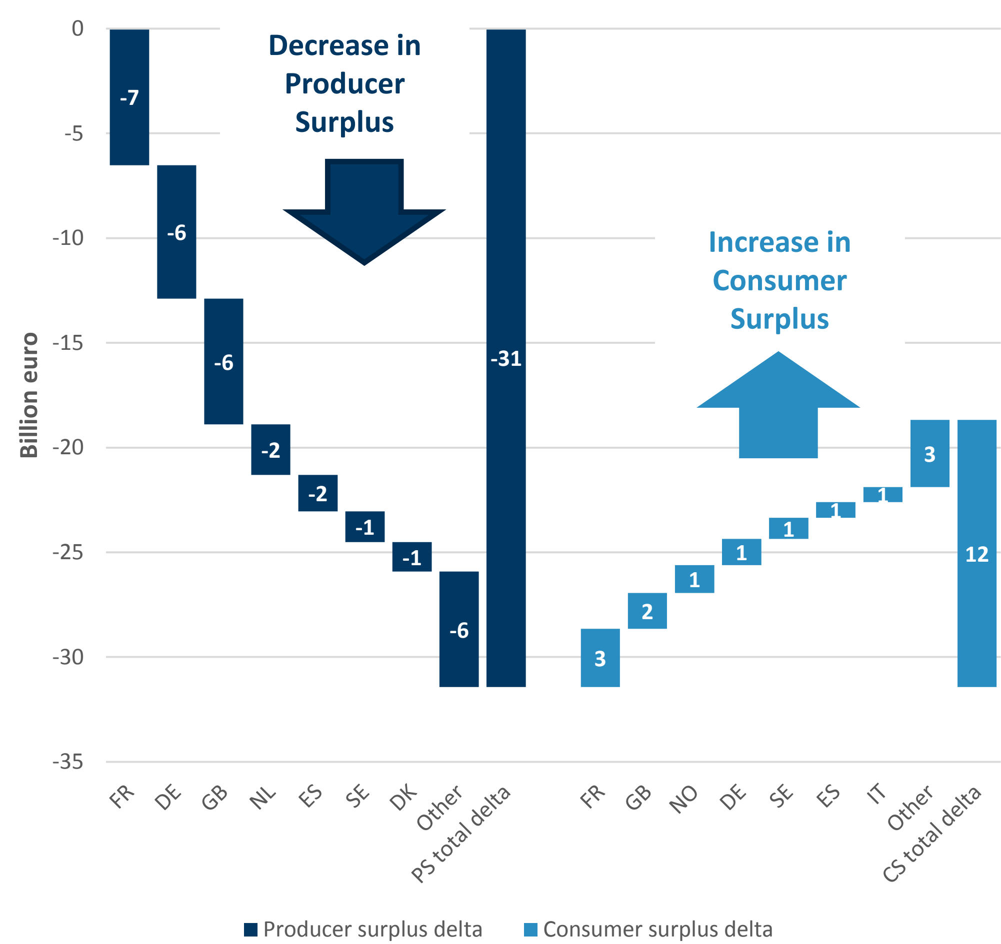
Notes: Power price paid may vary by sector; Domestic demand represents residential and tertiary demand. CPF Countries include Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden and Finland. Our analysis does not include electricity network costs or charges which could be affected.

Consumers would benefit from lower power prices, producers would see lower revenues

Socioeconomic impacts – consumers benefit

- Socioeconomic impacts were assessed by calculating the **consumer and producer surplus**
- Lower power prices in the CPFH scenario compared to R2 would lead to consumers paying less for power
- Capacity costs could rise in order to ensure security of supply, and the support costs for legacy renewable support schemes could also increase with lower power prices
- But the net effect is shown on the chart to the right – **a net saving for consumers** of €12bn in 2030
- The largest power producers (FR, DE) would face the largest falls in producer surplus
- The difference between the total amounts of producer and consumer surplus represent **revenues going to Government** (tax receipts from the CPF), to the **providers of capital for new investments in the power sector, and to interconnectors**

Producer and consumer surplus, CPF Zone 2030 (difference R2 to CPFH)



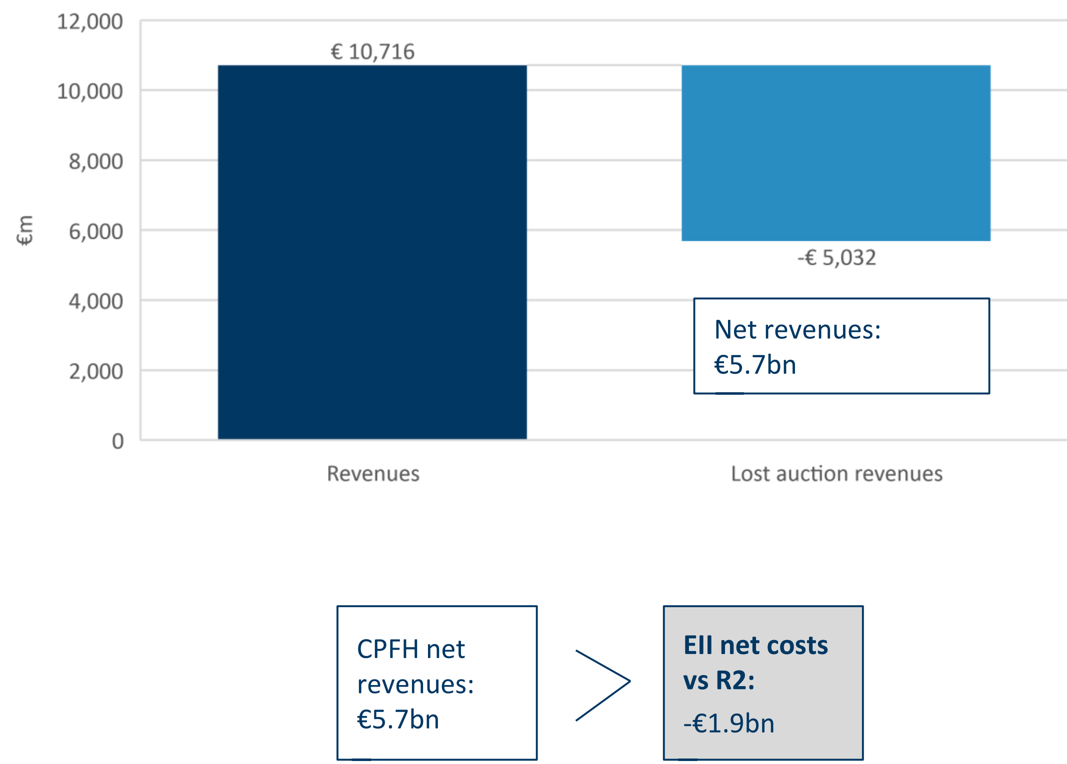
Impacts on Energy Intensive Industries will depend on power price impacts, and are manageable with additional carbon revenues

Impacts on Energy Intensive Industries (EII)

- Carbon leakage, as well as relocation of economic activity or investment to jurisdictions with lower carbon costs – is a concern for Energy Intensive Industries
- **Within the EU ETS,** some of these sectors are protected from such competitiveness impacts through free EUA allocation
- The **EU regulations** also allow for member states to **compensate Energy Intensive Industries** for other direct and indirect costs (electricity price)
- Our modelling suggests that the CPF could reduce power prices by 2030, leading to a net energy cost savings for **the Energy Intensive Industries** (a saving of €1.9bn in CPFH compared to R2)
- **Carbon revenues to Governments from a CPF** (net of the cost of the complementary policies i.e. lost auction revenues) would be over €5.7bn

Carbon revenues and Energy Intensive Industry costs 2030

Government CPF Revenues - comparison of CPFH vs R2 scenario



Our study shows the limitations of the recent ETS reform and the potential benefits from a Carbon Price Floor (CPF)

Context: More ambitious decarbonisation is needed

- The European Commission has reaffirmed and increased its commitment to decarbonise the EU economy
- Power sector decarbonisation is key – and requires strong carbon price signals

The problem: The ETS reforms will not deliver sufficient investment signals

- The EU ETS CO2 price – despite the boost from recent reforms – is insufficient in the short term to drive significant coal gas switching , creates a risk of lock in of fossil plants, and does not provide a strong and credible enough signal for renewables investment in the medium to long term
- The ETS price is volatile with significant downside risk – this raises the cost of capital (WACC) and reduces access to finance
- The impact of the ETS price risk on electricity prices compounds this uncertainty – which could undermine investment at a time when clean technologies are increasingly bearing market risk

A Carbon Price Floor (CPF) would enhance the efficiency of the power sector transition

- CPF acts as an insurance mechanism for investors, protecting them against sudden ETS price drops caused by a significant demand/supply imbalance, and against potential weak macroeconomic conditions leading to oversupply and insufficient abatement*
- Emissions in the CPF countries could be significantly reduced in 2030, and indeed reduced across the EU as whole
- Electricity and emissions leakage through cross-border flows can be minimised by the MSR as well as complementary policy to maintain ETS demand levels, and through ensuring that the CPF zone is of a minimum acceptable size
- Renewables investment would be supported in a world where projects are increasingly exposed to merchant price risk
- A CPF would drive greater coal to gas switching, and provide a clearer investment signal to avoid lock-in of fossil plants
- Power price impacts depend on the interaction of two effects – the CPF would increase power prices to the extent and for as long as fossil fuel plants remain on the system and set market prices. This is counterbalanced by the “merit order effect”- if the CPF encourages higher renewables penetration, this shifts the merit order and lowers market prices
- Impacts on consumers and Energy Intensive Industries (EIIs) may be positive insofar as power prices are lower with a CPF
- If there were additional costs, these can be mitigated using Government revenues raised from the CPF

* The academic literature has for many years discussed the higher efficiency of hybrid price and quantity instruments like a CPF in tandem with the ETS see e.g. Newbery et al (2018), Pizer (2002), Nordhaus (2007)

1 Context and objectives of study

In the context of the debate on how to accelerate the energy transition, this study assesses the role of a carbon price floor (CPF)

Objectives

- Identify potential scenarios for a multi-country, regional carbon price floor (CPF) in Europe
- Provide a quantitative assessment of the impact of different CPF scenarios on the ETS and emissions
- Model the impact on power sector decarbonisation – including on coal and gas generation, and on renewable energy investment cases
- Analyse some key socio-economic impacts including on consumer energy costs, Energy Intensive Industries and Government revenues

Contribute to the public debate on potential means to strengthen the short and long-term carbon price signal within the EU so as to accelerate the energy transition

Study committee members

Eneco, Siemens Gamesa, EDF, Ørsted, edp, Iberdrola, Vestas, Shell, Engie, EnBW

What could be the impact of a Carbon Price Floor (CPF)?

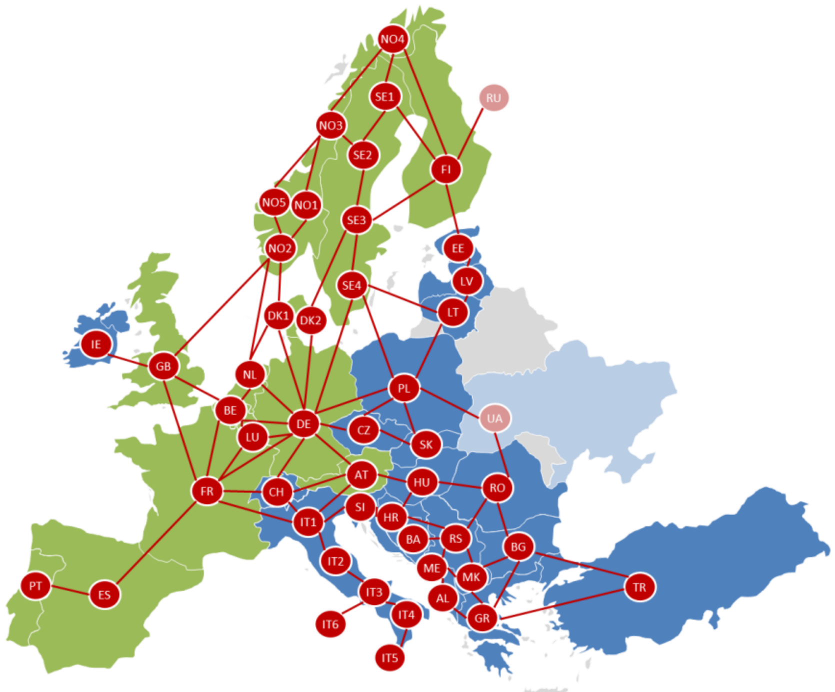
- A **Carbon Price Floor (CPF)** is a mechanism that Governments can use to create a minimum carbon price in their countries.

- **Different implementation models could be used :***
  - As a **top up tax** on the power sector above the EU ETS price (the UK model)
  - **Permit buy backs** – the Government or a market operator could commit to buying EUAs at a minimum price
  - As an **auction reserve price** – e.g. the Government could hold back permits from auction if the price went below a certain level

- In this study **we have not considered implementation questions**, but have assumed that the CPF is implemented in a way which is credible to the market and investors in a '**coalition of the willing' grouping 12 EU member states – in order to minimise unintended consequences such as carbon leakage**.

- In this study, we assume that:
  - The CPF is implemented in **12 Member States as a top up tax**
  - The CPF only impacts the **power sector**
  - **The MSR** will absorb some of the surplus allowances generated by the CPF - **Complementary policies** (such as EUA cancellations) are introduced and absorb the rest in order to maintain the effectiveness of the ETS and minimise leakage to the non-CPF Zone.

We have modelled a CPF introduced in 12 EU member states (the UK is assumed to keep its CPF)



CPF Countries: Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden, Norway and Finland.

- *Newbery et al (2018): When is a carbon price floor desirable? , EPRG Working Paper – Note permit buy backs would only work at EU level*
- *There is also another option whereby regulation would require companies within the CPF zone to surrender additional allowances*

Study methodology: we have used our ETS and EU power market models to analyse the role of a Carbon Price Floor (CPF)

FTI-CL's modelling approach is based on:

- FTI-CL Energy's in-house European power market model and EU ETS model , grounded in reputable modelling platform; and
- Background assumptions based on third party studies compatible with EU objective of (i) energy consumption reduction and (ii) decarbonisation of the EU wide economy.

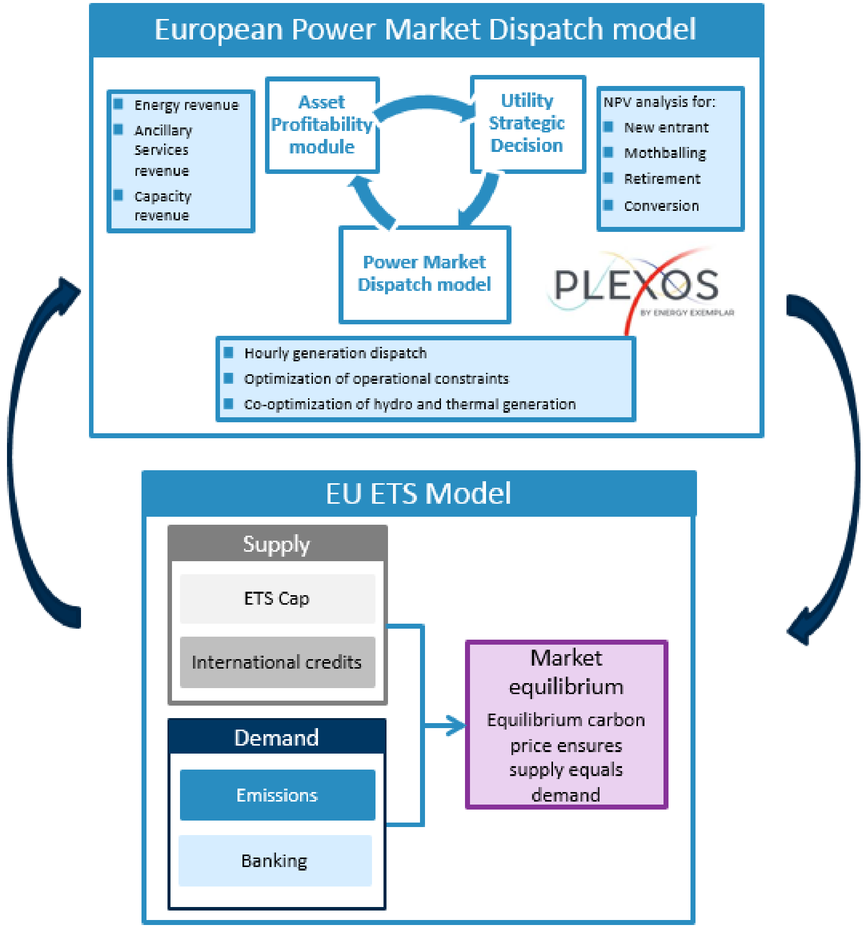
A two-step optimisation process is performed by our power market model:

- **Dynamic optimisation of the generation mix** based on the economics of RES, thermal plants and storage, to ensure security of supply and meet EC objectives at the least cost; and
- **Short term optimisation of dispatch** of the different units on a hourly basis.

This study has used our proprietary models to investigate:

- The ETS price outlook and resulting progress against EU objectives
- The possible contribution of a CPF to an efficient decarbonisation of the power sector

We have used our EU power market model and our EU ETS model



Note: The EU ETS modelling approach is inspired from the ZEPHYR model developed by Raphaël Trotignon & Boris Solier (Paris Dauphine University, Chaire Economie du Climat : http://www.chaireeconomieduclimat.org)

We have used a robust modelling approach together with assumptions based on recognized third parties

- FTI-CL modelling approach is based on:
  - ➢ **Fact-based modelling**, grounded in reputable modelling platform; and
  - ➢ **Assumptions based on third parties recognized independent studies**.

- **The modelling of the different scenarios leverages FTI-CL Energy's in-house European power market model and EU ETS model complemented by a range of additional indicators, and uses the following approach:**

1. **Background assumptions** based on third party studies compatible with EU objective of (i) energy consumption reduction and (ii) decarbonisation of the EU wide economy.
2. **Design of alternative EU ETS price and Carbon Price Floor scenarios** reflecting different degrees of ambition for the role of carbon pricing in decarbonising the EU power sector.
3. **For each of these scenarios**, European power markets are modelled using FTI-CL power market model:
   - ➢ **Dynamic optimisation of the generation mix** based on the economics of RES, thermal plants and storage, to ensure security of supply and meet EC objectives at the least cost; and
   - ➢ **Short term optimisation of dispatch** of the different units on a hourly basis.
4. **Assessment of the scenarios** on a number of **security, economic** and **sustainability criteria** derived from outputs of the European power market modelling, complemented by a range of additional indicators.

Our CPF scenarios are designed to reflect different degrees of ambition for the role of carbon pricing

	Scenario name	Description	Purpose/Rationale
Contrast Scenarios			
R1	**ETS Low**	Parallel policies incl. national RES support contracts, abatement occurs outside ETS, price is lower	• A reference point showing current policies carried forward, with results in line with EC studies/IAs
R2	**ETS High**	No further renewables support contracts post 2020, ETS drives most GHG abatement, price is higher	• A reference point showing potential impact on renewables investment if support contracts are withdrawn from 2020 • A clear comparison point for assessing the impacts of a CPF
R3	**ETS Price Fall**	Based on R2, but with an unexpected fall in demand for CO2 allowances, and associated ETS price drop	• To illustrate the potential impact of an unexpected demand reduction in the ETS and subsequent price collapse. A benchmark for showing the benefits of Low CPF
Carbon Price Floor (CPF) Policy Scenarios			
CPFH	**High CPF**	CPF set to achieve the 2030 national RES objective without further renewables support contracts post 2020. Set at €20/t in 2020 rising to €60/t in 2030.	• To demonstrate that the CPF could be used to meet the 2030 national RES objective
CPFL	**Low CPF**	CPF set at €20/t in 2020 rising to €30/t in 2030	• To show the role of a CPF as a risk management tool, and insurance for investors against low carbon price scenarios
CPFL*	**Low CPF with EU ETS Price Fall**	The same unexpected ETS price fall, but with a CPF set at the level of the Low CPF scenario	• Showing the benefit to investment in renewables from a CPF, even at the low level, as an insurance policy against carbon price collapse

Note: (1) CPFH RES new capacities are set at R1 RES new capacities to meet national RES objective in CPF countries. (2) R2, R3 and CPFL RES new capacities are built based on a least cost capacity mix expansion optimization.

To assess the potential role of a CPF, we have modelled a range of scenarios

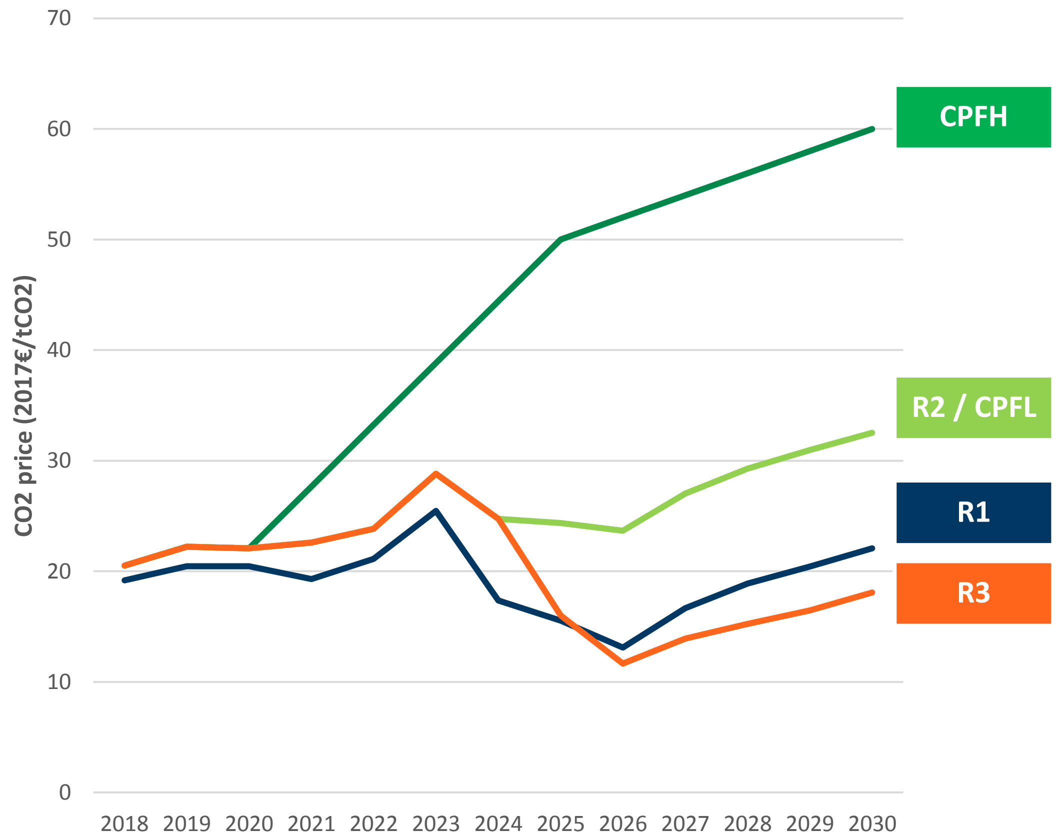
Contrast Scenarios

- **R1 scenario (ETS Low):** ETS prices remain low on the basis of current parallel national RES policies
- **R2 scenario (ETS High):** ETS prices are higher as a result of phasing out parallel RES policies and RES being more exposed to merchant price risk
- **R3 scenario (ETS Price Fall)** illustrates the plausible impact of a demand reduction on ETS prices (based on analysis of historical precedent)

Carbon Price Floor Scenarios

- **Carbon Price Floor High (CPFH)** sets the CPF at €20/t in 2020 rising to €60/t in 2030. This scenario illustrates a higher ambition world in which policymakers want to put a major policy emphasis on the carbon price instrument to meet their national RES objectives. (The CPFH line illustrates the CO2 price in the CPF Zone. The ETS price in the Non-CPF zone is assumed to be kept at the R2 level)
- **Carbon Price Floor Low (CPFL)** sets the CPF at €20/t rising to €30/t in 2030. This illustrates the role the CPF can play even when set at a similar level to the expected ETS price, as an insurance policy against sudden ETS price falls. (As above the ETS price in the Non-CPF Zone is assumed also to be kept at the R2 level)

Carbon Price Scenarios to 2030



Note: (1) CPFH RES new capacities are set at R1 RES new capacities to meet national RES objective in CPF countries. (2) R2, R3 and CPFL RES new capacities are built based on a least cost capacity mix expansion optimization.

2 Study findings

Content of the section

A. The problem: The ETS reforms will not deliver sufficient decarbonisation signals

B. Implementing a High CPF would accelerate the power sector transition

C. Implementing a Low CPF as an insurance mechanism

A

The problem: The ETS reforms will not deliver sufficient decarbonisation signals

Content

Section overview

- **The recent ETS reform will be insufficient to accelerate the transition of the EU power sector as per the four issues outline below:**

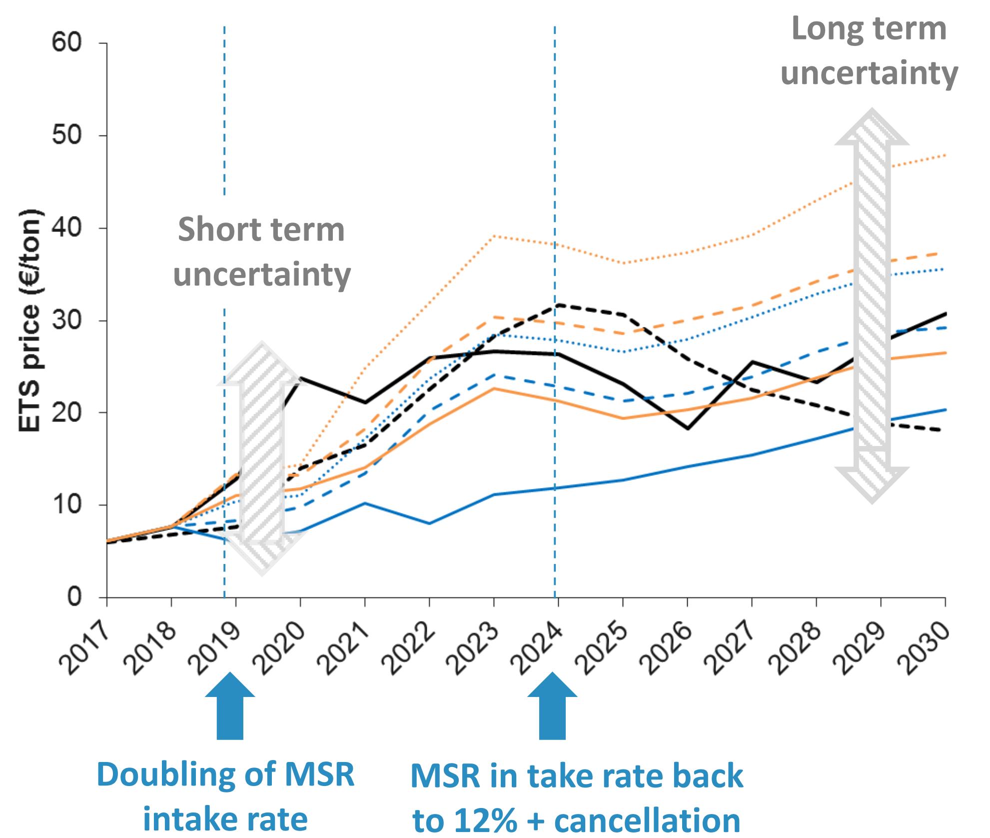
  - The ETS reforms have delivered a boost to CO2 prices, but price **is not sufficient to drive sustained coal to gas switching or investment in capital intensive renewable energy projects**
  - The ETS price outlook provides inefficient intertemporal signals – **decarbonisation requires high carbon prices in the long term implying a steeply rising curve in the 2030s,** but current investment decisions do not factor this in creating the risk of technology lock-in and stranded assets
  - **The risk embedded in ETS prices impacts financing conditions –** this increases the cost of capital (WACC) and reduces access to finance
  - **The impact of the ETS price on electricity prices amplifies this uncertainty –** which creates an inefficient signal for investment
  - **A Carbon Price Floor (whether High or Low) could help address these challenges**

A.2: Insufficient ETS price post reform

EU ETS reforms in 2018 will help tackle oversupply, but also leads to continued long term price uncertainty, affecting investment

		Key features	EC Reform
Restore demand/ supply balancing		**Higher Linear reduction factor**	2.2% from 2021
		Doubling of MSR intake rate and cancellation	Doubling to 24% for 5 years, starting in 2019. Starting 2024, allowances in the MSR above allowances auctioned during the previous year no longer valid.
Mitigating carbon leakage risk and preserving competitiveness	Structural measures	**Ratio of auction vs. free allocation share**	57%, up to 3% shift if CSCF is triggered.
		Carbon leakage list	Binary approach. Narrowing to 50 sectors (from 177 initially).
		Benchmarks	Subject to the average improvement rate = 0.5% - 1.5% depending on industry. No caps.
	Support funds + NER	**New Entrance Reserve (NER)**	250 million allowances from MSR, plus unallocated Phase III allowances.
		Indirect costs	No EU fund. To be compensated through optional national State Aids.
		Innovation Fund	400 million funded with free allowances, plus 50 unallocated allowances MSR.
		Just Transition Fund	Not mentioning.
		Modernisation Fund	2% of auctioned allowances.

ETS price projections, 2017-2030



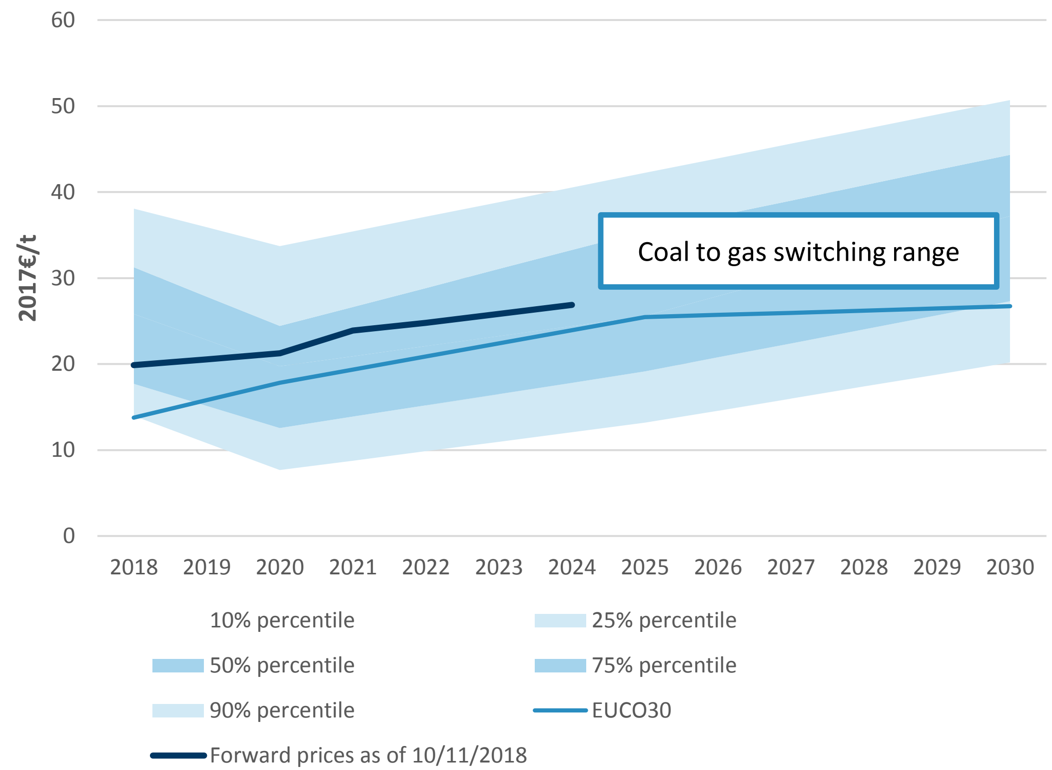
Source: FTI CL Energy modelling, various benchmark studies

ETS prices are insufficient in the short term to drive the decarbonisation of the EU power sector

ETS reform is helping but not enough

- Current prices around €20/t are due to the **ETS reforms** (MSR, cancellation, linear reduction factor), market fundamentals (fuel prices, demand and weather) and hedging behaviour.
- However **parallel policies** such as energy efficiency, RES support, nuclear support, coal phase outs reduce the prospects for a sufficient carbon price – RES support schemes create abatement outside of the ETS.
- **Sustained coal and lignite to gas** switching across Europe would require prices around €15-35/t in the near term, but in the 2020s would require around €20-50/t according to our analysis.
- Current **forward prices are too low** to :
  - Drive a full switching between coal and gas units – the most recent coal plants and lignite plants are resilient
  - Incentivize large scale renewables to be developed on a merchant basis

EU ETS carbon price pathways (real 2017)



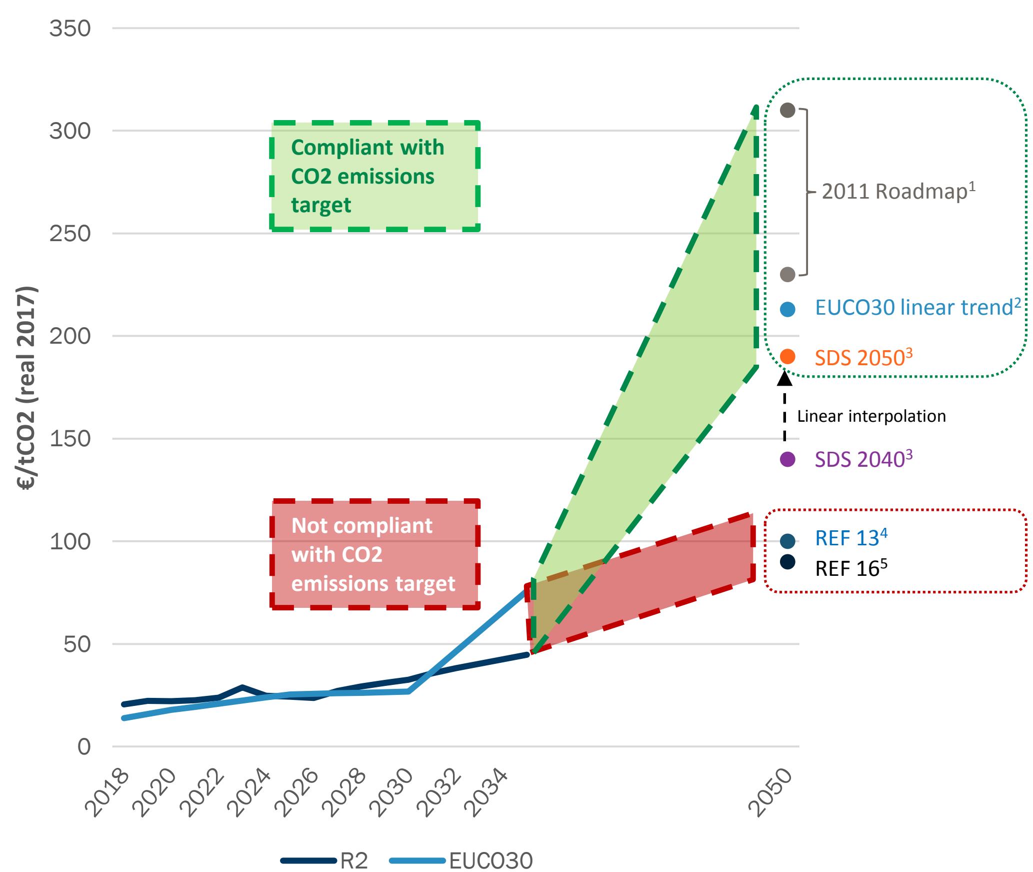
Source: EEX, European Commission

Long term carbon prices may need to rise significantly to complete decarbonisation of some sectors

ETS prices are not intertemporally efficient

- In the long run, **carbon prices may need to reach between 130-150 €/t from 2040** based on Commission and IEA modelling
  - The marginal cost of reducing emissions increases as cheaper abatement options are gradually exhausted.
  - However, new or more efficient abatement technologies would potentially reduce these long term carbon price rises
- Such estimates also raise the issue of the ETS ability to send **long term predictable and credible price signals** to investors.
- Too low and unclear price signals in the medium term could lead to:
  - **Technology lock-in for fossil fuel technologies** and the risk of stranded assets
  - **Inefficient investment signals in renewables and low carbon technologies**

Long term EU carbon price (real 2017)



Source: FTI CL Energy modelling, European Commission (EC), International Energy Agency (IEA)

[1] 2011 EC Roadmap to 2050

[2] EC scenario to achieve the 2030 energy and climate targets, interpolated from 2030-2035

[3] IEA Sustainable Development Scenario, 2050 figure interpolated from 2040 figure

[4] 2013 EC Reference scenario

[5] 2016 EC Reference scenario

Carbon price risks affect investment decisions

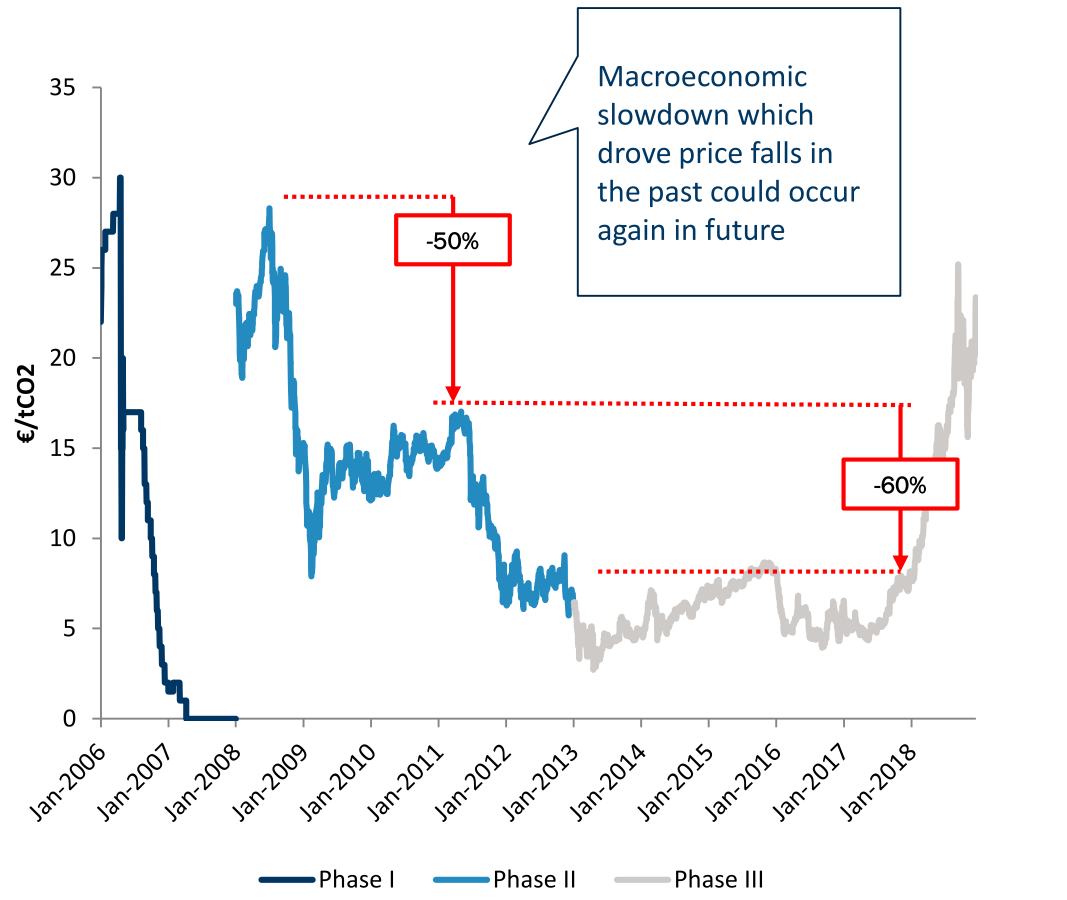
Investors in clean technologies see falling technology costs, but increasing market risk

- **Technology costs** are coming down, improving the business case for renewables investment
- But **revenues are increasingly uncertain:**
  - Support contracts awarded by auction with very low prices means the investment case is more dependent on market revenues at the end of support contracts
  - Some projects are beginning to be developed without support contracts, on a "**pure merchant**" basis
  - Greater reliance on power prices (and carbon prices as they affect power prices) **increases investor risk**

Investors focus on the *expected* carbon price and the risk that the price in the future may be lower than anticipated

- **Anticipated carbon prices** included in investors' business plans include a significant discount compared to base case projections reflecting the risk of a future price shock / decrease
- ETS prices may stay at €20/t, but they could also drop down to €10-15/t. In the **past ETS prices have fallen by 50% or more** in a few months. The drops were motivated by reductions in emission levels driven by the 2008 economic crisis but also by the increase in energy efficiency and the deployment of renewable energy sources*.
- It is efficient for Governments to protect investors against policy risk which markets cannot accurately price

ETS prices 2006-2018, a history of price falls (downside risk)

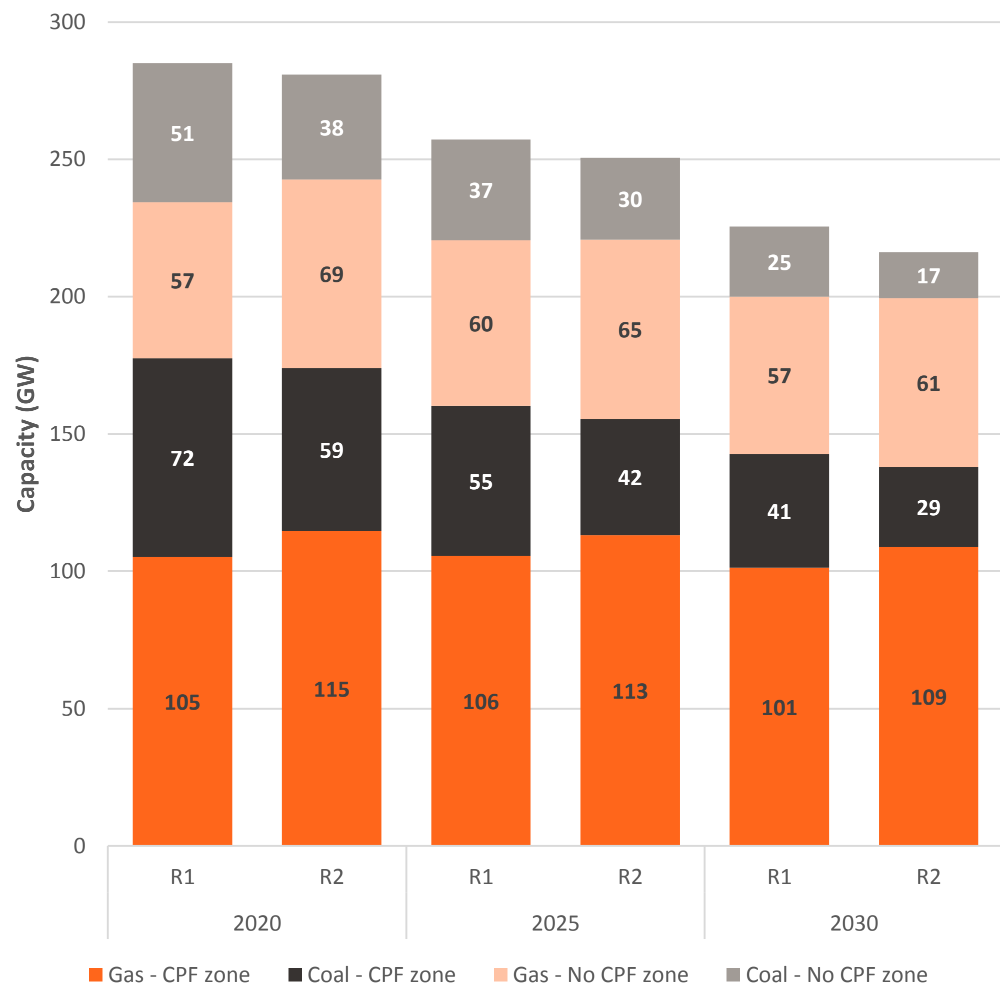


*Source: I4CE, " Aligning the 2030 EU climate and energy policy framework to meet long-term climate goals.

Higher carbon prices will drive the closures of coal units

- The results shows that in the **R1 scenario, low carbon prices do not give the right signal to high-carbon fossil fuel plants (coal) to close, while in the R2 scenario slightly higher carbon prices give a signal in the right direction –** high-carbon fossil fuel plants start closing.
  - Indeed in the **R1 scenario**, the low carbon price outlook means that high-carbon fossil fuel plants remain lower cost than lower-carbon fossil fuel plants, putting efficient and low-carbon gas plants at risk of stranding.
  - While in the **R2 scenario**, slightly higher carbon prices lead to accelerated closure of high-carbon capacity. By 2030, our model expects **20 GW of additional coal closures** compared to the R1 scenario.

Thermal capacity with lower and higher CO2 prices



Notes: Lignite capacity included in coal

Falling renewables costs could boost investment, …

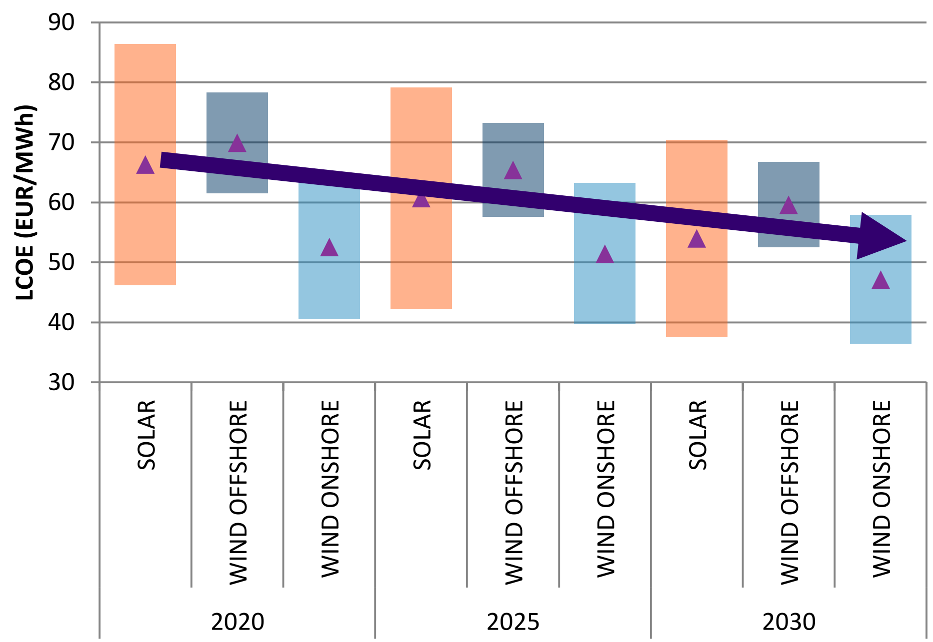
Falling costs make renewables more competitive

- Capex costs have fallen significantly over the last 10 years for wind onshore and offshore and solar
- At the same time the technologies have improved and load factors have increased

> ➢ **As a result the cost per unit of energy produced has come down substantially over the last 10 years**.

- A number of studies, amongst which the European Commission "*Technology pathways in decarbonisation scenario*" to be used for the future energy roadmap to 2050, feature further cost reduction in the coming years.
- In order to capture this future cost reduction potential, we have assumed a continuation of cost reduction in line with forward looking technology cost studies.
- However, there are significant **risk distributions** around future technology costs

Renewables Levelised cost of energy (LCOE) 2020-2030



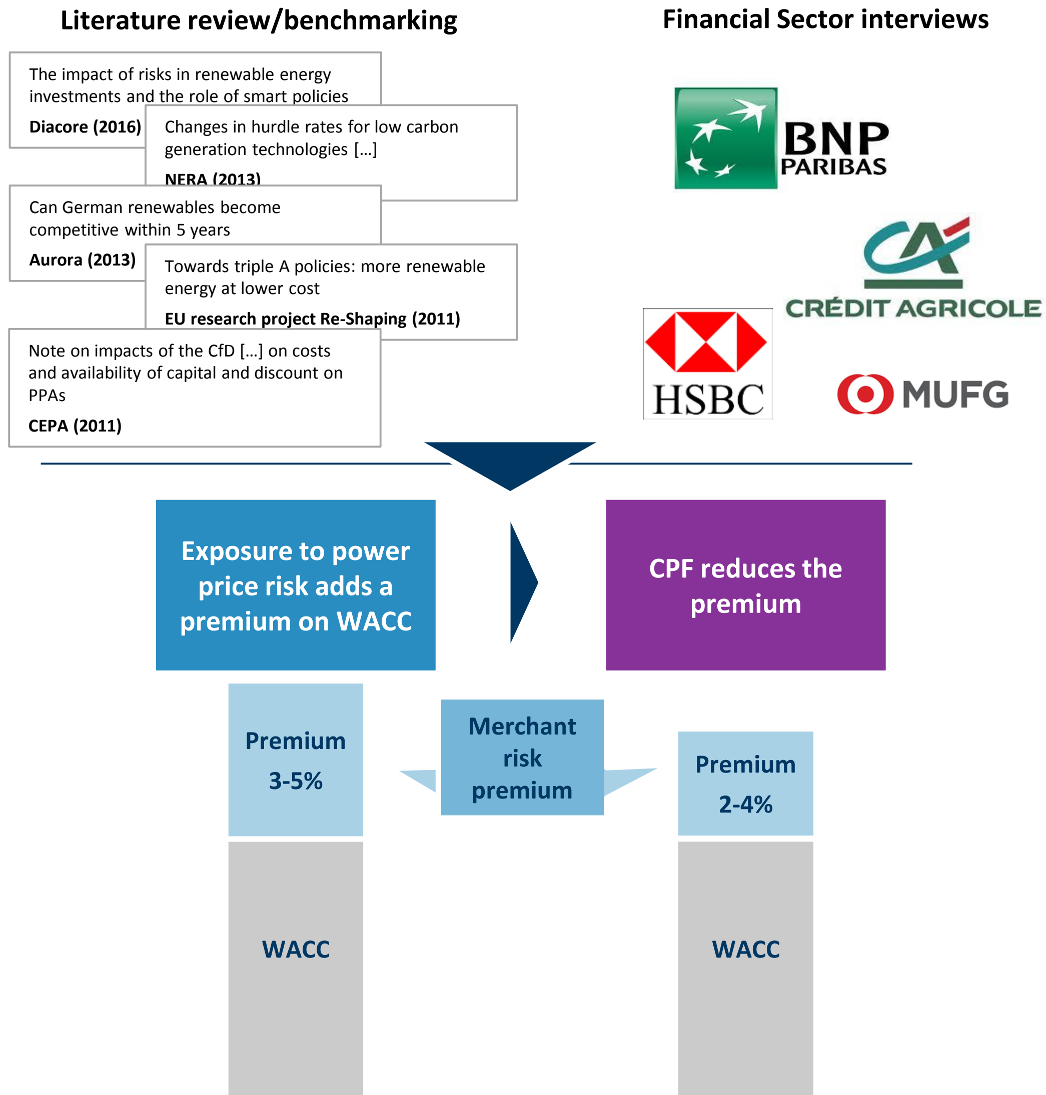
Note: these results are based on R2 WACC (including 3% premium for merchant price risk). LCOEs vary across countries depending on their capacity factor and WACC

…, but power price risk increases risk premiums and financing costs

- Renewable energy projects currently enjoy low cost of capital and access to a wide range of investors due to being considered quasi regulated assets with low risk profiles, **greater exposure to power price risk** (“merchant risk”) would
  - **Increase the risk premium** required by investors
  - **Reduce the pool of investors** willing to fund projects

- **Literature review/benchmarking –** we reviewed a range of studies that suggested that power price risk could add around **3-5% at least onto the WACC for power plant investments**.
- **Financial sector interviews** have broadly supported this range, or even a higher impact, and further stressed the diversity of financial investors, with very **different tolerance for risk**.
  - We have therefore differentiated between:
    - Investors/financiers with high risk tolerance requiring a lower uplift (first mover investors accounting for 20%) on the WACC; and
    - Investors with lower risk tolerance requiring a higher return uplift (conservative majority investors accounting for the remainder (80%)

Price risk (power, carbon) increases financing costs



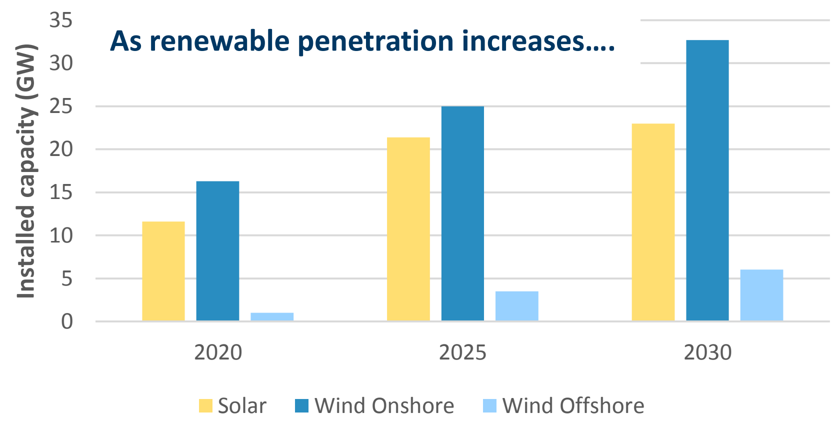
… at a time when most competitive renewables are increasingly bearing market risk

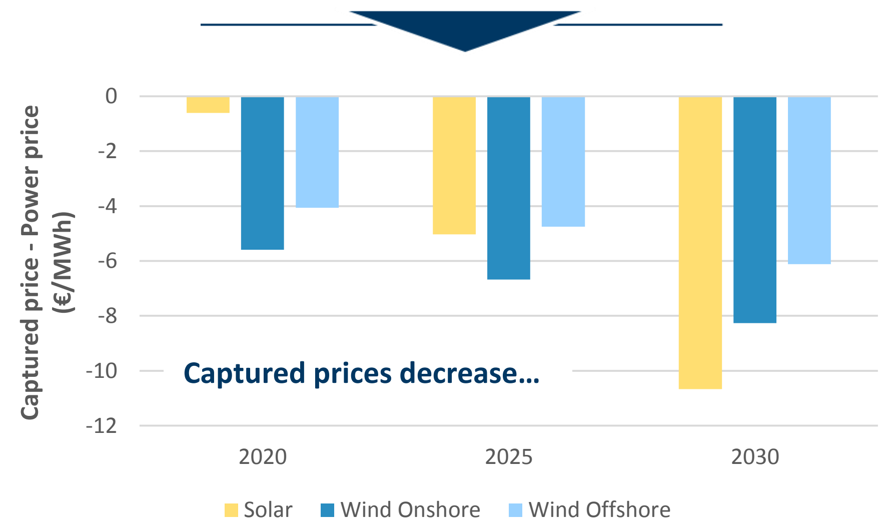
Renewable projects and the "merit order effect"

- Renewables are **low marginal cost** – they push out fossil generation from the merit order
  - **Wholesale prices fall** as a results of increased renewables penetration
- But investors see a **correlated revenue risk** (referred to as 'cannibalisation of revenues')
  - The **captured prices** by wind and solar projects refers to the price achieved during half-hours when wind and solar are generating
- **Carbon price risk** amplifies power price risk and is driven by hard to predict policy decisions
  - The effect on wind and solar revenues will **become worse over time** as renewables penetration increases
  - Additional **storage and other forms of flexibility** on the system would act to smooth out prices

Merit order effect and RES Captured prices

(France to 2030)





The combined impact of CO2 prices and RES merit order effect weakens the investment signal for renewables (1/3)

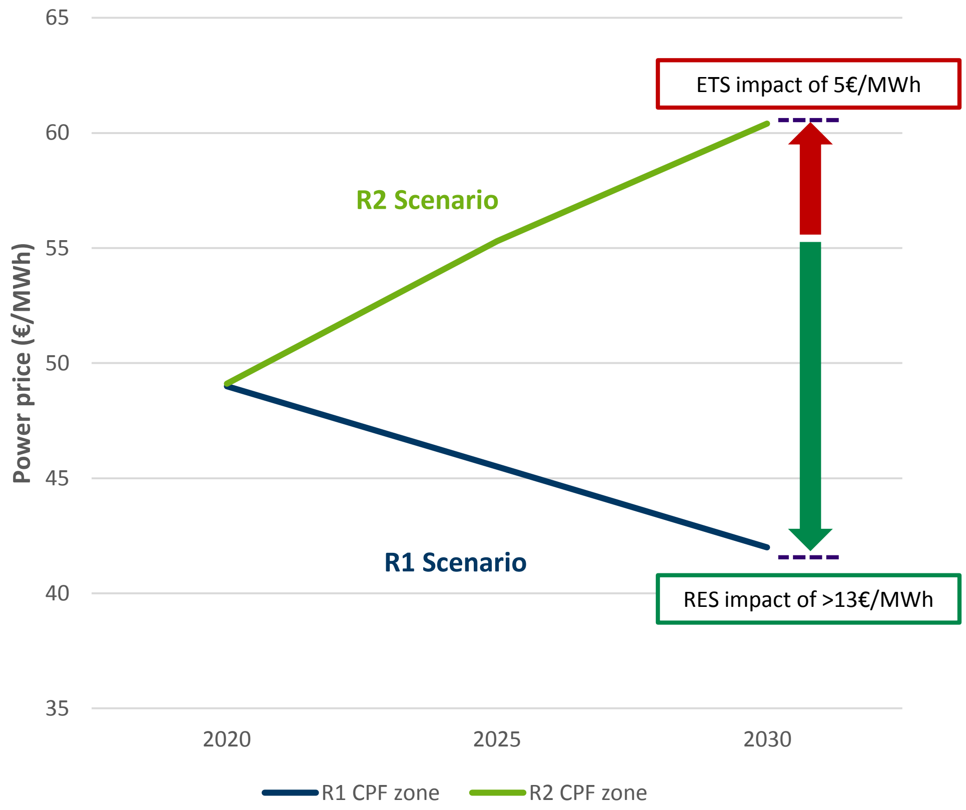
ETS impact on power prices

- In the R1 scenario, featuring support to 2030, and relatively low EU ETS price (23€/tCO2), the wholesale power price remain below the 50€/MWh threshold.
- On the contrary, in the R2 scenario, featuring no more RES support contracts from 2020, and a higher EU ETS price (33€/tCO2), the power prices reach 60€/MWh by 2030.
- Of this price difference by 2030, c5€/MWh could be attributed to the ETS price impact (c10€/tCO2) on thermal generation cost reflected in power prices.

RES impact on power prices – Merit order effect impact on revenues

- When renewables generation is high (due to wind and solar conditions) this tends to depress the power price (high supply leads to lower prices) – this effect is called **Merit order effect**
- This is shown in the comparison between power prices in R1 and R2. In parallel to the ETS price impact, the impact of different RES penetration between R1 and R2 explains the remaining price difference (>c13€/MWh).
- **The higher RES penetration in R1 leads to higher merit order effect than in R2 and much lower power prices than in R2,** thus further increasing the need of support to achieve the targets. (cf following slide)

R1 and R2 power prices in CPF zone



Note: Load-weighted average price in the CPF zone

The combined impact of CO2 price risk and RES merit order effect weakens the investment signal for renewables (2/3)

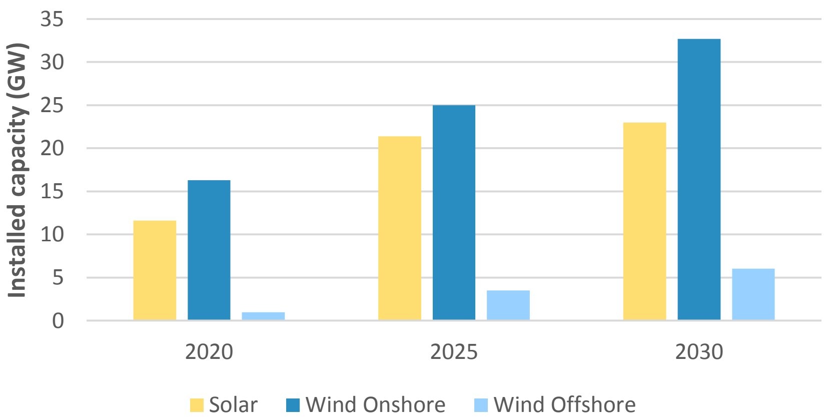
RES merit order impact on revenues

- The merit order effect of RES on power prices and on their energy revenues makes the large scale deployment of RES difficult as RES put a significant downward pressure on power prices, especially when they generate at high output.
- While the merit order effect of RES is a feature driven by the low marginal cost of production nature of variable RES, this could be mitigated through a higher pricing of the carbon externality which would be reflected in power prices.

Merit order effect of RES revenues illustration

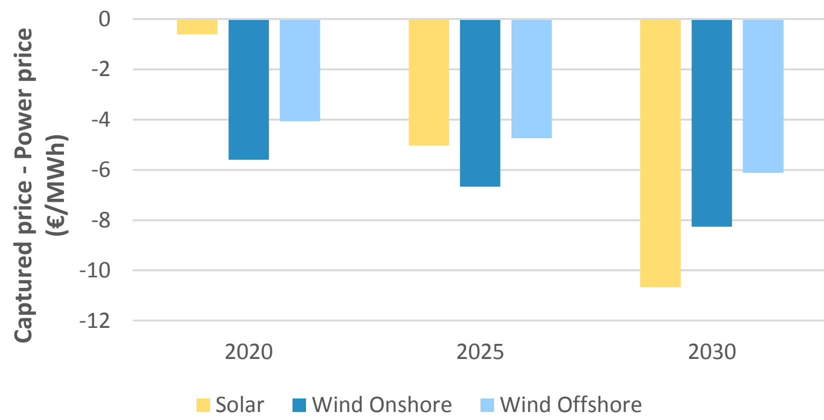
As renewable penetration increases…

(France to 2030 – increases in Renewables capacity)



…merit order effect for renewables gets worse

(France to 2030 – captured prices for wind and solar, discount on market price)



The combined impact of CO2 prices and RES merit order effect weakens the investment signal for renewables (3/3)

The combined effect leads to lower investment in RES, especially with greater merchant price exposure going forward

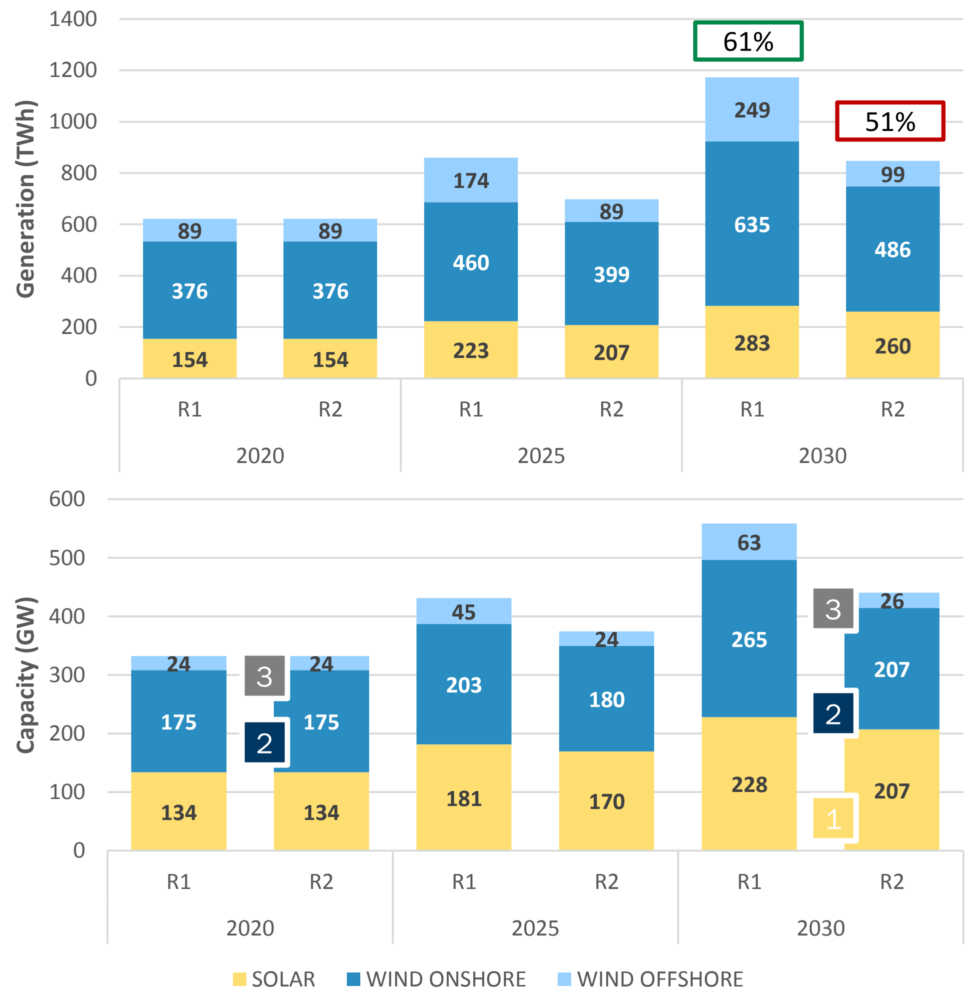
- The results of our modelling shows that in scenario R2 with greater merchant price exposure, the RES penetration target in 2030 would be missed.

1 Solar: Beyond the growth of solar auto-consumption, only **14GW** of large scale solar PV would be built on a merchant basis between 2020 and 2030.

2 Wind Onshore: Only **32GW** of onshore wind would be built on a merchant basis between 2020 and 2030, less than half of the >**90GW** necessary to meet the national plans

3 Wind Offshore: Only **2GW** of offshore wind would be built on merchant basis in the second half of the decade, significantly lower than the **40GW** offshore wind capacity plans.

Renewable energy generation and capacity



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B

Implementing a High CPF would accelerate the power sector transition

Content

Section overview

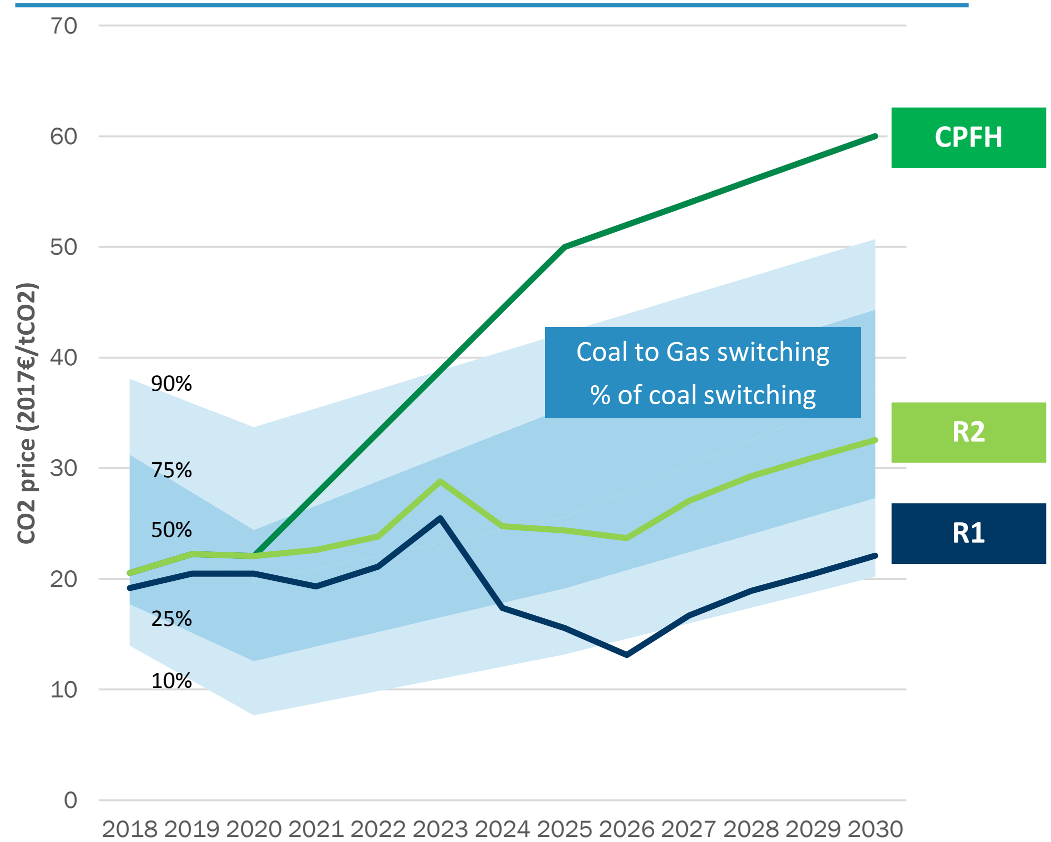
- **The implementation of a High CPF would allow:**
  - **Greater coal to gas switching in the CPF** zone thanks to higher incentives via a stronger and more stable carbon price
  - **Avoided lock-in of emissions**: coal plant closures happen sooner as investors have more confidence in the carbon price signal
  - **Greater renewables investment** than in a scenario where carbon price uncertainty exacerbates merchant price exposure and affects financing conditions
  - **Support to power prices enables additional cost-effective investment in renewables**

The CPF High scenario rises from around €23/t in 2020 to €50/t in 2025 and €60/t in 2030 boosting coal to gas switching

- **Carbon Price Floor High (CPFH)** sets the CPF at €20/t in 2020 rising to €60/t in 2030. This scenario illustrates a world in which policymakers wanted to put a major policy emphasis on the carbon price instrument. (The CPFH line illustrates the CO2 price in the CPF Zone. The ETS price in the Non-CPF zone is assumed to be kept at the R2 level)

- **The high levels of the carbon price will enable an accelerated reduction of emissions in the CPF zone:**
  - The coal to gas switching will be boosted with a total switching expected by 2025 in the CPF zone.
  - High carbon prices will also support renewable investment.

Carbon Price Scenarios to 2030



CPF Countries: Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden, Norway and Finland.

In the long term, the High CPF scenario will be back to R2 levels

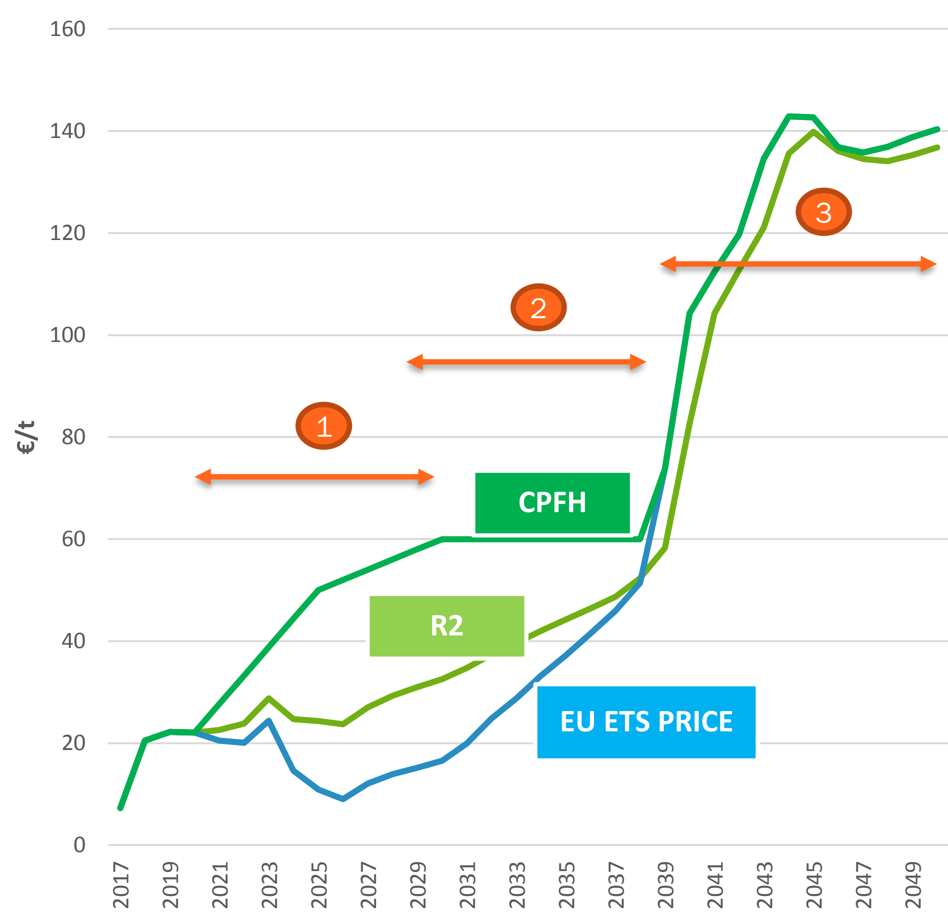
- We expect EU ETS carbon prices to reach the CPF High level by 2039. **From 2039, carbon prices in the two zones will therefore be similar.** This is because the R2 prices are consistent with reaching the 2050 targets, and there is no good policy reason to keep the CPF prices higher than this.

- **Post 2040, the EU ETS market prices in the High CPF will be similar to the ones in the R2 scenario** driven by:
  - Similar levels of emissions or surplus
  - Similar targets of emissions reduction across Europe

- Only **a small change is expected in carbon prices driven by the persistence of emissions reduction in the industry sector**. We estimate that about 10% of total industry emission reductions are deemed to be long term in the sense that they result from investment in low carbon equipment rather than mere fuel switching or reduce output.

- The High CPF scenario drives additional abatement in the power sector thus limiting the required long term investment in the industry sector. This will results in slightly higher carbon prices in the long term.

ETS carbon prices to 2050 (real 2017)



In order to reach the decarbonisation targets, all scenarios converge toward a decarbonised system by 2050

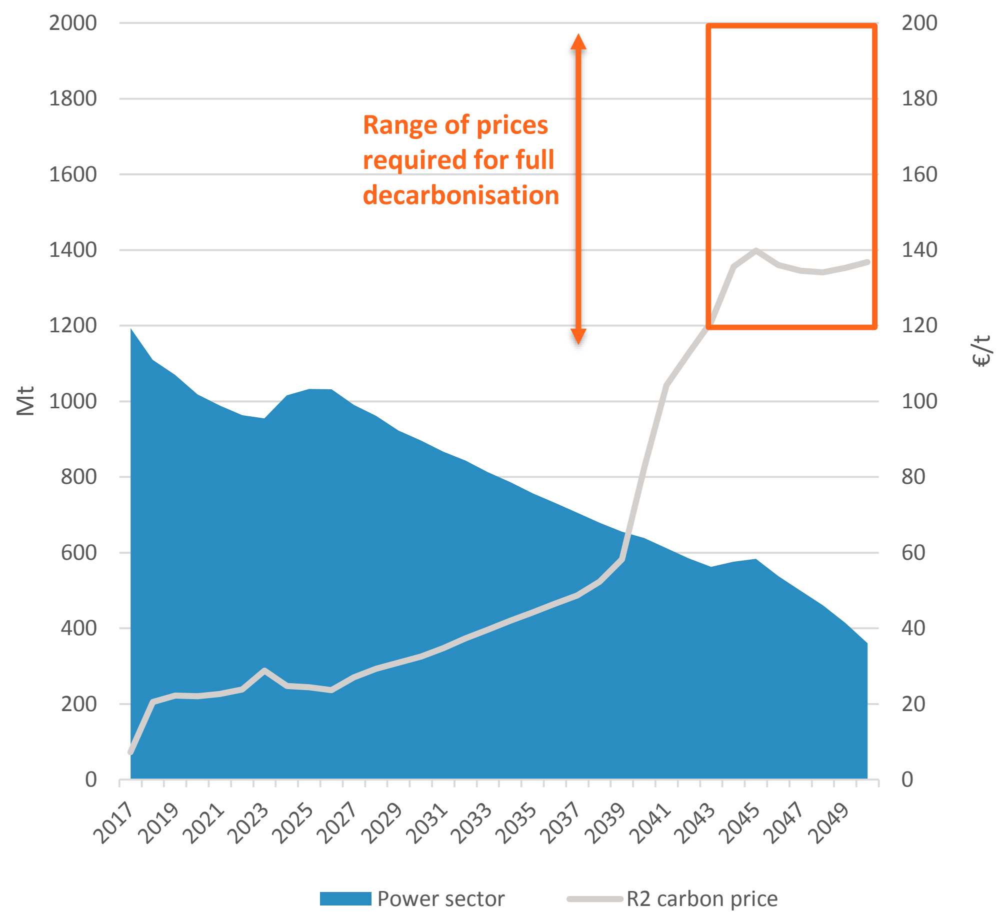
The decarbonisation targets will require the EU energy system to complete its transformation by 2050

- From 2040, we expect renewables combined with storage to compete with gas plants to satisfy the new power demand coming from the electrification of other sectors.
- In order to reach the emission targets, the carbon prices will be progressively increased. We model carbon prices reaching between 140 and 200€/t to achieve this objective.

By 2050, we expect all power scenarios to converge

- Carbon prices in the range 120-200€/t
- High electrification of all energy sectors
- Most of the electricity generation provided by renewables
- Strong reduction of emissions with levels close to the decarbonisation objectives (at least 85% GHG emission reduction compared to 1990 and at least 90% for the EU ETS sector)

EU ETS emissions and carbon price to 2050



** Notes: The emission reduction is based on the current EU ETS LRF (2.2%) and therefore doesn't reach the 2050 Targets (GHG 80-95% -100Mt).*

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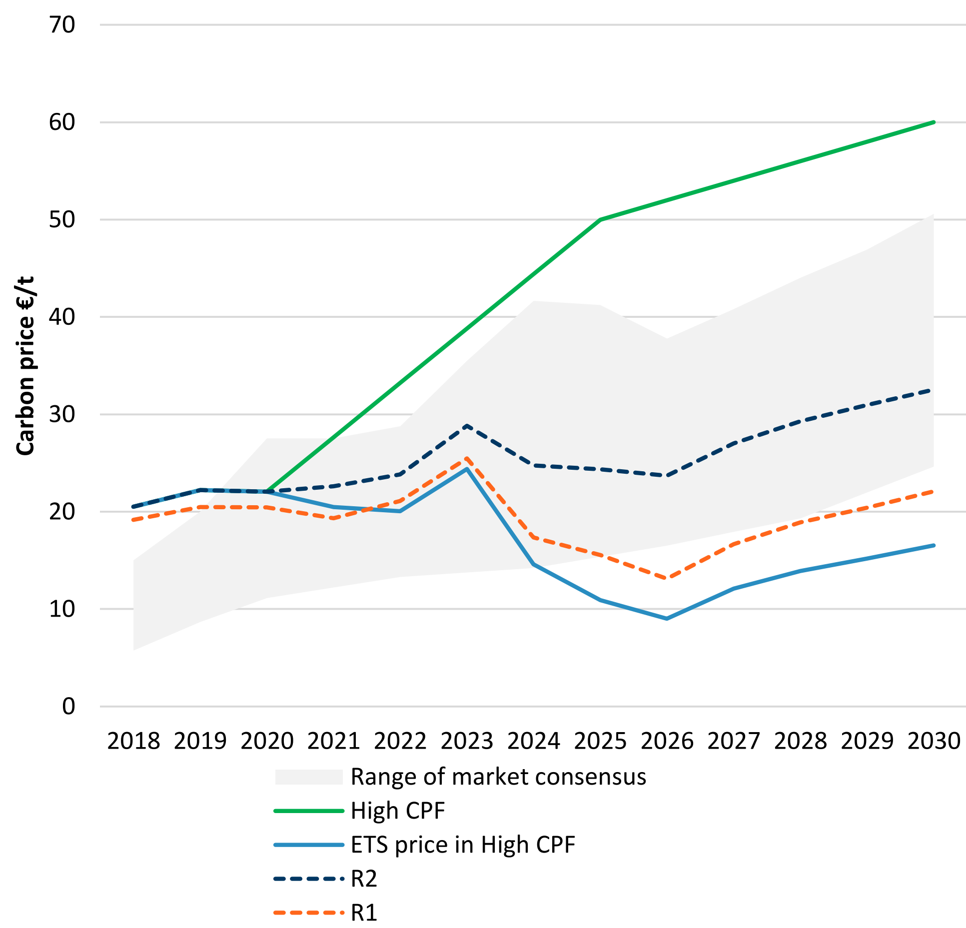
Implementing a high CPF could impact the ETS price, but complementary policies would neutralise the effect

- The CPF scenarios introduce a separate carbon price in the CPF zone from the price in the ETS
- **In the High CPF scenario, ETS prices could fall to 11€/t in 2025 and 17€/t in 2030**
- This is due to **reduced demand for EUAs in the no CPF zone** setting EU ETS prices:
  - The CPF prices is reducing emission in the CPF zone
  - The remaining emission abatements to be performed in the no CPF zone is limited
  - This small level of required emission reduction set the prices of EU ETS at lower levels than in the R2 scenario.
- **The MSR** would absorb some of the surplus from the CPF, but it’s effectiveness and impact is uncertain
- We assume that **complementary policies** in the EU ETS markets would be implemented to offset the CPF impact on ETS prices.

CPF impact on ETS price (without complementary policies)

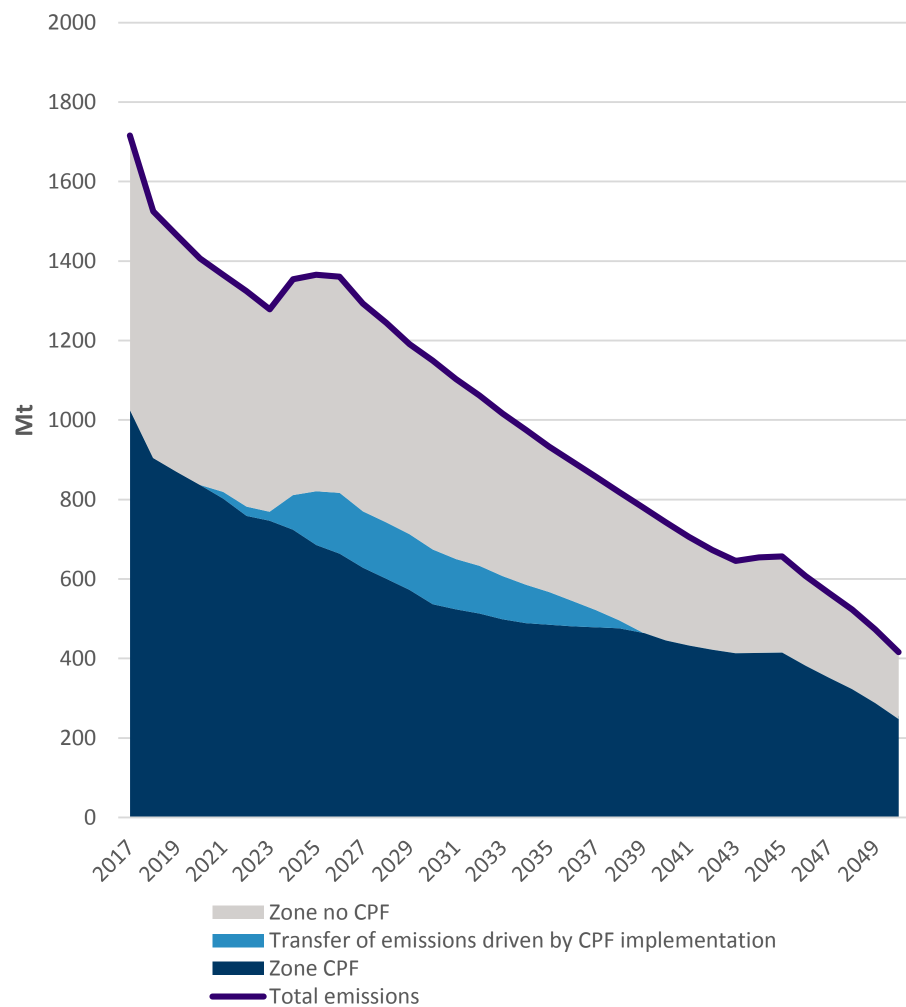


Complementary measures can be implemented so as to ensure reduce the total level of emissions

- The introduction of a CPF in the CPF zone will reduce **the total emission in CPF zone by 1662 Mt between 2021 and 2039**.
- This abatement in the CPF zone would create a surplus of EUAs within the EU ETS, which would be at least partially absorbed by the MSR.
- However, as the MSR is unlikely to absorbe the entire surplus a large amount of allowances could be **sold into the no CPF zone to balance the EU ETS market** during the period 2021-2039, creating much lower prices for the EU ETS.

- To offset the impact on the EU ETS market, specific **complementary policies** could be implemented with the aim of tightening the supply of credits so as to adjust to the drop in demand.
  1. **Voluntary cancellation mechanism** by member states to cancel an amount of allowances corresponding to the additional abatement driven by the CPF in the CPF area.
  2. **Adjustment of the market cap** or the linear reduction factor.
  3. **Adjustments of the MSR parameters**: intake rate, period, cancellation of surplus, etc.
- We consider these further below

EU ETS emissions for each zone

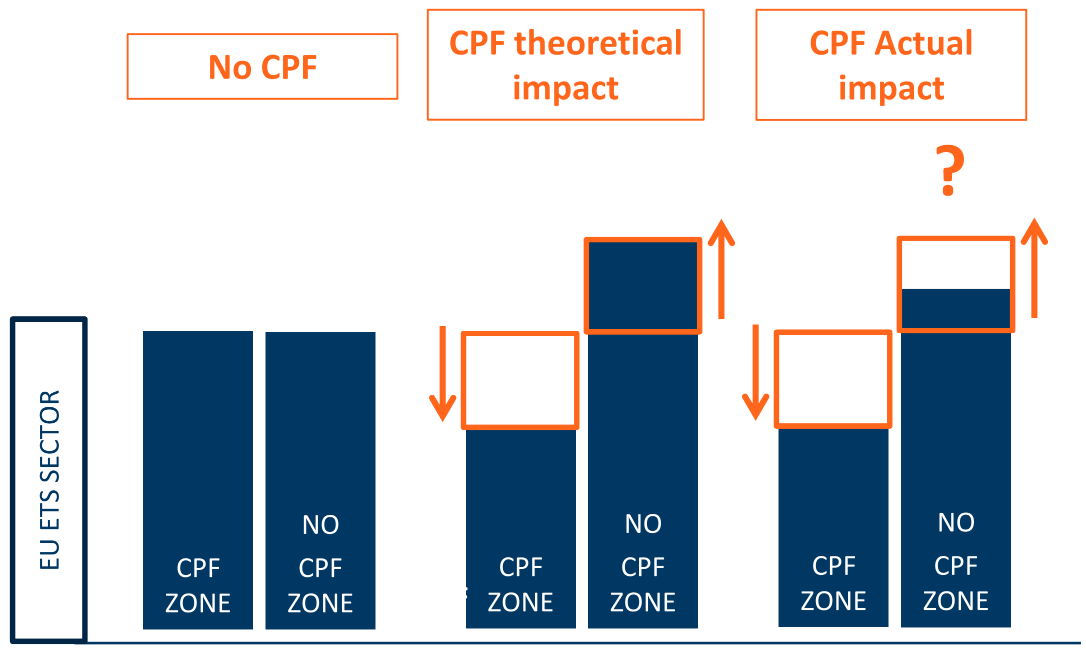


** Notes: The emission reduction is based on the current EU ETS LRF (2.2%) and therefore doesn't reach the 2050 Targets (GHG 80-95% -100Mt).*

The CPF and the ETS: current reforms may not be sufficient, but cancellations or continued reform can preserve emissions reductions

- The **ETS reforms** planned for 2019 will start to remove the surplus supply of EUA allowances in the market
- The **introduction of a CPF** would need to be managed carefully to protect the EU wide carbon (ETS) price
- The **theoretical impact** of a CPF would be to reduce demand for EUAs as CPF induced abatement in the CPF zone. Within the overall EU wide cap this could lead to a surplus of EUAs and falling ETS prices.
- **In theory the MSR could absorb the surplus supply relative to demand, but is unlikely to do so in its current definition**
- **In practice** demand and prices especially in the industrial sectors (33% of total EUA demand) may be "sticky"
- We have taken a **conservative approach** in our modelling assuming that the theoretical impact prevails and therefore complementary policies would be required to underpin the EU wide ETS price (e.g. cancellation of allowances or continued ETS reform such as the MSR intake rate increased to 48% of surplus, or linear reduction factor increased).
- However, the adjustment of industrial output may be lower or slower meaning that the **complementary policies may not be needed as quickly or to the same extent**

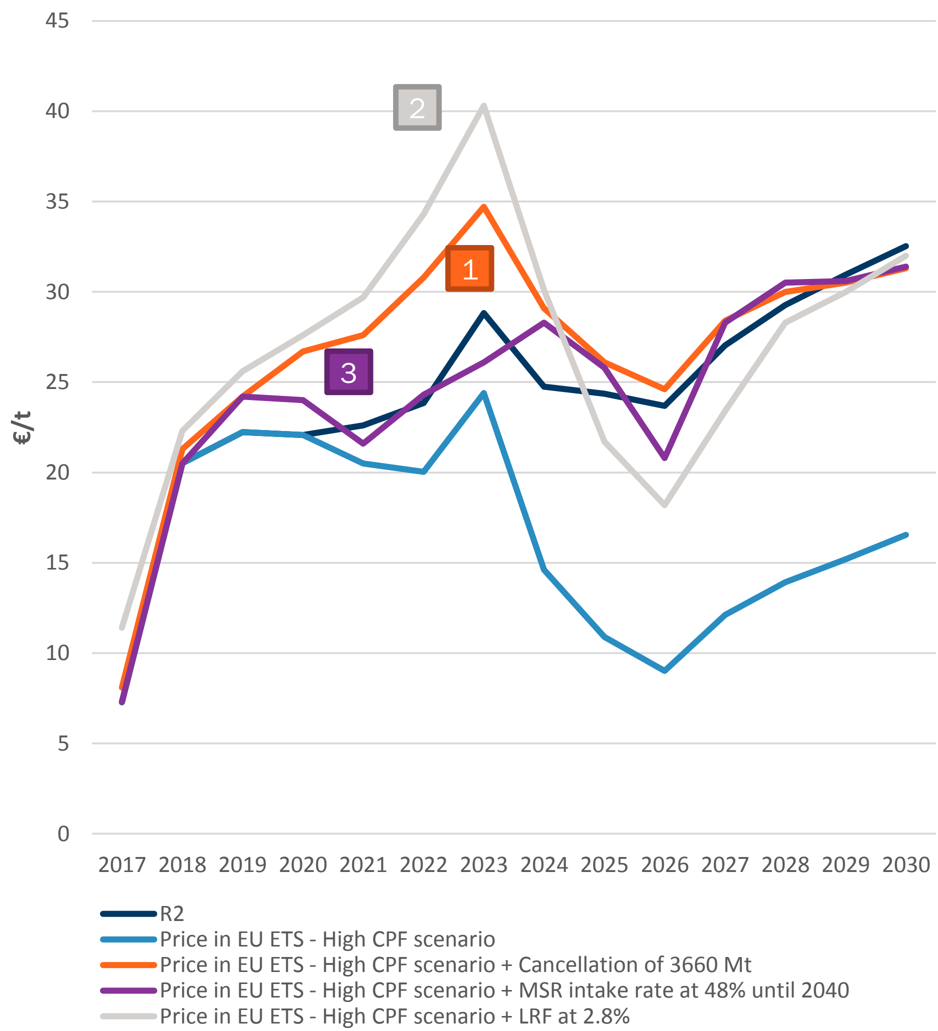
Emissions in 2030 with CPF implementation



A voluntary cancellation mechanism would be an effective way to ensure the CPF does not distort EU ETS prices

- The CPF could create a surplus of EUAs – these would be partially absorbed by the MSR. Remaining surplus could be offset by one of the following mechanisms
  1. **Voluntary cancellation mechanism** – Governments would need to remove **2.2 times the avoided emissions in the CPF zone** to bring back carbon prices to the R2 level. This is because the cancellation would need to offset the emission reductions **but also the associated hedging volume** decline over the period.
  2. **Adjustment of the market cap or the linear reduction factor.** Our analysis shows that increasing **LRF rate post-2023 to 2.8%** would bring carbon prices to the R2 level over the period 2025-2035.
  3. **Adjustments of the MSR parameters.** Our analyses show that **the MSR intake rate would need to be increased to reach 48% over the period 2023- 2040** in order to offset the impact of CPF on carbon prices as compared to 12% in our base case scenario.
- The **best alternative seems to be the cancellation mechanism** as this does not require a fundamental change in the rules of the EU ETS market. In addition, this mechanism allow to adjust the market on an yearly basis avoiding unexpected long term impacts.

Carbon prices (€/t 2017)



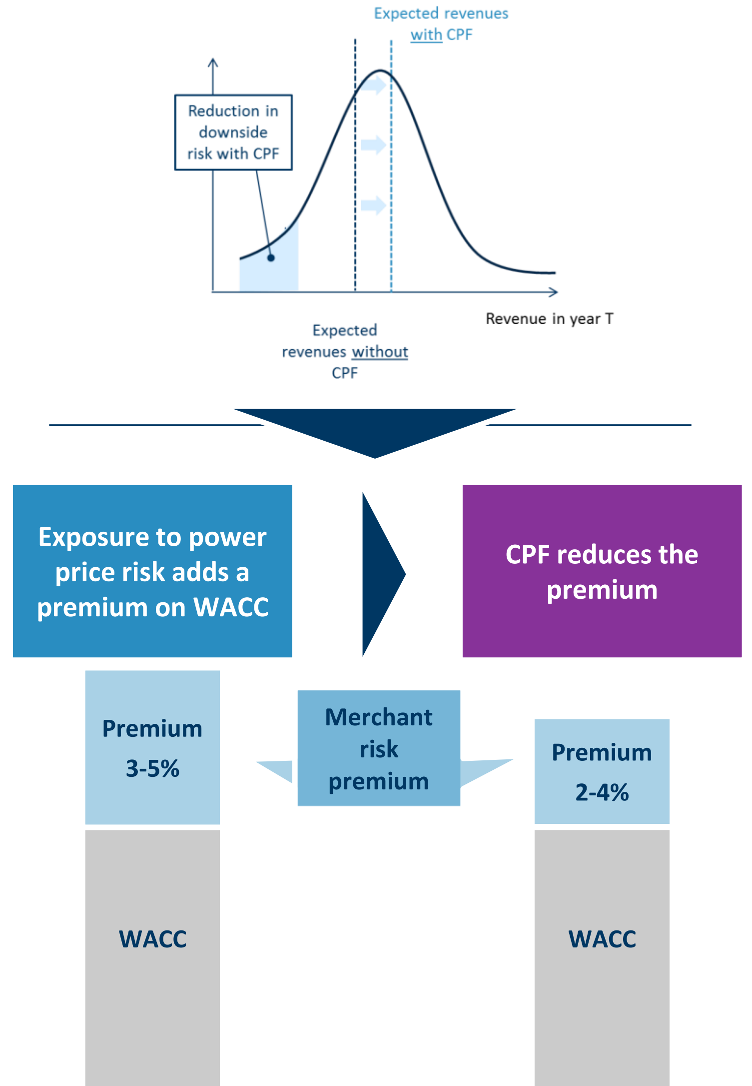
Reduced CO2 price risk reduces energy revenue volatility and thus reduces cost of capital

We have used a range of evidence sources to understand the impact of a CPF on financing conditions and costs

- **Literature review/benchmarking** – we reviewed a range of studies that suggested that **exposure to full merchant power price risk could add around 3-5%** at least onto the WACC for power plant investments, and a **CPF could reduce this by 1.5%.**
- **Industry interviews in the finance sector** – we have conducted structured interviews with 7 banks and other investors
- **Financial modelling** – we have used **financial modelling** to estimate the cost of **carbon price insurance** based on the Black Scholes model for pricing derivatives.

- Based on the above analysis, we have inferred that the enhanced predictability of future CO2 prices in a CPF scenario, **could reduce the cost of capital risk premium in a merchant world by 1%.**
  - This reduction is applied homogeneously to all investors profile (first mover investors and conservative investors)
  - This reduction of cost of capital translates into a reduction of overall RES levelized cost

Price risk reduction under Carbon Price floor



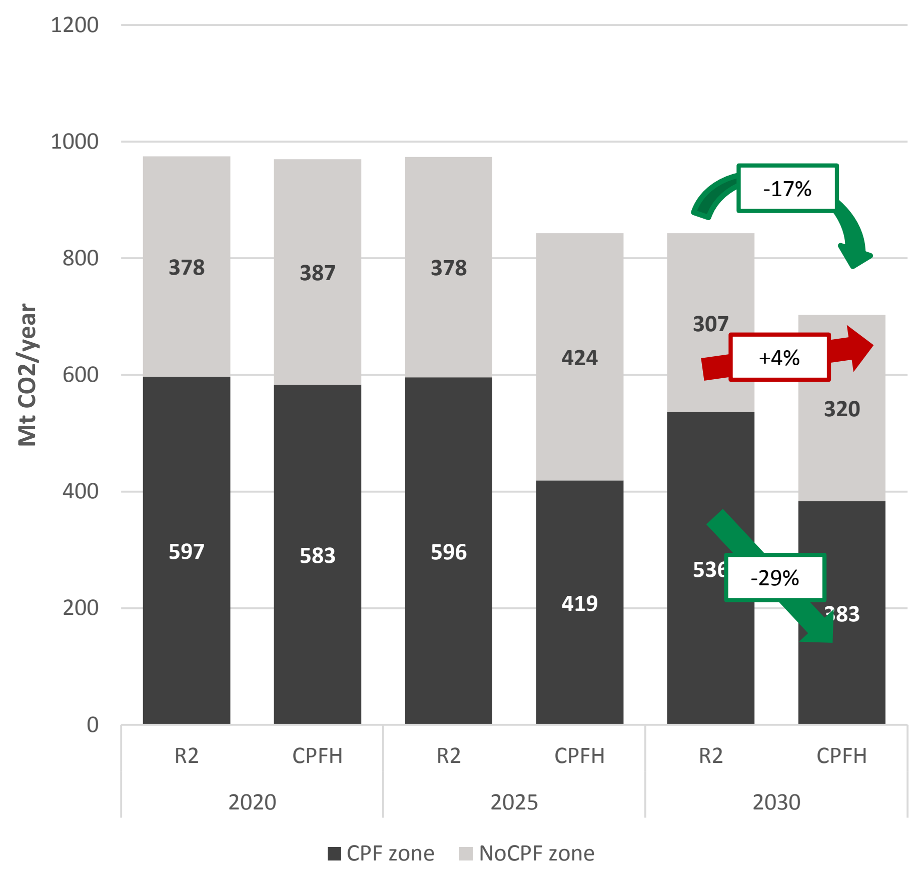
A High CPF would immediately reduce power sector emissions at the EU level, despite electricity leakage to non-CPF countries

Emissions in the EU 28 are 17% lower in 2030 than in R2, and 7% lower than in R1

- A High CPF would reduce emission from the power sector at the EU level through **coal to gas switching**, as well as **renewable investment**.
- The introduction of a High CPF (CPFH) would reduce the emissions in the CPF zone by 29% compared to R2 due to more renewable generation and less thermal production.
- The emissions in the non CPF zone would increase by 4% driven by additional cheap thermal generation being produced into this zone.
- ➢ **Overall, the emission will drop by 17% compared to R2 scenario**.

- Furthermore compared to R1, the emission will be reduced by 7% driven by lower installed coal capacity in the High CPF scenario (CPFH), **illustrating that the carbon price is well suited to rapid decarbonisation**.

EU ETS Power Sector Emissions (MtCO2e/year)

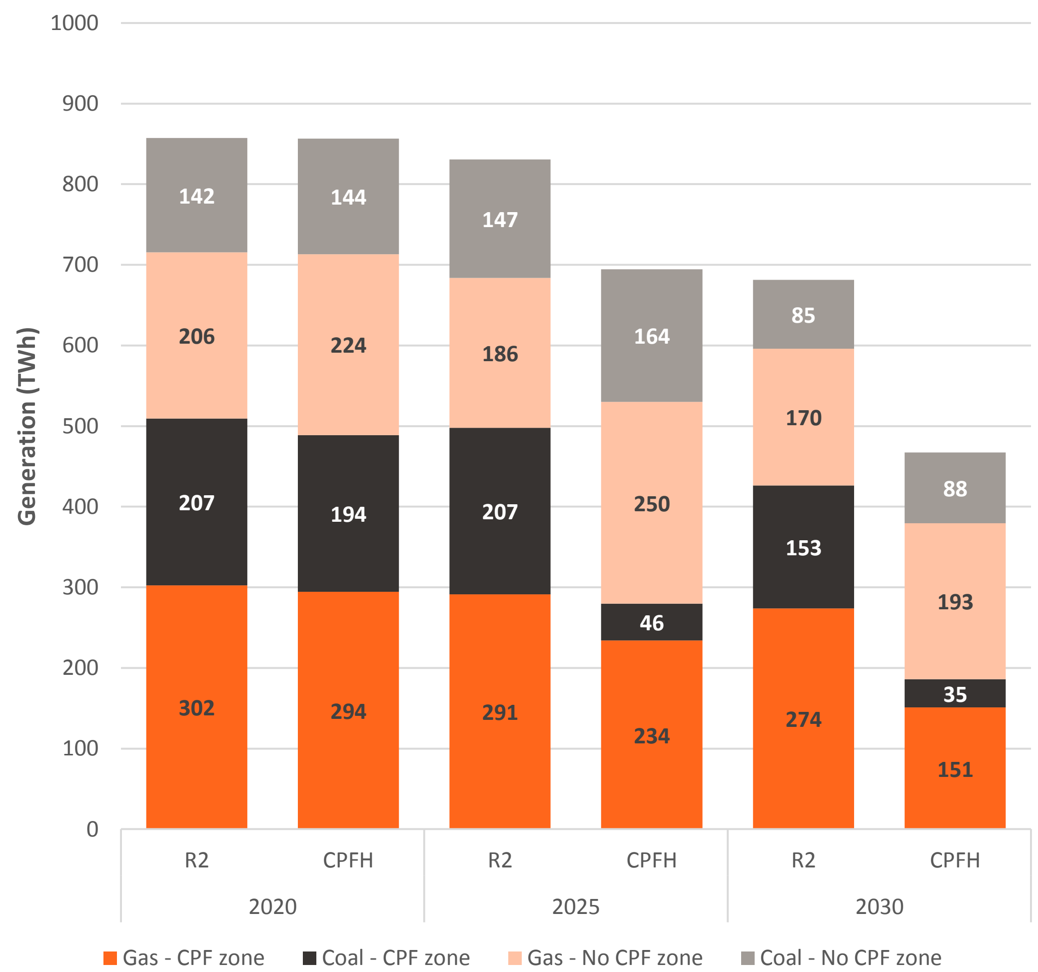


A High CPF would give an early signal to coal phase-out and avoid lock-in of thermal plants and stranded assets

A High CPF would give an early signal to coal phase-out and avoid lock-in of thermal plants

- **It would increase costs for high carbon fossil-fuel generation compared to lower carbon fossil fuel generation** in the short term optimisation of the power markets – coal to gas switching;
- **It would alter medium to long term operation decisions of thermal plants by providing a strong and early signal** of phase-out to high carbon fossil-fuel generation;
- The results show that under the High CPF price level (CPFH), both signals have an impact on the generation mix:
  - The High CPF (CPFH) features a lower total thermal generation, with a greater impact on high carbon fossil-fuel (Coal) generation than lower carbon fossil-fuel (gas) as illustrated when comparing R2 and CPFH
  - The High CPF (CPFH) features a lower installed capacity of high carbon fossil-fuel than the R1 and R2 scenarios driven by a high deployment of renewable capacity and a higher carbon price
- **The results show that the introduction of a CPF could support the transition by sending stronger signals to thermal plant operators**

Gas and Coal generation

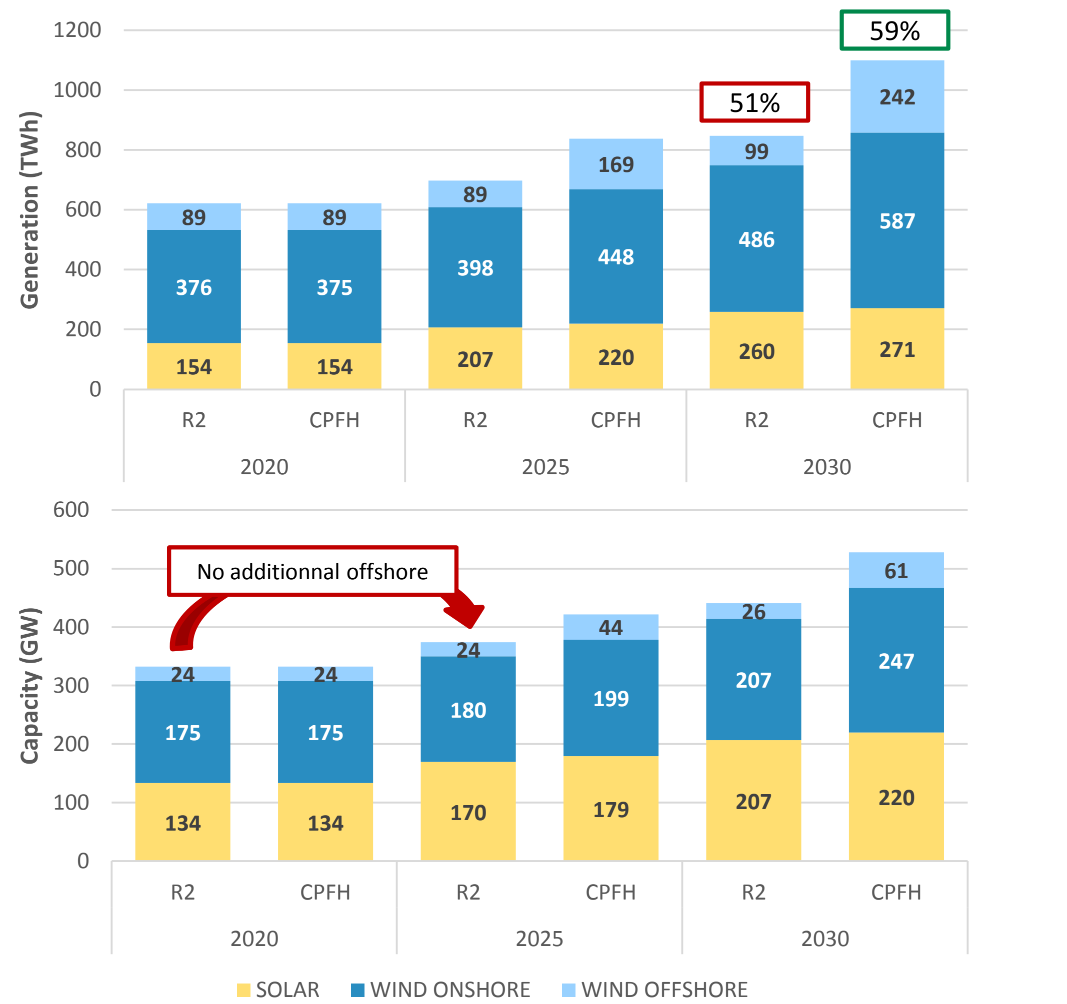


A High CPF would support RES investment as it would reduce the gap between power prices and RES cost and reduce financing costs

A High CPF combined with a credit cancellation mechanism could boost renewables investment by reducing financing costs, and increasing power prices in the short term (to 2025):

- With the enhanced predictability and lower cost of capital impact, a strong CPF would incentivise low carbon generation over high carbon generation.
- The CPFH scenario also has higher carbon prices and higher power prices (in the short term to 2025) which will also affect the investment decision for renewables
- This translates into a higher penetration of RES in the generation mix – helping to meet RES targets
- The results show that the under the High CPF scenario all three impacts materialise:
  - The CPFH shows a higher RES share than R2 in both 2025 and 2030.
  - The CPFH facilitates the transition from subsidy to merchant especially for high capital cost technologies like offshore wind. Indeed while in the CPFH scenario new RES materialises in 2025, the R2 scenario shows a material slow-down.
  - The CPFH helps meet the 2030 RES target by reaching 59% RES penetration in 2030.

Renewable energy generation and 2030 targets

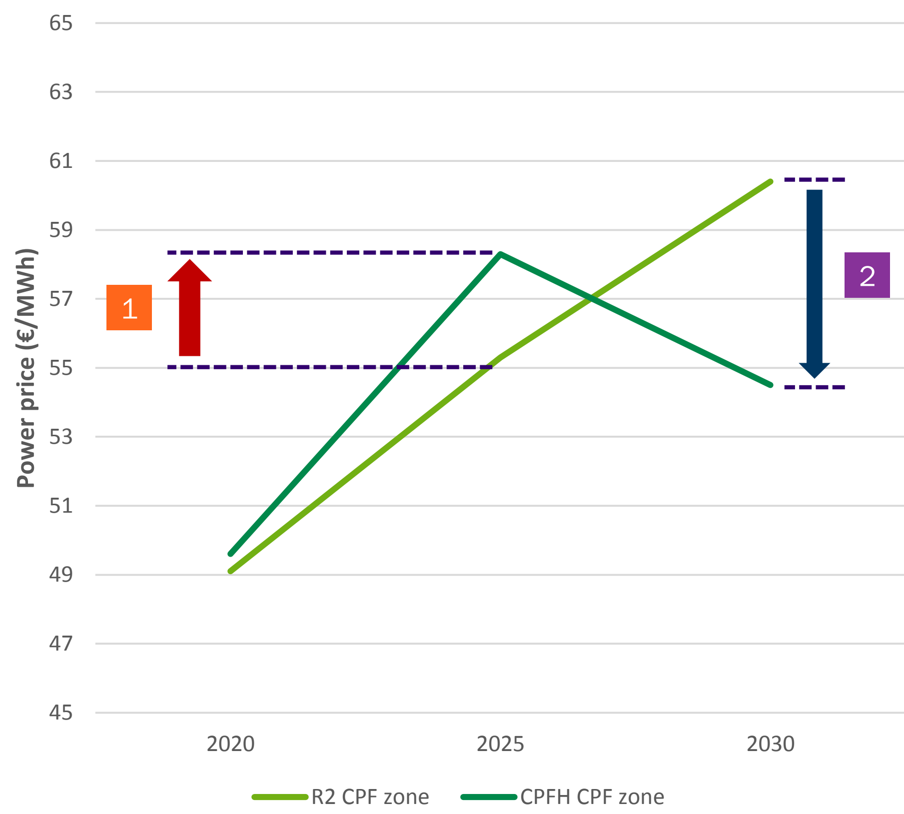


A High CPF could support the energy transition while mitigating power price increases for end consumers in the medium and long term

Power prices in 2030 are lower than in the R2 pure merchant scenario

- A higher carbon price signal would lead to higher power prices when set by fossil generation 1
- Higher power prices and lower WACC enables greater RES penetration which pushes down power prices (through the merit order effect). 2
- The results of this new equilibrium shows that under the High CPF price level - set at €60/tCO2 by 2030, twice as high as in the R2 scenario - power prices in the CPFH scenario are lower than the ones in the R2 scenario in 2030 owing to more renewable generation in this scenario.
- **The results show that the introduction of a CPF could support the energy transition while mitigating power prices increase for end consumers.**

Power prices in CPFH vs R2 – CPF Zone



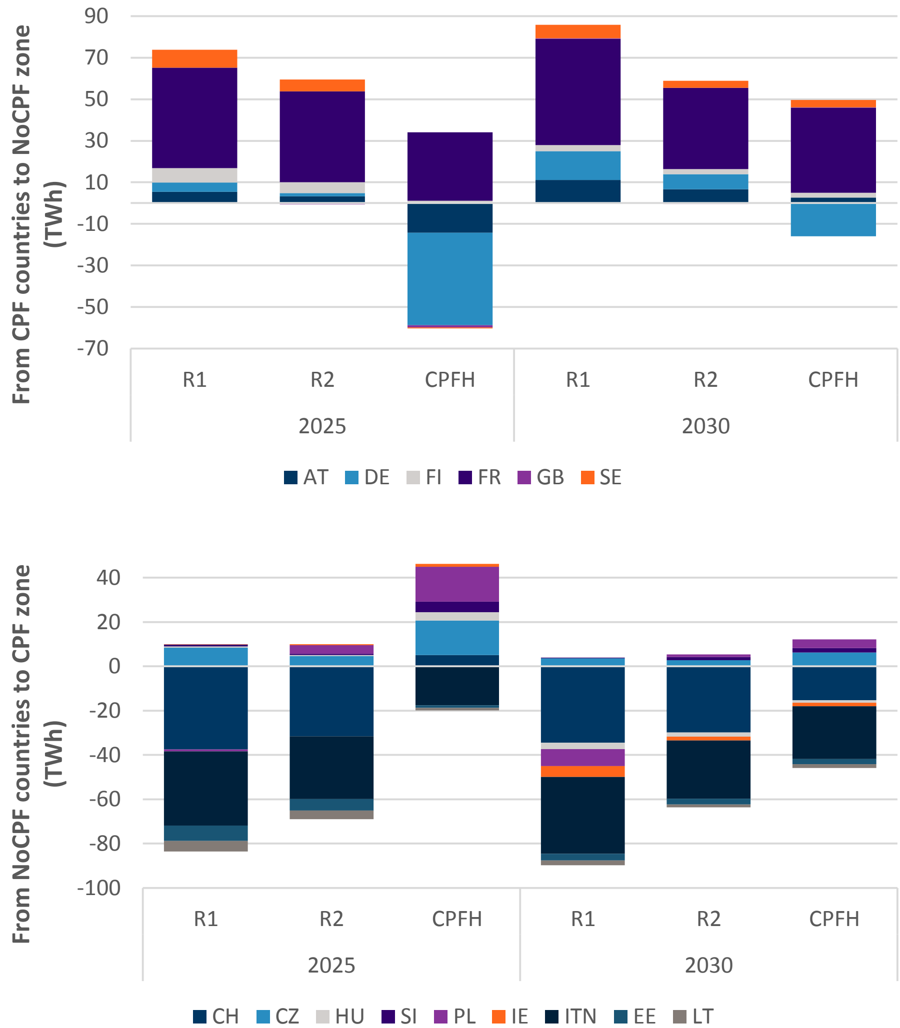
Note: Load-weighted average price in the CPF zone

To minimise the effect of power flow leakage on emissions, a wider coverage of the CPF is preferable

The CPF Zone remains a net exporter of power, but volumes fall by 42% in 2030, and Germany becomes a net importer

- By penalizing thermal generation in the CPF zone compared to the non-CPF zone, the net export balance between both zones would materially change in CPFH.
  - The change would be specially important in 2025. Indeed, Austria and Germany will become net importers for this year driven by material carbon prices difference between the CPF zone and the non-CPF zone.
  - The trend will be reduced in 2030 because of the increased renewable generation in the CPF zone lower prices.

Net power flows



Socio-economic impacts from a CPF are moderate, and manageable with additional carbon revenues

Impacts on consumers

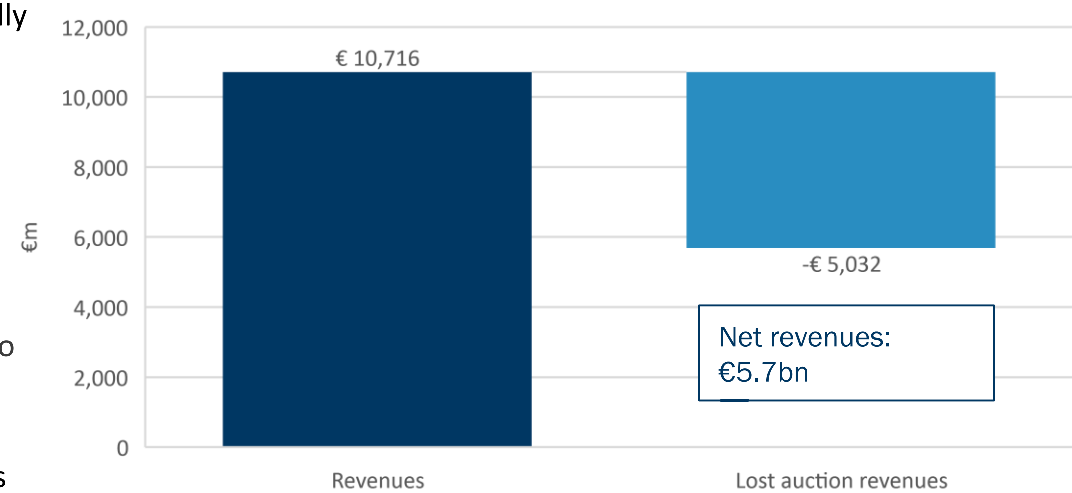
- The impact on consumers would depend on power prices – but also the effect on renewables support costs. In 2030 consumer costs are €37bn (6%) lower in CPFH than in R2, wholesale energy costs are lower though partially offset by somewhat higher RE support costs (as most RE support regimes are like CfDs where the support cost goes up if power prices go down and vice versa). The increase in RE support costs is €10bn.
- Lower power prices via the merit order effect could lead to lower consumer energy bills by 2030 (see modelling results below)

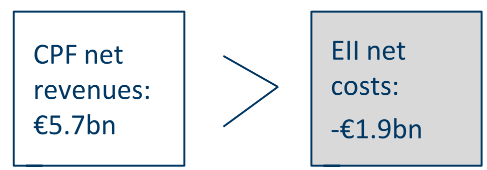
Impacts on Energy Intensive Industries (EII)

- Carbon leakage, as well as relocation of economic activity or investment to jurisdictions with lower carbon costs – can be a concern for Energy Intensive Industries
- **Within the EU ETS** these sectors are protected from such competitiveness impacts through free EUA allocation
- The **EU regulations** also allow for member states to **compensate Energy Intensive Industries** for other direct and indirect costs (electricity price)
- Our modelling suggests that the **cost impact on the Energy Intensive Industries**' by 2030 would be a net saving even in CPFH
  - No additional direct carbon costs as we have assumed the CPF is only applied to the power sector
  - Indirect costs via the electricity price are actually net savings as power prices are lower in 2030 (a saving of €1.9bn)
  - **Carbon revenues to Governments from a CPF** (net of the cost of the complementary policies) would be over €5.7bn – potentially enough to compensate for any short term higher power prices

Carbon revenues and Energy Intensive Industry costs 2030

Government CPF Revenues - comparison of CPFH vs R2 scenario





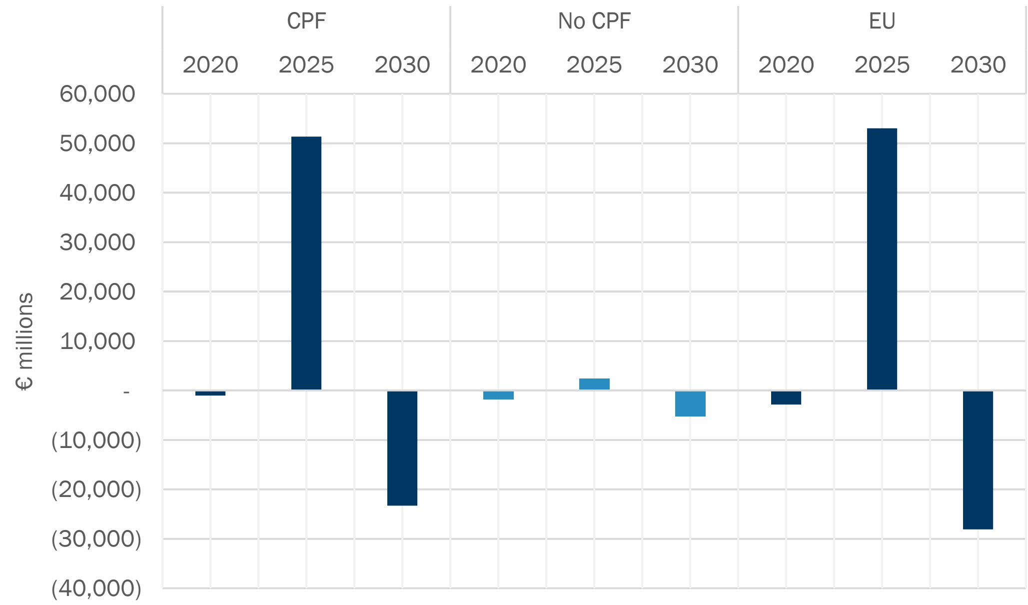
Consumer Electricity Costs are lower in the long term in the High CPF scenario than in R2 – due to lower power prices

- We calculate the consumer costs by combining for each scenario
  - Energy costs (at the wholesale level)
  - Support costs (for RES support contracts)
  - Capacity costs (to ensure counties meet their security of supply targets)
- The charts on the right shows the difference between scenarios of this combined consumer cost
- We do not take account of network costs or network cost changes

CPF Zone impacts

- **CPFH vs R2:** In 2025 consumer costs are higher in the CPFH scenario than in the R2 scenario – due to higher power prices. In 2030 households could save around €22 billion on their energy bills in the CPFH scenario.
- A full NPV comparison of the cumulative impacts over time was not possible within the scope of this project

Net Impact on Consumer Costs – CPFH versus R2



Carbon Prices per tonne CO2 in CPF countries (ETS + CPF)
R2: €21 (2020), €16 (2025), €22 (2030)
CPFH: €22 (2020), €50 (2025), €60 (2030)

***Average CPF Country Load Weighted Power Prices:**
R2: €49 (2020), €55 (2025), €60 (2030);
CPFH: €49/MWh (2020), €58/MWh (2025), €54/MWh (2030);

***Average Non-CPF Country Load Weighted Power Prices:**
R2: €52 (2020), €56 (2025), €62 (2030);
CPFH: €51/MWh (2020), €57/MWh (2025), €60/MWh (2030);

Source: FTI Power Price and ETS models; Technical report on Member State results of the EUCO policy scenarios, E3MLab & IIASA, December 2016

Notes: Power price paid may vary by sector; Domestic demand represents residential and tertiary demand. CPF Countries include Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden and Finland.

Energy competitiveness in policy discussions have centered around production costs, although many factors drive competitiveness.

Porter's 5 forces provides a framework to analyse industry competitiveness and factors affecting CPF cost passthrough.

Positive impact on cost passthrough | Negative impact on cost passthrough

Important barriers to entry
- Economies of scale
- Product differentiation
- Capital requirements
- Switching cost to buyers
- Access to distribution channels
- Government policies
- Incumbents' defense of market share
- Industry growth rate

Strong supplier power
- Supplier concentration
- Availability of substitute inputs
- Importance of suppliers' input to buyer
- Supplier product differentiation

Competitive Rivalry
- Number of competitors (concentration)
- Overcapacity
- Relative size of competitors (balance)
- Industry growth rate
- Production costs
- Product differentiation

Buyer Power
- Price sensitivity
- Number / volume of buyers
- Product differentiation
- Switching costs
- Buyers' profit margins
- Buyers' threat of backward / forward integration

Threat of Substitutes
- Heterogenous products
- Complex products and importance of relationship
- Switching costs
- Regulatory standards
- Transport costs

- Production costs are a key factor impacting manufacturing competitiveness, **but must be assessed in conjunction** with several other domestic and international factors.
- The bottom line economic impact of the CPF on the EIIs will depend on the degree to which they can **pass on input costs** to their customer market
- If steel producers can pass through costs, then **profitability can be maintained** and relocation of production or investment avoided
- This in turn **depends on the competitive environment** for the specific sector and product market - outlined in the graphic
- **Some studies** for the EU have suggested that rates of cost-passthrough for EIIs might be relatively high (CE Delft and Oeko, 2015)
- The higher **carbon pricing in competitor regions becomes**, the better the ability for EIIs to pass through costs.

Case Study A: German Steel Industry
A highly competitive sector facing price competitiveness risk

Industry Overview

- The German steel industry is the fifth largest in the world and the largest in the EU, comprising 25% of European steel production.
- Germany produced 43.4 million tonnes of steel in 2017 and employed 71.7k workers. Annual average production levels have remained relatively flat since 2010.
- Price competitiveness concerns are prevalent for German steel stakeholders due to existing high electricity prices relative to EU and global competitors due to the EEG, which are compounded by American import taxes on steel.
- However, several factors contribute to sector competitiveness. Germany manufacturers typically pay high labour prices and are subject to changes in import penetration, global supply changes, demand contraction due to economic crisis / overall sector demand and currency strength.
- The steel sector has experienced sustained employment decline averaging approximately 1% year over year since 2004.

Important barriers to entry

- Economies of scale are extremely important for long term viability
- There are very high capital requirements
- There is overcapacity in the European and global steel industries

Strong supplier power

- High volatility of raw material prices demonstrates supplier power

Highly competitive sector

- National producers face price competition (particularly in China and Korea) and margin pressure
- Relatively large number of competitors
- Part of production is differentiated but the other part is commodity
- High capex is an important exit barrier

Buyer power is strong in the commodity but less so in the specialty segment

- Specialty: Large buyers buy large volumes, but long term co-design relationship makes switching costly
- Commodity segment: low differentiation, price is key purchase criterion

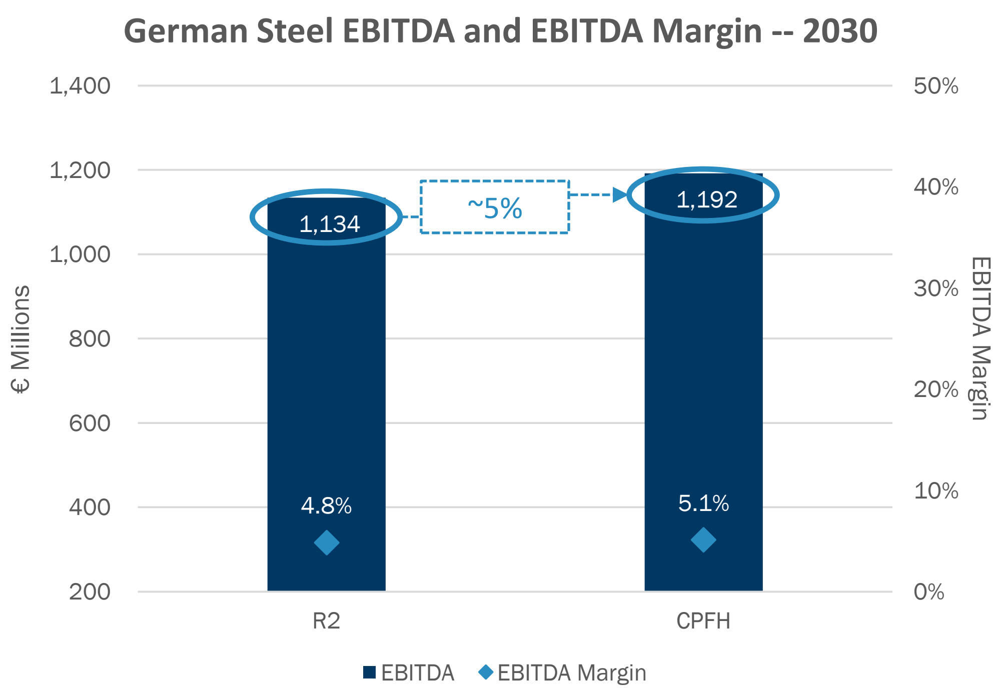
Price risk to import substitution

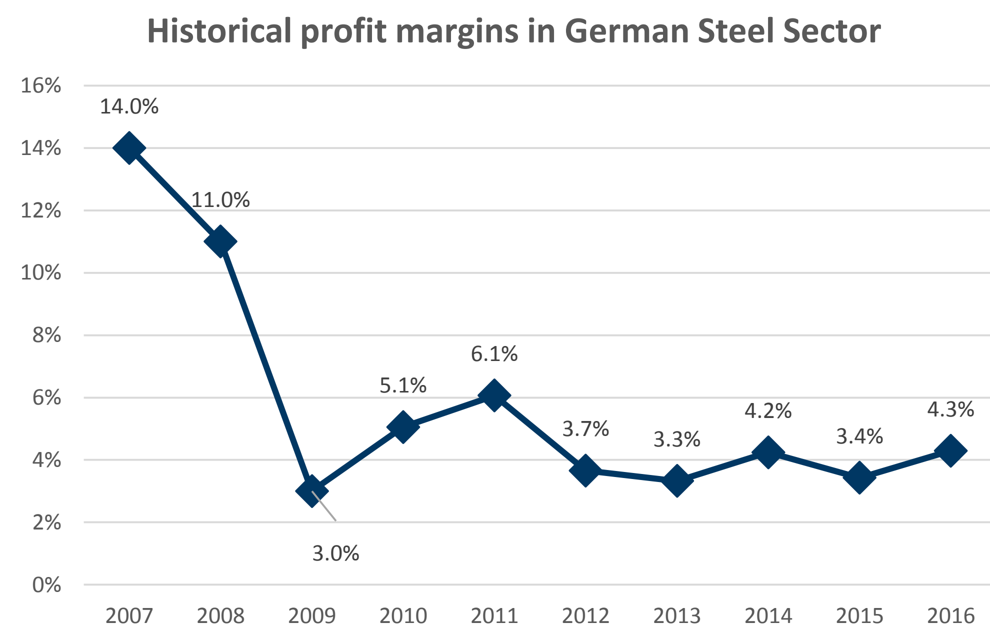
- Imports constrained by issues such as exchange rate volatility, lead time, working capital restrictions, lot sizes, serviceability, etc.
- Price competitiveness drives import risk.
- High electricity prices relative to EU and global competition due to the EEG – though steel and carbon leakage sectors are largely exempt from these costs.

1. ECOFYS “Composition and Drivers of Energy Prices and Costs”

German Steel Sector deep dive: Steel producers would face lower indirect costs in CPFH

- We have analysed the German steel sector using our proprietary sectoral financial models. The models capture fundamentals about the sectors incl. profit/EBITDA margins, steel prices and production costs (for both EAF and BOF technologies), and steel price elasticities
- There are no additional direct carbon costs as the CPF is applied only to the power sector
- Indirect (electricity) costs are in fact lower in CPFH than R2, as power prices are lower
- The models suggest such effects would result in a marginal 5% improvement in EBITDA in the CPFH relative to the R2 scenario.
- Historically, profit margins fell very significantly after the financial crisis, and tend to move up and down from year to year.
- **German steel producers would not experience negative impacts to EBITDA or employment due to indirect costs from the carbon price floor.**





2030 Carbon Price: R2 = €22.1/tonne CO2, CPFH = €60/tonne CO2
2030 Power Price: R2 = 60.6 €/MWh, CPFH = 55.7 €/MWh (avg. Germany load-weighted)

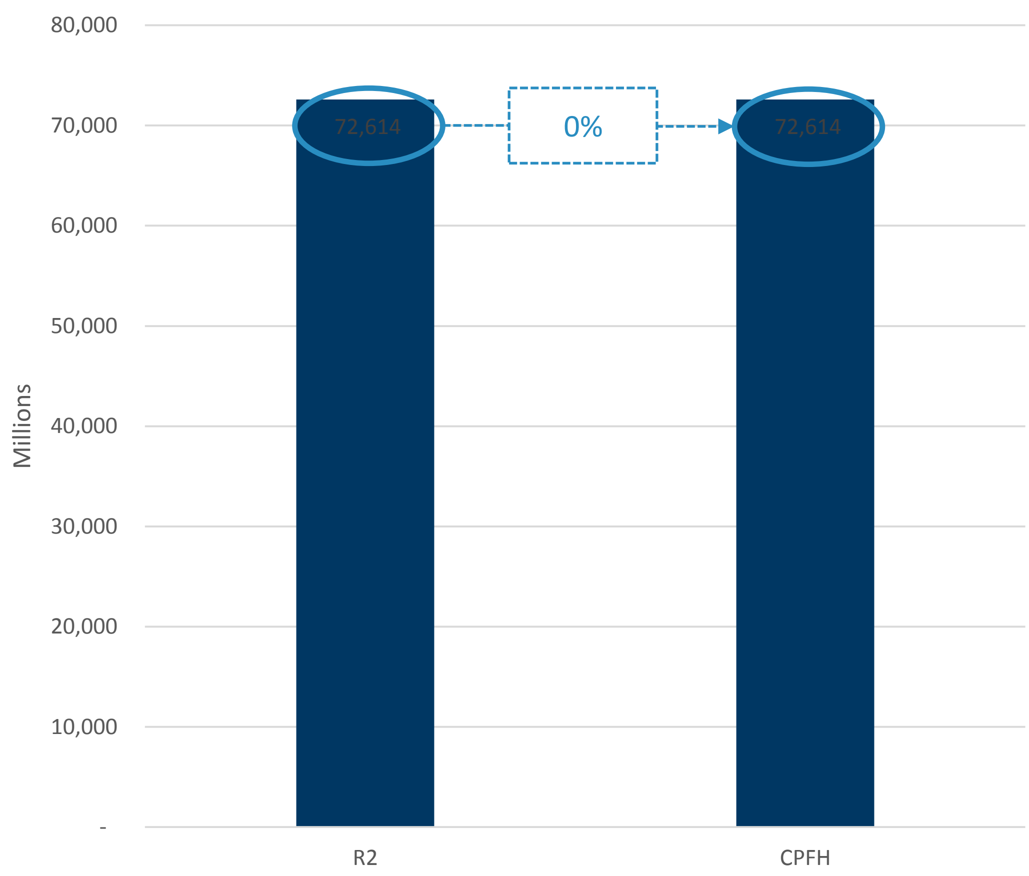
Source: FTI analysis, Eurostat, industry data, FTI ETS and Power Price models

German Steel Sector deep dive: EIIs would not require compensation for indirect costs

Impacts would not require compensation

- Our industry models can also be used to calculate the impact on employment (in FTE)
- The relationships in the model are based on the link between profitability and employment
- We calculate indirect costs associated with the CPF and feed these into the model. Higher input costs for this sector could in lead to a need to absorb the higher costs, as well as demand reduction (to the extent that input costs are passed on through final prices charged to customers). However, the CPFH scenario indicates indirect costs are lower in 2030 than in the R2 scenario, resulting in a slight net improvement in EBITDA.
- Employment volumes would remain unaffected.

German Cement Employees (FTE) – 2030



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Source: FTI analysis, Eurostat, industry data, FTI ETS and Power Price models

Case Study B: German Cement Industry
Strong incumbents strong power, but facing overseas cost competition

Industry Overview

- Germany ranks 16th in world production and first in Europe at 33 million tonnes per year with high labour productivity and high-quality products.
- The German cement industry employs approximately 7,900 workers and has exhibited relatively stable employment since 2010.
- The national cement industry is under pressure due to dropping transport rates and lower overseas production costs, resulting in price sensitivity to climate protection regulations and government-induced increases in electricity prices.
  - German construction-material corporations are expanding globally to diversify geographically and protect against economy-related risks to stabilise the domestic cement-production sector.
  - The German cement association, the VDZ, has asked the government for substantial tax relief in compensation for the loss of subsidies related to the Renewable Energy Resources Act.
- The Carbon Price Floor would compound existing sector price pressures, although sufficient CPF revenues are expected to compensate cement producers.

High barriers to entry

- High fixed costs – new plant cost equivalent to 3x annual turnover
- Limited access to raw materials, typically controlled by incumbents
- Transport costs limit competitive geographical market
- European cement dominated by small number of established, incumbent firms including Heidelberg Cement.

Limited supplier power

- Vertically integrated industry, (quarrying, processing, manufacturing, sales and distribution)

Established companies with limited rivalry in Germany and the EU

- Collusive behaviour has been punished throughout the EU
- Limited geographical scope place limits on fierce rivalry

Weak buyer power

- Limited availability of alternative suppliers
- Buyers include large construction firms as well as smaller purchasers

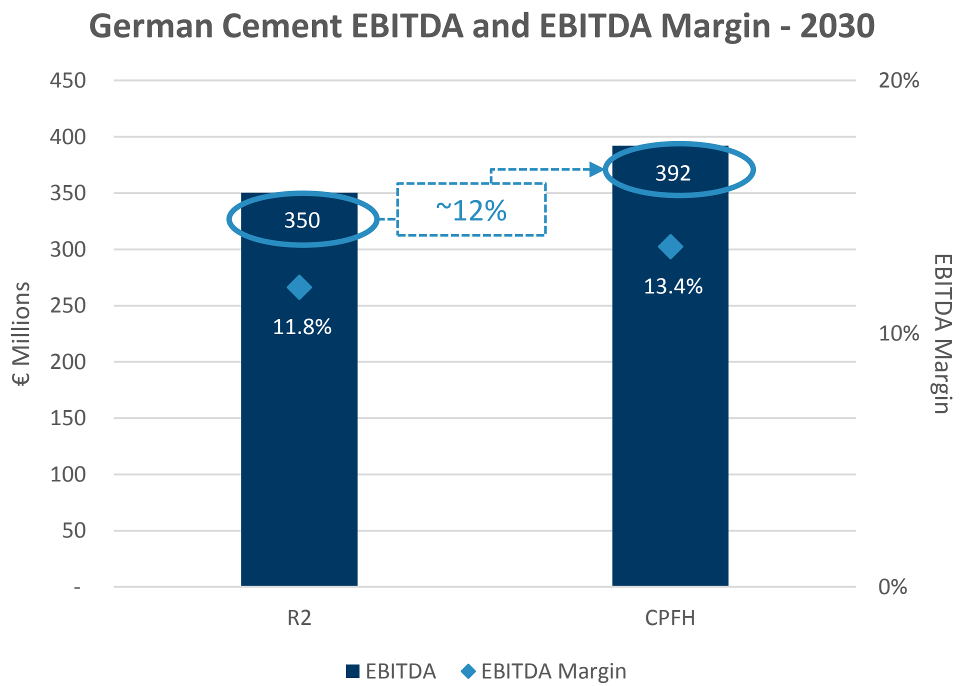
Limited risk of substitutes

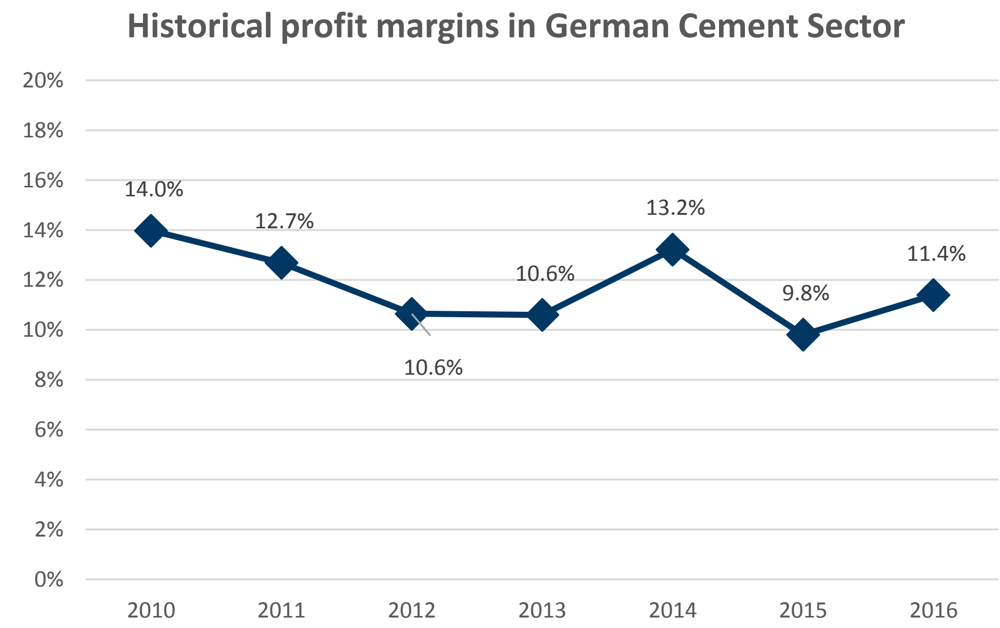
- Homogeneous product with few substitutable goods
- EU restrictions on quality of cement to use - incumbents typically supply all accepted grades
- German cement is typically high quality

1. ECOFYS "Composition and Drivers of Energy Prices and Costs"

German Cement Sector deep dive: Cement producers would face lower indirect costs in CPFH

- FTI CL's modelling indicates that a High CPF is unlikely to reduce profitability and employment levels in the cement industry.
- There are no additional direct carbon costs as the CPF is applied only to the power sector
- Indirect (electricity) costs are in fact lower in CPFH than R2, as power prices are lower
- The models suggest such effects would result in a 12% improvement in EBITDA in the CPFH relative to the R2 scenario.
- **German cement producers would not experience negative impacts to EBITDA or employment due to indirect costs from the carbon price floor.**





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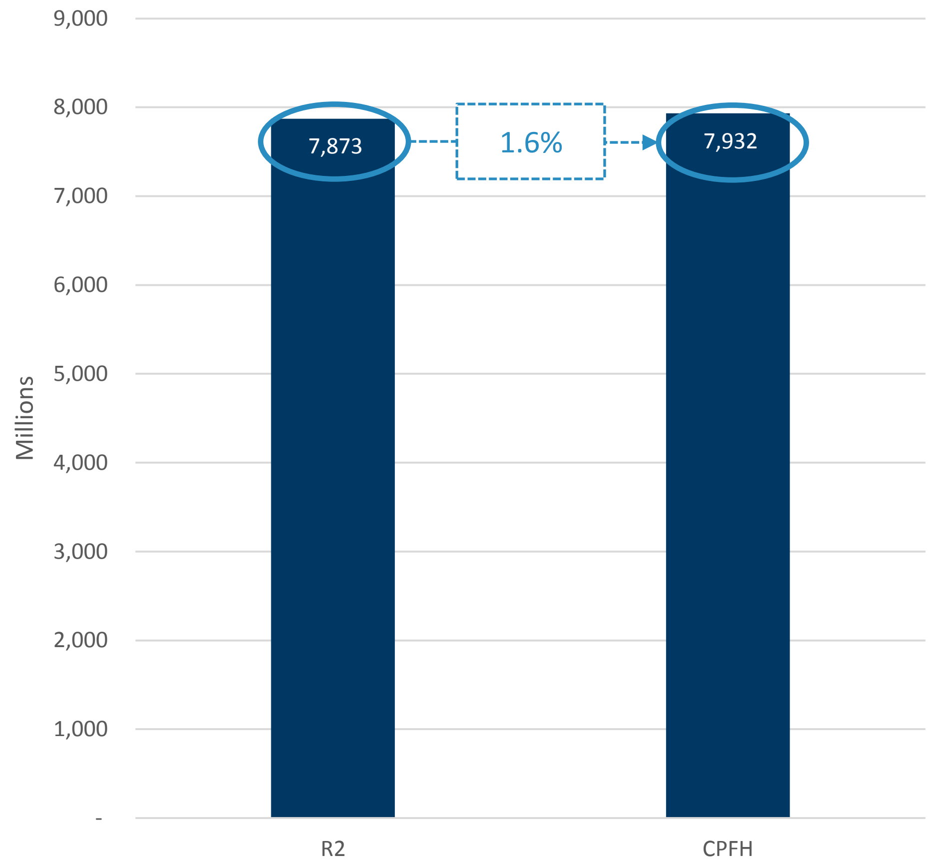
Source: FTI analysis, Eurostat, industry data, FTI ETS and Power Price models

German Cement Sector deep dive: EIIs would not require compensation for indirect costs

Impacts are not modelled to be significant

- Our industry models can also be used to calculate the impact on employment (in FTE)
- The relationships in the model are based on the link between profitability and employment
- Stakeholders are concerned that input costs for this sector could in lead to a need to absorb the higher costs, as well as demand reduction (to the extent that input costs are passed on through final prices charged to customers), although the model indicates this is offset by the reduced power price in the CPFH scenario relative to R2 in 2030.
- Higher EBITDA would eventually feed through into a slight increase in employment
- The regulatory framework for compensating EIIs already exists – and earlier slides show that carbon revenues would be sufficient for this – if actual CPF costs did negatively impact EIIs.

German Cement Employees (FTE) – 2030



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2030 Power Price: R2 = 60.6 €/MWh, CPFH = 55.7 €/MWh (avg. Germany load-weighted)

Source: FTI analysis, Eurostat, industry data, FTI ETS and Power Price models

In addition, a range of compensation mechanisms could mitigate the impact on some industrial / consumer sectors

- Modelling does not indicate EIIs would suffer from the impact of a CPF in the long term. However, stakeholders face concerns over price competition. Multiple compensation mechanisms exist for governments to alleviate the costs of the Carbon Price Floor and safeguard the competitiveness of energy intensive industries if the CPF did negatively impact input prices. Examples include:

Mechanism	Description	Pros	Cons
Exemption from CPF	Exclusion from carbon price floor mechanism	Protects sector competitiveness and defends against carbon leakage	Weakens the signal to reduce carbon emissions efficiently
Rebate from CPF revenues	Government CPF revenue returned to taxpaying corporation	Maintains CPF price signals more so than full CPF exemption	Undermines the signal to reduce carbon emissions efficiently
Reduction in other taxes	Compensation reductions such as through reductions in corporate or labour taxes	Enforces CPF price signals whilst mitigating net impact	Undermines impact or revenues derived from other tax legislation
Spending tax revenue on industry priority	Benefits stakeholders exposed to greatest impact / risk	Supports stakeholders most impacted by impacts to costs and competitiveness	Extensive assessment required to identify relevant priorities across geographies and industries
Trade adjustment policy	Market adjustments such as retraining and relocation assistance for workers and companies most affected by trade-related structural change	Supports sector adjustment to industries that face a cost increase resulting from carbon pricing and heavy international trade	Comprehensive policies and training required to help workers navigate economic restructuring

- The UK, which implemented a Carbon Price Floor in 2013, has introduced several compensation measures for “electro-intensive” industries. Not all energy intensive industries qualify to accesses these compensation measures:
  - **2011 Support Package:** £250 million to compensation EIIs for the indirect costs of the EU EUTS and the UK’s CPF.
  - **2014 Support Package:** Extended the compensation for qualifying electro-intensive sectors to 2019-20 and introduced a new compensation scheme to help qualifying sectors with higher electricity costs resulting from the renewables obligation and small-scare feed in tariffs for renewable generation.

Source: “Carbon Price Floor (CPF) and the price support mechanism,” House of Commons Library, January 2018; “Competitiveness impacts of carbon policies on UK energy-intensive industrial sectors to 2030,” Cambridge Econometrics, March 2017

C

A Low CPF acts as an insurance policy for low-carbon investors

Content

Section overview

- The role of this lower CPF would be as **an insurance mechanism for investors –** against ETS price collapse scenarios which are plausible based on past history

- **Some of the benefits of a CPF are weaker in the low CPF scenario**
  - There is less coal to gas switching and the emissions reductions are not as strong
  - Coal retirements are not as rapid
  - Investment in renewables is less extensive – the 2030 Renewables target would not be met based on the carbon price alone

- **However there are also advantages from the low CPF scenario**
  - Clearer investment and retirement signals than in the R2 scenario
  - Cross border flows – the CPF zone remains a net exporter at virtually the same levels as in R1 and R2

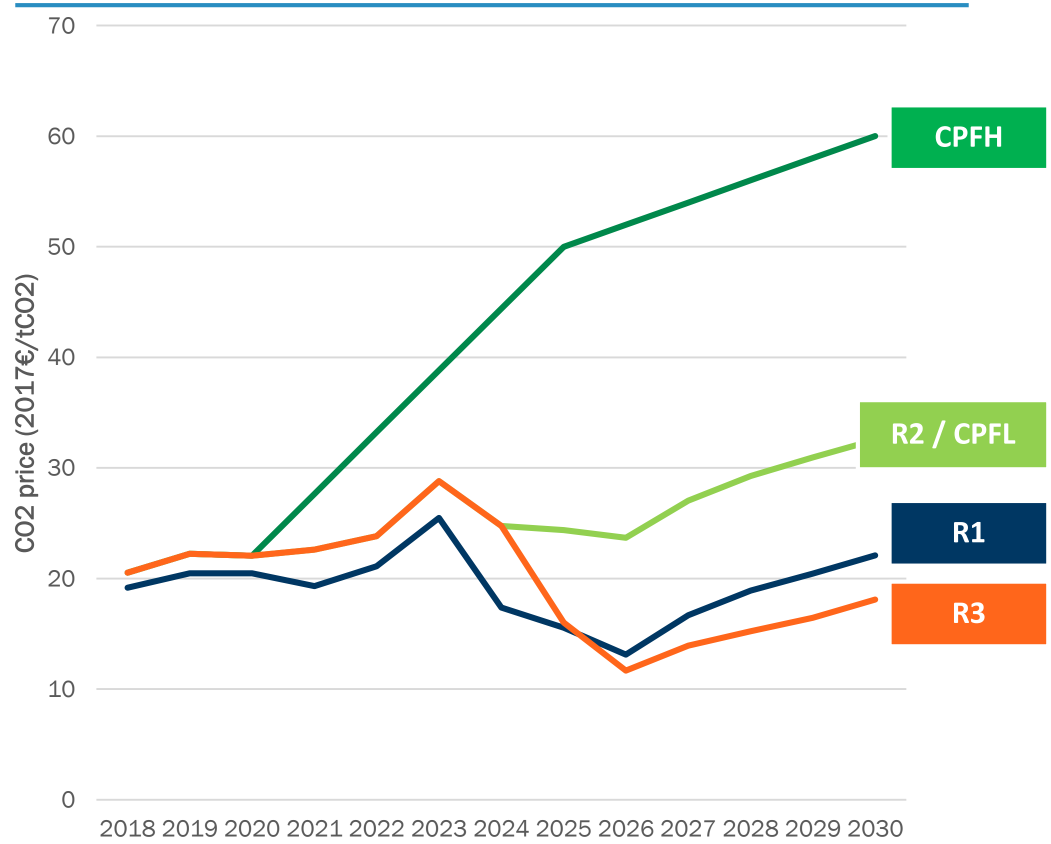
The CPF Low scenario rises from around €23/t in 2020 to €30/t in 2030, following the R2 (ETS High) Scenario

Carbon Price Floor Scenarios

- **Carbon Price Floor Low (CPFL)** sets the CPF at €23/t rising to €30/t in 2030. This illustrates the role the CPF can play even when set at a similar level to the expected ETS price, as an insurance policy against sudden ETS price falls. (The R2/CPFL line illustrates the CO2 price in the CPF Zone and in the No CPF Zone (the ETS price)).

- **R3 ETS Price Fall** shows the impact on ETS prices of a sustained fall in prices such as could be caused by a regulatory intervention phasing out coal, or a new technology which dramatically reduced demand for emissions from the industrial sector.

Carbon Price Scenarios to 2030

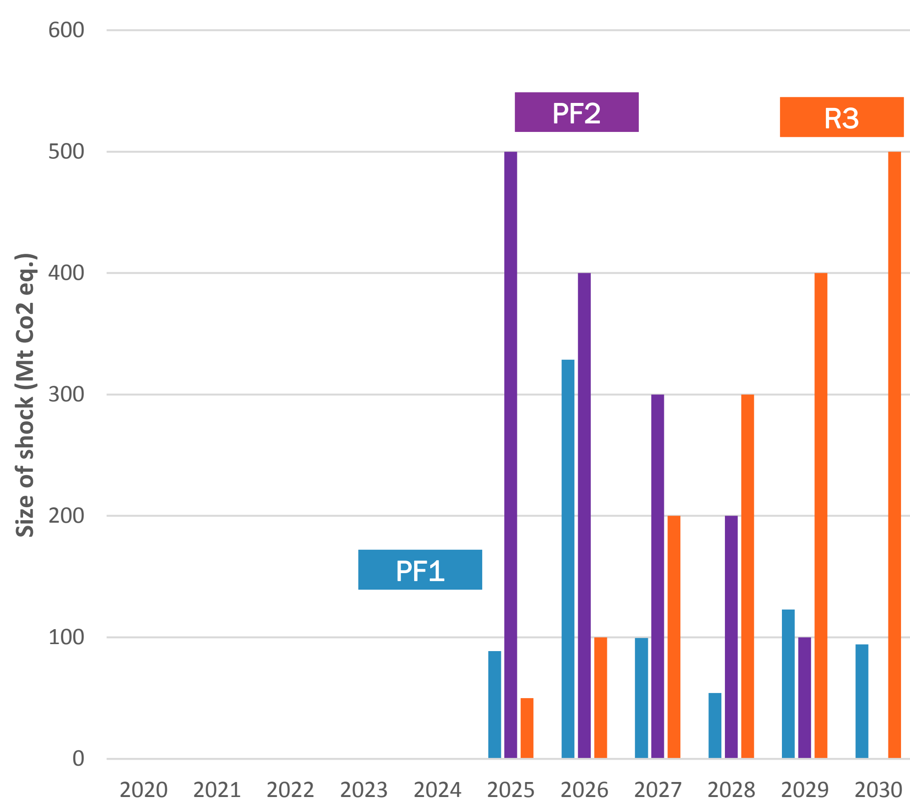


CPF Countries: Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden, Norway and Finland.

ETS Price Fall scenarios could be caused by several plausible events

ETS Price Fall Scenario	Driver	Presentation	Impact in Mt CO2
PF1	**Economic crisis**	Crisis impact over a period of 6 years based on the reduction of emission over the period 2008-2014 (Source: I4CE)	788 Mt over the period (6 years)
PF2	**Improvement in energy efficiency**	In this scenario, the improvement in energy efficiency is calculated as twice the annual contribution of energy efficiency and renewable energy policies in emission reduction. (Source:I4CE)	440 Mt in 2025 progressively reduced to 0 in 2030 as we as we are back on track with the energy efficiency targets
PF3: R3 scenario	**Coal phase out in Europe**	Anticipated closures of 36 GW of coal and 18 GW of Lignite capacity in Europe in 2025-2030 (anticipated closures of the period 2030-2040)	50 Mt in 2025 to increase to reach 400Mt in 2030

Different shocks in the carbon markets – emission reductions



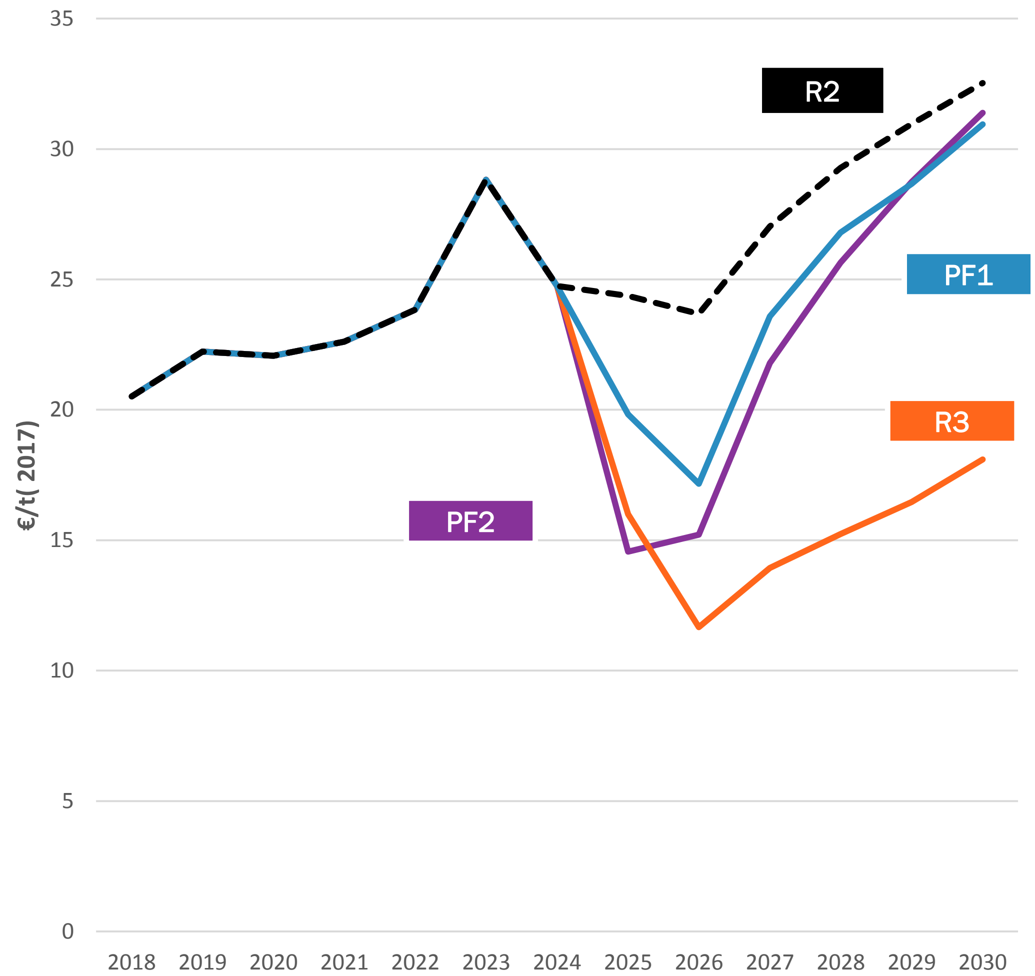
Historically plausible falls in EUA demand show such events could have a material impact on the ETS price

Price falls in the EU ETS is a plausible risk

- We have modelled stress test scenarios with price falls in the EU ETS for a range of plausible events based on historical precedent
  - **Economic recession (PF1)** : 330 Mt reduction in demand for credits in 2026 then following impact of the crisis.
  - **Energy efficiency technology (PF2)** : 400 Mt reduction in demand for credits in 2025, progressively reducing to 0 Mt in 2030.
  - **Regulatory intervention (PF3 – R3 scenario)** : For example the gradual closing of all coal fired power stations. Progressive reduction in demand for credits, from 0 Mt in 2025 to 400 Mt in 2030.
  - **Slower electrification of heat and transport**: this could lead to lower electricity demand than expected, and lower demand for EUAs

- **CPF as insurance:** The introduction of a CPF would have prevent such a drop in "carbon price " for the power sector in the CPF area.

EU ETS carbon price (real 2017)

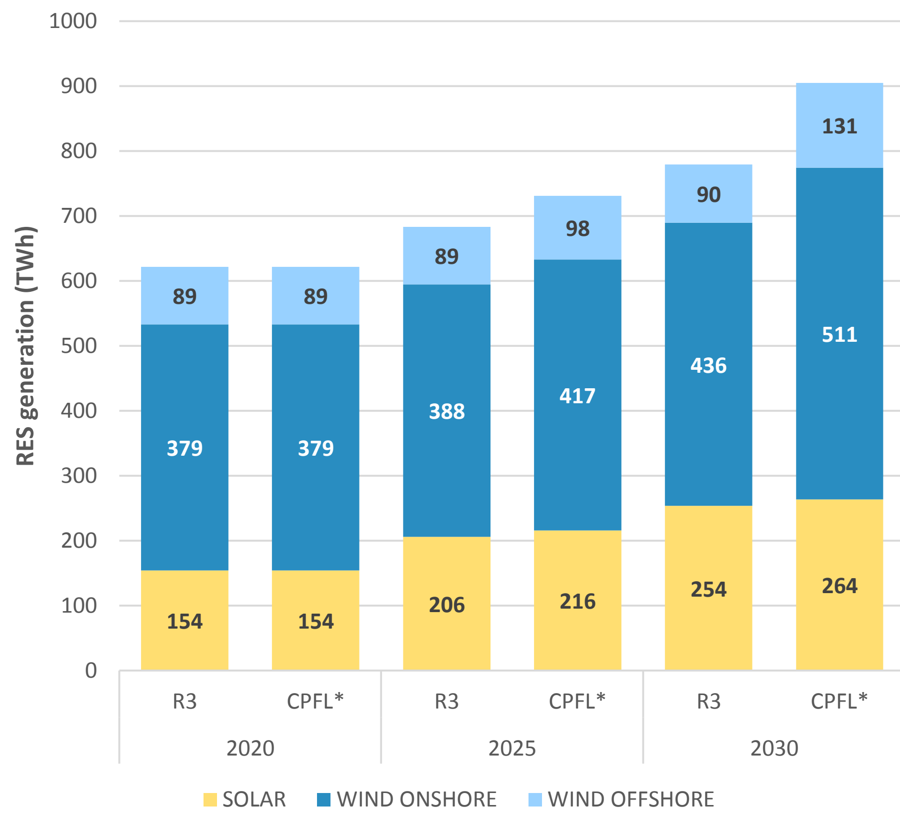


Renewables investment and deployment is kept high, despite the fall in ETS prices

The benefit of the low CPF as an insurance mechanism is also seen in RES deployment and generation

- The R3 scenario shows that investment in renewables slows down between 2025 and 2030
- The CPFL* scenario shows how a low CPF policy instrument could help in the case of an R3 type fall in the ETS price
  - Offshore wind generation in 2030 is 46% higher in the low CPF scenario
  - Onshore wind is around 17% higher
  - Solar is around 4% higher
- This illustrates the material contribution a low CPF insurance mechanism could make to meeting the 2030 **renewable energy target**

Renewables investment and output is kept high

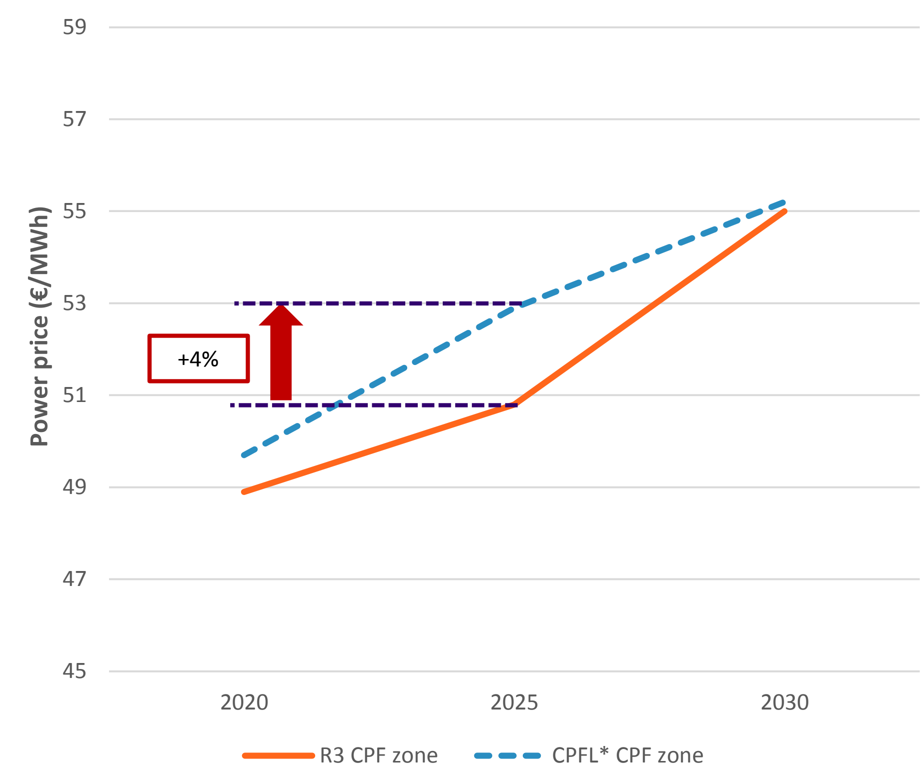


A CPF would act as an insurance policy against very low carbon and power prices, reassuring investors in renewables

A sudden fall in ETS prices would affect power prices

- The R3 scenario shows that with ETS price falls down to €10-15/t, the impact is that the power price is kept lower
- This would affect revenues and the investment case for renewables
- By contrast in the CPFL* scenario with the same ETS price drop power prices in the CPF zone are 4% higher in 2025 and slightly higher in 2030
- **The results show the value of the Low CPF as an insurance mechanism – maintaining stable levels of renewables investment even if there are unexpected and material falls in the ETS price.**

Power prices in R3 vs CPFL* - CPF zone



Note: Load-weighted average price in the CPF zone

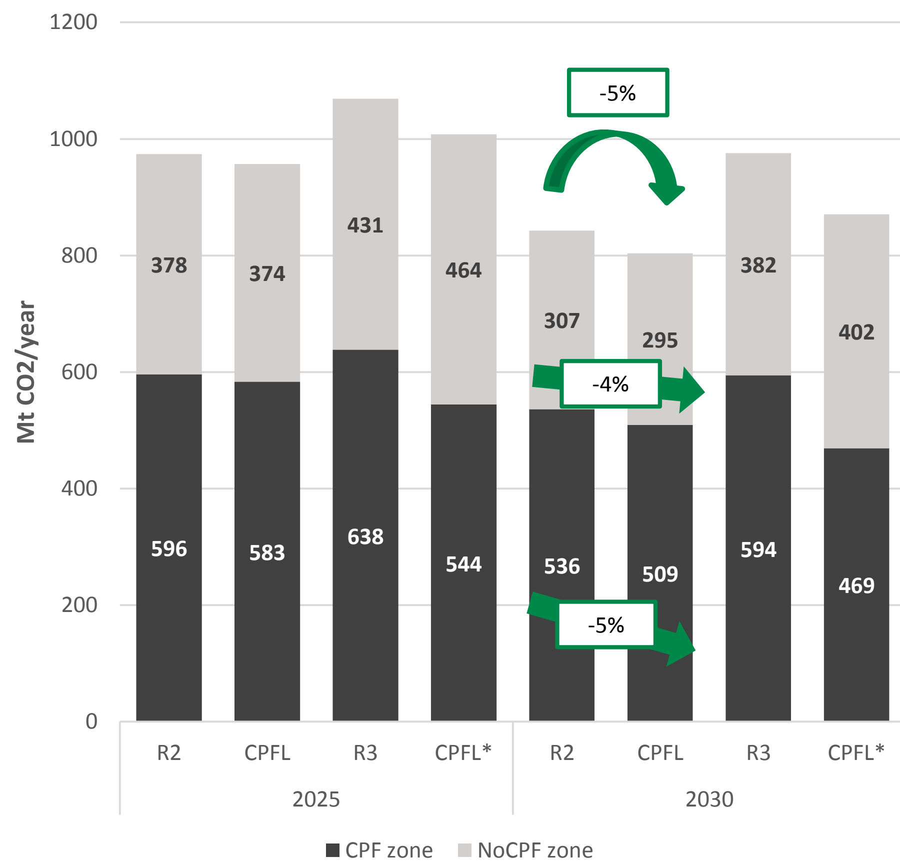
A low CPF would reduce power sector emissions at the EU level, despite some electricity leakage to non-CPF countries

A low CPF would reduce power sector emissions at the EU level, despite electricity leakage to non-CPF countries

- A low CPF would reduce emission from the power sector at the EU level by replacing thermal generation by renewable generation.
- The introduction of a Low CPF would reduce the emissions in the CPF zone by 5% compared to R2 due to more renewable generation and less thermal production.
- The emission in the no CPF zone are expected to decrease by 4% driven by additional low carbon exports from CPF zone to non-CPF zone.
- ➢ **Overall, the emission will drop by 5% compared to the R2 scenario**.

- And in a **ETS Price Fall scenario (R3)** emissions would rise significantly by around 150 Mt a year in 2030, however half of this can be **avoided through a CPF** (the CPFL* scenario shows how the CPF can help even at the Low level in the case where there is a significant ETS price fall)

Emissions per zone in the four scenarios

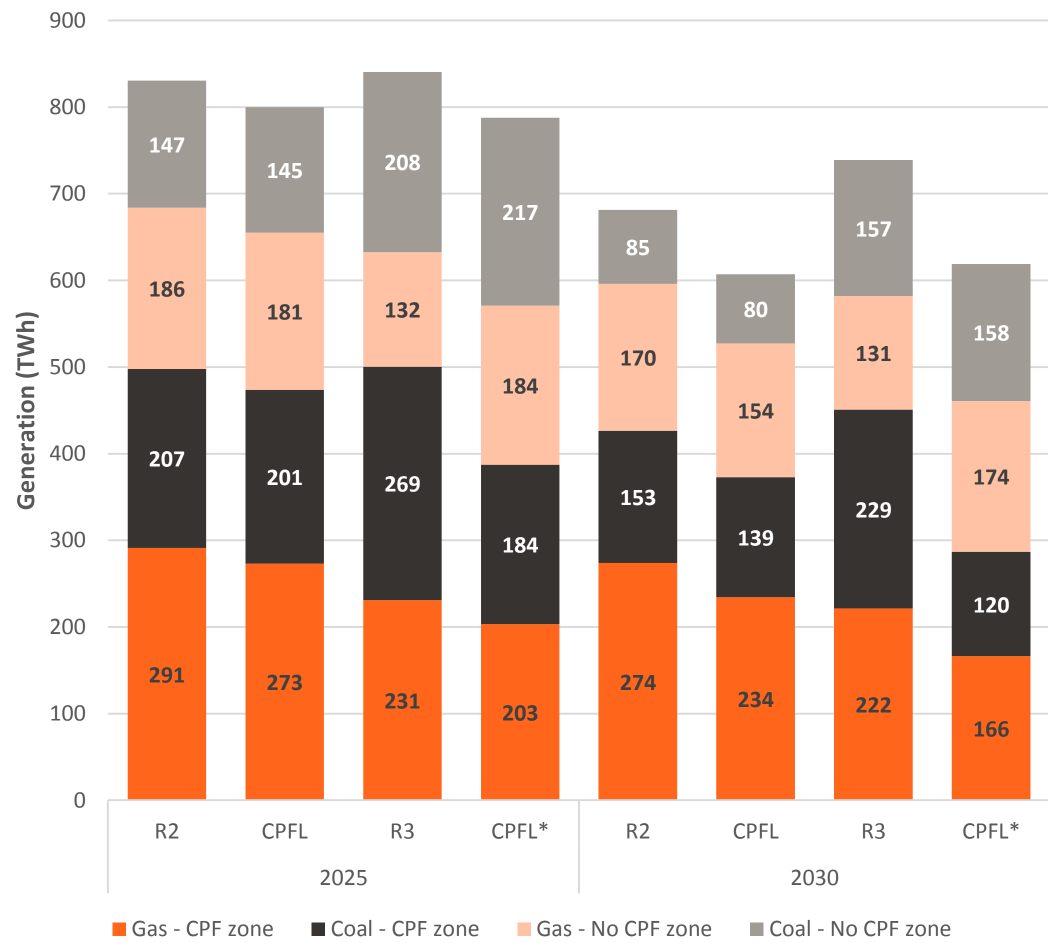


CPFL provides a less strong signal to fossil generators & investors – but higher RES investment would impact fossil generation

The CPFL carbon price signal would not drive significant coal to gas switching or retirements

- As the carbon price is at the same level as in R2, there is no increase in coal to gas switching or retirements
- However **CPFL increases RES generation from 2025 onwards,** and therefore **reduces fossil-fuel generation** as well as emissions (see previous slide).
- Furthermore, a low CPF level would **be robust in the event of an ETS price fall**.
  - R3 ETS Price Fall shows that with a lower ETS price the thermal generation increases compared to R2
  - However, with a CPF set at the same *expected* level of carbon prices as in R2, the impact of the ETS price fall is neutralised – CPFL* has the same level of thermal generation as CPFL even though the ETS price in CPFL* is at the level of R3 ETS Price Fall
  - Note that, in emissions terms the benefits of reduced overall thermal generation are offset by the increased of the coal generation in the non-CPF zone.

Gas and Coal installed generation



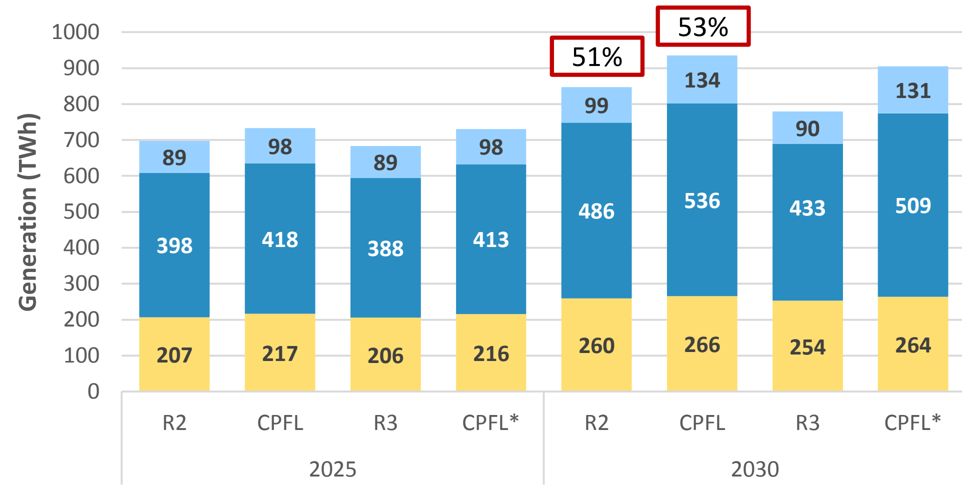
Notes: Coal represents coal and lignite generation

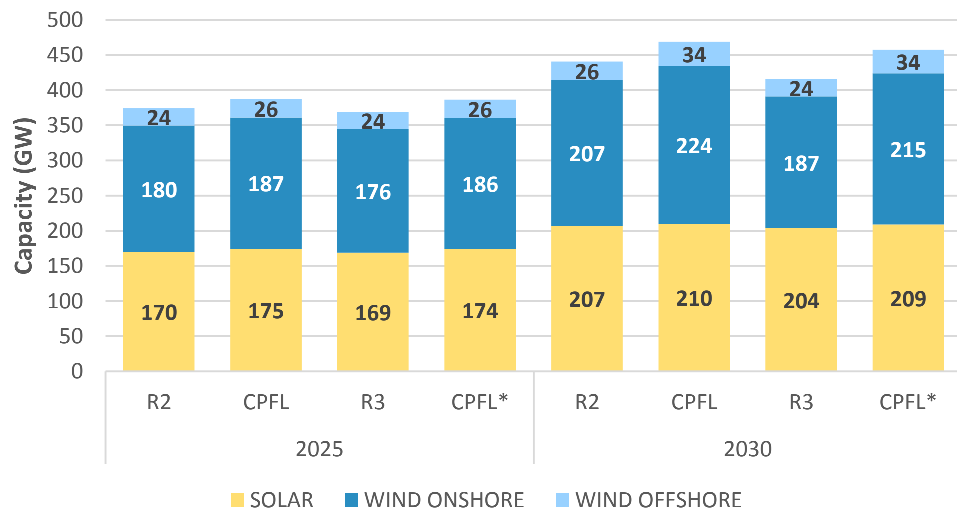
A Low CPF would contribute to the 2030 renewable energy target

Renewables capacity and generation are higher than in R2

- With the enhanced predictability and lower cost of capital impact, a low CPF would incentivise low carbon generation over high carbon generation.
  - **This would translate into a higher penetration of low carbon generation in the generation mix;**
  - **This would facilitate the transition to merchant; and**
  - **This would help meet the 2030 RES target – but not without further renewables support contracts**
- The results show that the under the Low CPF scenario all three impacts materializes:
  - The CPFL shows a higher RES share than R2 in both 2025 and 2030.
  - The CPFL facilitates the transition from subsidy to merchant especially for high capital cost technologies like offshore wind. Indeed while in the CPFL scenario new RES materialises in 2025, the R2 scenario shows a material slow-down.
  - The CPFL helps meet the 2030 RES target by reaching 53% RES penetration in 2030.
- **The results show that the introduction of a low CPF could contribute to the 2030 targets**

Renewable energy generation and 2030 targets



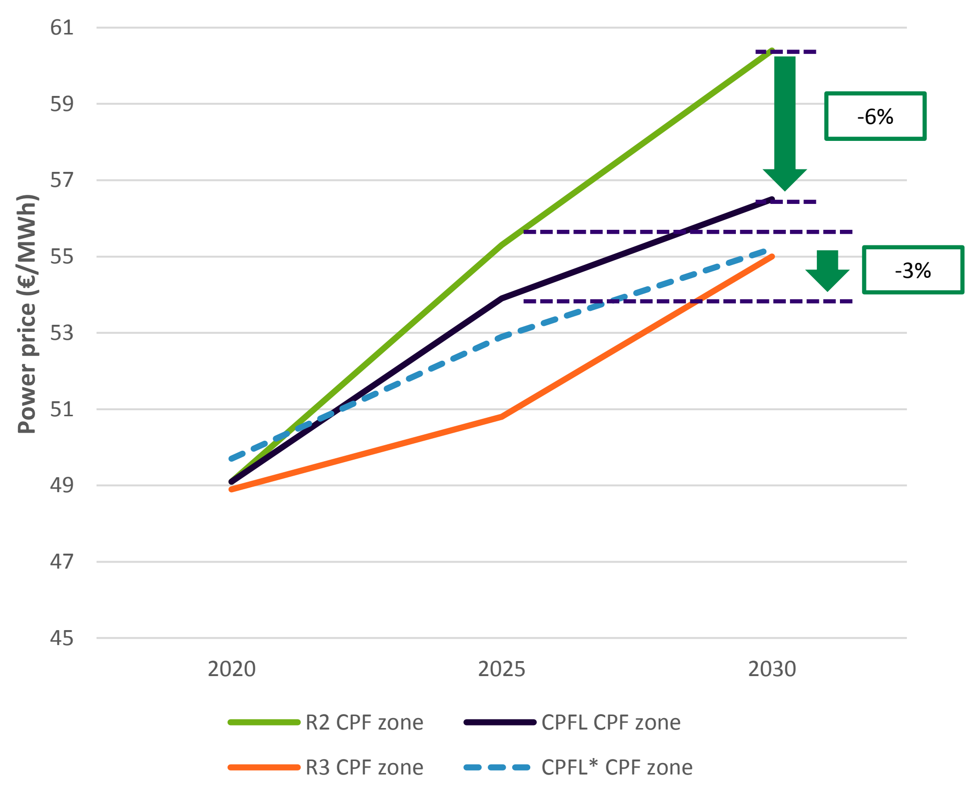


The Low CPF scenario delivers lower 2030 power prices than R2

A lower power price in 2030 due to higher RES investment

- The low CPF has a similar CO2 price to the R2 scenario – so the key difference is the impact of the CPF on financing costs (WACC)
- This effect leads to greater investment in RES and through the merit order effect to lower power prices in 2030 (than R2)
- Indeed, a Low CPF would lead to lower WACC, which would enable higher RES penetration, thus putting a downward pressure on power prices.
- A different equilibrium would be reached in terms of optimal generation mix featuring **higher low carbon generation** through higher RES penetration;
- The results of this new equilibrium show that under the Low CPF price level - set at €33/tCO2 by 2030, the level of R2 scenario - power prices in the CPFL scenario are lower than the ones in the R2 scenario in 2030 owing to more renewable generation in this scenario.
- **Overall the introduction of a low CPF could support the transition while mitigating power prices increase for end consumers.**

Power prices in CPFL, CPFL* vs R2



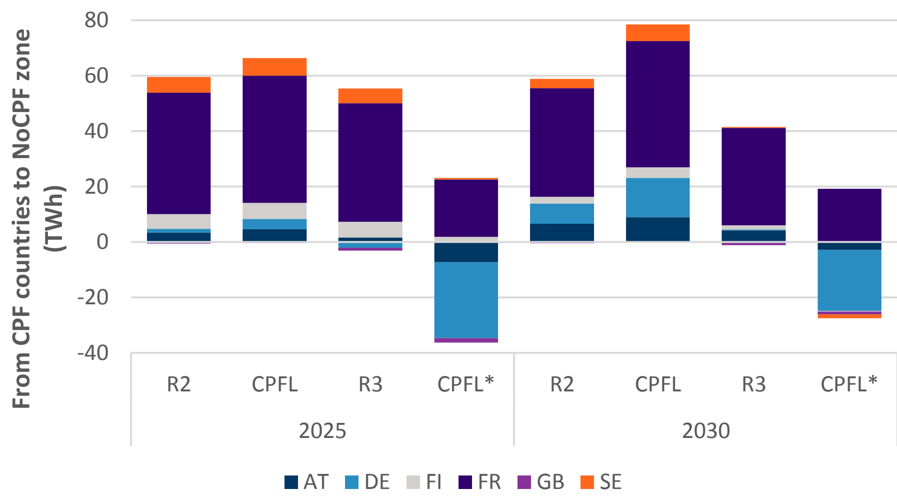
Note: Load-weighted average price in the CPF zone

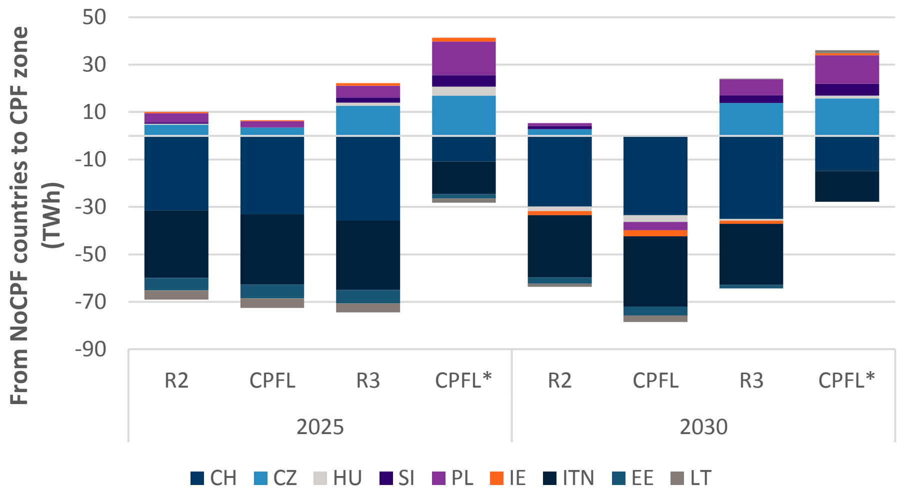
Cross border flows are similar in the Low CPF scenario to the R2 scenario

Net exports are virtually the same in low CPF and R2

- In both 2025 and 2030, the CPF zone continues to be a net exporter of power, the low CPF does not significantly affect this
- However, in the R3 scenario where ETS prices drop, the CPF zone reduces the amount of net exports – and Germany becomes a net importer
- In the low CPF scenario with the same price drop in the ETS, these effects are even stronger as producers in Germany face the CPFL carbon price, while power producers outside the CPF Zone face far lower carbon prices

Net power flows





The Low CPF scenario has lower power prices, and lower energy costs than R2

Impacts on consumers

- The impact on consumers would depend on power prices – but also the effect on renewables support costs
- Lower power prices via the merit order effect would lead to lower consumer energy bills (see next slide)

Impacts on EIIs

- In the Low CPF scenario the carbon price is the same as in R2 – so there are no additional carbon revenues
- Our modelling suggests that the **cost impact on the Energy Intensive Industries**' by 2030 would be a net saving in CPFL
  - No additional direct carbon costs as we have assumed the CPF is only applied to the power sector
  - Indirect costs via the electricity price are actually net savings as power prices are lower in 2030 (a saving of €1.3bn)

Carbon revenues and EII costs 2030

Government CPF Revenues - comparison of CPFL vs R2 scenario

CPF net revenues: €0bn

EII net costs: -€1.3bn

Source: FTI CL Energy modelling

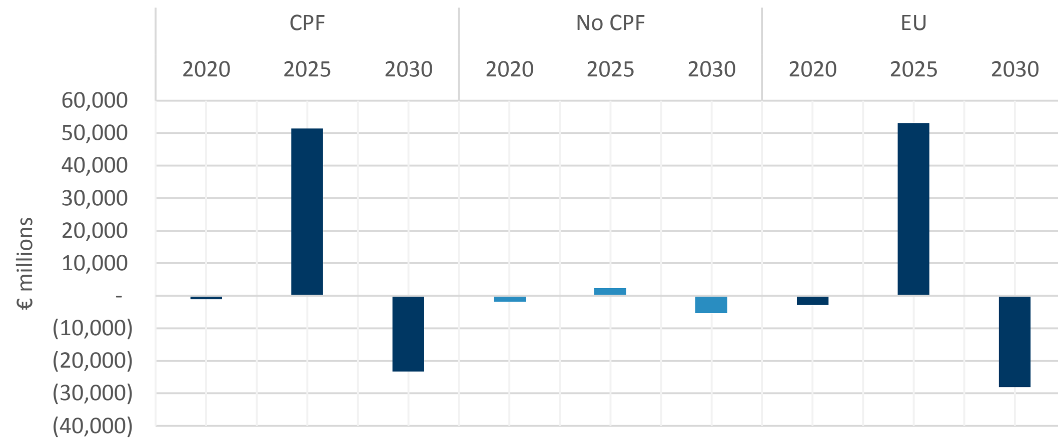
Consumer Electricity Costs are lower in the low CPF scenario than in R2

- We calculate the consumer costs by combining for each scenario
  - Energy costs (at the wholesale level)
  - Support costs (for RES support contracts)
  - Capacity costs (to ensure counties meet their security of supply targets)
- The charts on the right shows the difference between scenarios of this combined consumer cost
- We do not take account of network costs or network cost changes

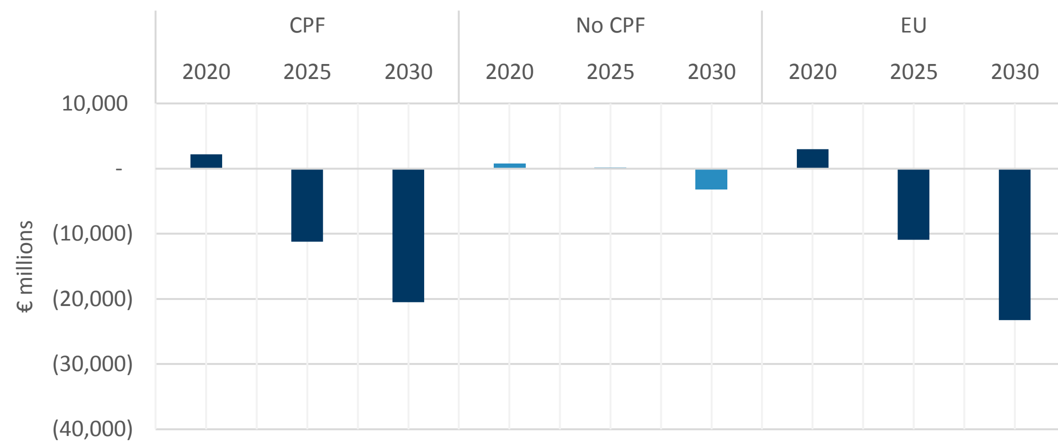
CPF Zone impacts

- **CPFL vs R2:** Consumer costs are slightly higher in 2020, but there is a net saving by 2025 which grows bigger by 2030. In 2030 households could save around €20 billion on their energy bills in the CPFL scenario. This reducing is mainly driven by low power prices in the CPFL scenario compared to R2.

Net Impact on Consumer Costs – CPFH versus R2



Net Impact on Consumer Costs – CPFL versus R2



Carbon Prices per tonne CO2 in CPF countries (ETS + CPF)
R2: €21 (2020), €16 (2025), €22 (2030)
CPFH: €22 (2020), €50 (2025), €60 (2030)

***Average CPF Country Load Weighted Power Prices:**
R2: €49 (2020), €55 (2025), €60 (2030);
CPFH: €49/MWh (2020), €58/MWh (2025), €54/MWh (2030);

***Average Non-CPF Country Load Weighted Power Prices:**
R2: €52 (2020), €56 (2025), €62 (2030);
CPFH: €51/MWh (2020), €57/MWh (2025), €60/MWh (2030);

Source: FTI Power Price and ETS models; Technical report on Member State results of the EUCO policy scenarios, E3MLab & IIASA, December 2016

Notes: Power price paid may vary by sector; Domestic demand represents residential and tertiary demand. CPF Countries include Germany, Austria, France, Spain, Portugal, Belgium, Netherlands, Luxembourg, UK, Denmark, Sweden and Finland.

4 Appendices

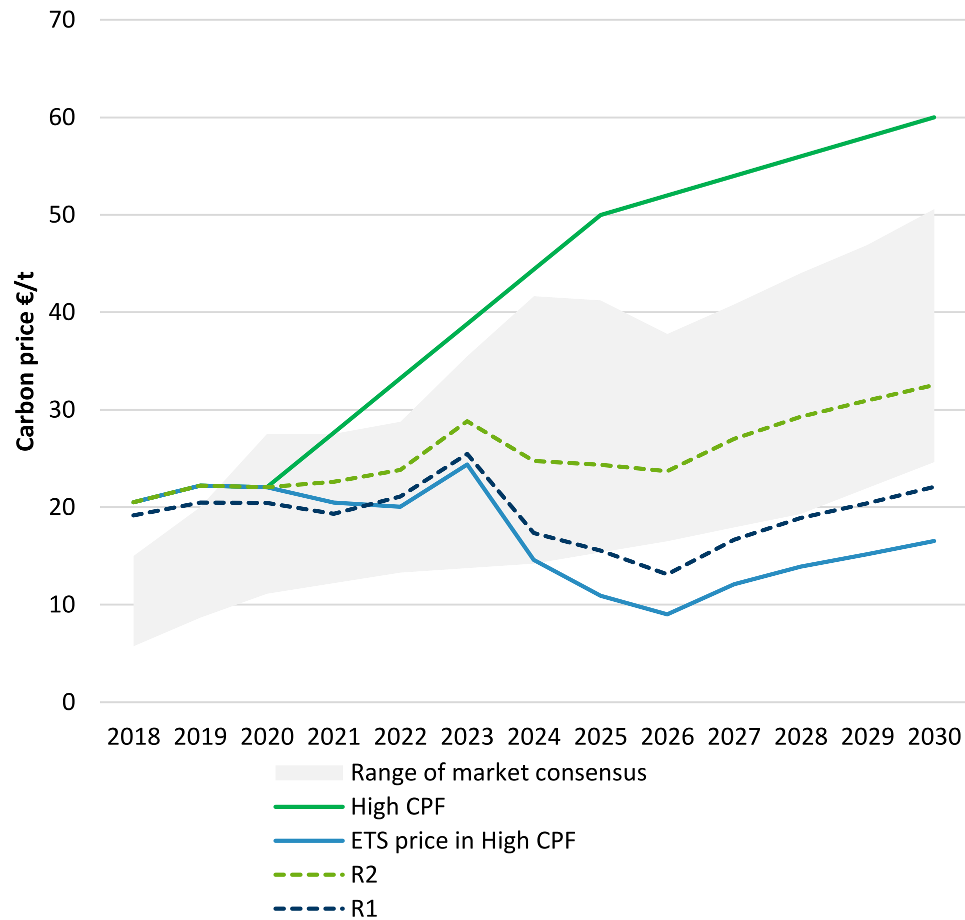
Contents

Appendix 4A: Impact of the CPF on the EU ETS market

Implementing a high CPF would impact the ETS price under current ETS reforms, but compensation measures could neutralise the effect

- The CPF scenarios introduce a separate carbon price in the CPF zone from the price in the ETS
- **In the High CPF scenario, ETS prices could fall to 11€/t in 2025 and 17€/t in 2030**
- This is due to **reduced demand for EUAs in the no CPF zone** setting EU ETS prices:
  - The CPF prices is reducing emission in the CPF zone
  - The remaining emission abatements to be performed in the no CPF zone is limited
  - This small level of required emission reduction set the prices of EU ETS at lower levels than in the R2 scenario.
- Some change in the EU ETS markets could be implemented to offset the impact on carbon prices.

CPF impact on ETS price



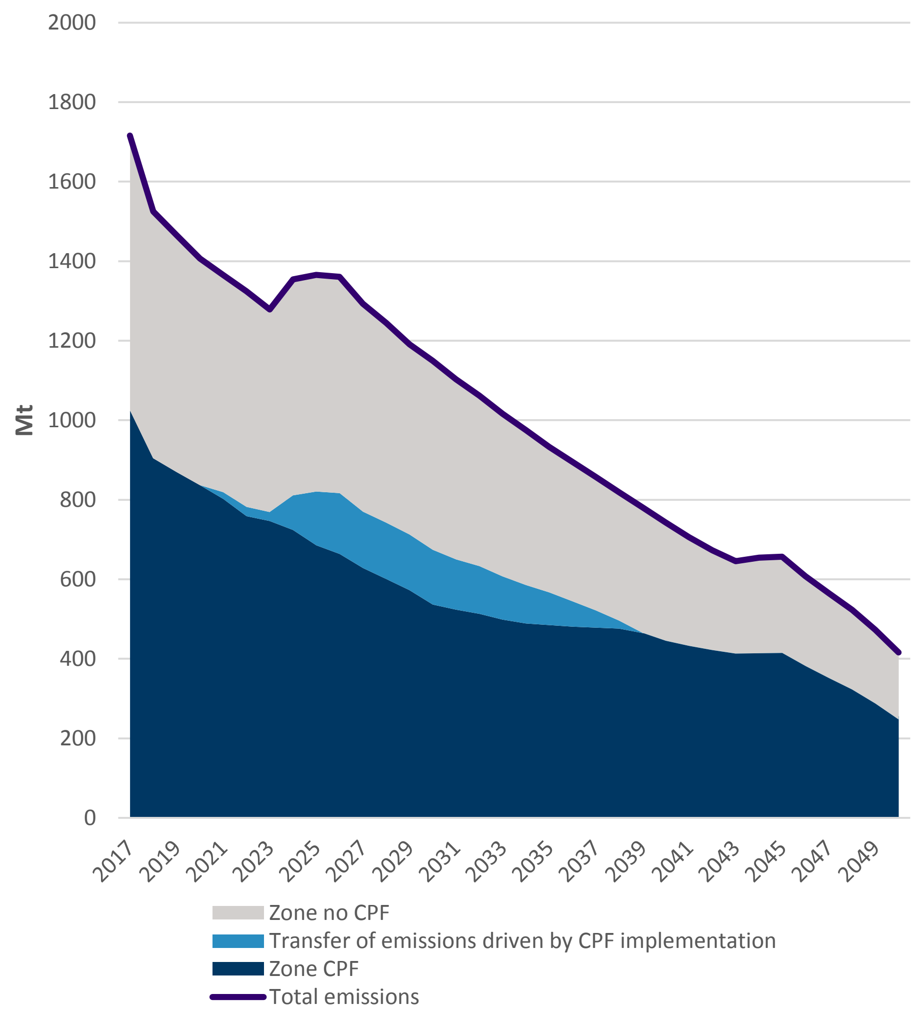
Complementary measures can be implemented so as to ensure reduce the total level of emissions

- The introduction of a CPF in the CPF zone will reduce **the total emission in CPF zone by 1662 Mt between 2021 and 2039**.
- This abatement in the CPF zone would create a surplus of EUAs within the EU ETS, which would be at least partially absorbed by the MSR.
- However, as the MSR is unlikely to absorbe the entire surplus a large amount of allowances could be **sold into the no CPF zone to balance the EU ETS market** during the period 2021-2039, creating much lower prices for the EU ETS.

- To offset the impact on the EU ETS market, specific **complementary policies** could be implemented with the aim of tightening the supply of credits so as to adjust to the drop in demand.

1. **Voluntary cancellation mechanism** by member states to cancel an amount of allowances corresponding to the additional abatement driven by the CPF in the CPF area.
2. **Adjustment of the market cap** or the linear reduction factor.
3. **Adjustments of the MSR parameters**: intake rate, period, cancellation of surplus, etc.

EU ETS emissions for each zone



A voluntary cancellation mechanism could be a way forward – more certificates than avoided emissions would need to be removed

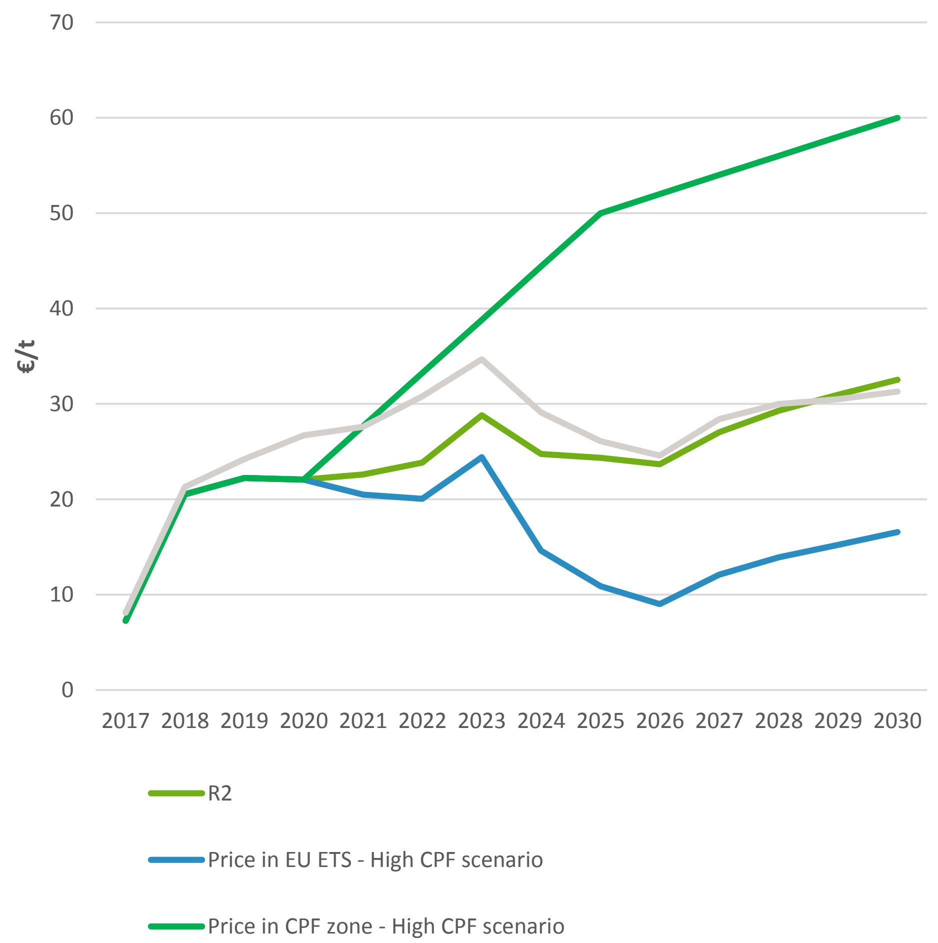
- The **voluntary cancellation mechanism will push carbon prices to higher levels** closer to the R2 scenario. This mechanism will **modify the balance of the market** and the emission reductions are expected to be more important than the current European targets.

- Our analysis shows that the mechanism would **need to remove more emissions than the avoided levels in the CPF zone** to bring back carbon prices to the R2 level. Indeed, the cancellation would need to offset the emission reductions but also the associated hedging volume drop during the period.

- We consider that the reduction in emissions will drive a decrease in hedging volumes. We estimate hedging volumes as 40% of future emissions with a look ahead of three years. For 1 ton of reduced emission, the hedging volumes are diminished by 0.4*3=1.2 tons.

- To fully offset the implementation of the CPF, **governments would need to cancel 2.2 time** (1 + 1.2 from hedging volumes) the emission reductions in the CPF zone to reach scenario R2 levels.

Carbon prices (€/t 2017)



LRF rate would need to be increased from 2.4% to 2.8% to offset the CPF effect on carbon prices

- A higher **LRF rate would help reducing the surplus of the market and pushing EU ETS carbon prices to higher levels**. This mechanism will modify the balance of the market to offset the negative impact of the CPF mechanism on carbon prices. With this measure, the total emissions of the EU ETS system will be lower than the current European target in 2050.

- Our analysis shows that **increasing LRF rate post-2023 to 2.8% would bring carbon prices to the R2 level over the period 2025-2035**. This reduction in allowances would allow a new balance of the EU ETS market prices and so higher carbon prices closer to the R2 scenario.

- The rate of 2.8% will allow to reduce additional 61 Mt per year and to offset 1660 Mt over the period 2023-2050.

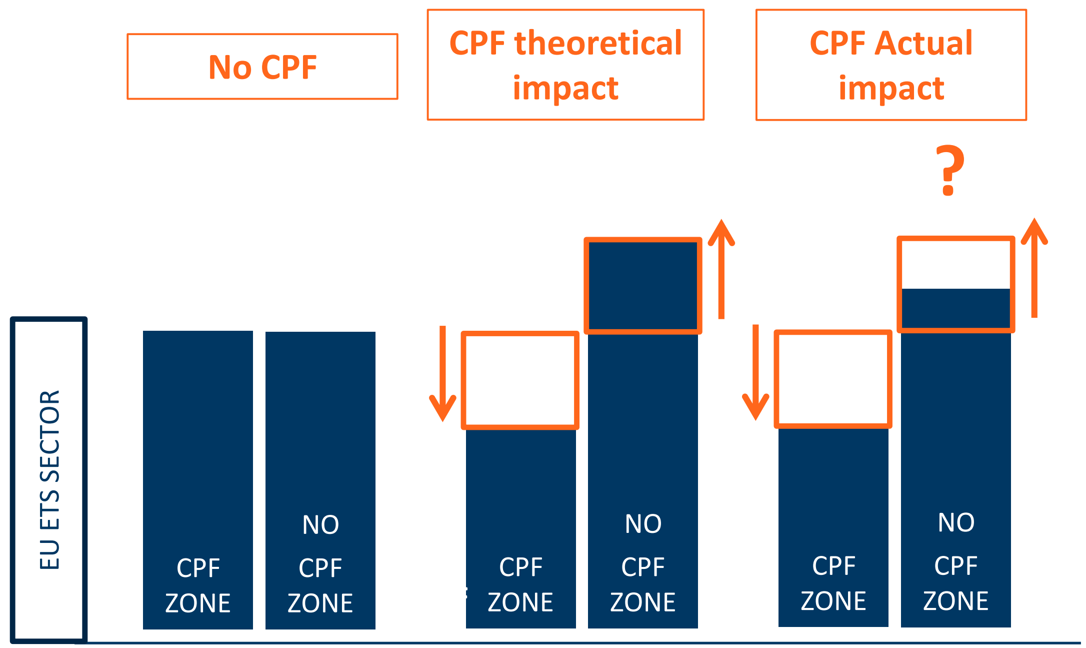
- However, the fit with R2 prices won't be perfect. This change in the EU ETS market results in higher carbon prices in the short term driven by the expectations of higher LRF but also the long term driven by important reduction of emissions.

Carbon prices (€/t 2017)

The CPF and the ETS: current reforms may not be sufficient, but cancellations or continued reform can preserve emissions reductions

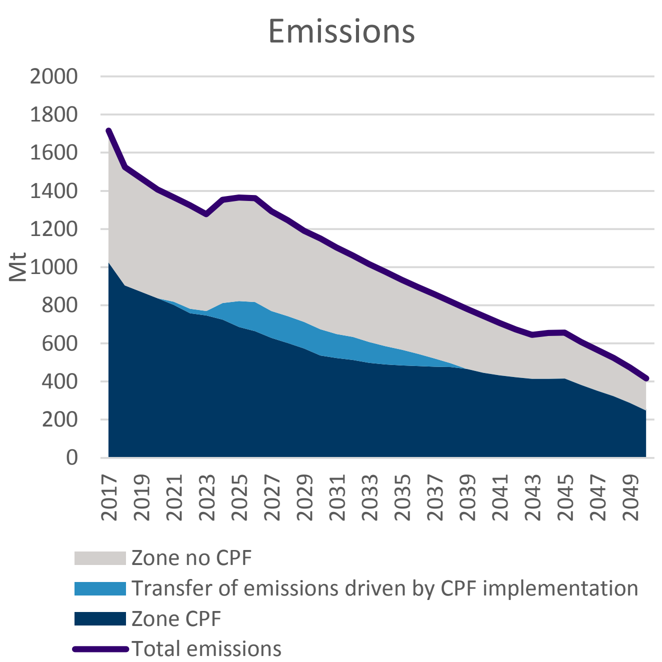
- The **ETS reforms including the MSR** planned for 2019 will start to remove the surplus supply of EUA allowances in the market
- The **introduction of a CPF** would need to be managed carefully to protect the EU wide carbon (ETS) price and emissions reduction signals
- The **theoretical impact** of a CPF would be to reduce demand for EUAs as CPF induced abatement in the CPF zone. Within the overall EU wide cap this could lead to a surplus of EUAs and falling ETS prices. **In theory the MSR could absorb the surplus supply relative to demand, but is unlikely to do so in its current definition**
- **In practice** demand and prices especially in the industrial sectors (33% of total EUA demand) may be "sticky" – Industrial sector demand for emissions allowances will be principally driven by global industrial product demand and other macroeconomic factors
- We have taken a **conservative approach** in our modelling assuming that the theoretical impact prevails and therefore complementary policies would be required to underpin the EU wide ETS price (e.g. cancellation of allowances or continued ETS reform such as the MSR intake rate increased to 48% of surplus, or linear reduction factor increased)However, we acknowledge that the real world adjustment of industrial output may be lower or slower meaning that the **complementary policies may not be needed as quickly or to the same extent**

Emissions in 2030 with CPF implementation

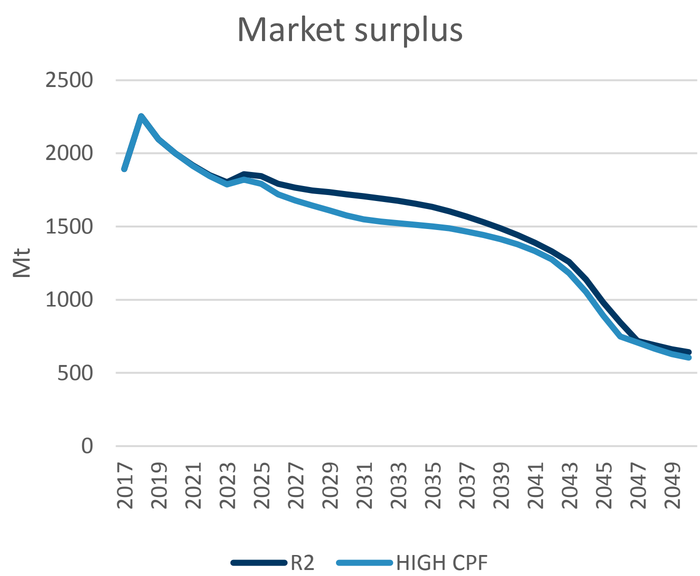


The current MSR cancellation mechanism would not ensure significant reductions to offset the effects from the CPF

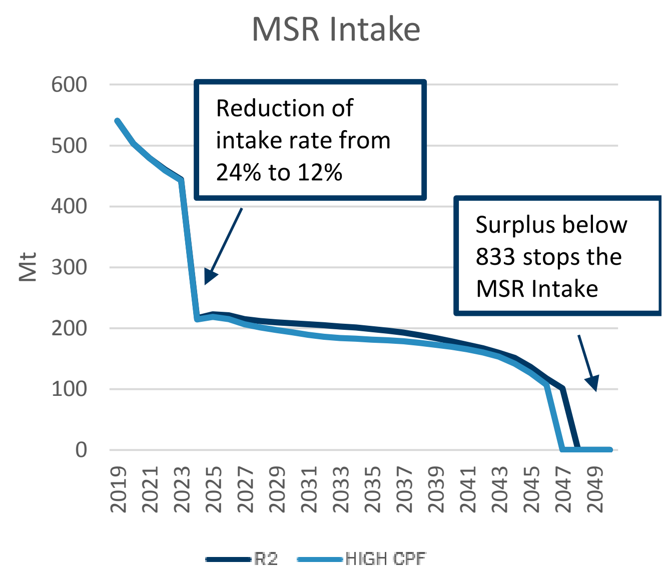
The reduction of emissions in the CPF area would be compensated by emissions in the noCPF area to ensure market balance…



… so that no material impact on the size of the surplus would be expected…



… and on the amount of credits to be withdrawn by the MSR.



The MSR will have a limited impact on the market effect created by the CPF.
A strong structural change of the MSR mechanism would be required to impact carbon prices.

The MSR intake rate would need to be increased to 48% until 2040 to offset the impact of CPF on ETS prices

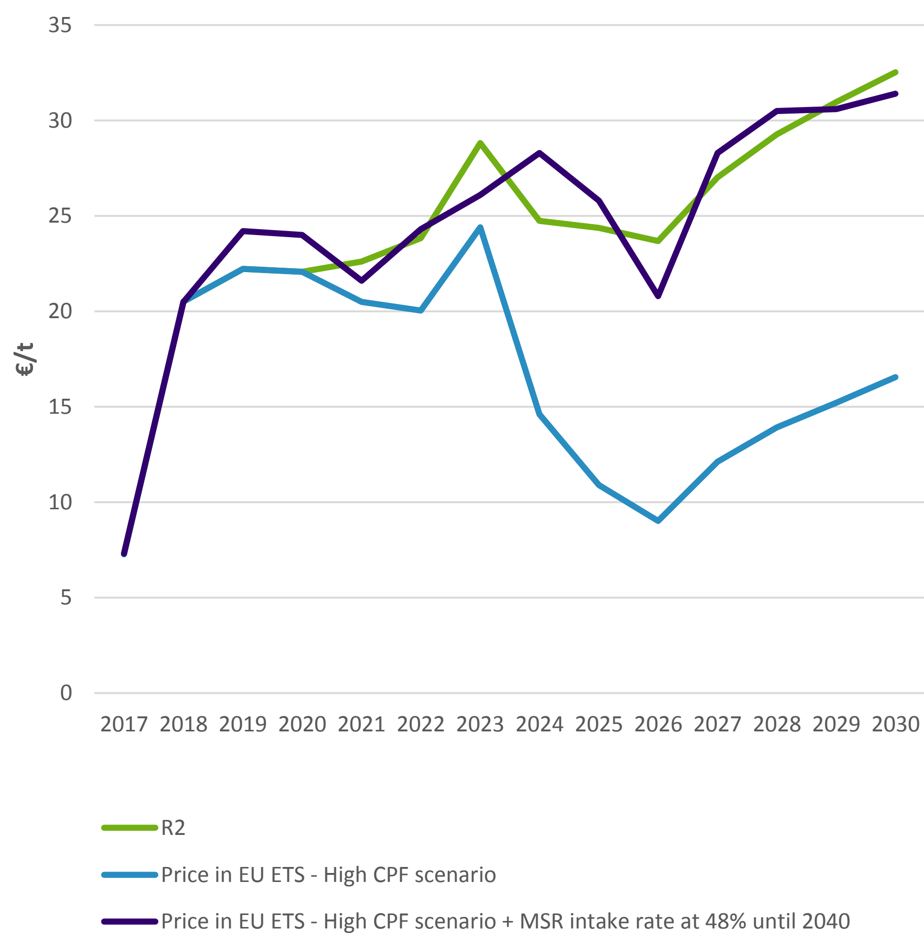
- An higher MSR intake rate associated with the cancellation mechanism of the MSR will rebalance the EU ETS market to reach the R2 carbon price levels.

- Our analyses show that **the MSR intake rate would need to be increased to reach 48% over the period 2023- 2040** in order to offset the impact of CPF on carbon prices as compared to 12% in our base case scenario.

- This specific high level of intake is required to take advantage of the small additional surplus in the CPF scenario. **This high rate will create volatility in the carbon market.**

- Indeed, we expect to have the MSR size close the 833Mt from 2030. The high intake rate of the mechanism will change the surplus of the system from one year to the other one and **activate/deactivate the intake mechanism of the MSR creating an important volatility in carbon prices**.

Carbon prices (€/t 2017)



Conclusion: various approaches are possible to compensate for the effect of a CPF on the ETS

- Our carbon model shows that the downward effect on carbon prices could be partially offset with one of the following measures:

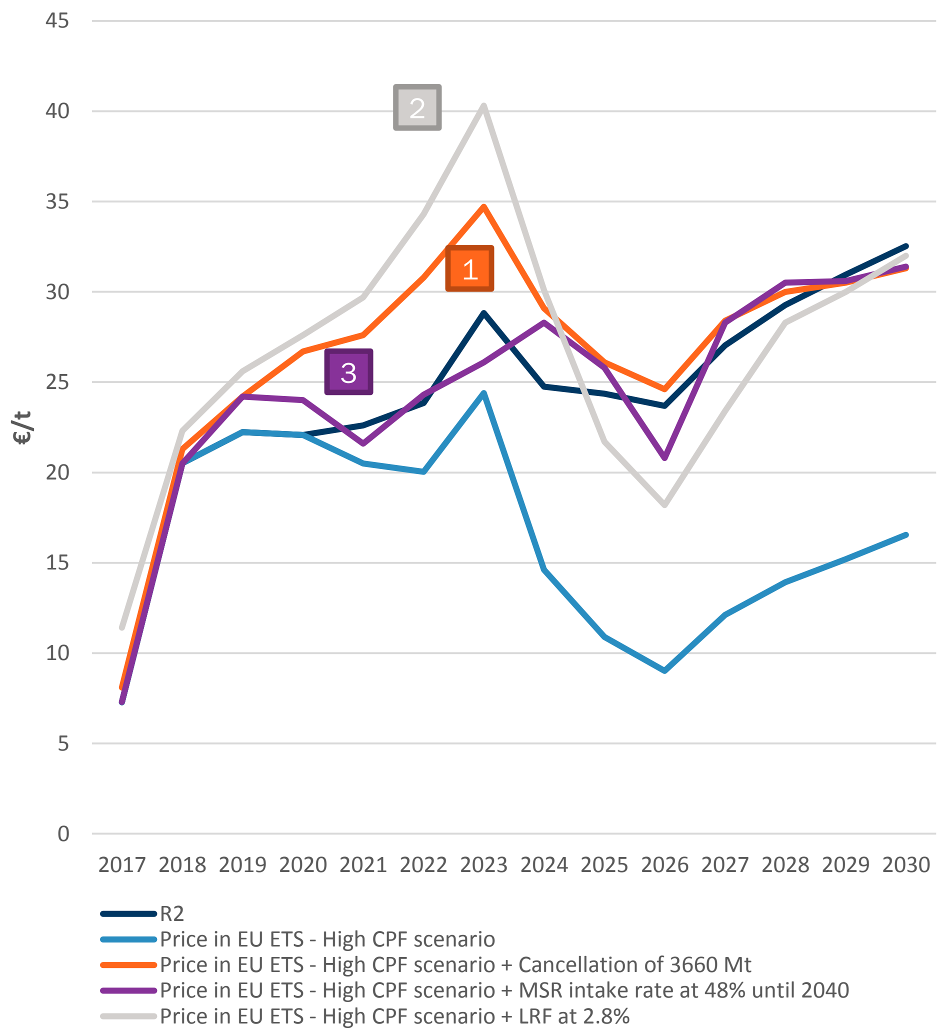
1 **Voluntary cancellation mechanism** need to remove **2.2 time the avoided emissions in the CPF zone** to bring back carbon prices to the R2 level. This is because, the cancellation would need to offset the emission reductions **but also the associated hedging volume** decline over the period.

2 **Adjustment of the market cap or the linear reduction factor.** Our analysis shows that increasing **LRF rate post-2023 to 2.8%** would bring carbon prices to the R2 level over the period 2025-2035.

3 **Adjustments of the MSR parameters.** Our analyses show that **the MSR intake rate would need to be increased to reach 48% over the period 2023- 2040** in order to offset the impact of CPF on carbon prices as compared to 12% in our base case scenario.

- The **best alternative seems to be the cancellation mechanism** as this one can be performed without a fundamental change in the rules of the EU ETS market. In addition, this mechanism allow to adjust the market on an yearly basis avoiding unexpected long term impacts.

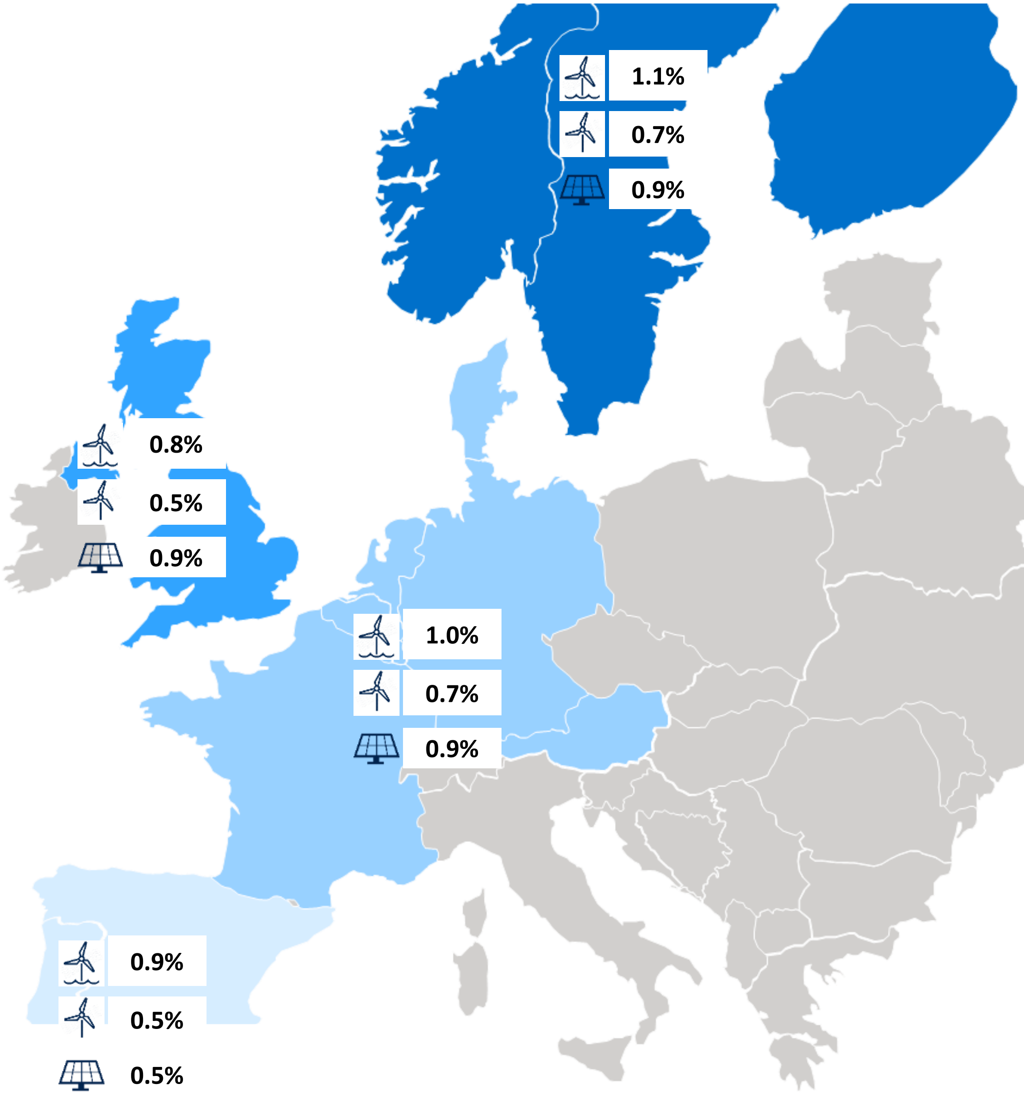
Carbon prices (€/t 2017)



Appendix 4B: WACC impact of a CPF – Financial modelling

WACC Impact of a CPF – Key results of our financial modelling of the ‘carbon risk premium’

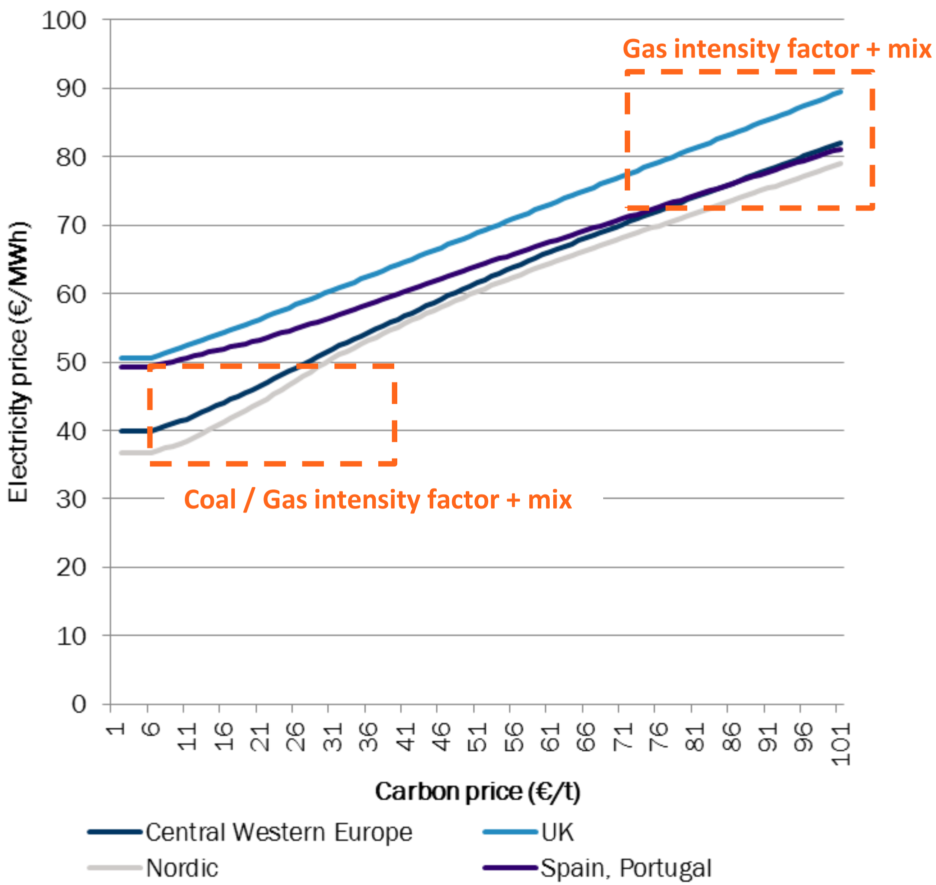
WACC Impact



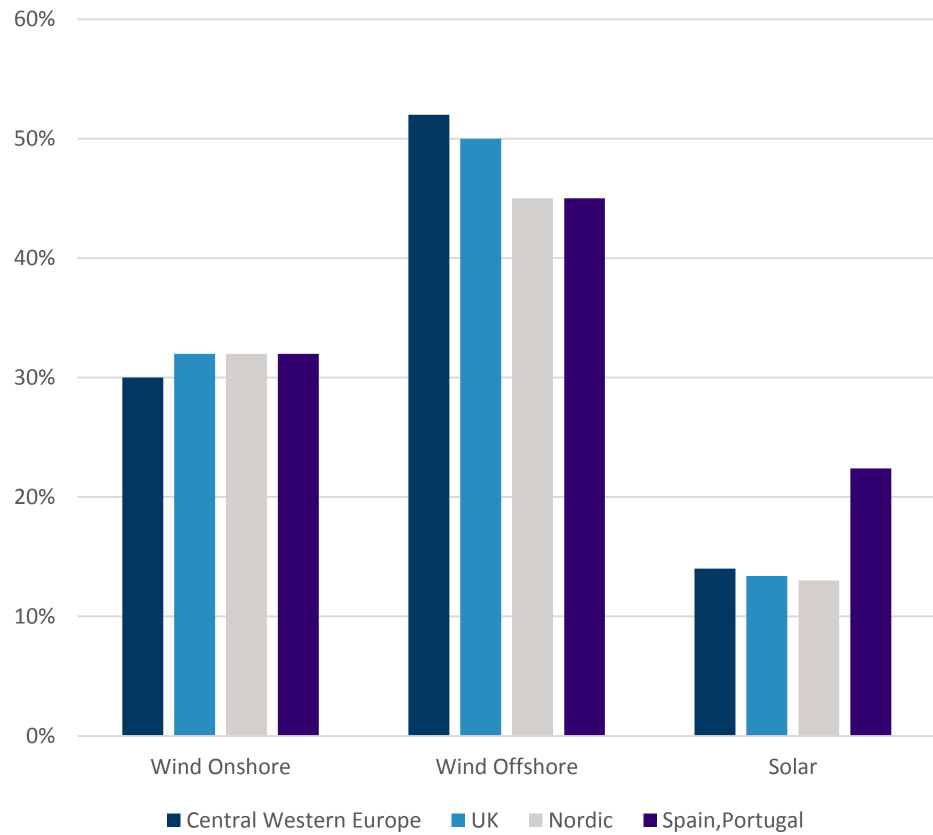
- We have used financial modelling of the volatility of the ETS price and the rationally expected price the market would be willing to pay for an insurance product against ETS price risk
- We find evidence that the CPF could reduce the risk premium associated with merchant price risk
- The size of the CPF related reduction could be **between 50 to 110 basis points on the WACC.**
- The **range reflects :**
  - **The different exposures to carbon prices across different national markets**. Markets with a large proportion of high carbon generation (such as coal) will lead to a higher risk premium.
  - **The different load factor across different national markets and technologies.**

WACC Impact of a CPF – local specificities explain differentiated ‘carbon risk premium’

1 **Exposures to carbon prices across different national markets, 2025 (Wind Onshore)**



2 **Load factor across different national markets and technologies, 2025**



- **Change in the capacity mix and its carbon intensity** would drive the exposure to carbon prices – as measured by the slope of the curve.

- The **load factor would explain the volume of electricity produced to hedge** against carbon price variations – so the price of the insurance and the corresponding premium.

We benchmark our estimates for the 'carbon risk premium' against existing studies

Study	Risk premium under consideration	Methodology	Range of estimates for the risk premium
DiaCore, "The impact of risks in renewable energy investments and the role of smart policies", 2016	• Changes of WACC under changing policy designs for wind investments, from FIP to FIT (onshore wind)	• Interviews • Comparison on financial costs across Europe	• Changes of WACC from FIT to FIP regime : **175 – 225 basis points** • Proxy of risk premium for **market power price exposure**
NERA, "Changes in hurdle rates for low carbon generation technologies due to the shift from the UK Renewables Obligation to a contracts for Difference regime", 2013	• Changes of WACC under changing policy designs in the UK, from RO to CfD (onshore / offshore wind)	• Survey of experts • Measurement of the WACC difference between merchant and contracted Plant • Review of betas for UK utility sector • Analysis of historic revenue volatility	• Changes of WACC from RO to CfD regime (only reduced power price risk): **50 – 175 basis points** • Proxy of risk premium for **market power price exposure**
Aurora, "Can German renewables become competitive within 5 years?", 2018	• Changes of WACC under changing policy designs in Germany: merchant, PPAs and carbon price floor (renewables)	• No detail	• Changes of WACC from PPA to merchant regime : **300 basis points** • **Changes of WACC from CPF to merchant regime : 150 basis points**
CEPA, "Note on impacts of the CfD support package on costs and availability of capital and on existing discounts in power purchase agreements", 2011	• Changes of WACC under changing policy designs in the UK, from RO to CfD (onshore / offshore wind)	• Survey of experts	• Changes of WACC from RO to CfD regime (only reduced power price risk): **0 – 80 basis points** • Proxy of risk premium for **market power price exposure**
European research project Re-Shaping "Towards triple-A policies: more renewable energy at lower cost", 2011	• Levelized cost saving potential of various political policies for an average wind onshore or PV project	• Interviews • Literature review	• Changes of WACC from FIT to FIP regime : **200 basis points** • Proxy of risk premium for **market power price exposure**

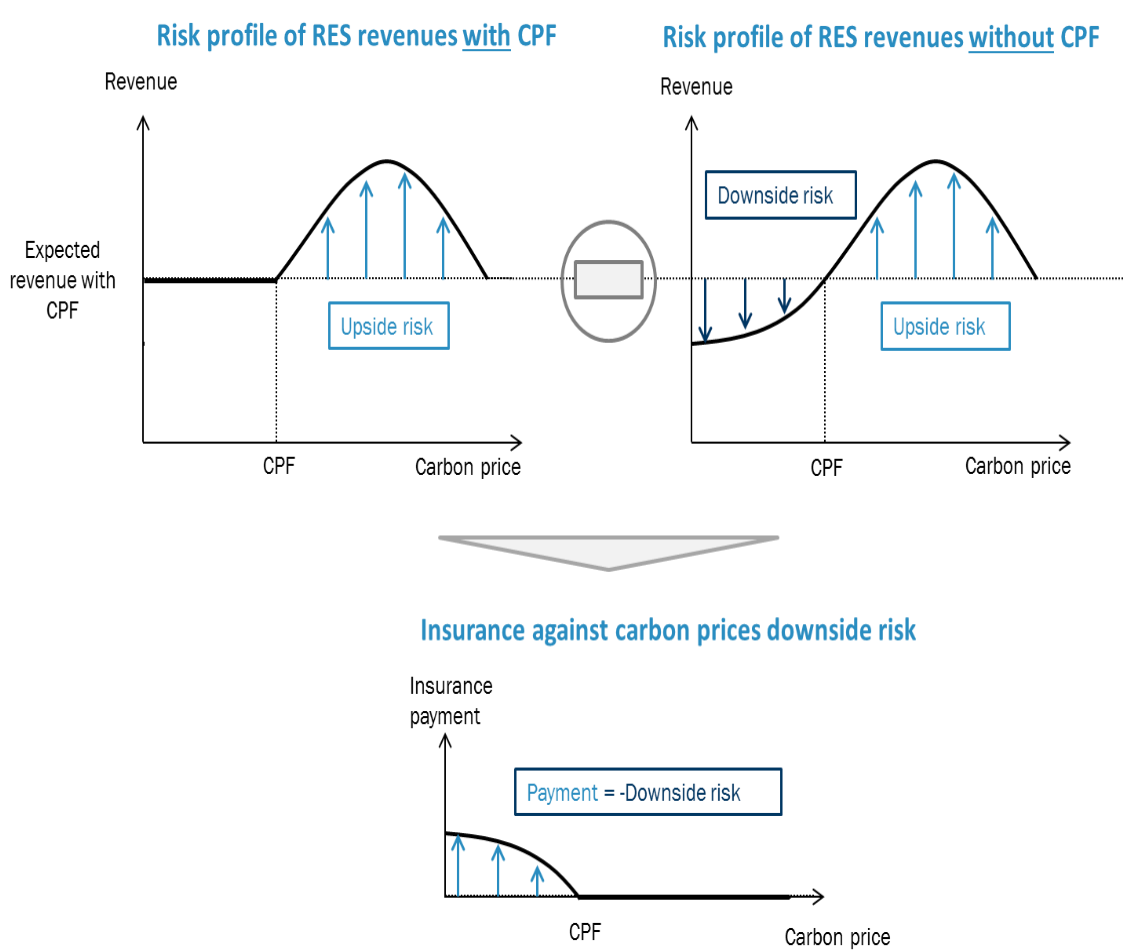
Note: Most existing studies focus on impact of all power price risk
Carbon Price represents some proportion of the power market revenues – so impact will be lower

Methodology: Determine the price of an insurance covering the risk of low carbon prices

- We determine the characteristics of an insurance that would allow a total **transfer of the indirect** (through electricity price) **exposure to changes in carbon price**.

  - The insurance is characterized by a sequence of financial cash flows, expressed as a (non-linear) function of future carbon prices.
  - The sequence of cash flows is derived from the stream of revenues that an investment in clean technologies is expected to generate on an annual basis.
  - For a given year, the annual revenue is computed as the annual volume of electricity produced – likely to be independent of the carbon price for intermittent generation – times the average selling price of electricity.
    - Estimation of the annual revenue requires modelling the link between carbon prices and electricity prices.
    - To do so, we rely on an empirical estimate of the relationship between electricity prices and carbon prices while controlling for relevant factors such as other commodity prices (e.g. coal, gas, etc.). **This is an output of our power sector model**.

Determination of the required insurance



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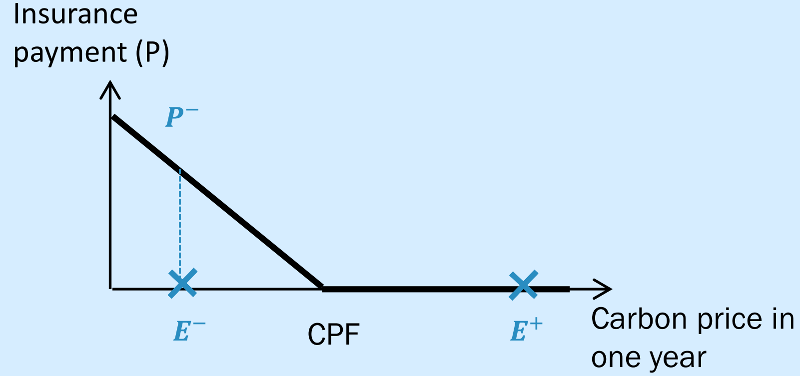
Methodology : Convert the cost of the insurance into a risk premium

- We determine **the value of the insurance based on financial theory**
  - The price of the insurance is equal to the amount required to implement a **self-financing trading strategy in** (i) **carbon credits** (or future contracts) and (ii) the **risk-free asset** that perfectly replicates the payments of the insurance.
  - The price of the insurance is a **function of the carbon price and its volatility as of the date of assessment (Black Scholes pricing model)**.
- In line with standard financial theory **we assume there are no arbitrage opportunities** – i.e. investors cannot make riskless profits above the market

Illustrative example : Pricing of an insurance

- Consider an insurance hedging against low carbon price - with payments in one year as described below.



- For the sake of simplicity, assume :
  - E_0 is the carbon price today.
  - Carbon price in one year can take two values, i.e. a low value (below the CPF) E^- and a high value (above the CPF) E^+.
  - Zero interest rate.
- The trading strategy put in place today that replicates the insurance payment due in one year consists in :
  - Selling $P^-/(E^+ - E^-)$ credits
  - Lending $E^+ \times P^-/(E^+ - E^-)$
- With a **no arbitrage argument**, the cost of the insurance is $(E^+ - E_0) \times P^-/(E^+ - E^-)$.

Methodology: The cost of the insurance is converted into a "carbon" risk premium

- The value of an investment without carbon price risk is equal to **the value of the same investment facing carbon price risk** plus the value of an **insurance hedging for that risk**.

- Therefore, we determine the risk premium of a project exposed to carbon price changes. To do so, we **estimate the NPV of a project with and without exposure to carbon price risk**:
  - **NPV 1** : The net present value of project cash flows not exposed to carbon price risk discounted at the cost of capital for risky investment.
  - **NPV 2** :The sum (i) of the insurance price and (ii) the net present value of the discounted project cash flows exposed to carbon price risk at the cost of capital for risky investment.

- We determine the risk premium (**Δ**) by imposing the **equality of the NPVs of the two projects**, i.e.

$$\underbrace{\sum_{k=0} \frac{\mathbf{FCF_k}}{(\mathbf{1} + \mathbf{WACC})^{\mathbf{k}}}}_{\text{NPV of project without carbon exposure}} = \mathbf{Insurance} + \underbrace{\sum_{k=0} \frac{\widetilde{\mathbf{FCF}}_{\mathbf{k}}}{(\mathbf{1} + \mathbf{WACC} + \boldsymbol{\Delta})^{\mathbf{k}}}}_{\text{NPV of project with carbon exposure}}$$

Appendix 4C: Modelling results

Summary results – R1 scenario

	Item	Zone	Technology	Unit		2020		2025		2030	
R1	Carbon price	CPF zone		*€/tCO2*		20.5		15.6		22.1	
		NoCPF zone		*€/tCO2*		20.5		15.6		22.1	
	Power price	CPF zone		*€/MWh*		49.0		45.5		42.0	
		NoCPF zone		*€/MWh*		53.7		48.6		48.2	
	Power sector emissions	CPF zone		*Mt CO2*		620		571		461	
		NoCPF zone		*Mt CO2*		431		405		296	
	Power capacity / Generation	CPF zone	Coal[1]	*GW*	*TWh*	72	245	55	229	41	133
			Gas[2]	*GW*	*TWh*	105	255	106	149	101	105
			Wind	*GW*	*TWh*	164	396	206	542	264	734
			Solar	*GW*	*TWh*	100	111	141	170	164	198
			Nuclear	*GW*	*TWh*	105	728	85	590	72	473
			Other[3]	*GW*	*TWh*	241	711	256	742	290	784
		NoCPF zone	Coal	*GW*	*TWh*	51	202	37	192	25	105
			Gas	*GW*	*TWh*	57	149	60	100	57	66
			Wind	*GW*	*TWh*	34	69	42	92	64	150
			Solar	*GW*	*TWh*	34	44	40	52	64	85
			Nuclear	*GW*	*TWh*	16	112	17	118	20	135
			Other	*GW*	*TWh*	123	286	121	292	128	309
	Net power flows	CPF -> NoCPF		*TWh*		72		73		86	
	%RES generation			*%*		41%		50%		61%	
	Energy cost	CPF zone		*Bn€*		346		526		287	
		NoCPF zone		*Bn€*		162		242		141	
	RES support costs	CPF zone		*Bn€*		13		38		35	
		NoCPF zone		*Bn€*		2		7		7	
	Capacity costs	CPF zone		*Bn€*		3		10		72	
		NoCPF zone		*Bn€*		3		7		24	
	CPF Carbon revenues	CPF zone		*Bn€*		0		0		0	
		NoCPF zone		*Bn€*		0		0		0	

Notes: [1] Coal and lignite, [2] Gas and CCGT, [3] Hydro, storage, OCGT, oil, other.
Capacity costs are calculated to meet an assumed security of supply target for each country whether or not they actually have a capacity mechanism.
Network costs/charges are not included in our consumer costs analysis.

Summary results – R2 scenario

	Item	Zone	Technology	Unit		2020		2025		2030	
R2	Carbon price	CPF zone		€/tCO2		22.1		24.4		32.5	
		NoCPF zone		€/tCO2		22.1		24.4		32.5	
	Power price	CPF zone		€/MWh		49.1		55.3		60.4	
		NoCPF zone		€/MWh		51.5		56.1		62.2	
	Power sector emissions	CPF zone		Mt CO2		597		596		536	
		NoCPF zone		Mt CO2		378		378		307	
	Power capacity / Generation	CPF zone	Coal[1]	GW	TWh	59	207	42	207	29	153
			Gas[2]	GW	TWh	115	302	113	291	109	274
			Wind	GW	TWh	164	396	169	417	191	491
			Solar	GW	TWh	100	111	131	158	151	185
			Nuclear	GW	TWh	105	728	85	591	72	498
			Other[3]	GW	TWh	240	708	256	734	280	759
		NoCPF zone	Coal	GW	TWh	38	142	30	147	17	85
			Gas	GW	TWh	69	206	65	186	61	170
			Wind	GW	TWh	34	69	34	71	42	94
			Solar	GW	TWh	34	44	38	49	55	75
			Nuclear	GW	TWh	16	112	17	116	20	139
			Other	GW	TWh	115	284	118	290	125	302
	Net power flows	CPF -> NoCPF		TWh		79		59		58	
	%RES generation			%		41%		45%		51%	
	Energy cost	CPF zone		Bn€		347		640		412	
		NoCPF zone		Bn€		156		281		186	
	RES support costs	CPF zone		Bn€		13		10		4	
		NoCPF zone		Bn€		2		2		1	
	Capacity costs	CPF zone		Bn€		5		11		11	
		NoCPF zone		Bn€		4		7		5	
	CPF Carbon revenues	CPF zone		Bn€		0		0		0	
		NoCPF zone		Bn€		0		0		0	

Notes: [1] Coal and lignite, [2] Gas and CCGT, [3] Hydro, storage, OCGT, oil, other.
Capacity costs are calculated to meet an assumed security of supply target for each country whether or not they actually have a capacity mechanism.
Network costs/charges are not included in our consumer costs analysis.

Summary results – CPFH scenario

	Item	Zone	Technology	Unit		2020		2025		2030	
CPFH	Carbon price	CPF zone		€/tCO2		22.1		50.0		60.0	
		NoCPF zone		€/tCO2		22.1		24.4		32.5	
	Power price	CPF zone		€/MWh		49.6		58.3		54.5	
		NoCPF zone		€/MWh		50.9		57.3		60.1	
	Power sector emissions	CPF zone		Mt CO2		583		419		383	
		NoCPF zone		Mt CO2		387		424		320	
	Power capacity / Generation	CPF zone	Coal[1]	GW	TWh	54	194	36	46	23	35
			Gas[2]	GW	TWh	111	294	110	234	106	151
			Wind	GW	TWh	164	396	206	543	264	729
			Solar	GW	TWh	100	111	141	170	164	197
			Nuclear	GW	TWh	105	728	85	582	72	472
			Other[3]	GW	TWh	240	707	259	743	280	772
		NoCPF zone	Coal	GW	TWh	40	144	32	164	19	88
			Gas	GW	TWh	73	224	70	250	66	193
			Wind	GW	TWh	34	69	35	73	43	96
			Solar	GW	TWh	34	44	38	49	55	74
			Nuclear	GW	TWh	16	112	17	116	20	137
			Other	GW	TWh	113	283	117	292	124	306
	Net power flows	CPF -> NoCPF		TWh		59		-26		34	
	%RES generation			%		41%		50%		59%	
	Energy cost	CPF zone		Bn€		350		674		372	
		NoCPF zone		Bn€		154		287		178	
	RES support costs	CPF zone		Bn€		12		10		13	
		NoCPF zone		Bn€		2		2		1	
	Capacity costs	CPF zone		Bn€		5		13		14	
		NoCPF zone		Bn€		4		7		5	
	CPF Carbon revenues	CPF zone		Bn€		Not calculated		Not calculated		5.7	
		NoCPF zone		Bn€		0		0		0	
	EII costs (benefits)	CPF zone - CPFH vs R1		Bn€		Not calculated		Not calculated		4.0	
		CPF zone - CPFH vs R2		Bn€		Not calculated		Not calculated		(1.9)	

Notes: [1] Coal and lignite, [2] Gas and CCGT, [3] Hydro, storage, OCGT, oil, other.

Capacity costs are calculated to meet an assumed security of supply target for each country whether or not they actually have a capacity mechanism.

Network costs/charges are not included in our consumer costs analysis.

EII costs (benefits) reflect indirect costs in CPFH vs R1 and R2

Summary results – CPFL scenario

	Item	Zone	Technology	Unit		2020		2025		2030	
CPFL	Carbon price	CPF zone		€/tCO2		22.1		24.4		32.5	
		NoCPF zone		€/tCO2		22.1		24.4		32.5	
	Power price	CPF zone		€/MWh		49.1		53.9		56.5	
		NoCPF zone		€/MWh		51.5		55.7		60.5	
	Power sector emissions	CPF zone		Mt CO2		597		583		509	
		NoCPF zone		Mt CO2		378		374		295	
	Power capacity / Generation	CPF zone	Coal[1]	GW	TWh	59	207	42	201	29	139
			Gas[2]	GW	TWh	115	302	113	273	109	234
			Wind	GW	TWh	164	396	177	443	215	570
			Solar	GW	TWh	100	111	136	167	154	190
			Nuclear	GW	TWh	105	728	85	589	72	492
			Other[3]	GW	TWh	240	708	254	736	277	761
		NoCPF zone	Coal	GW	TWh	38	142	30	145	17	80
			Gas	GW	TWh	69	206	65	181	61	154
			Wind	GW	TWh	34	69	34	71	43	98
			Solar	GW	TWh	34	44	38	49	56	75
			Nuclear	GW	TWh	16	112	17	116	20	139
			Other	GW	TWh	115	284	118	290	125	303
	Net power flows	CPF -> NoCPF		TWh		79		66		78	
	%RES generation			%		41%		46%		54%	
	Energy cost	CPF zone		Bn€		347		625		385	
		NoCPF zone		Bn€		156		279		180	
	RES support costs	CPF zone		Bn€		13		12		7	
		NoCPF zone		Bn€		2		2		1	
	Capacity costs	CPF zone		Bn€		5		11		11	
		NoCPF zone		Bn€		4		7		5	
	CPF Carbon revenues	CPF zone		Bn€		Not calculated		Not calculated		0.0	
		NoCPF zone		Bn€		0		0		0.0	
	EII costs (benefits)	CPF zone - CPFL vs R1		Bn€		Not calculated		Not calculated		4.7	
		CPF zone - CPFL vs R2		Bn€		Not calculated		Not calculated		(1.3)	

Notes: [1] Coal and lignite, [2] Gas and CCGT, [3] Hydro, storage, OCGT, oil, other.

Capacity costs are calculated to meet an assumed security of supply target for each country whether or not they actually have a capacity mechanism.

Network costs/charges are not included in our consumer costs analysis.

EII costs (benefits) reflect indirect costs in CPFL vs R1 and R2

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Summary results – R3 scenario

	Item	Zone	Technology	Unit		2020		2025		2030	
R3	Carbon price	CPF zone		€/tCO2		22.1		16.0		18.1	
		NoCPF zone		€/tCO2		22.1		16.0		18.1	
	Power price	CPF zone		€/MWh		48.9		50.8		55.0	
		NoCPF zone		€/MWh		51.4		51.0		55.7	
	Power sector emissions	CPF zone		Mt CO2		607		638		594	
		NoCPF zone		Mt CO2		396		431		382	
	Power capacity / Generation	CPF zone	Coal[1]	GW	TWh	72	224	55	269	42	229
			Gas[2]	GW	TWh	113	281	111	231	107	222
			Wind	GW	TWh	164	396	165	405	176	447
			Solar	GW	TWh	100	111	131	156	149	180
			Nuclear	GW	TWh	105	728	85	592	72	500
			Other[3]	GW	TWh	239	708	253	737	276	762
		NoCPF zone	Coal	GW	TWh	43	161	37	208	26	157
			Gas	GW	TWh	65	191	62	132	58	131
			Wind	GW	TWh	34	69	34	70	35	76
			Solar	GW	TWh	34	44	38	49	55	73
			Nuclear	GW	TWh	16	112	17	116	20	139
			Other	GW	TWh	117	284	117	290	125	302
	Net power flows	CPF -> NoCPF		TWh		76		52		40	
	%RES generation			%		41%		45%		49%	
	Energy cost	CPF zone		Bn€		346		588		376	
		NoCPF zone		Bn€		155		255		166	
	RES support costs	CPF zone		Bn€		13		17		7	
		NoCPF zone		Bn€		2		4		2	
	Capacity costs	CPF zone		Bn€		5		10		10	
		NoCPF zone		Bn€		3		6		5	

Notes: [1] Coal and lignite, [2] Gas and CCGT, [3] Hydro, storage, OCGT, oil, other.

Capacity costs are calculated to meet an assumed security of supply target for each country whether or not they actually have a capacity mechanism.

Network costs/charges are not included in our consumer costs analysis.

Summary results – CPFL* scenario

	Item	Zone	Technology	Unit		2020		2025		2030	
CPFL*	Carbon price	CPF zone		€/tCO2		22.1		24.4		32.5	
		NoCPF zone		€/tCO2		22.1		16.0		18.1	
	Power price	CPF zone		€/MWh		49.7		52.9		55.2	
		NoCPF zone		€/MWh		50.9		51.9		55.9	
	Power sector emissions	CPF zone		Mt CO2		595		544		469	
		NoCPF zone		Mt CO2		401		464		402	
	Power capacity / Generation	CPF zone	Coal[1]	GW	TWh	59	215	42	184	29	120
			Gas[2]	GW	TWh	106	272	104	203	100	166
			Wind	GW	TWh	164	396	177	442	212	560
			Solar	GW	TWh	100	111	136	166	154	190
			Nuclear	GW	TWh	105	727	85	589	72	494
			Other[3]	GW	TWh	240	709	263	743	286	769
		NoCPF zone	Coal	GW	TWh	43	157	37	217	26	158
			Gas	GW	TWh	71	211	68	184	64	174
			Wind	GW	TWh	34	69	34	70	36	79
			Solar	GW	TWh	34	44	38	49	55	73
			Nuclear	GW	TWh	16	112	17	116	20	139
			Other	GW	TWh	115	284	116	291	119	303
	Net power flows	CPF -> NoCPF		TWh		57		-13		-8	
	%RES generation			%		41%		46%		53%	
	Energy cost	CPF zone		Bn€		351		612		377	
		NoCPF zone		Bn€		154		260		167	
	RES support costs	CPF zone		Bn€		12		14		8	
		NoCPF zone		Bn€		2		4		2	
	Capacity costs	CPF zone		Bn€		3		12		12	
		NoCPF zone		Bn€		4		7		5	

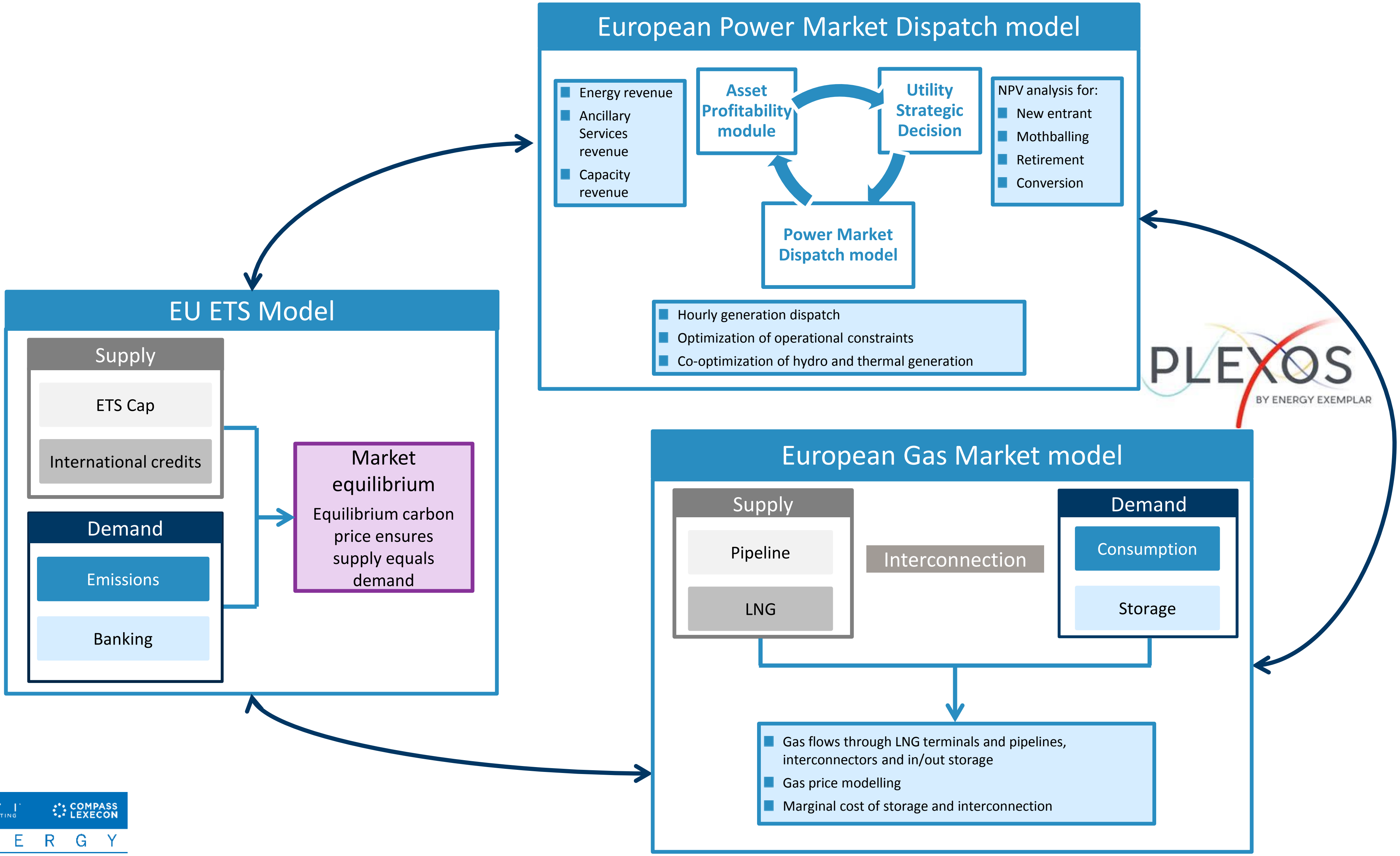
Notes: [1] Coal and lignite, [2] Gas and CCGT, [3] Hydro, storage, OCGT, oil, other.

Capacity costs are calculated to meet an assumed security of supply target for each country whether or not they actually have a capacity mechanism.

Network costs/charges are not included in our consumer costs analysis.

Appendix 4D: FTI-CL Energy power market model

FTI-CL Energy has an integrated proprietary modeling suite covering the European electricity, gas and CO_2 markets



FTI-CL European power market dispatch model covers all European power markets

Overview of FTI-CL Energy's power market model

- GB and Ireland
- France, Germany, Belgium, Switzerland, Austria and the Netherlands
- Spain, Portugal and Italy
- Nordic countries: Denmark, Norway, Sweden and Finland
- Poland and the Baltic countries
- Eastern Europe and Greece, as well as Turkey

Model structure

- The model constructs supply in each price zone based on individual plants.
- Zonal prices are found as the marginal value of energy accounting for generators' bidding strategies
- Takes into account the cross-border transmission and interconnectors and unit-commitment plant constraints
- The model is run on the commercial modelling platform Plexos® using data and assumptions constructed by FTI-CL Energy

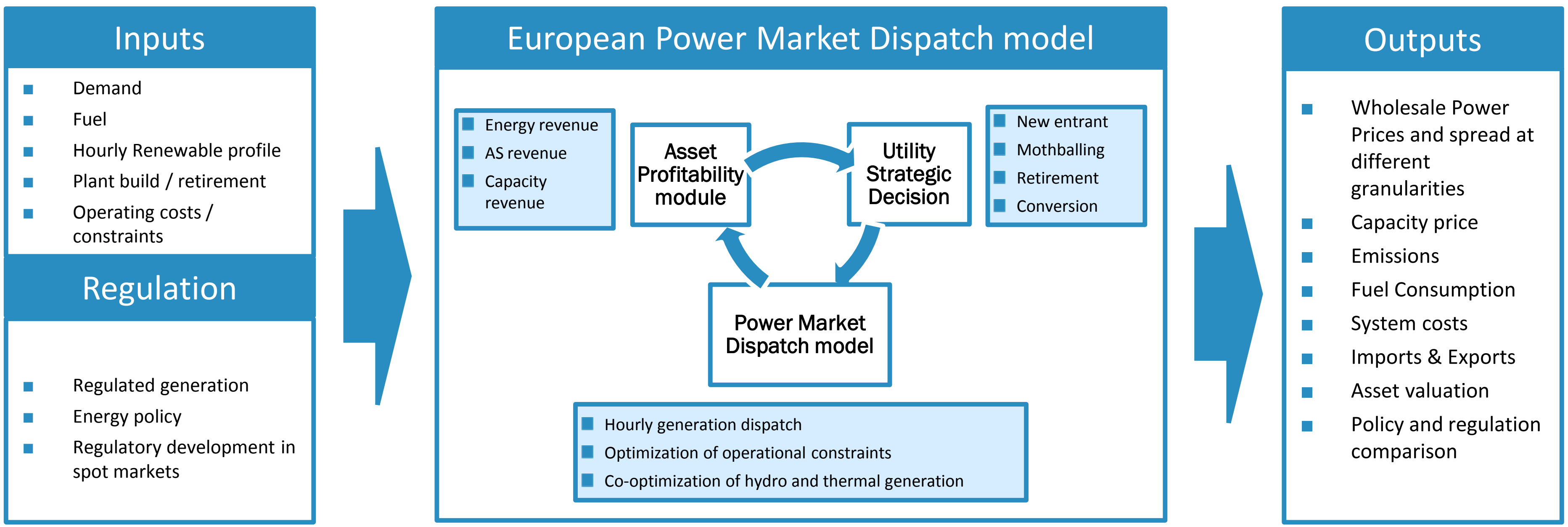
Geographic scope of the model

FTI-CL Energy’s power market model relies on a dispatch optimisation software with detailed representation of market fundamentals

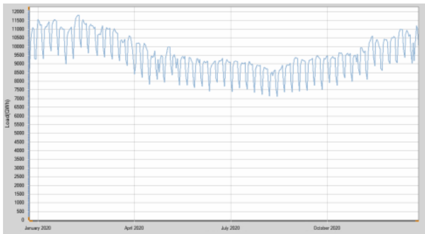
Dispatch optimisation based on detailed representation of power market fundamentals

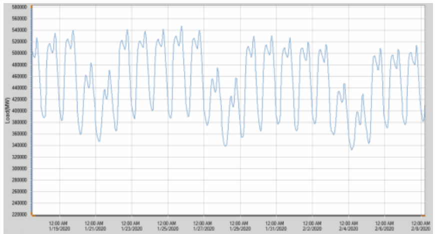
- At the heart of FTI-CL Energy’s market modelling capability lies a dispatch optimisation software, Plexos®, based on a detailed representation of market supply and demand fundamentals at an hourly granularity. Plexos® is globally used by regulators, TSOs, and power market participants.
- FTI-CL Energy’s power market model is specifically designed to model renewable generation:
  - Wind: Hourly profiles are derived from our in-house methodology that converts consolidated wind speeds into power output.
  - Solar: Hourly profiles are derived from our in-house methodology that converts solar radiation into power output.
  - Hydro: Weekly natural inflows are derived from our in-house methodology that convert rainfall, ice-melt and hydrological drainage basin into energy. Generation is derived from a state-of-the-art hydro thermal co-optimization algorithm embedded at the heart of Plexos®.

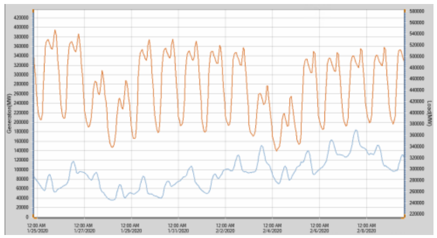
FTI-CL Energy’s modelling approach (input, modules and output)

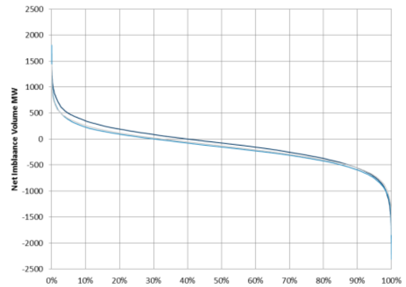


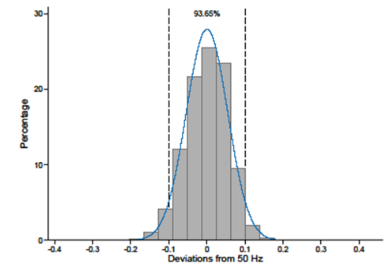
FTI-CL Energy’s power market suite allows to capture the flexibility and market arbitrage values on short time frames

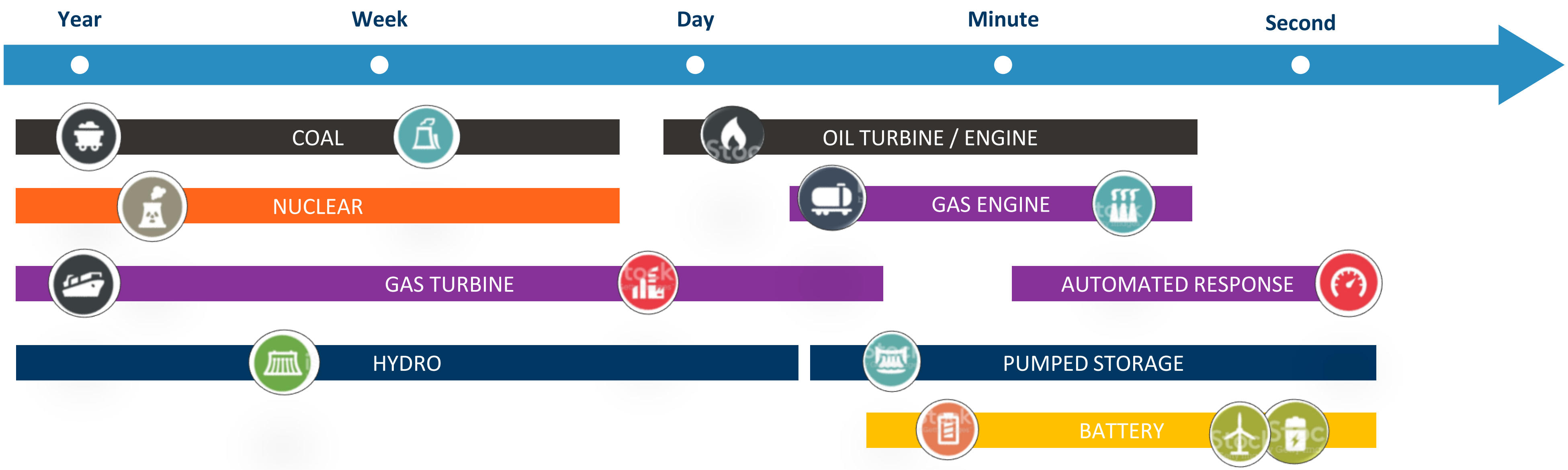










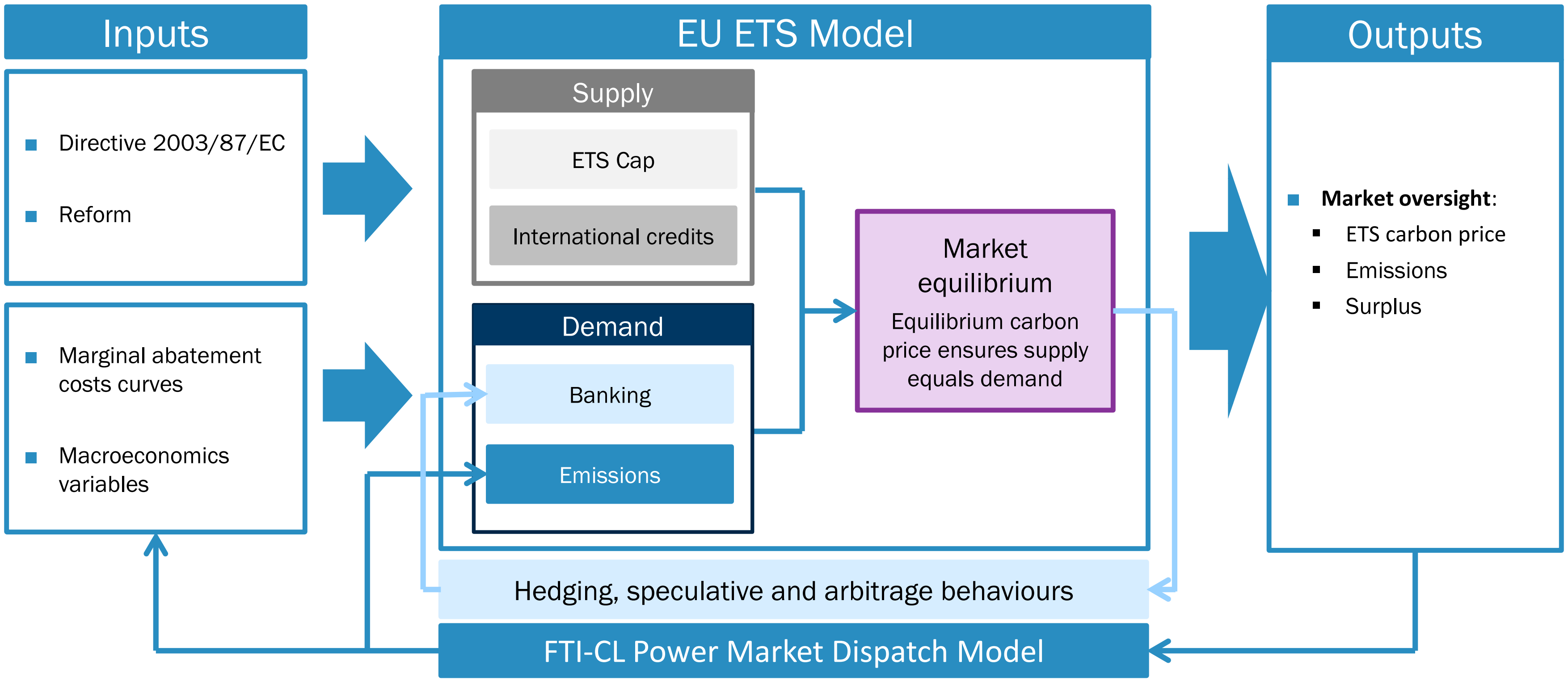


Appendix 4E: FTI-CL Energy carbon market model

For each of the scenarios, the EU ETS market is modelled using our in-house model

- FTI-CL in-house **EU ETS model calculates the EU ETS carbon price and emissions from the power and industrial sectors**, based a detailed representation of ETS market supply and demand fundamentals.

- FTI-CL in-house EU ETS model factors in the inter-temporality and anticipations from the different market participants, which are crucial to appreciate the effective impact of a reform.



Note: FTI-CL Energy's EU ETS modelling approach is inspired from the ZEPHYR model developed by Raphaël Trotignon & Boris Solier (Paris Dauphine University, Chaire Economie du Climat: http://www.chaireeconomieduclimat.org)

Modelling of banking of surplus emissions allowances encompasses both hedging, speculative and arbitrage behaviours

- The **EU ETS Market is an intertemporal market** in which agents follow different banking behaviours…
  - **Arbitrage** – To buy allowances and simultaneously sell forward, so as to avoid exposure to carbon price risk.

    Empirical evidence : An early study on the EU ETS identified the possible arbitrage opportunities in the market (Milunovich and Joyeux 2007). In recent years, front-year contracts for 2011 were traded at about 3-5% discount below 2012 contracts, and contracts for 2012 at 7% below 2013 contracts (Neuhoff, 2012).

  - **Hedging** – To hold allowances to meet future carbon credit needs, and thus avoid the exposure to carbon price risk.

    Empirical evidence: Interviews with power, industry and finance actors confirmed discounts on future prices are applied in the order of 5% per year (Eurelectric, 2009 – References Documents of main European utilities). Studies found that power generators generally hold CO_2 allowances in the EU ETS to hedge for future power sales (Schoop and Neuhoff, 2013).

  - **Speculation** – To take an open position, carrying risk in expectation that the carbon price will evolve favourably.

    Empirical evidence: Studies based on trading volume and open interest data found that there is a high degree of speculative behaviour at various points throughout each EU ETS Phase – particularly Phase II (Lucia et. al. 2012). Experiences from other commodities suggest that speculative buyers generally expect returns in the range of 10-15% per annum (Bessembinder 1992, Wang 2001).

- … that **should properly be taken into account to reflect both the static and intertemporal dimensions** of options for EU ETS reform
  - **Static impact** – The reform will reduce the aggregate stock of emissions available in the market at given point(s) in time;
  - **Intertemporal impact of the reform** – Given the expected static impact of the measure, market participants will adjust their banking behavior – if the reform is **predictable and credible**. The adjustment will smooth the expected impact of the reform across time.

Source : Karsten Neuhoff and al (2012), "Banking of Surplus Emissions Allowances Does the Volume Matter?"; Eurelectric (2009), "EU ETS Phase 3 Auctioning – Timing and Futures versus Spot", Ahrens, Joachim, *Governance and Economic Development: A Comparative Institutional Approach*, Edward Elgar (Northampton, MA: 2002), page: 132.;Wara, Michael and David Victor, "A Realistic Policy on International Carbon Offsets", Program on Energy and Sustainable Development Working Paper #74 (2008), page: 23.

Our modelling of banking of surplus emissions allowances captures both hedging, speculative and arbitrage behaviours

Scope and assumptions

Scope

- The EU ETS Market is an intertemporal market in which agents follow different banking behavior that should properly be taken into account to reflect both the static and intertemporal dimensions of options for EU ETS reform.
- Literature identifies three main banking behaviors, namely (i) hedging ; (ii) speculation ; and (iii) arbitrage. We follow this approach

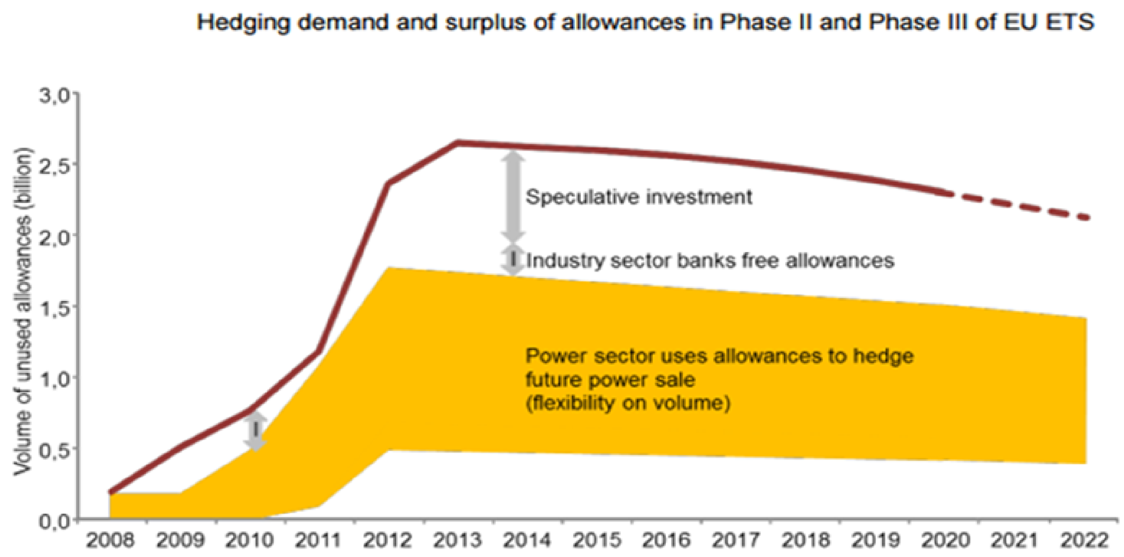
Assumptions

- The model departs from (theoretical) anticipations in order to reflect actual behaviors observed in the EU ETS market.
- Hedging: Myopic agents bank allowances in proportion of the difference between their anticipated emissions and allowances they will receive for free (in the next 3 years)
- Long-term speculation: Myopic agents take speculative positions when they foresee an increase in ETS price (within the 5 coming years)– i.e. when they perceive a difference between anticipated emissions and total future allowances in the market (Departure from the Zephyr Model)

Source

- Literature review/surveys (e.g. Karsten Neuhoff 2012, Eurelectric 2009, Annual Reports of European utilities, Eurostat, etc.).

Breakdown of emissions surplus (Neuhoff, 2012)



Source: Karsten Neuhoff and al (2012), "Banking of Surplus Emissions Allowances Does the Volume Matter?", https://www.diw.de/documents/publikationen/73/diw_01.c.394484.de/dp1196.pdf

Eurelectric (2009), "EU ETS Phase 3 Auctioning – Timing and Futures versus Spot", http://www.eurelectric.org/media/43893/eu_ets_phase_3_auctioning_23_oct_2009-2009-030-1015-01-e.pdf

Banking behaviors are driven by anticipated market and individual emission reduction efforts

- In our framework, **banking behaviours are driven by anticipated market and individual emission reduction efforts**.

- **Market behaviours of hedgers** depend on the **current position** ($P_{i,t}$) and of hedging needs ($\Delta_{i,t}$) over an anticipation period of three years. Their demand for permits ($D^H_{i,t}$) is given by the following formula :

$$\mathbf{D^H_{i,t} = -\,sig\left(P_{i,t}\right) \times \left|P_{i,t}\right| + 1_{\{\Delta_{i,t}>0\}}\omega \times \left|\Delta_{i,t}\right|}$$

Where,

- The current position is defined as the difference the difference between (i) the surplus – i.e. the stock of banked allowances that participants hold on their accounts at the beginning of each year, plus freely allocated allowances received for the current year – and (ii) participants surrendered allowances/verified emissions over the year.
- Hedging needs are measured by the difference between expected future emissions over the anticipation period and amount of allowances received for free. In accordance with the literature, the anticipation period is set to three years.

- **Market behaviours of speculators** would only look at the future **tightness of the market** ($\Delta_{M,t}$) within a period of five years. Each year, they unlock part of their speculative positions – corresponding to a constant fraction of their portfolio. The demand (D^S_t) and supply (S^S_t) from speculators in year t is thus given by the following formula:

$$\mathbf{D^S_t = 1_{\{\Delta_{M,t}>0\}}\omega \times \left|\Delta_{M,t}\right| \text{ and } S^S_t = K^S_t / L_S}$$

Where,

- K^S_t represents the surplus – i.e. the stock of banked allowances that speculators hold on their accounts at the beginning of each year.
- The anticipated tightness of the market is measured by the difference between expected supply (free + auctioned) and demand.

The actual emissions of sectors covered by the EU ETS respond to carbon price according to marginal abatement costs curves

Scope and assumptions

Scope

- Sector – Power + Industrial sectors as a whole
- Region - All 31 country participating in the EU ETS (EU 28, Iceland, Liechtenstein and Norway)

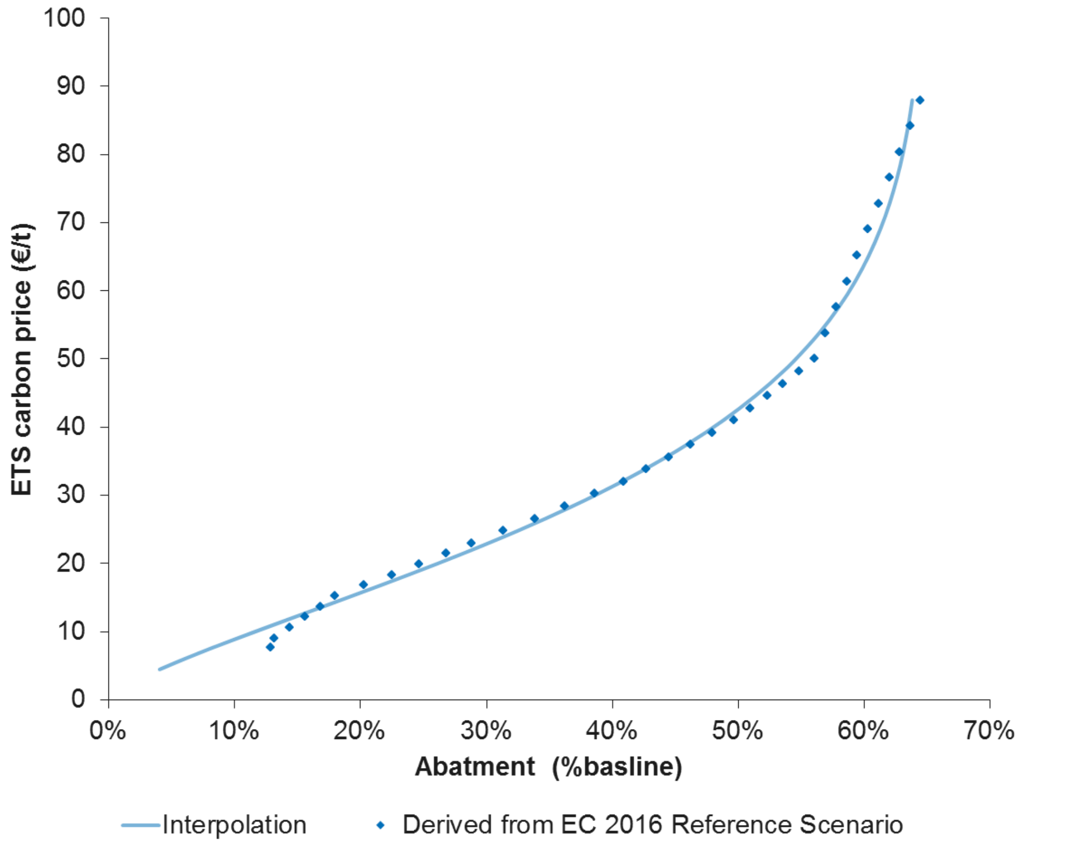
Assumptions

- Given ETS carbon price, sectors decide either to reduce their emissions or to buy ETS credits. The trade-off is done in accordance with marginal abatement costs curves (MACC).
- The curve shows the abatment we would observed for a given carbon price, as compared to emissions with a price of carbon equal to 0.

Source

- MACC of the power sector: FTI-CL power sector model (cf. hereafter)
- MACC of industrial sectors: Same for all sectors, Derived from the EC 2016 Reference scenario to 2050
  (Reference scenario gives the level of emissions for different carbon prices - i.e. for each years of the period 2016 - 2050. It defines implicitly a demand curve for CO_2 credits)

Industrial sector MACC curve - 2020



Source: EC - http://ec.europa.eu/clima/policies/ets/cap/index_en.htm

EC (2016), « Reference scenario to 2050 », https://ec.europa.eu/energy/sites/ener/files/documents/20160712_Summary_Ref_scenario_MAIN_RESULTS%20(2)-web.pdf

We have relied on our plant-by-plant EU power market dispatch model to derive the power sector MACC curves

Scope and assumptions

Scope

- The model covers all countries included by the EU ETS.

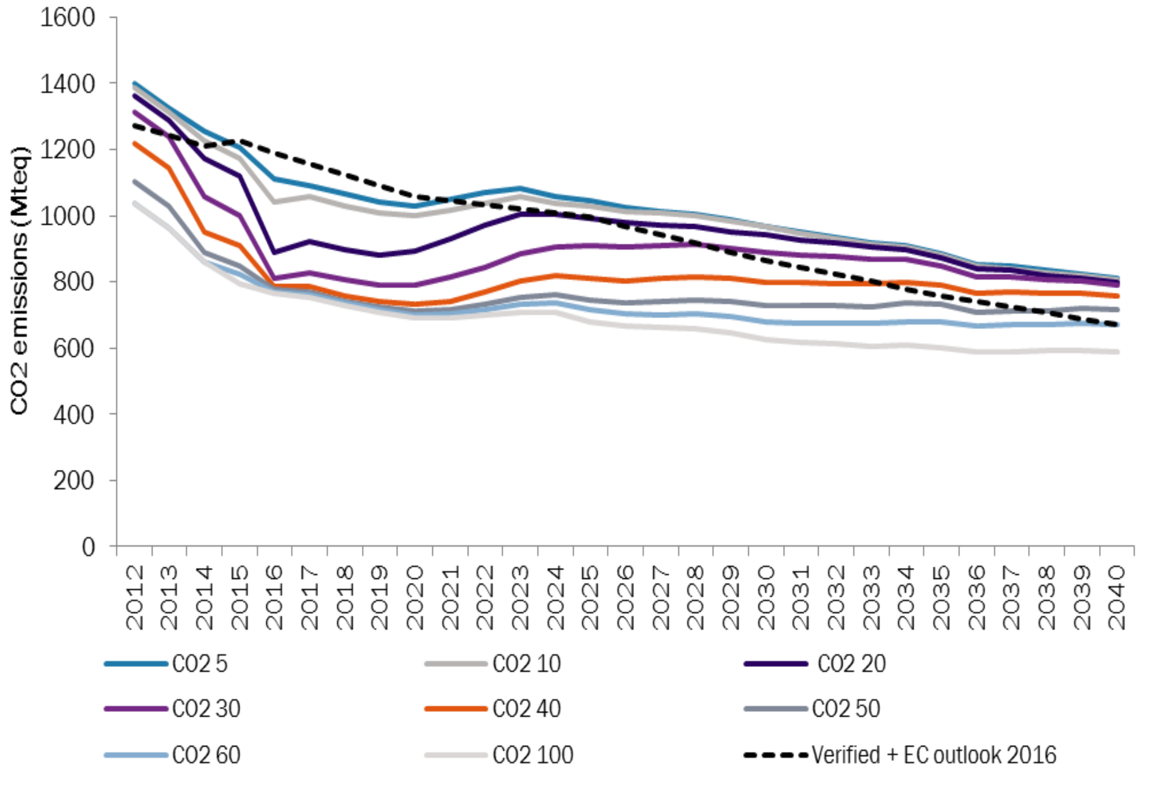
Assumptions

- The model constructs supply in each price zone based on individual plants
- The model is run on a commercial modelling platform Plexos® using data and assumptions constructed by FTI-CL Energy
- The curve shows the level of power sector emissions we would observed for a given carbon price. For each year, depending on the carbon price, we would read the power sector emissions level.

Source

- **Nuclear** : Includes latest development on nuclear phase–down policies and nuclear new projects under construction
- **Renewable energy** : Includes latest renewable energy targets to achieve by 2020-25 and median long-term scenario derived from ENTSO-E Visions (2 and 3).
- **Thermal capacity :** Includes latest announcements from market participants on future decommissioning. Other decommissioning is based on a combination of standard lifetime and NPV analysis of the future revenues. Future new builds are developed on a economic (NPV) basis, combining energy revenues, ancillary revenues, capacity revenues and annualised cost (CAPEX and OPEX)

Power sector MACC curve



Appendix 4F: Key modelling assumptions

The power market model is set up with a range of inputs derived from latest announcements from TSOs, regulators and market players

Key power price driver	Sources	Optimization
Demand		
Power demand	■ Long term electrification based on EUCO scenarios and Eurelectric	■ Fixed set as demand to be met
Supply		
RES capacity	■ Meet 2020 objective as per ENTSOE Best Estimate ■ CAPEX and OPEX outlook based on latest data from EC and E3M (June 2018)	■ Capacity dynamically optimised thereafter based NPV of anticipated costs and revenues
Nuclear capacity	■ Latest National plans on phase-down or phase-out ■ Latest announcement on plants' life extension and new projects	■ Dispatch optimized by hourly dispatch model
Thermal capacity	■ Latest announcements from operators and National plans on phase-out or conversion to biomass ■ Latest announcement on refurbishment and new projects in the short-term ■ CAPEX and OPEX outlook based on latest data from EC and E3M (June 2018)	■ Capacity dynamically optimised in the longer term based on NPV of anticipated costs and revenues ■ Dispatch optimized by hourly dispatch model
Storage technologies	■ CAPEX and OPEX outlook based on latest data from EC and E3M (June 2018)	
Commodity prices		
Gas	■ Forwards until 2020, converge to IEA WEO 2017 New Policy by 2025	■ Fixed set as an input (see appendix)
Coal ARA CIF	■ Forwards until 2020, converge to IEA WEO 2017 New Policy by 2025	■ Fixed set as an input (see appendix)
CO2 EUA	■ Calculated through FTI-CL EU ETS model	
Interconnections		
Interconnection	■ ENTSO-E TYNDP 2018 outlook for new and existing interconnections	■ Fixed set as an input (see appendix)

Note: Further details are presented in the Appendixes

(1) MAF: Medium term adequacy forecast; (2) TYNDP: Ten Years Network Development Plan; (3) WEO: International Energy Agency World Energy Outlook

The power demand outlook features high energy efficiency and high electrification, in line with European 2030 and 2050 objectives

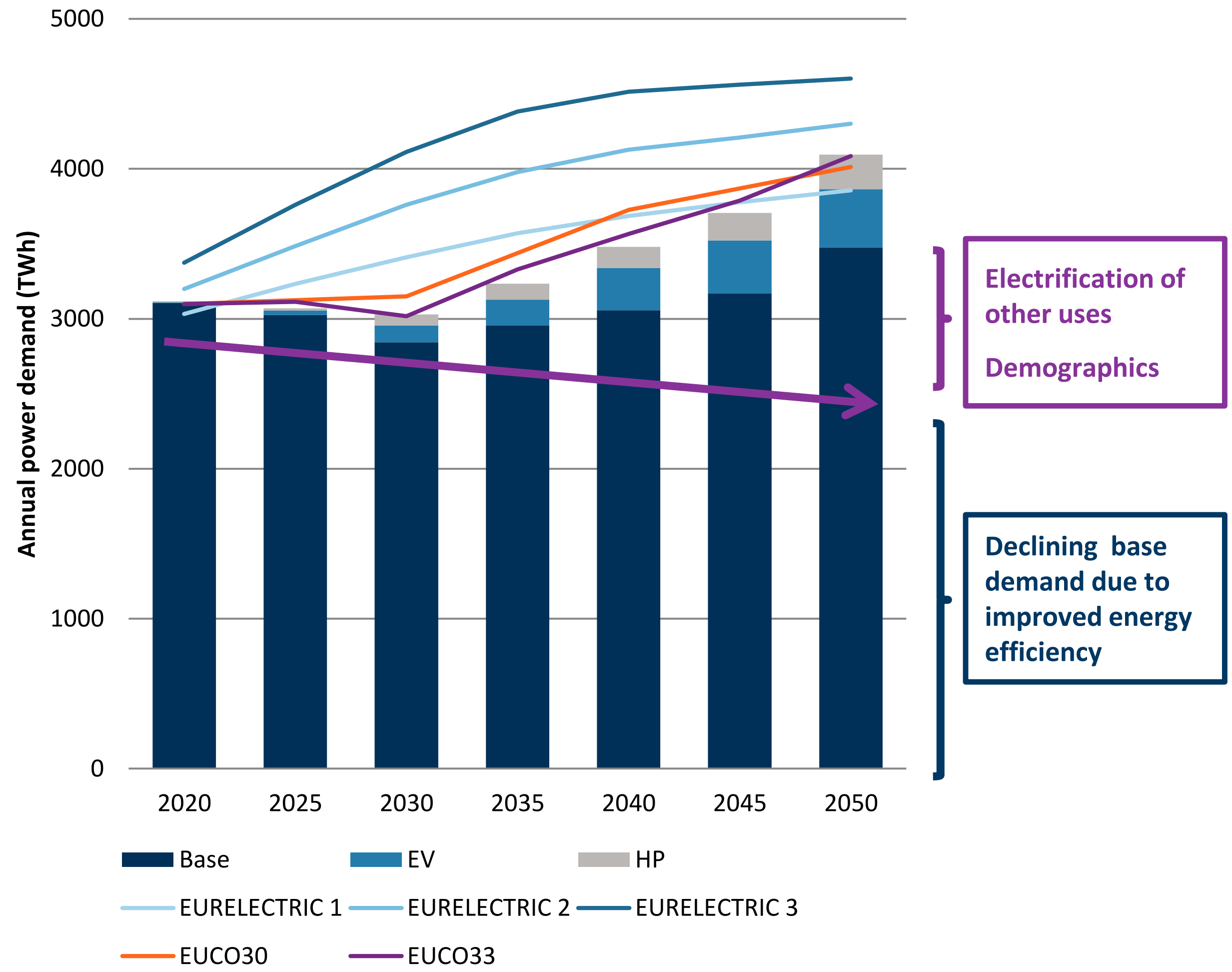
Power demand outlook to 2050

- Our demand scenario is designed to replicate **EUCO33* outlook total EU28 demand** to **include the latest efficiency targets,** defined by 2030, as well as the **long term electrification** necessary to decarbonise the European economy.
  - It features a **fast EV and HP development** as well as an on-going electrification of other sectors (industry and other transports).
- As a results of these two drivers, European power demand decreases from 3110TWh in 2020 down to 3030TWh in 2030 (-0.02% YoY growth rate); then increases to **4095TWh in 2050** (+1.5% YoY growth rate) with EV and HP accounting for <400TWh and >200TWh respectively.

The power demand outlook captures both energy efficiency measures and future electrification resulting in an increased overall demand in the longer term.

* EUCO33 outlook is the PRIMES sensitivity reaching 33% energy efficiency reduction in 2030 and long term decarbonisation objective developed by E3M with the European Commission.

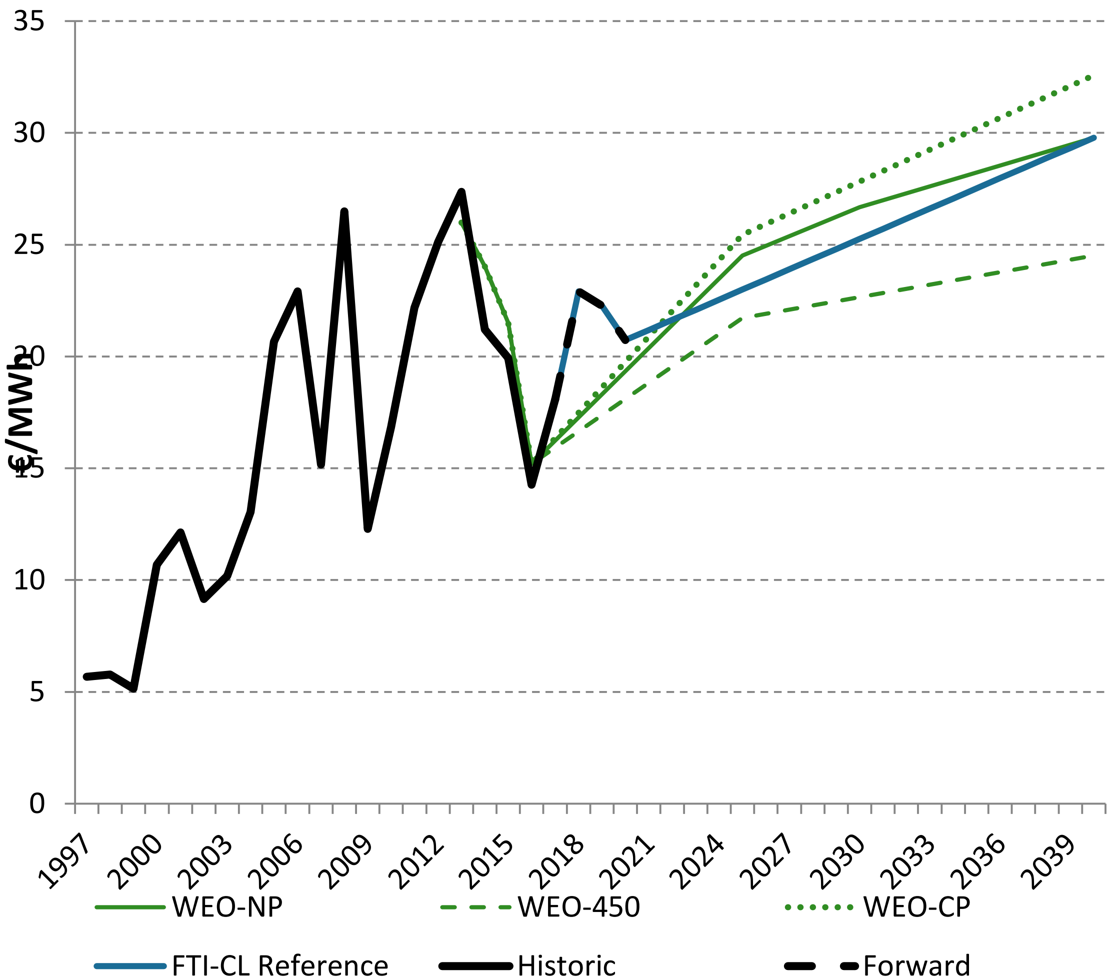
Power demand outlook compared to benchmarks



Source: FTI-CL Energy, Eurelectric, European Commission

European Gas outlook shows an upward trend converging towards IEA WEO NP scenario

European gas outlook to 2050 (real 2017)



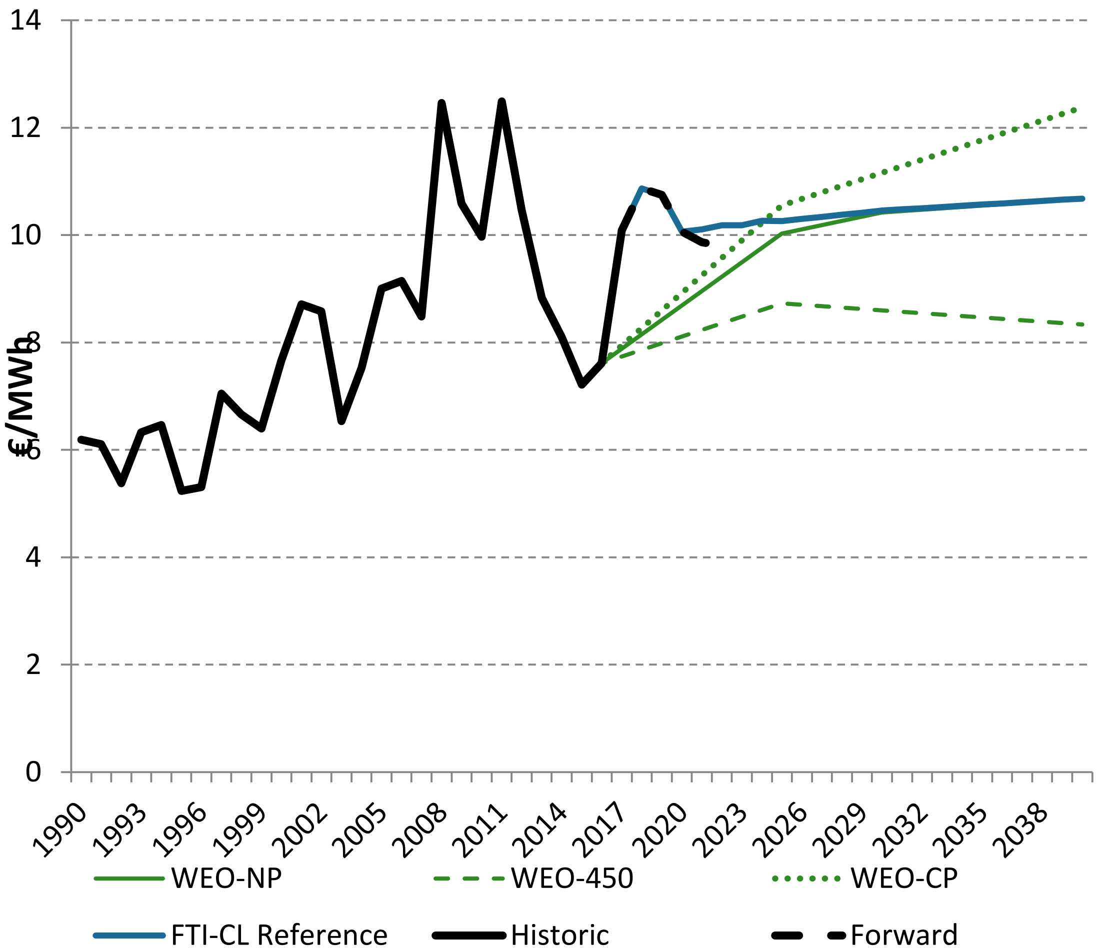
Source: FTI-CL Energy based on Bloomberg and IEA World Energy Outlook

Historic and expected gas price evolution

- European gas prices reached €11/MWh August 2016, their 5-years minimum. Since then, they increased back to c. €20/MWh in Q4 16 / Q1 17 (nearly doubling in 6-months' time), before reaching their current level of €23/MWh.
- To be comparable with European Commission and other European outlooks, our gas price outlook combines
  - Latest forward prices in the short-term and
  - IEA 2017 World Energy Outlook (WEO) scenarios. In particular, we assume that **gas prices converge to the WEO New Policies scenario by 2040.**

Coal ARA CIF outlook shows an slightly upward trend converging towards the IEA WEO NP scenario

Coal ARA CIF outlook to 2050 (real 2017)



Source: FTI-CL Energy based on Bloomberg and IEA World Energy Outlook

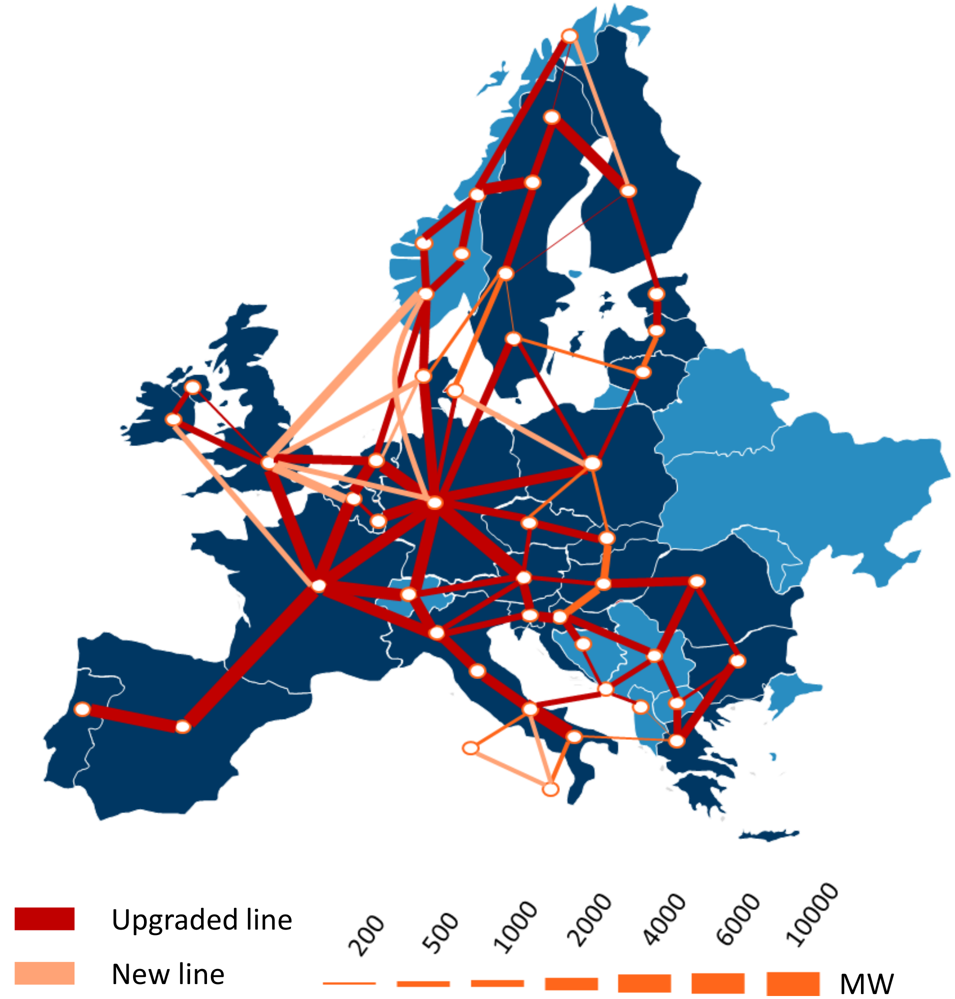
Historic and expected coal price evolution

- The coal price reached $42/t in March-April 2016, its lowest level since 2000.
- Since then, the coal price increased back to an average of $80/t by end 2016, nearly doubling in 6 months' time.
- To be comparable with European Commission and other European outlooks, our coal price outlook combines
  - Latest forward prices in the short-term and
  - IEA 2017 World Energy Outlook (WEO) scenarios. In particular, we assume that **coal prices converge to the WEO New Policies scenario by 2040.**

Our interconnection NTC development is based on ENTSOE TYNDP 2018 development plan featuring a doubling of NTC by 2050

Network in 2015 **NTC: 225 GW**

Network in 2050 **NTC: 439 GW**



Note:

1- NTC stands for Net Transfer Capacity

2- Interconnection NTC development represents the capacity available for trade between bidding zones. The NTC is lower than the physical cross-border capacity.

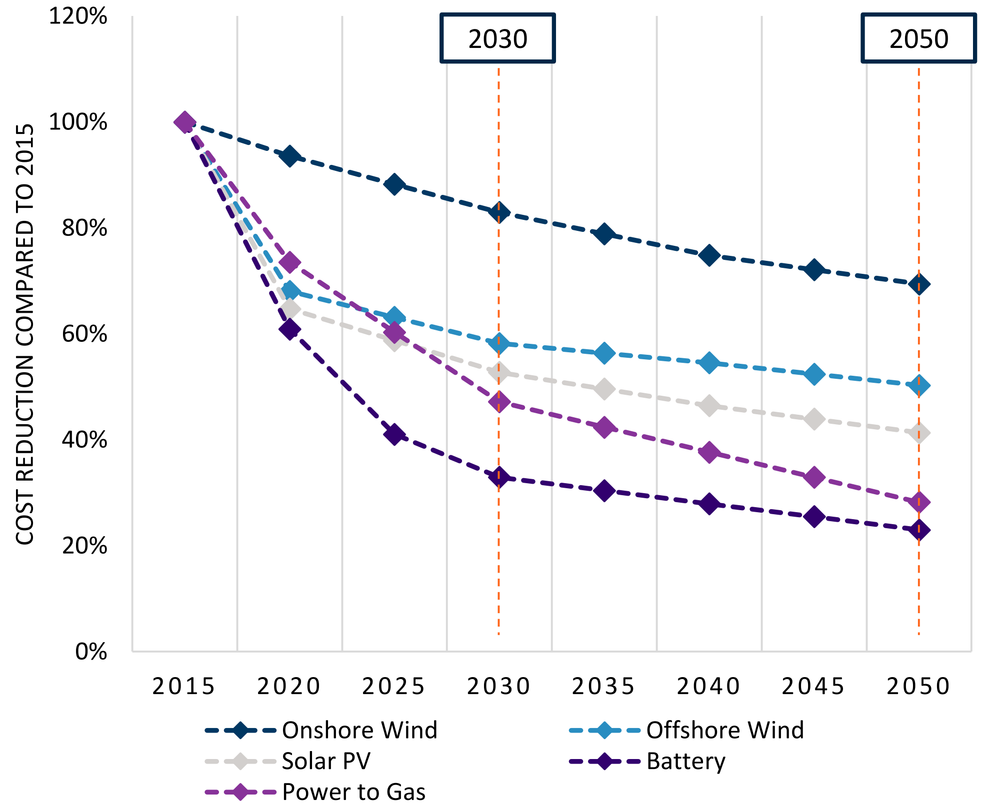
Renewable technologies and storage technologies CAPEX outlook assume a steep reduction by 2030 thanks to further learning effect

RES and storage cost assumptions are based on various European relevant sources

- While, the Commission has set up a market wide review of technology cost outlook to ensure their robustness and representativeness of the current projects, in the process of the new Energy roadmap 2050 (E3M technology roadmap), other European organisations such as the Danish Energy Agency (DEA) publish technology cost outlooks.
- FTI-CL Energy cost outlook combines the latest outlooks to account for the latest improvements.

% reduction compared to 2015	2030	2050
Wind onshore	17%	31%
Wind offshore	42%	50%
Solar PV	47%	59%
Power to gas	53%	72%
Battery	67%	77%

RES and storage cost reduction (%)



Source: FTI-CL Energy analysis, DEA, E3M

RES and batteries improvement and expected cost reduction would be due to learning effects in several domains

- Solar panels cost standardization through Europe.
- Reduction in supply chain margins following increasing competition.
- Further technological improvement following historical learning rates.

- Wind turbines improvement implying better capacity factors, especially at low wind speeds.
- Better identification of wind resources further improving wind turbines capacity factor.
- Improvement in components reliability reducing FO&M.

- Intense competition provoking several disruptions in the market including new chemistries development.
- Convergence toward production best practices.

Bibliography

#	Slides	Source	Link
1	6	"The EU's Vision of a modern, clean and competitive economy", Miguel Arias, Brussels, 10 July 2018	Link
2	10, 40	"Aligning the 2030 EU climate and energy policy framework to meet long-term climate goals", I4CE, June 2018	Link
3	13, 23, 26	"When is a carbon price floor desirable?", EPRG Working Paper, Newbery et al, 2018	Link
4	23	"Combining price and quantity controls to mitigate global climate change", William Pizer, 2002	Link
5	23	"The Challenge of Global Warming: Economic Models and Environmental Policy", William Nordhaus, July 2007	Link
6	27	ZEPHYR model, Raphaël Trotignon & Boris Solier, Paris Dauphine University, Chaire Economie du Climat	Link
7	66, 89, 115, 117	"Technical report on Member State results of the EUCO policy scenarios", E3MLab & IIASA, December 2016	Link
8	68, 71	"Composition and Drivers of Energy Prices and Costs", ECOFYS, June 2016	Link
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