Analysis of the CO2 power emission factor for indirect compensation related to the EU ETS

Final report

UNIDEN
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ÉNERGIE ET COMPÉTITIVITÉ DES INDUSTRIES

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Presented To:

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Contents of the presentation

Executive summary

Context and objectives

- **The Guidelines of the EU Emissions Trading Scheme (EU ETS), established by the European Commission (EC) in 2012, allow Member States to compensate some electro-intensive parties for part of higher electricity costs (indirect costs) related to the introduction of a carbon price. The aim of such compensation is to avoid carbon leakage.**
- **The compensation level is based on an emission factor (tCO2/MWh) that estimates the increase in power prices associated with an increase in carbon prices.**
- **The future of the compensation mechanism in the context of the revised EU-ETS scheme (phase IV: 2021-2030) is yet to be determined and the CO2 emission factor could be revised by the European Commission.**
- **In this context, Compass Lexecon was mandated by UNIDEN to perform an independent analysis of the emission factor evolution. This report describes the analysis conducted:**
  - Review of the different possible approaches for emission factor calculation as well as the relevant geographic market for France;
  - Empirical analysis of the past level of the CO2 emission factor (2013-18); and
  - Prospective analysis of the future level of the CO2 emission factor (2019-25).
- **The temporal scope of the analysis is voluntary restrained to 2019-25 as beyond this period there are many uncertainties regarding the evolution of European power markets that make it difficult to project the evolution of the emission factor.**

The two possible approaches for estimating the emission factor

The counterfactual analysis

- The indirect costs paid by the industrials are directly linked to the increase of power prices related to the implementation of the ETS market. We define the **counterfactual analysis** as the methodology deriving the impact on the power price of a 1€/tCO2 increase in the carbon price.

- To perform this analysis, we use our dispatch model that replicates the day-ahead power markets across Europe*. We run two scenarios :
  - A real scenario with the ETS market (with carbon price); and
  - A counterfactual scenario without the ETS market and so without carbon price.

- The emission factor (t/MWh) is determined as follows :

$$\boxed{\frac{(Power\ price_{\ Real} - Power\ price_{\ Counterfactual})}{Carbon\ price}}$$

- This factor represents the increase in power prices in €/MWh that will result from a 1€/tCO2 rise in carbon prices.

* Our power price model is presented in annexe.

The existing method

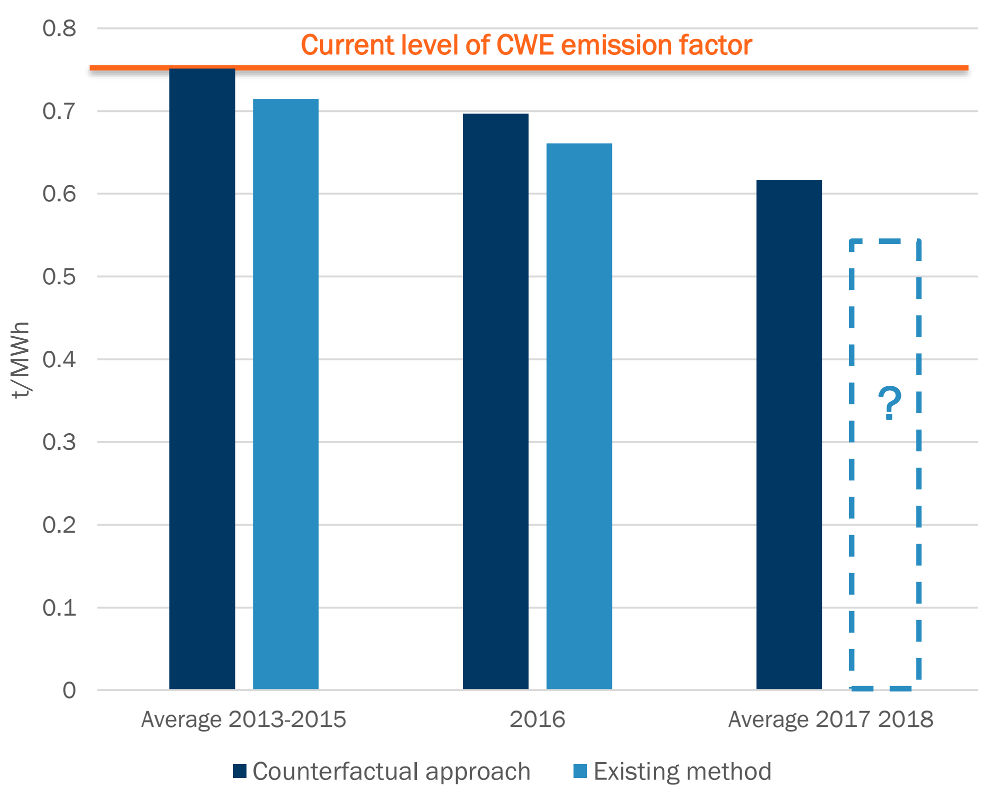
- The Guidelines 2012 set the **existing method** to calculate the emission factor as follows:

$$\boxed{\frac{Emissions\ from\ the\ energy\ industry}{Gross\ thermal\ generation}}$$

- The reasons for using this simplified method are presented in the EC impact assessment (2012):
  - No EU wide electricity market model was available in 2012 to run a counterfactual scenario ; and
  - The existing approach tends to replicate a counterfactual analysis by focusing only on the thermal generation (mostly the marginal units in power markets).
- The 2012 Guidelines pooled countries per zone based on the electricity market integration**. The relevant geographical area for assessing the French coefficient is the CWE zone** (Central-West Europe : Austria, Belgium, Luxembourg, France, Germany and Netherlands) **and the emission factor is currently set at 0.76 tCO2/MWh.**
- The existing method does not mention the reference year used for the determination of the current emission factor. Historical data shows that the year 2005 might have been used especially for the CWE zone.

Comparison of the two approaches over the period 2013-2018: existing proxy versus counterfactual approach

Emission coefficients in the CWE region



Source: FTI-CL Energy modelling results, FTI-CL Energy analysis based on Eurostat data

Notes: Historical data for years 2017-2018 was not available on Eurostat website when this analysis was released.In the counterfactual approach, the CWE coefficient is calculated as a simple average of national coefficients.

- To perform a comparison of the two approaches:
  - We run a **counterfactual analysis** with our dispatch model; and
  - We use historical verified data to assess the emission factors with the **existing method**
- Our analysis shows that :
  - **The counterfactual approach gives an emission factor at 0.75t/MWh, aligned with the EC's existing coefficient (0.76) for the period 2013-15.**
  - **The existing method results in lower coefficients compared to the counterfactual approach for the CWE zone**. The countries with significant gas generation have a lower emission coefficient with the existing method / a higher coefficient with the counterfactual approach as their power prices are often set by neighbouring markets with coal capacity*.
  - **With the counterfactual approach, the coefficient decreases after 2016**. However, this estimate cannot be compared with the existing method as verified data was not published when this report was released.
  - **Despite these small differences, the two methods therefore show similar results.**

*Notes: *the emission factor varies from around 0.4t/MWh for gas assets to more than 1t/MWh for lignite plants .*

The counterfactual approach shows a consistent level of the emission factor with EC's existing coefficient (0.76). Despite small differences, the existing method is consistent with the counterfactual analysis over the period 2013-2016.

To validate the previous results, we replicate the dynamics of spot & forward electricity prices using econometric models

- **We validate the coefficients presented previously with two econometric models :**
  - One model replicates spot power prices over the period 2015-2018; and
  - One model focuses on the forward prices and provides a coefficient for each period defined by structural breaks in electricity and carbon markets.

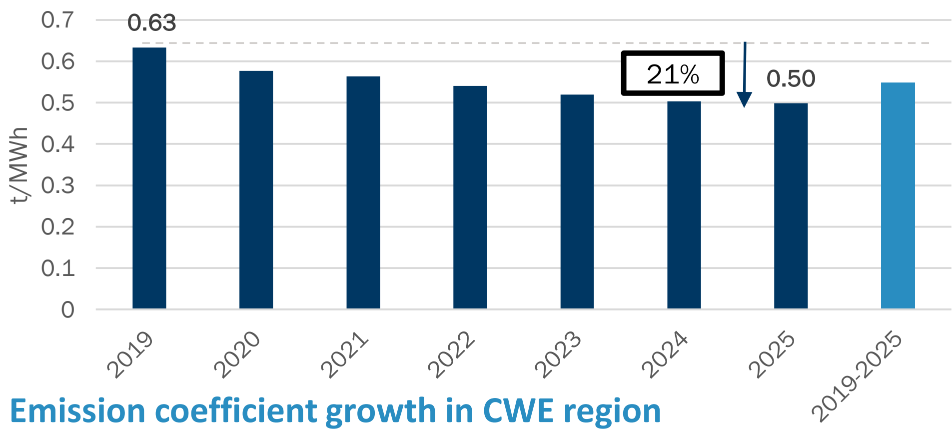
- **Our work on the econometric model focussing on spot prices suggests that :**
  - The specificities of French power spot market need to be taken into account in the regression, therefore we use residual load as a control factor;
  - The results indicates a coefficient at 0.591t/MWh for the period 2015-18. This coefficient ranges between 0.45 and 0.73t/MWh at 95% confidence level.

- **Our analysis on the econometric model focussing on forward prices shows that :**
  - The period 2011-18 can be split into seven sub-periods with identified structural breaks;
  - The regression provides one coefficient for each structural break: emissions factors vary between 0.53 and 1.23 depending on the period considered;
  - For the year 2018, the regression provides 0.76 as emission factor. In periods characterised by a strong increase in carbon prices, the econometric model leads to similar results to the other two approaches. This outcome is particularly interesting because these periods result in high compensation levels from the Member States to the industrials.

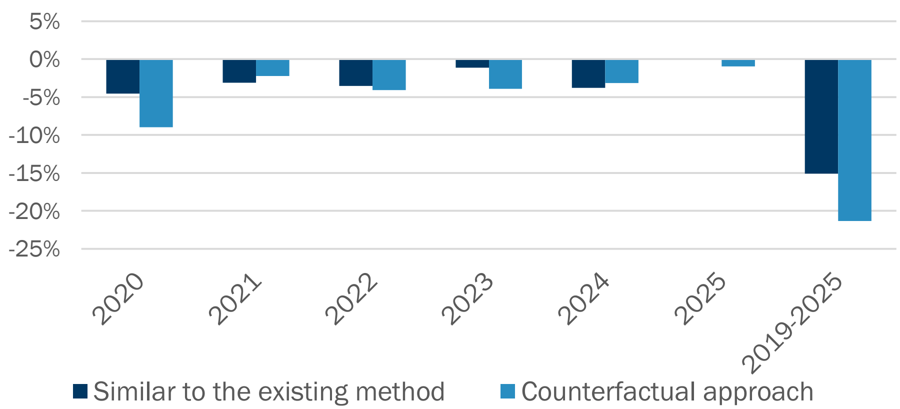
Both econometric models confirm that the results from previous approaches (existing and counterfactual) are aligned with historical trends, especially during periods with growing carbon prices.

Projected evolution of emission factors over the period 2019-25

Emission coefficients in CWE region – Counterfactual analysis



Emission coefficient growth in CWE region



Source: FTI-CL Energy modelling results

Notes: In the counterfactual approach, the CWE coefficient is calculated as a simple average of national coefficients.

- **We use our dispatch model under the base case scenario to assess the evolution of the emission factor until 2025 in CWE.** Our assumptions for the base case scenario are based on recognized third parties such as IEA, ENTSOE, RTE.
- As it is complicated to project the verified data used in the existing method (cogeneration, net to gross ratio for thermal units, total emissions…), **we elaborate a simplified version of the existing method to be able to perform a comparison of the future coefficients**. This proxy is based on the net generations and emissions from the thermal units in the CWE zone from our power model.
- The results show that :
  - **With both methods, the coefficient is expected to decrease over the period 2019-2025; and**
  - **The counterfactual analysis shows the most important decrease of the emission factor (21%) from 0.63t/MWh in 2019 to 0.50t/MWh in 2025, driven by coal closures partially replaced by less emitting technologies.**
- Sensitivities around the base case scenario lead to factors in the range 0.48-0.52 for the year 2025, showing that the base case results are robust.

The counterfactual analysis indicates an emission factor at 0.63t/MWh for year 2019. Both approaches project a decrease in the CWE emission factors. The counterfactual coefficient is projected to reduce to 0.50t/MWh in 2025.

Conclusions

- **The EC impact assessment (2012) and Guidelines (2012/C 158/04) explain the choice of the existing method for deriving the emission factor:**
  - No EU wide power market model was available to run a counterfactual analysis; and
  - The aim of the simplified method was to replicate a counterfactual analysis.

- **The results of our empirical analysis of historical emission factors indicate:**
  - An emission factor around 0.75t/MWh for the CWE region in 2013-15 with the counterfactual method. This result is consistent with the historical emission factor used by the EC over the period 2013-2015.
  - Similar levels for the emission factors within the CWE zone confirming that CWE is the relevant geographic scope for France.
  - When comparing the existing and counterfactual approaches, we find that the two methods show consistent results.
  - The counterfactual analysis tends to provide higher coefficients in the short term but is also more sensitive to power market changes.

- **Our projections of the emission factor rely on a set of recognised third party assumptions for the evolution of the power sector and suggest the following:**
  - The counterfactual analysis indicates that the emission coefficient will vary in the range [0.48;0.63]t/MWh over the period 2019-25 as a result of the changes in the generation mix.
  - Both approaches lead to similar decrease in the emission factor over the next years.

Context and objectives of the study

Context

- **The Guidelines of the EU Emissions Trading Scheme (EU ETS), established by the European Commission (EC) in 2012, allow Member States to compensate some electro-intensive parties for part of the increase in electricity costs (indirect costs) related to the introduction of a carbon price.** The aim of such compensation is threefold:
  - minimising the risk of carbon leakage;
  - preserving the EU ETS objectives to achieve cost-efficient decarbonisation; and
  - minimising competition distortions in the internal market.

- **EC's Communications 2012/C158/04 and 2012/C 387/06 define a formula to compute the maximum aid payable per installation for indirect carbon costs incurred in year t :**

$$\boldsymbol{Amax_{t-1} = Ai_t * C_t * P_{t-1} * E * BO}$$

With Ai_t : Aid intensity (%)

P_{t-1} :EUA forward price at year t-1 (EUR/tCO2)

E : product-specific electricity consumption efficiency benchmark (MWh/t)

BO : Baseline output (t), average production 2005-2011.

- **The compensation level is based on an emission factor C_t (tCO2/MWh) that represents the share of an increase in carbon prices that is passed through power prices.**
- **For France, the geographical area is the CWE zone (Central-West Europe: Austria, Belgium, Luxembourg, France, Germany and Netherlands) and the emission factor is 0.76 tCO_2/MWh.**

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Objectives of the study

- **The future of the compensation mechanism in the context of the revised EU-ETS scheme (phase IV: 2021-2030) is yet to be determined and the CO_2 emission factor could be revised by the Commission.**

- **In this context, Compass Lexecon was mandated by UNIDEN to perform an independent analysis of the emission factor evolution. Compass Lexecon delivered the following analysis:**
  - Review of the different possible approaches for the calculation of the CO_2 emission factor as well as the relevant geographical scope for France;
  - Empirical analysis of the past level of the CO_2 emission factor (2013-18) ; and
  - Prospective analysis of the future level of the CO_2 emission factor (2019-25).

- **The temporal scope of the analysis is voluntary restrained to 2019-25 as beyond this period there are many uncertainties regarding the evolution of European power markets that make it difficult to project the evolution of the emission factor.**

The approaches: counterfactual approach versus existing proxy

A. **Power price formation**

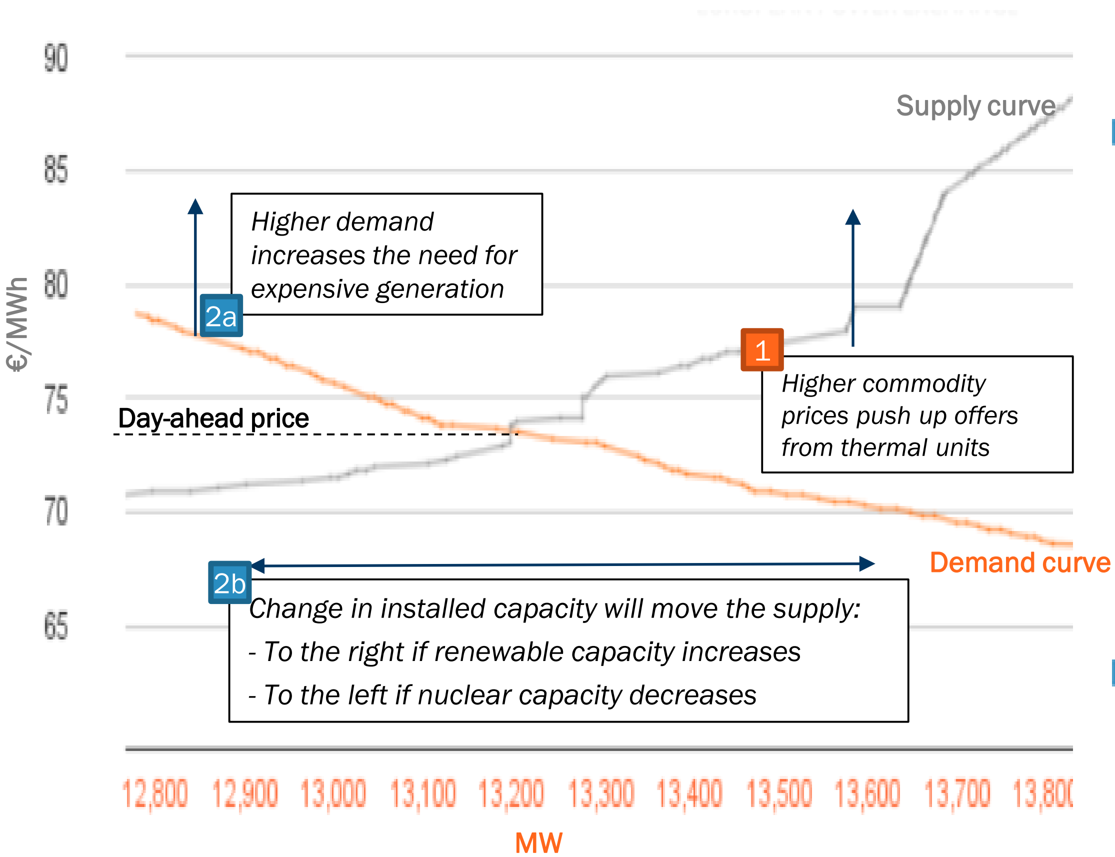
B. **The counterfactual analysis**

C. **The existing method**

D. **Conclusions**

Introduction: Drivers of day-ahead power prices in Europe

Illustration of power price formation on the day-ahead market



Source: FTI-CL Energy analysis based on EPEX Spot data

- The main market for trading electricity in Europe is the day-ahead market. This market is organized as an auction for each hour of the day. The hourly power price is defined by the most expensive plant required to produce in order to meet the hourly demand, based on a merit-order curve.

- **Two main factors drive** the wholesale power prices :
  1. Offers made by power plants, which are defined by their short-run marginal costs whose main driver is **the commodity prices** (coal, gas, CO_2…)
  2. The power market tightness, namely the **supply and demand levels** and the relationship between the two. For example:
     - 2a A higher demand increases the need for higher cost generation ;
     - 2b The deployment of low short run marginal cost technology (e.g. renewables) tends to decrease power prices.

- The carbon costs of power producers are passed to power prices through their offers in the day-ahead market.

The carbon costs of power producers are passed to power prices (consumers) through theirs offer on the day-ahead market.

The counterfactual analysis - definition

- The indirect costs paid by the industrials are directly linked to the increase of power prices related to the implementation of the ETS market.

- We define the **counterfactual analysis** as the methodology deriving the impact on the power price of a 1€/tCO2 increase in the carbon price

- To perform this analysis, we use our dispatch model that replicates the day-ahead power markets across Europe*. We run two scenarios :
  - A real scenario with the ETS market (including a carbon price)
  - A counterfactual scenario without the ETS market and so without carbon price.

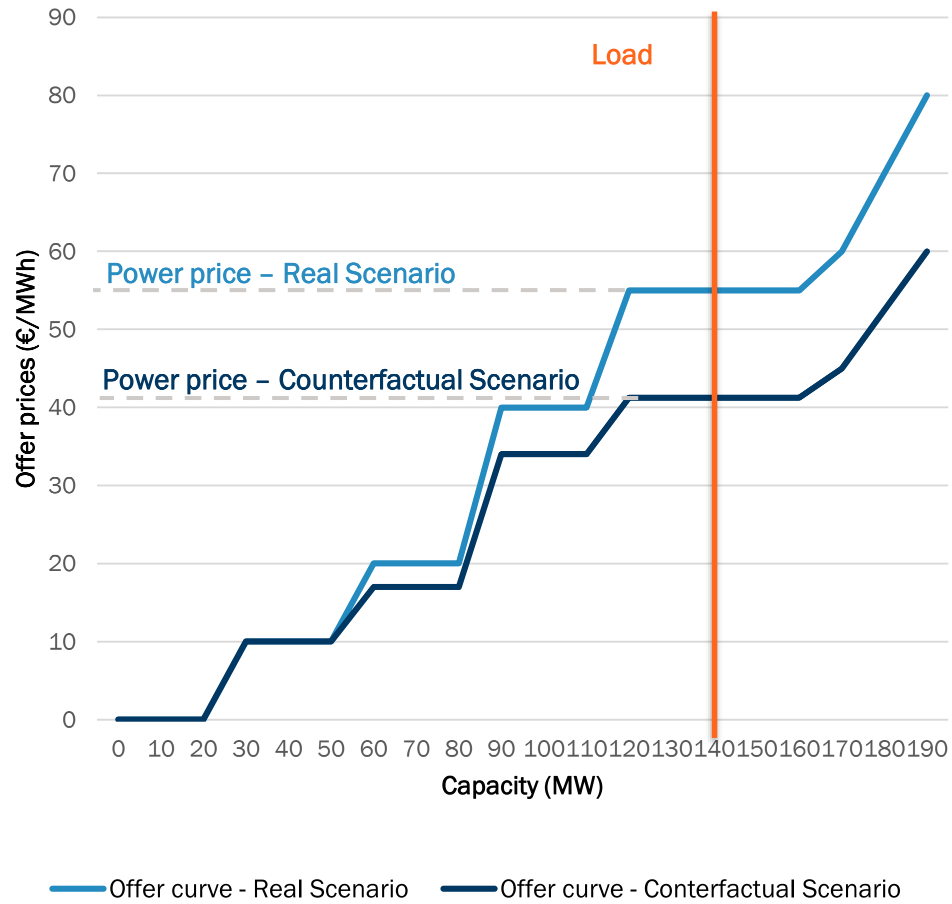
- The emission factor (t/MWh) is determined as follows :

$$\frac{(Power\ price_{\ Real} - Power\ price_{\ Counterfactual})}{Carbon\ price}$$

- This factor represents the increase in power prices in €/MWh that will result from a 1€/t rise in carbon prices.

* Our power price model is presented in annexe.

Merit order curves in the two scenarios – Illustrative graph



Source: FTI-CL Energy analysis

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The exiting method defined in the Guidelines 2012/C 158/04

- The EC 2012 Guidelines set the **existing method** to calculate the emission factor:
  - *"CO2 emission factor in tCO2/MWh, means the weighted average of the CO2 intensity of electricity produced from fossil fuels in different geographic areas. **The CO2 factor is the result of the division of the CO2 equivalent emission data of the energy industry divided by the gross electricity generation based on fossil fuels in TWh**."* *Source: EC, 2012.*

- The formula to calculate the emission factor used in the existing method is therefore the following* :

$$\boxed{\frac{Emissions\ from\ the\ energy\ industry}{Gross\ thermal\ generation}}$$

- The reasons behind this simplified method are presented in the EC impact assessment (2012):
  - The EC mentions that an EU wide electricity market model could have been used to run a counterfactual scenario without ETS to assess the emission factor. However such a model was not available in 2012.
  - The alternative proxy approach used in the impact assessment to evaluate the emission factor focusses on the marginal generation which set wholesale power prices. Since the marginal units are often thermal units, only the thermal generation is used for the ratio calculation (emissions divided by thermal generation)

- **This simplified approach would only remain relevant if the marginal units continue to be thermal plants in Europe.**

* We present the data to be used for the calculation on the slide 22

The EC 2012 Guidelines introduced a simplified method to calculate the emission factor used in the indirect cost compensation. This method aims to replicate a counterfactual analysis.

The geographic scope defined in the Guidelines 2012/C 158/04

- The choice of geographic scope is described as follows:
  - *"For the purposes of these Guidelines, the areas are defined as geographic zones (a) which consist of submarkets* ***coupled through power exchanges****, or (b) within which no declared congestion exists and, in both cases****, hourly day-ahead power exchange prices within the zones showing price divergence in euros (using daily ECB exchange rates) of maximum 1 % in significant number of all hours in a year.*** *Such regional differentiation reflects the significance of* ***fossil fuel plants for the final price set on the wholesale market and their role as marginal plants in the merit order"***
  - ***"Given the lack of relevant data at sub-national level, the geographic areas comprise the entire territory of one or more Member States.*** *On this basis, the following geographic areas can be identified: Nordic (Denmark, Sweden, Finland and Norway), Central-West Europe (Austria, Belgium, Luxembourg, France, Germany and Netherlands), Iberia (Portugal, Spain), Czech and Slovakia (Czech Republic and Slovakia) and all other Member States separately"*

Source: EC, 2012.

- **For France, the relevant geographical area is the CWE zone (Austria, Belgium, Luxembourg, France, Germany and Netherlands) and the emission factor is 0.76 tCO_2/MWh.**

- The existing method does not mention the reference year used for the determination of the current emission factor.

The 2012 Guidelines gathers countries per zone based on the market integration between these Member States.
The relevant geographical area for France is the CWE zone.

Conclusion on the different approaches

- **As a conclusion, the EC impact assessment and the EC 2012 Guidelines suggest that:**
  - The original aim of the EC was to rely on a counterfactual analysis with an EU wide power market model (using a counterfactual scenario without ETS)
  - As no EU wide power model was available to run a counterfactual analysis, a simplified method was used
  - This proxy aims to replicate a counterfactual analysis by focusing only on the thermal generation.

- **Two different approaches could therefore be used:**
  - **The existing method**
    - This approach is simple and transparent and has been validated by the EC but will however likely be questioned in future years as the number of hours with thermal marginality in the power market is expected to decrease.
  - **A counterfactual analysis**
    - This approach would capture in a more precise way the actual impact of carbon prices on power prices but would likely be less transparent as it is based on a European power market model which entails making some assumptions about a number of parameters and assumptions.

  => We compare the results of these two approaches on the period 2013-2018 in the following section

- **In the EC Guidelines, the choice of the geographic zone is based on the degree of market integration within the zone.** We investigate in the following sections whether the CWE zone remains relevant for France.

Empirical analysis of the historical emission factor

A. **The counterfactual analysis**

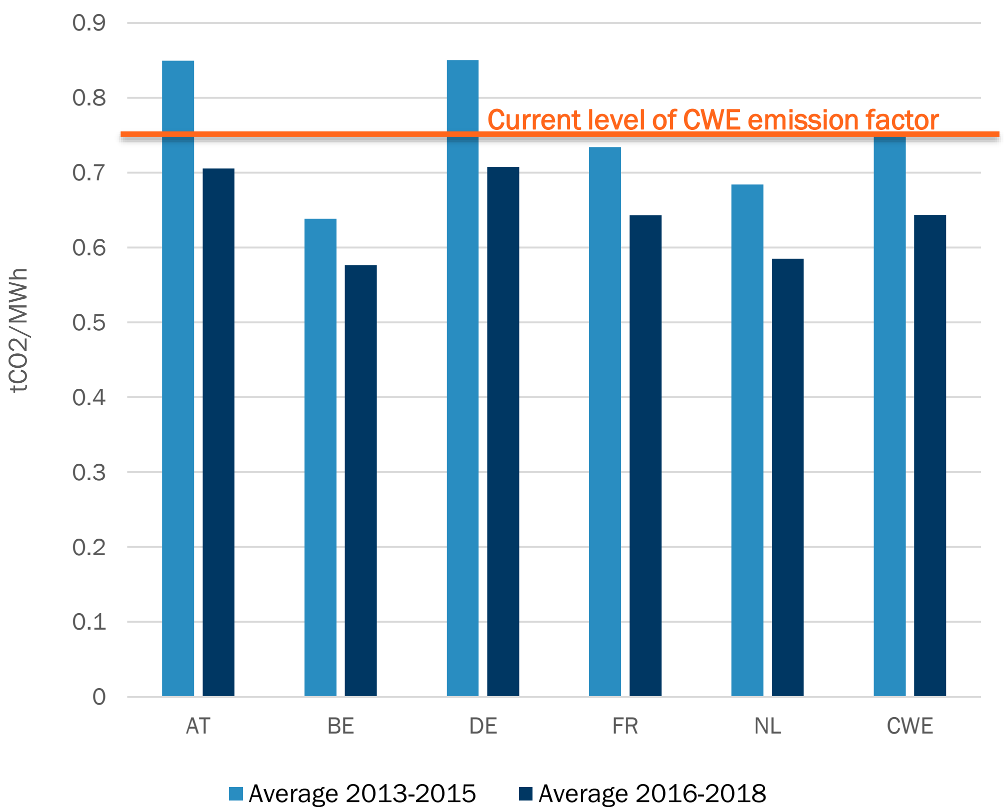
B. **The existing method**

C. **Comparison of the two approaches**

D. **Validation of the results with econometric models**

We use our power market model to estimate the emission factor for the CWE region over 2013-15 with a counterfactual analysis

Historical emission coefficients – Counterfactual approach



Source: FTI-CL Energy modelling results

- We use our European dispatch power model to assess the impact of the carbon price on power prices with a counterfactual method as described in the previous section.
- **The result for the CWE region (0.75) for period 2013-2015 is similar to the current coefficient (0.76) set by the existing method of the EC presented in previous slides.**
- **The results show a decrease in the emission factor from 2016 for all countries in the CWE zone. This reduction is driven by emission standards and coal closures partially replaced by less emitting technologies.**

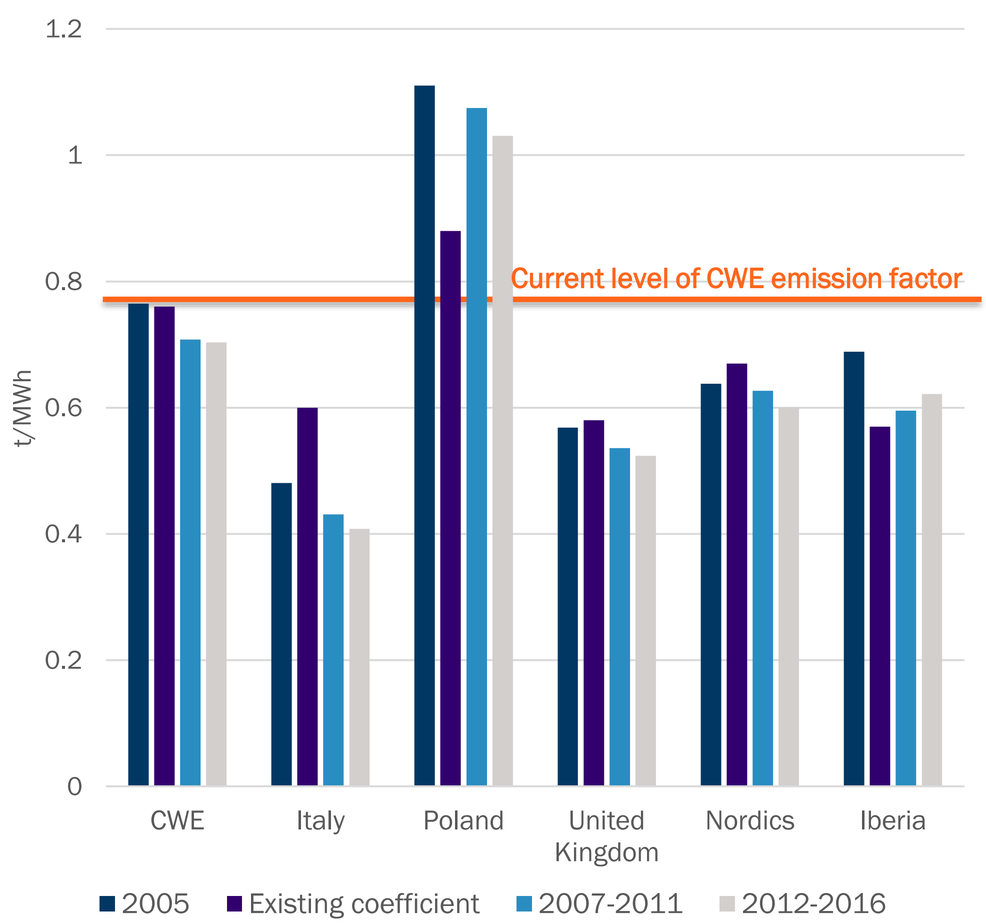
Geographical Market

- **As expected, emission factors are similar in the CWE zone due to market integration.**
- **These results confirm that the CWE region was the relevant geographic market for France over the period 2013-18.**

Our European power market model indicates an emission factor around 0.75t/MWh for the CWE region in 2013-15 aligned with the existing emission factor. This analysis also confirms that the CWE zone is the relevant market for France.

Historical emission factors based on the existing method used by EC

Historical emission factors – existing method



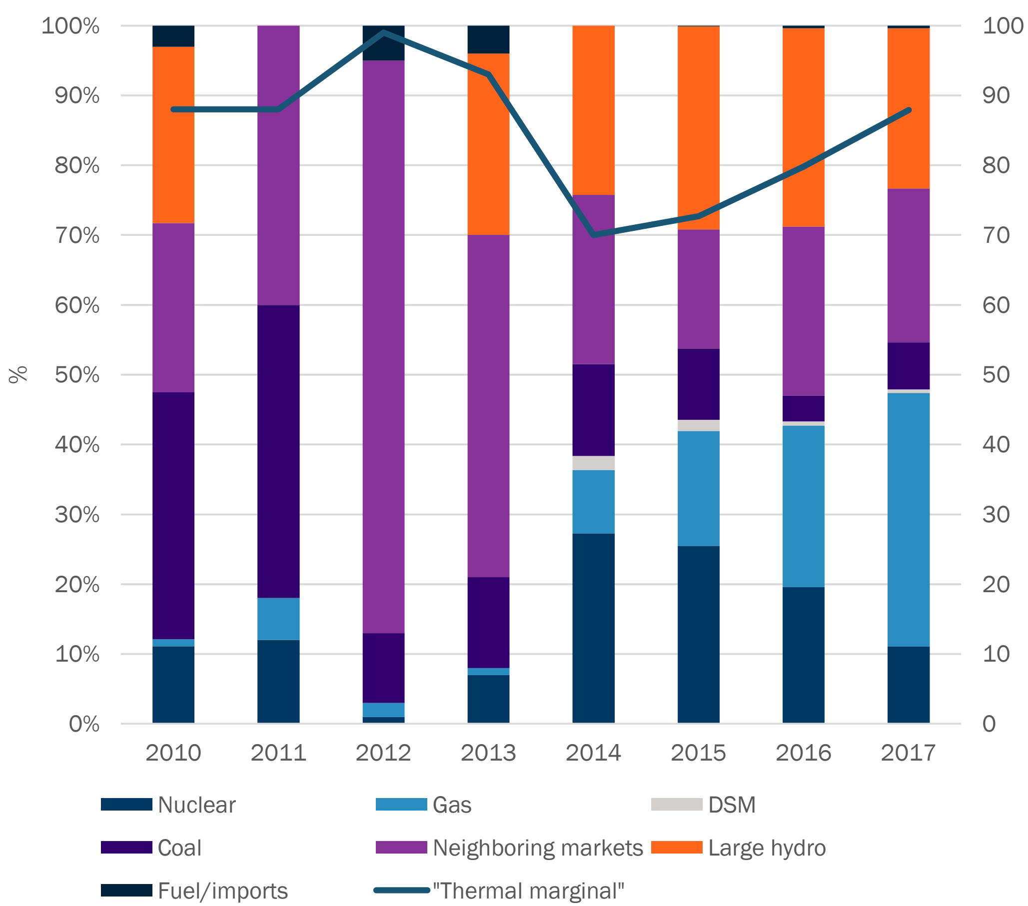
Source: FTI-CL Energy based on Eurostat data

- **We apply the existing method (provided by the European Commission) to historical data to analyse the historical evolution of emission factors.**
- **The existing method does not stipulate exactly the data to be used in the calculation. Our calculation is based on :**
  - The total gross power generation from fossil fuel (Eurostat)
  - The emissions from "*fuel combustion in public electricity and heat production*" (Eurostat).
- The existing method does not mention the reference year used for the determination of the current emission factors. Historical data suggest that the year 2005 might have been used for the CWE zone.
- **Our results over the period 2007-2016 are consistent with the EC's existing emission factors.**
- **Historical data show a slight decrease in emission factors for most regions between 2007 and 2016, mainly driven by :**
  - A reduction of coal/lignite capacity
  - Measures targeting emissions such as IED and LCPD
  - A reduction in peak oil unit production

Historical data shows a consistent level of the CWE emission factor with EC's existing emission factor, and a slight decrease over recent years.

Analysis of historical marginal fuel in France

Historical marginal fuel in France



Source: FTI-CL Energy based on CRE data

Notes: « Thermal marginal » is calculated as the sum of Gas, Nuclear, Neighbouring markets, Hydro and Fuel/imports.

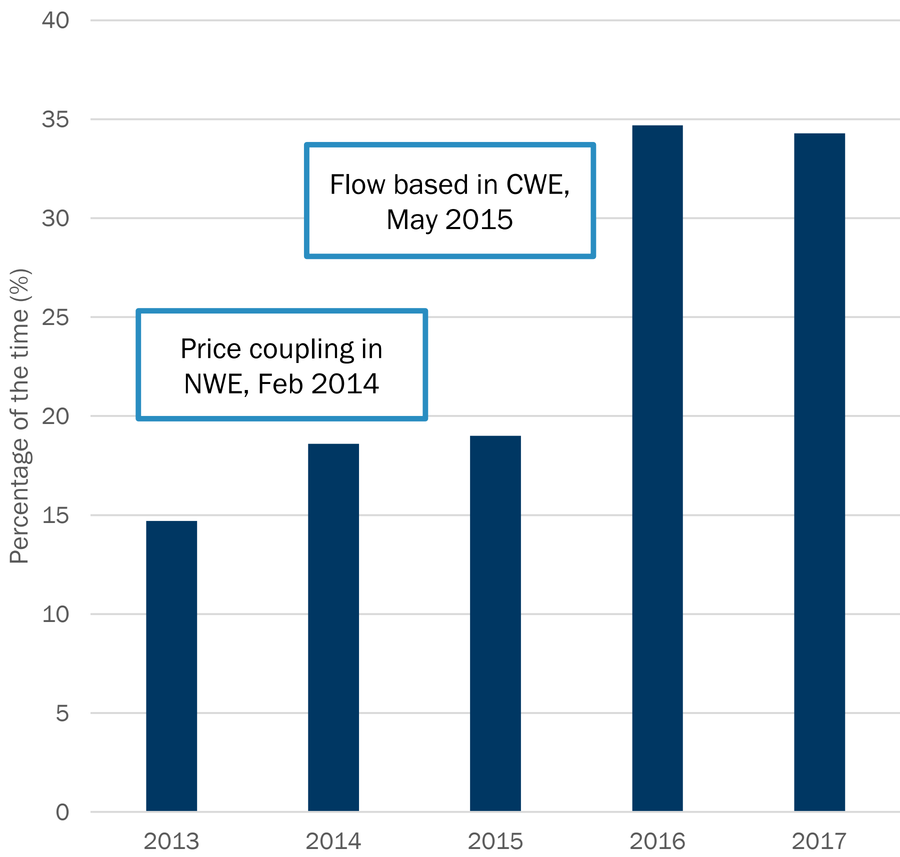
2018 data was not available when the analysis was performed.

- The existing method remains relevant if marginal units are mostly thermal plants.
- The French energy regulator (CRE) provides information regarding the marginal technology in France. The historical data show:
  - A stable distribution of the marginal technology across different generation types between 2014-2017 after important fluctuations between 2010-2013; and
  - The national thermal capacity was marginal 22-43% of the time during the period 2014-2017.
- Considering that large hydro and neighbouring markets are priced to some extent with reference to the costs of thermal units:
  - The number of hours with "thermal marginal" have slightly decreased over the period 2010-2017;
  - However, this number remains significant.
- These results show that despite a small decrease in the number of hours set by "thermal marginal", the prices in France are still largely determined by fossil plants. Therefore the existing method for deriving the emission factor remains relevant.

Historical data show that thermal generation continues to frequently set the price in France, either directly or indirectly.
The existing method therefore remains relevant for estimating the emission factor.

Geographic market : The use of the CWE zone for estimating the French coefficient

Occurrence of one unique price within the CWE zone



Source: FTI-CL Energy analysis based on RTE data

Notes: The price convergence translates in one unique price within the CWE zone.

2018 data was not available when the analysis was performed.

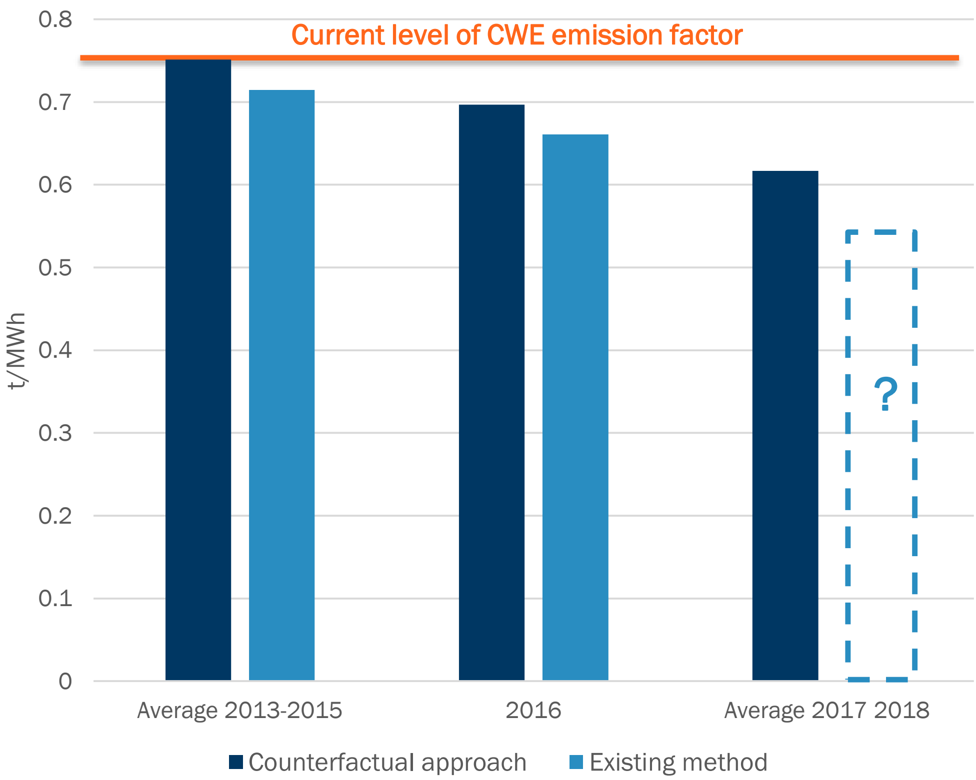
- In the existing method, the countries in the CWE zone are pooled in one unique group. This pooling is based on the current market integration within the zone that results in similar impacts of a carbon price increase on power prices.
- The CWE zone remains the relevant geographic market for France:
  - The number of hours with full convergence (one unique price) within the CWE zone has been increasing since 2013.
  - Our analysis also shows that the price spreads are lower than 5€/MWh during 63% of the time on average in the zone CWE* in 2016-18; and
  - Our counterfactual analysis shows similar emission factors within the CWE zone justifying the utilisation of one unique coefficient for the zone.
- Additional cross border capacity within the CWE zone will continue to increase the market integration within the CWE zone in the coming years. We expect the following additions over the next 6 years:
  - FR-BE : +1 GW
  - DE-FR: +0.7/1.2 GW
  - BE-DE: +1 GW
  - BE-NL: +1/2 GW
  - DE-NL:+0.75 GW

** This analysis is presented in annexe.*

Historical data and our counterfactual analysis show that the CWE zone remains the relevant geographic market for France. Further convergence is expected with the deployment of 5 GW of additional interconnection capacity within the zone.

Comparison of the two approaches: existing versus counterfactual

Emission coefficients in CWE region



Source: FTI-CL Energy modelling results, FTI-CL Energy analysis based on Eurostat data

Notes: Historical data for years 2017-2018 is not available yet on Eurostat website.In the counterfactual approach, the CWE coefficient is calculated as a simple average of national coefficients.

- The comparison of the two approaches provides the following results :
  - **Despite small differences, the two approaches show similar results.**
  - **The existing method results in lower emission factors compared to the counterfactual approach**. This effect comes from the countries with important gas generation. These countries have a lower emission coefficient with the existing method / a higher coefficient with the counterfactual approach as their power prices are often set by neighbouring markets with coal capacity*.
  - **With the counterfactual approach, the coefficient decreases after 2016**. This number cannot be compared with the existing method as verified data is not published yet.
- The counterfactual method therefore leads to a higher coefficient in the short term but also potentially to a lower coefficient in the long term.

*Notes: *Emission factors varies from around 0.4t/CO2 for gas assets to more than 1t/CO2 for lignite plants.*

Despite small differences, the existing method provides similar estimates to the ones derived using the counterfactual analysis over the period 2013-2016. The existing method therefore remains relevant for deriving the emission factor.

Conclusions on the empirical analysis of historical emission factors

- **The counterfactual analysis with our European electricity market dispatch model shows that:**
  - The emission factor averages at 0.75t/MWh for the CWE zone for the period 2013-2015. This validates the historical coefficient used by the EC over this period.
  - Similar levels for the emission factors of different countries within the CWE zone confirming that CWE is the relevant geographic scope.

- **The calculation of the CWE emission factor coefficient with the existing method indicates:**
  - A consistent level with EC's existing coefficient.
  - A slight decrease of the coefficient over the period 2011-2016.

- **The existing method and the CWE geographic scope remain relevant for estimating the French emission factor:**
  - Historical data show that marginal units are still mainly thermal plants and therefore that the existing method is still relevant.
  - Historical data and the counterfactual analysis show that the CWE zone is still the relevant geographic market to consider for France.

- **The comparison of the two approaches shows that :**
  - Despite small differences, the results are consistent between the two approaches.
  - The existing method results in a lower coefficient compared to the counterfactual approach.
  - With the counterfactual analysis, the coefficient has been decreasing since 2016.

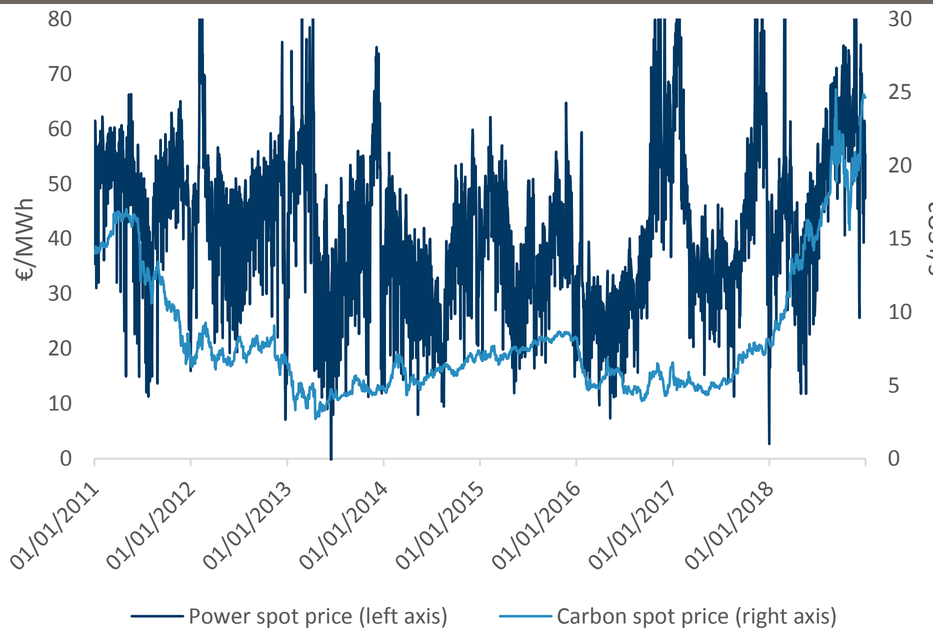
Our counterfactual analysis validates the historical coefficient used by the EC over the period 2013-2015. The two methods show similar estimates, which suggests that the existing method could therefore continue to be used for the next years.

To validate the previous results, we replicate the dynamics of spot & forward French electricity prices using econometric models

- We validate the estimates of the French emission factors presented previously with two econometric models* :
  - One model replicates spot power prices over the period 2015-2018; and
  - One model focuses on the forward prices for the period 2011-2018 and provides a coefficient for each period defined by structural breaks in power and carbon markets.
  - A literature review was performed to assess the best econometric models for emission factor estimation. The results of this overview of best practices are presented in annexe.

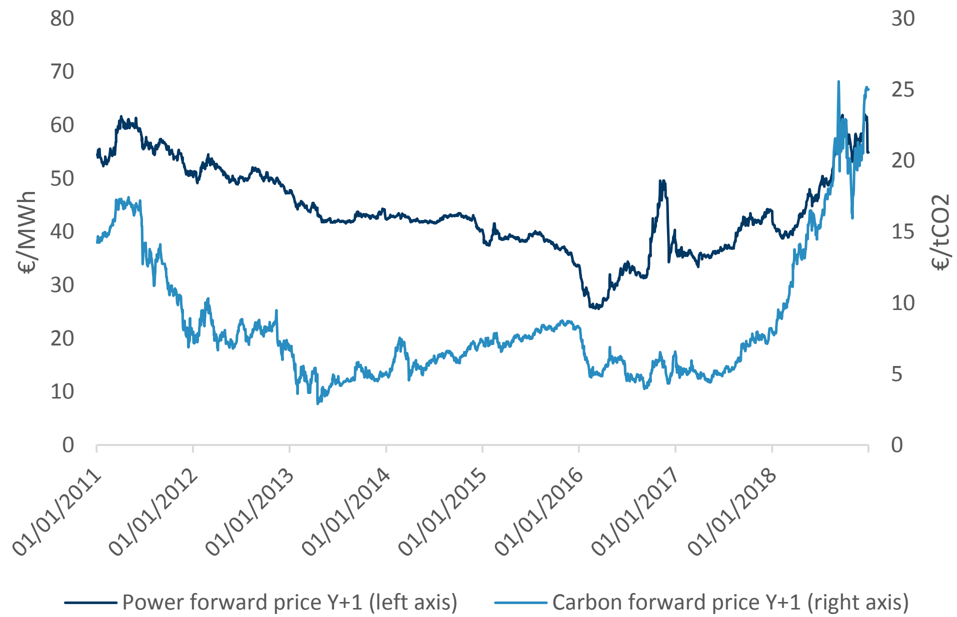
Spot electricity and carbon price series

High volatility of spot prices leaves a large amount of variations unexplained by CO2 price and other fundamentals.



Forward base electricity and carbon year-ahead (Y+1) price series

In contrast, the relationship between electricity and CO2 prices can be clearly observed in forward series, meaning that estimation of the CO2 pass-through rate would be more robust if it is based on forward series

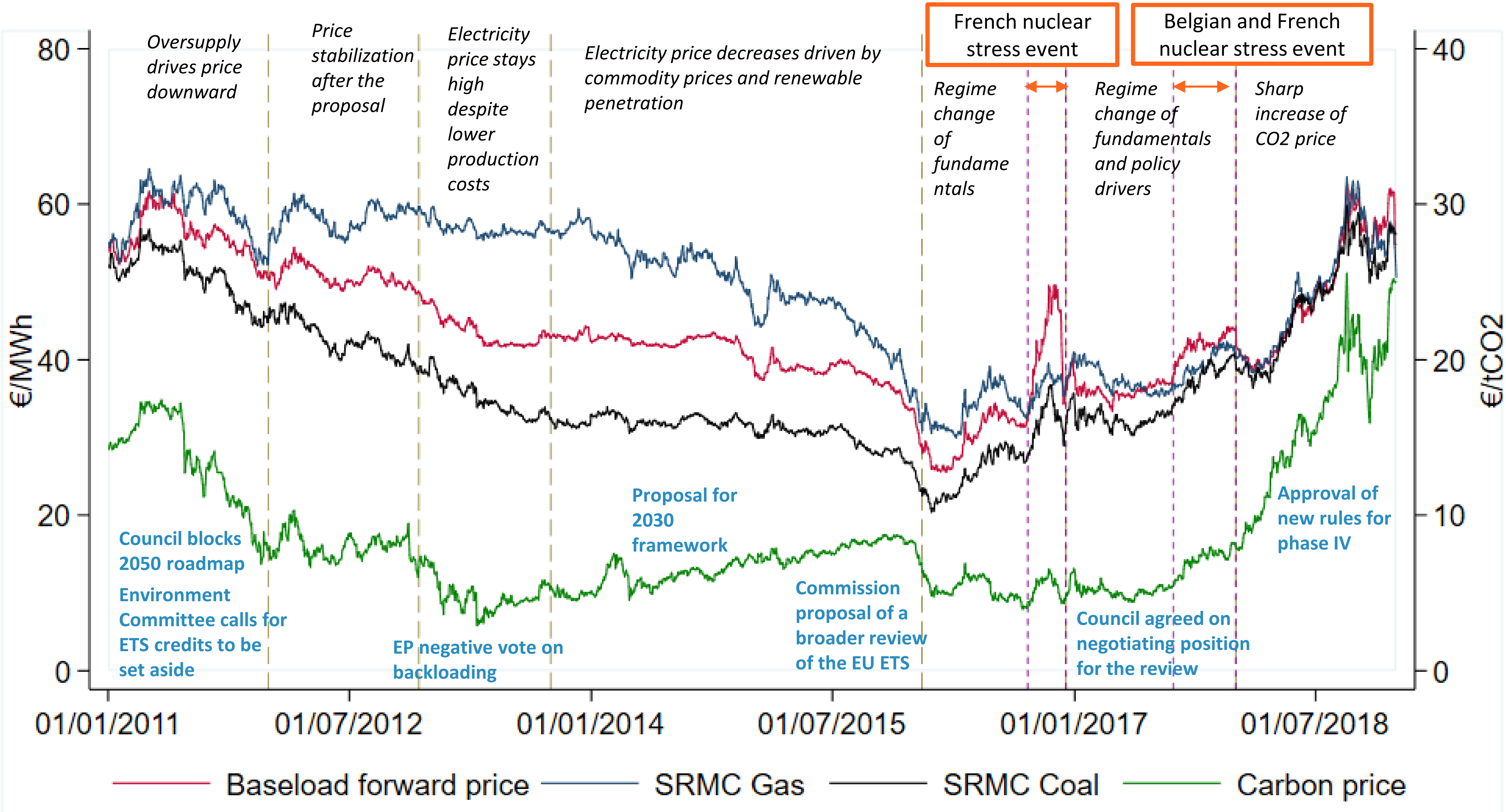


* The detail of our analysis is presented in annexe

Source: FTI-CL Energy analysis based on EnergyMarketPrice data

To estimate the evolution of the French emission factor, we identify structural breaks, accounting for policy drivers, market fundamentals and shocks on forward markets

	01/01/11-29/12/11	30/12/11-05/12/12	06/12/12-30/09/13	01/10/13-19/01/16	20/01/16-11/12/16	12/12/16-31/12/17	01/01/18-31/12/18
Emission factor	0.63	0.53	1.23	0.63	0.87	0.89	0.76



Source: FTI-CL Energy based on EnergyMarketPrice

Note: SRMC is the Short-Run Marginal Cost for a given type of generation.

The results of our econometric models using spot & forward power and CO2 prices for France

Spot analysis

- We estimate the carbon pass-through rate in France over the period of 2015-2018 accounting for residual demand, which explains to a large extent variations of the spot power price.
- **Over the period 2015-2018 using daily data, we obtain an average pass-through rate of 0.59, meaning that 1€/tCO2 increase is translated to an increase of 0.59€/MWh in French electricity price.** The coefficient ranges between 0.45 to 0.73 at 95% confidence level.
- **Our approach is consistent with the study from Bariss et al. (2016) taking into account market-specific fundamentals with an OLS (Ordinary Least Squares) regression.**
- **Our estimation results are in line with the majority of empirical studies in the literature**
  - Existing empirical studies demonstrate that the estimated coefficient is very sensitive to estimating periods and sometimes is not consistent with economic sense.

Forward analysis

- **We identify structural breaks in order to construct relevant estimation periods and ensure robust and stable relationships between Y+1 electricity price and Y+1 CO2 price.**
- Our analysis on the forward econometric model show that:
  - **The period 2011-18 can be split into seven sub-periods** with identified structural breaks;
  - The regression provides one coefficient for each structural break: **emissions factors vary between 0.53 and 1.23 depending on the period considered**;
  - **For the year 2018, the regression provides 0.76 as emission factor**. In periods characterised by a strong increase in carbon prices, the econometric model leads to similar results to the other two approaches. This outcome is particularly interesting because these periods result in high compensation levels from the Member States to the industrials.
- The emission coefficients for each period are presented on the previous slide.

Projections of the emission factor and sensitivities

A. **Base case scenario**

B. **Emission factors**

C. **Sensitivities**

For the projections of the electricity and carbon markets, we use a scenario based on IEA, ENTSOE & RTE outlooks

- **In order to have a robust and neutral scenario, we use assumptions based on recognized third parties such as:**
  - The 2018 World Energy Outlook (WEO) – IEA (International Energy Agency)
  - The 2018 Mid term Adequacy Forecast (MAF) – ENTSOE (European Network of Transmission System Operators for Electricity)
  - The 2018 French adequacy outlook (BP) – RTE (Réseau de transport d'électricité)

- **These sources are used as follows:**
  - WEO New Policy scenario for fuel and carbon prices
  - ENTSOE installed capacity and demand for neighbouring markets
  - 2018 BP RTE for French installed capacity and demand

- **We use RTE outlook instead of ENTSOE projections for the French market to reflect the latest policy decisions:**
  - RTE outlook is more aligned with most recent '*programmations pluriannuelles de l'énergie*' (PPE), published in 2018 by the French energy ministry (ENTSOE data expects a reduction in nuclear capacity by 2025).

We base the French prospective scenario on RTE BP, PPE & ENTSOE data for the modelling horizon between 2019-2025

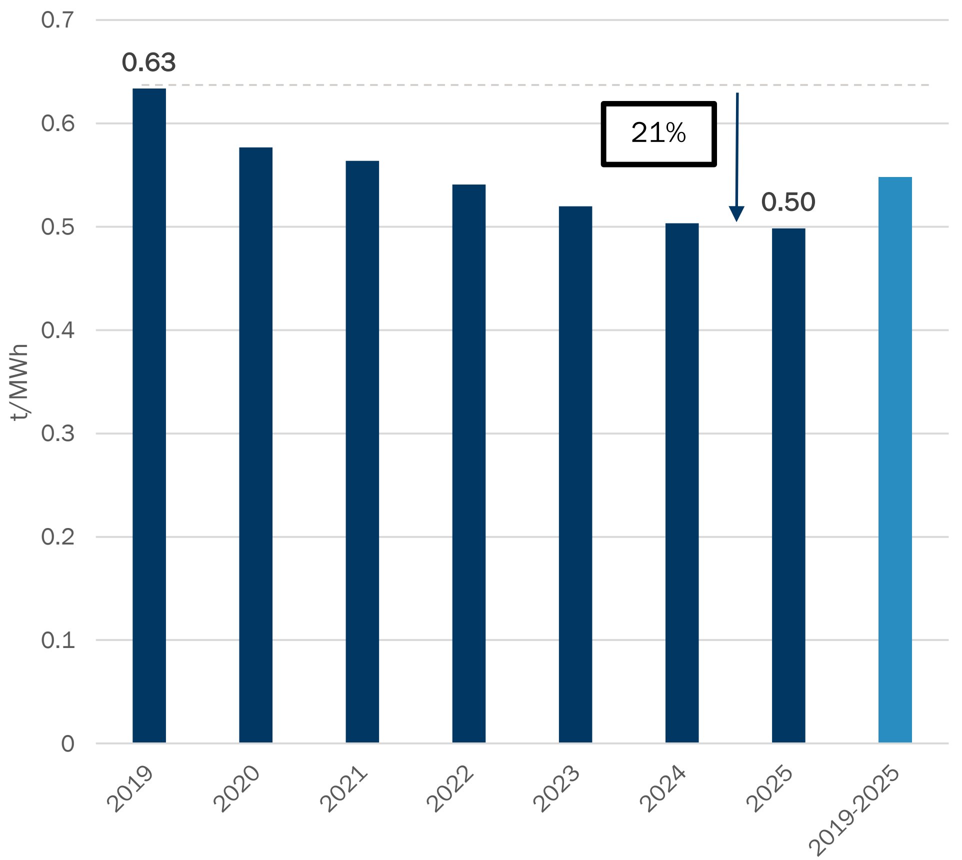
Power market price scenario	1 Power demand	2 Nuclear and thermal policy	2 Renewable policy	3 Commodities	4 Interconnections
BASE CASE	▪ Stable annual and peak outlooks throughout modelling horizon reflecting latest trends and RTE forecasts	▪ Nuclear capacity to remain stable until 2025 ▪ Thermal capacity follows PPE and RTE BP trajectory ▪ No new thermal capacity will come online	▪ Solar and wind capacity based on RTE base case scenario	▪ Coal and Gas prices are based on forward* and WEO – NP outlook. ▪ Carbon prices follow the forward* and WEO – NP outlook.	▪ Cross border capacity outlook is based on ENTSOE scenario expansion ▪ Load and installed capacity in neighbouring markets are based on ENTSOE MAF 2018
	• 2025 demand: 478 TWh	▪ Landivisiau will be commissioned in 2021 ▪ Coal phase out by 2022 ▪ Only Fessenheim will close before 2025	▪ Wind installed capacity : 23 GW onshore; 3 GW offshore in 2025 ▪ Solar installed capacity : 21.3 GW in 2025	▪ Coal: 10.3 €/MWh in 2025 ▪ Gas: 24 €/MWh in 2025 ▪ Carbon :29.4 €/t in 2025	▪ Imports capacity in 2025: 18 GW ▪ Exports capacity in 2025: 24.6 GW

Notes: the detailed inputs are presented in annexe

** We use the average of forward prices for the last three months*

Modelling results - Counterfactual analysis of the CWE emission factor

Emission factor in CWE region



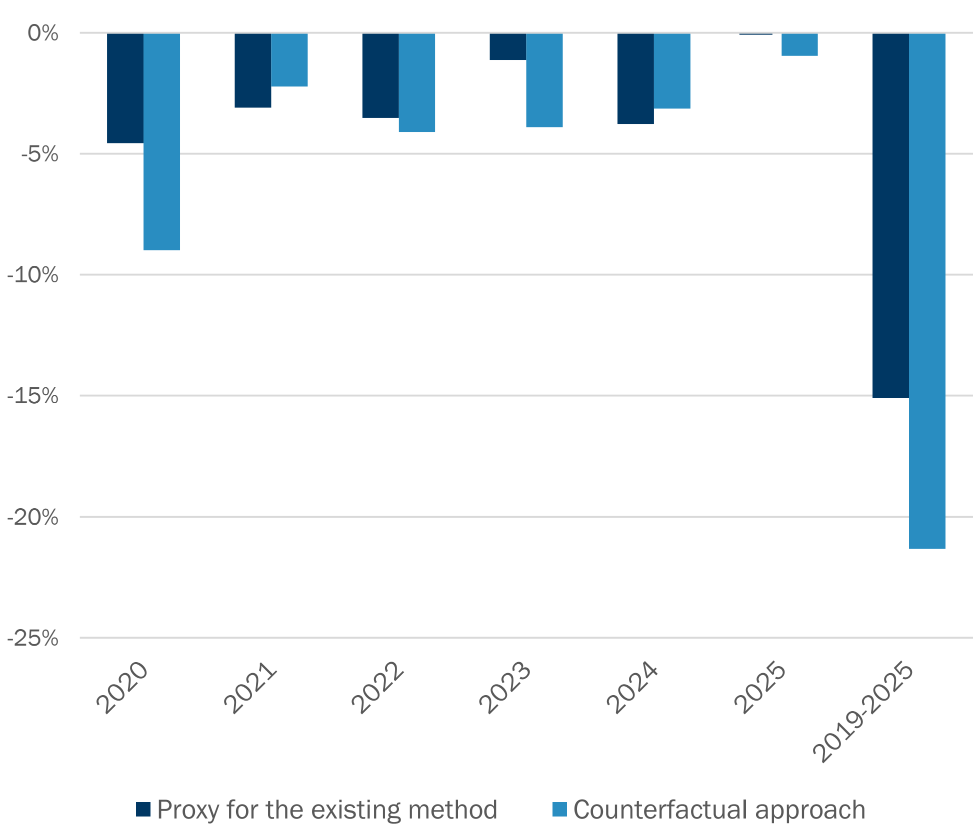
Source: FTI-CL Energy modelling results

- **We use our dispatch model under the scenario mentioned above to assess the evolution of the CWE emission factors until 2025:**
  - We run our power model with projected carbon prices
  - We run our power model with a carbon price at 0€/t. (counterfactual scenario without ETS mechanism).
  - We estimate the emission factor as the power price difference between the two runs divided by the historical carbon price for each year.
- The detailed results of the modelling (power prices and generation) are presented in annexe.
- **The results shows a decrease in the CWE emission factor:**
  - The average factor in the CWE zone is expected to reduce from 0.63t/MWh in 2019 to 0.50t/MWh in 2025.
  - This decrease is driven primarily by coal plant closures partially replaced by less emitting technologies.

The prospective counterfactual analysis shows a decrease in the CWE emission factor to 2025.
The emission factor is projected to reduce from 0.63t/MWh in 2019 to 0.50t/MWh in 2025.

Comparison between the two approaches

Emission factor year on year evolution in CWE region



Source: FTI-CL Energy modelling results

- As it is complicated to project the verified data used in the existing method (cogeneration, net to gross ratio for thermal units, total emissions…), we elaborated a simplified version of the existing method to be able to perform a comparison of the future coefficients.
- This proxy is based on the net generations and emissions from the thermal units in the CWE zone from our power model and provides indications regarding the evolution of the coefficient with the existing method.

- The results show that :
  - **With both methods, the emission factor is expected to decrease over the period 2019-2025**
  - **The counterfactual analysis is the most impacted by coal closures partially replaced by less emitting technologies and therefore shows the most important decrease.**

Both approaches show a consistent reduction of the emission factor over the next years.

Sensitivity analyses around the base case scenario

Sensitivity analyses

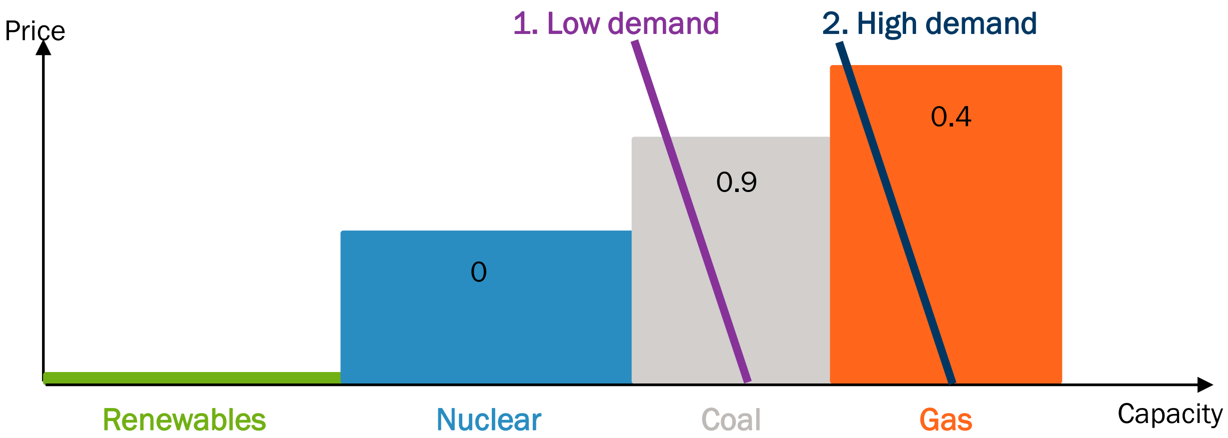
Scenario	Changes compared to the base case
Coal-to-gas switching	Carbon prices at 56€/t in 2025
Coal capacity reduction	9.4GW of coal capacity is closed in Germany, Netherlands and Italy
Low nuclear generation	Average French nuclear availability is reduced by 6 GW
Increase in renewable capacity	Renewable capacity is increased by: 22 GW for onshore wind 6 GW for offshore wind 26 GW for solar

- We perform four sensitivity analyses to assess the impact of some of the key assumptions in the base case scenario on the evolution of the CWE emission factor :
  - **Coal-to-gas switching**: The carbon prices are increased in order to have generation from coal units more expensive than gas generation.
  - **Coal capacity reduction**: Additional coal capacity is closed across Europe. These additional closures are based on recent announcements or intentions from European governments.
  - **Low nuclear generation** : We apply a 10% reduction on French nuclear availability. This could be driven by longer than expected ten-year inspections or by outages on the French nuclear fleet.
  - **Increase in renewable capacity**: A 15% capacity increase above and beyond the increase in the base case is implemented for countries in the CWE zone and its neighboring markets. The French capacity is based on the High PPE scenario.
- The aim of these sensitivities is to validate the robustness of the base case results presented on previous slides.

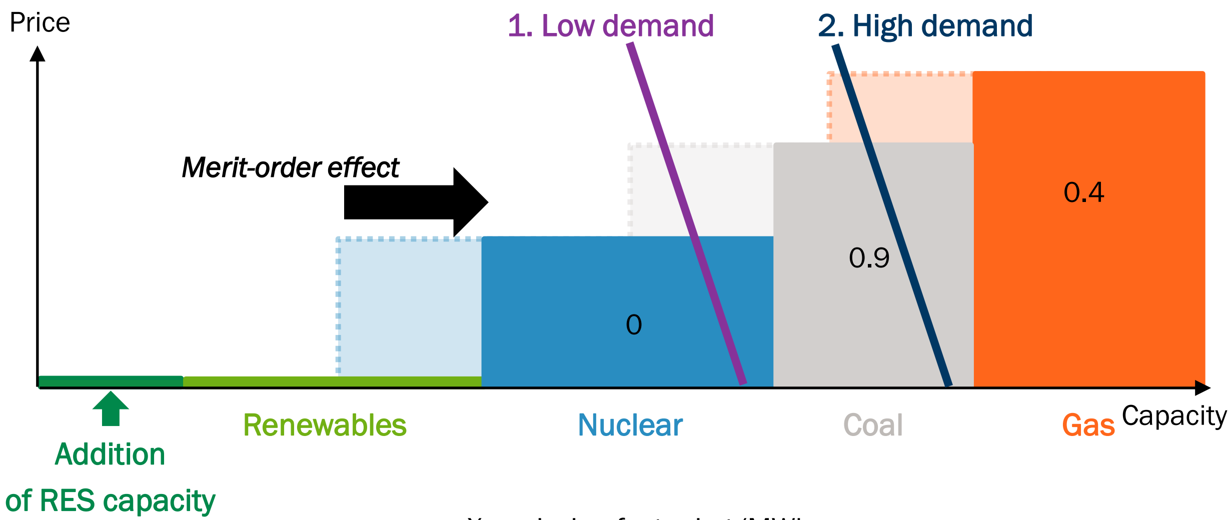
Source: FTI-CL Energy analysis based on data from ENTSOE, RTE

Illustration of the impact of renewable capacity additions on the emission coefficient

Base case scenario – illustrative graph



Increase in renewable capacity – illustrative graph



X: emission factor in t/MWh

1. During **off-peak hours**, the coal technology tends to be marginal: the marginal emission coefficient is then defined by **coal** during these hours (around 0.9)
2. During **peak hours**, the gas technology tends to be marginal: the marginal emission coefficient is then defined by **gas** during these hours (around 0.4)

Two **opposing effects** on the evolution of the emission coefficient:

- The overall effect depends on several factors (RES addition, original merit-order curve…)
- In our simulations, the **increasing effect is prevailing**: the emission coefficient increases as coal tends to replace gas as the marginal technology and nuclear being priced by neighbouring markets.

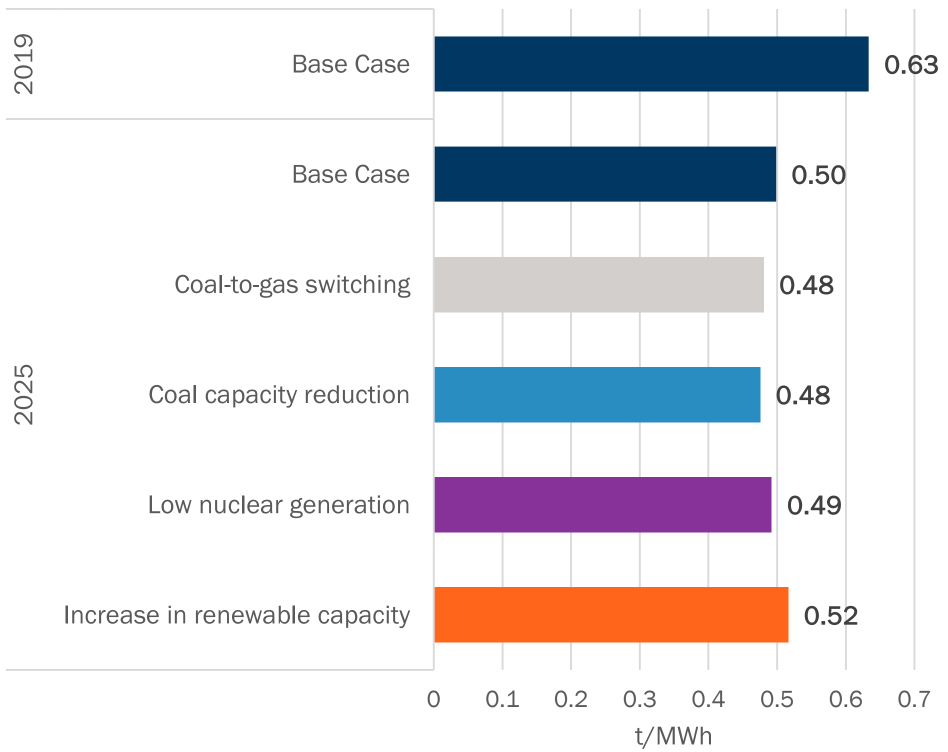
With the renewable additions:

1. **Nuclear technology becomes marginal** during off-peak hours. The marginal emission coefficient should **decrease** (from 0.9 to 0). However, the nuclear will **be exported to neighbouring countries** in this situation and priced at their thermal plant SRMCs, resulting in a **zero-impact on the emission factor level**.
2. **Coal technology is more often marginal** during peak hours. In this case, the marginal emission coefficient increases (from 0.4 to 0.9).

Notes: We assume that coal generation is cheaper than generation from gas units as in our base case.

Results of sensitivity analyses around the base case scenario

CWE emission factors in various sensitivity analyses



Source: FTI-CL Energy modelling results

- **Despite changes in the capacity mixes or fuel prices, the emission factor remains by 2025 in a narrow range of 0.48-0.52. This analysis shows the robustness of our base case scenario.**
- These results depend significantly on whether coal or gas plants are marginal. The fuel and carbon price assumptions in our base case make coal generation cheaper than the generation from gas units. This is also the case in the sensitivities except in the *coal-to-gas switching* sensitivity. This sensitivity indicates that the emission factor will be lower in the case in which gas generation would become cheaper than coal generation.
- The other sensitivity analyses show that :
  - Removing coal capacity from the power mix (with coal closures) will result in a lower emission factor for the CWE zone.
  - Increasing renewable generation leads to two opposing effects (c.f. previous slide) which with our base case commodity price assumptions lead to an overall increase of the emission factor.
  - The low nuclear scenario results in a higher emission factor for France. However it pushes the CWE zone to use more gas generation and therefore leads to a lower coefficient for the zone.

The CWE emission factor remains in the range of 0.48-0.52t/MWh for the year 2025 across the different sensitivity analyses, validating the robustness of the base case result.

Conclusions

Conclusions

- **The results of our analysis of historical emission factors across CWE indicate:**
  - An emission factor of 0.75t/MWh for the CWE region in 2013-15 with the counterfactual method, consistent with the historical emission factor used by the EC over the period 2013-2015 for the CWE zone.
  - Similar emission factors for the different countries within the CWE zone confirming that CWE is the relevant geographic market to estimate the French emission factor.
  - A reduction in the emission factors since 2016 corresponding to the changes observed in the generation mix over the last years.
  - The existing and counterfactual approaches provide consistent results, such that the existing method could therefore continue to be used for the next years. The counterfactual analysis tends to provide higher emission factors in the short term but is also more sensitive to power market changes.

- **We have confirmed the historical estimates of the French emission factor using two different models:**
  - The model using spot prices provides an emission factor at 0.59t/MWh over the period 2015-2018, but with significant variations across years.
  - The model relying on forward prices shows emission factors varying between 0.53 and 1.23 depending on the years considered. For the year 2018, the emission factor is 0.76t/MWh.

- **Our projections of the evolution of the CWE emission factor suggest that:**
  - Based on commodity prices and capacity mix from recognized third parties, the counterfactual analysis indicates that the emission coefficient will vary in the range [0.48;0.63]t/MWh over the period 2019-25 as a result of the changes in the generation mix.

Annexes

A. Power market model

B. Review of literature

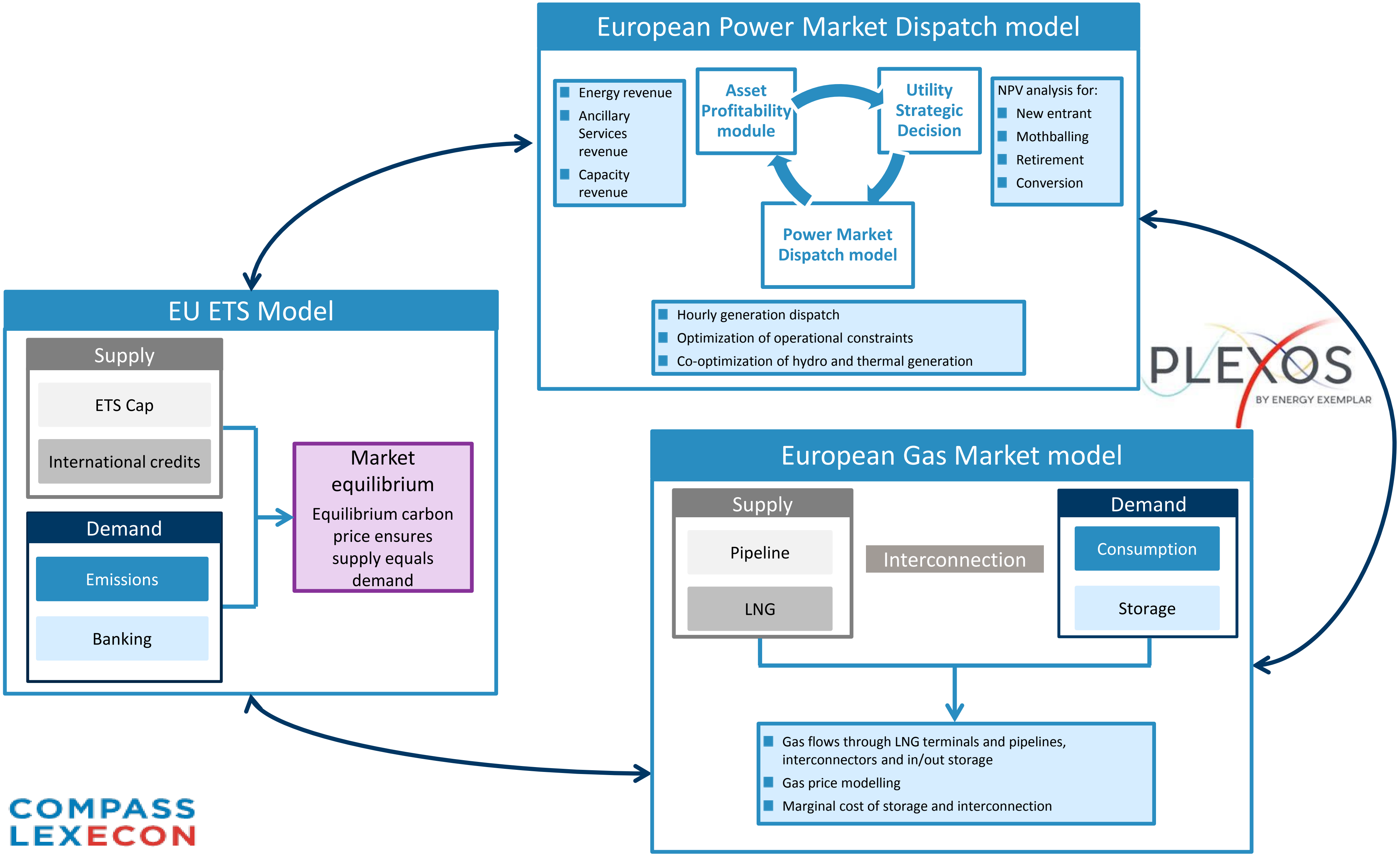
C. Relevant geographic market

D. Econometric analysis

E. Hypothesis for base case scenario

F. Results of the 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

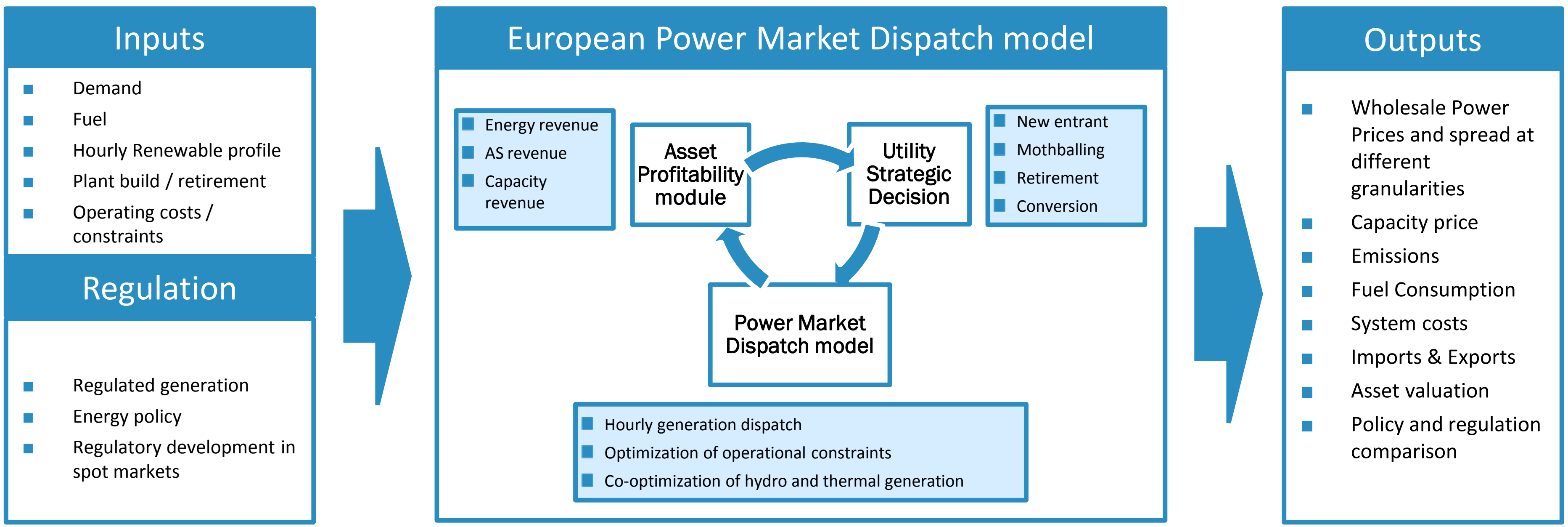
Geographic scope of the model

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)



We performed a literature review to investigate the carbon cost pass-through rate

- The existing literature can be categorised in three strands :

Theoretical work

- **Theoretical basis of the carbon cost pass-through to electricity prices has been established as regards competition, demand elasticity, supply function, merit order…**
  - Under the assumptions of Nash–Cournot competition and constant marginal cost, pass-through is 100% under perfect competition, and 50% for a monopoly
  - An incomplete pass-through is consistent with competitive behaviour under demand and supply inelasticity, market power, and internalization of emissions costs

Empirical work

- **A series of papers have empirically estimated the relationship between carbon markets and electricity markets**
  - The price driver approach shows that there is a significant relationship between carbon and electricity prices
  - The time series approach with price lags shows that there is a equilibrium between electricity and carbon prices
  - Some analyses try to quantify the pass-through rate of carbon costs to electricity prices with controls from market fundamentals, such as total demand, generation, temperature, etc.

Simulation with fundamentals

- **Some papers have explored simulation capability using various modelling tools**
  - The COMPETES model, covering a range of European countries, simulates the effects of differences in producer behaviour and wholesale market structures, including perfect versus oligopolistic competition based on scenarios
  - Other platforms, such as BID, VTT, TIMES, optimizes power generation and trade across Northern Europe based on detailed inputs for demand, generation capabilities, transmission capacities, commodity prices and availability of wind power

Literature review - Theoretical work

- Under perfect competition, electricity prices fully internalise the carbon opportunity costs
- Under market power, the extent to which carbon costs are passed through into electricity prices depends on many factors, such as (i) the degree of market concentration, (ii) the plant mix operated by either the dominant firm or the competitive fringe, (iii) the carbon price, and the available capacity in the market, i.e., whether there is excess capacity or not.

Theoretical work						
Literature	**Approach**	**Market**	**Period**	**Definition**	**Variables included/considered**	**Result**
Bonacina and Gulli, (2007)	Theoretical			Cost pass-through	Under market power, the impact of the ETS equals or exceeds the impact under the competitive scenario only when there is excess capacity and the share of most polluting plants in the market is low enough. Otherwise, the impact under market power is less than under perfect competition and significantly decreases in the degree of market concentration	
Fabra and Reguant (2014)	Theoretical simulation	Spain	01/2004-06/2007	Hourly spot price	Simulating marginal bid estimated by marginal cost according to the degree of competition	0.8 on average
Sijm et al. (2012)	Theoretical			Cost pass-through	The extent of pass-through depends on the degree of market concentration, competition, the carbon price, and available capacity in the market	
Bonacina and Gulli (2007)	Theoretical			Cost pass-through	Using a dominant firm facing a competitive fringe model, the short-run impact of CO2 emissions trading on wholesale electricity spot markets significantly depends on the structure of the electricity market	

The theoretical models typically suggest that the impact of the carbon cost pass-through on electricity prices depends on a range of factors. They assess the carbon pass-through across different market situations, but do not offer any quantification of the historical carbon pass-through.

Literature review – Empirical/econometric work

Empirical work						
Literature	**Approach**	**Market**	**Period**	**Definition**	**Variables included/considered**	**Result**
Bariss et al. (2016)	**OLS (Ordinary Least Squares)** regression	Nordic and Baltic	08/2010-05/2015	Daily spot price omitting 7 months outliers	Regional production/consumption, hydro production (monthly totals), coal and CO2 prices as monthly average of daily closing	0.55 Nordic; 0.67 Baltic (Poland)
Hintermann (2014)	OLS regression	Germany	January 2010 through November 2013	Hourly price (baseload, peak, off-peak)	Cost model with marginal costs and carbon cost; Price model with coal, gas, oil, and CO2 prices	0.98-1.06 from central estimates
Sijm et al. (2006)	OLS regression	Europe	2005	Daily forward power price and fuel cost spread	CO2 price	117% at the peak, 60% off-peak for Germany, and 78% peak (gas at the margin) and 80% off-peak (coal at the margin) for the Netherlands
Sijm et al. (2008)	OLS regression	Europe	2005-2006	Daily spark and dark spread	CO2 price	Forward estimate 0.66 for peak periods, 0.4 off-peak for France Spot estimate 1.96 at peak, 0.98 off-peak for France
Fezzi and Bunn (2009)	Time series regression	UK	04/2005-06/2006	Daily spot price difference	Gas price, carbon price, temperature stages	1% increase in carbon price, 0.32% in electricity price
Cotton and De Mello (2014)	Time series regression	Australia	2004-2010	Weekly price	Emission certificate, RES certificates, Gas and Elec price	No result on pass through rate
Freitas and da Silva (2015)	Time series regression	Spain	01/2008-12/2013	Daily spot price for working days	CO2, natural gas, and coal prices, temperature thresholds, hydro, wind	Long-term relationship between 0.2-0.37
Keppler and Mansanet-Bataller (2010)	OLS and Time series regression	France	04/2005-10/2007	Future price return for 2007 delivery Daily forward and spot price	OLS: CO2 price return, peak-load clean spark spread return TS: Gas, coal, carbon future price	OLS:1% increase in carbon price, 0.44% in electricity price Causality from CO2 future to electricity future price
Jouvet and Solier (2013)	Time series regression	Europe	06/2005-12/2010	Daily sport or forward spread with respect to fuel price	CO2 price	Numerous non-significant and negative coefficients possible, varying per year. 1.7 over peak periods for France in 2006

Empirical literature shows a wide range of results and that an OLS (Ordinary Least Squares) model that accounts for market fundamentals with adjustment for robust estimators is sufficient to give robust estimates of the CO2 pass-through coefficient.

Literature review – Simulation with fundamentals

- Using electricity market modelling platforms, some reports / papers examine the impact of carbon costs either from a backward- or forward-looking perspective
- Chen et al. (2008) is more theoretically founded, built on scenarios that account for different market situations
- Other studies explore optimisation modelling capability replicating the dispatch of electricity spot markets

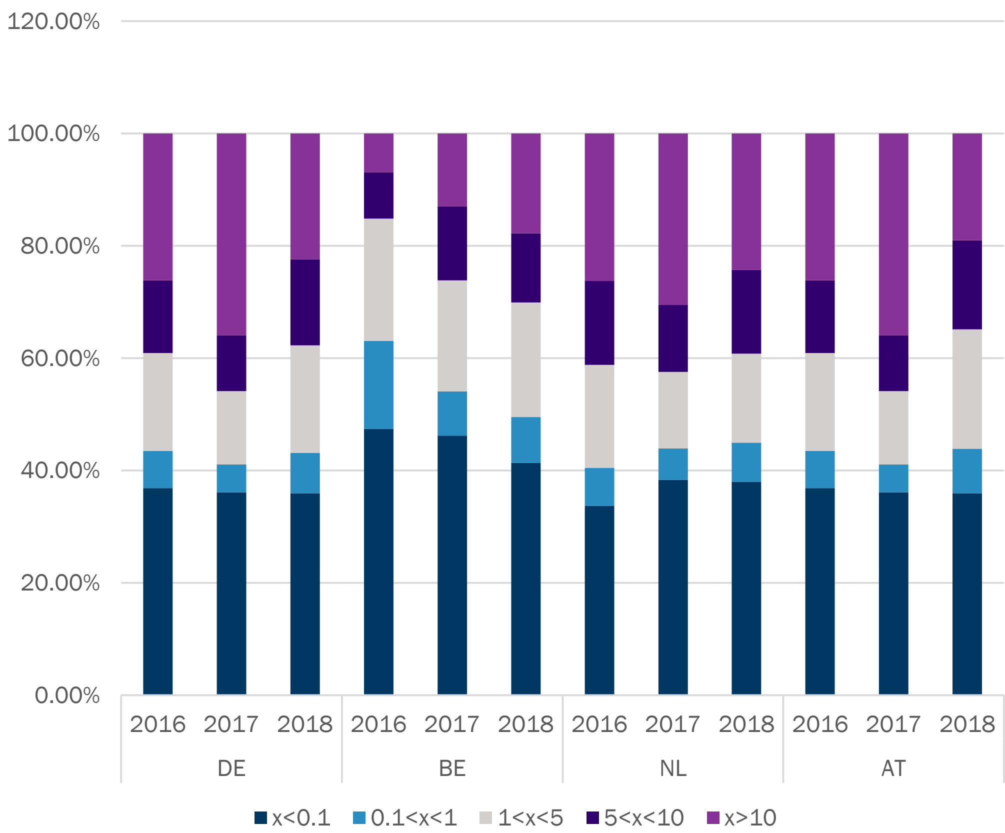
Simulation with fundamentals

Literature	Approach	Market	Period	Definition	Variables included/considered	Result
Kara et al. (2006)	Simulation with VTT market model	Nordic	2008-2012	Spot price	Market fundamentals	0.74€/MWh for 1€/tonne
Poyry (2011)	Simulation with BID model	Norway	2013	CO2 quantity	Market fundamentals	0.6 ton CO2/MWh for Norway
Hawkes (2014)	Simulation with TIMES model	UK	2010-2050	CO2 quantity	Market fundamentals	0.26-0.53 kg CO2/kWh
Chen et al. (2008)	Theoretical with simulation of an oligopoly	Northwestern EU (Belgium, France, Germany and the Netherlands)	2005	Capacity weighted emission rate; Average and Marginal pass-through	Market structure - competition, demand elasticity	Marginal rate ranges from 0.34 to 1.15 for France
Capros et al. (2008)	Primes Model	EU	2020 and 2030	CO2 quantity	Market fundamentals	No pass-through rate, but provided RES value, compliance cost for CO2 reduction, etc.

Simulation studies leveraging market fundamentals models aim at replicating market dispatch or market structure, offering a wide range of estimates for CO2 pass-through coefficient.

Geographic market definition: Price spreads with neighbouring countries

Price spreads with France



- We analyse hourly price spreads between France and its neighbouring markets, i.e. absolute price differences between France and a neighbouring country.
- Historical power prices shows that the price spreads are lower than 5€/MWh during 63% of the time on average in the zone CWE for the period 2016-18.
- These numbers confirm that market integration and price convergence remain strong within the CWE area. Therefore, the CWE can continue to be used in the methodology.

Source: FTI-CL Energy analysis based on hourly power prices from ENTSOE

Notes: x<0.1 corresponds to the number of hours with price spread between X and France lower than 0.1€/MWh

Historical data shows low price spreads between France and neighbouring markets. This suggests that market integration and price convergence remain within the CWE zone.

To validate the empirical results, we replicate the dynamics of spot electricity prices using an econometric model

Definition of pass-through in the econometric work

CO2 costs pass-through is defined as the average increase in power price over a certain period due to the increase in the CO2 price

1. The dynamics of electricity price is a result of interactions of different market fundamentals, including commodity and carbon prices. We would need to consider **the French market specific fundamentals in order to identify the impact of carbon pass-through**.

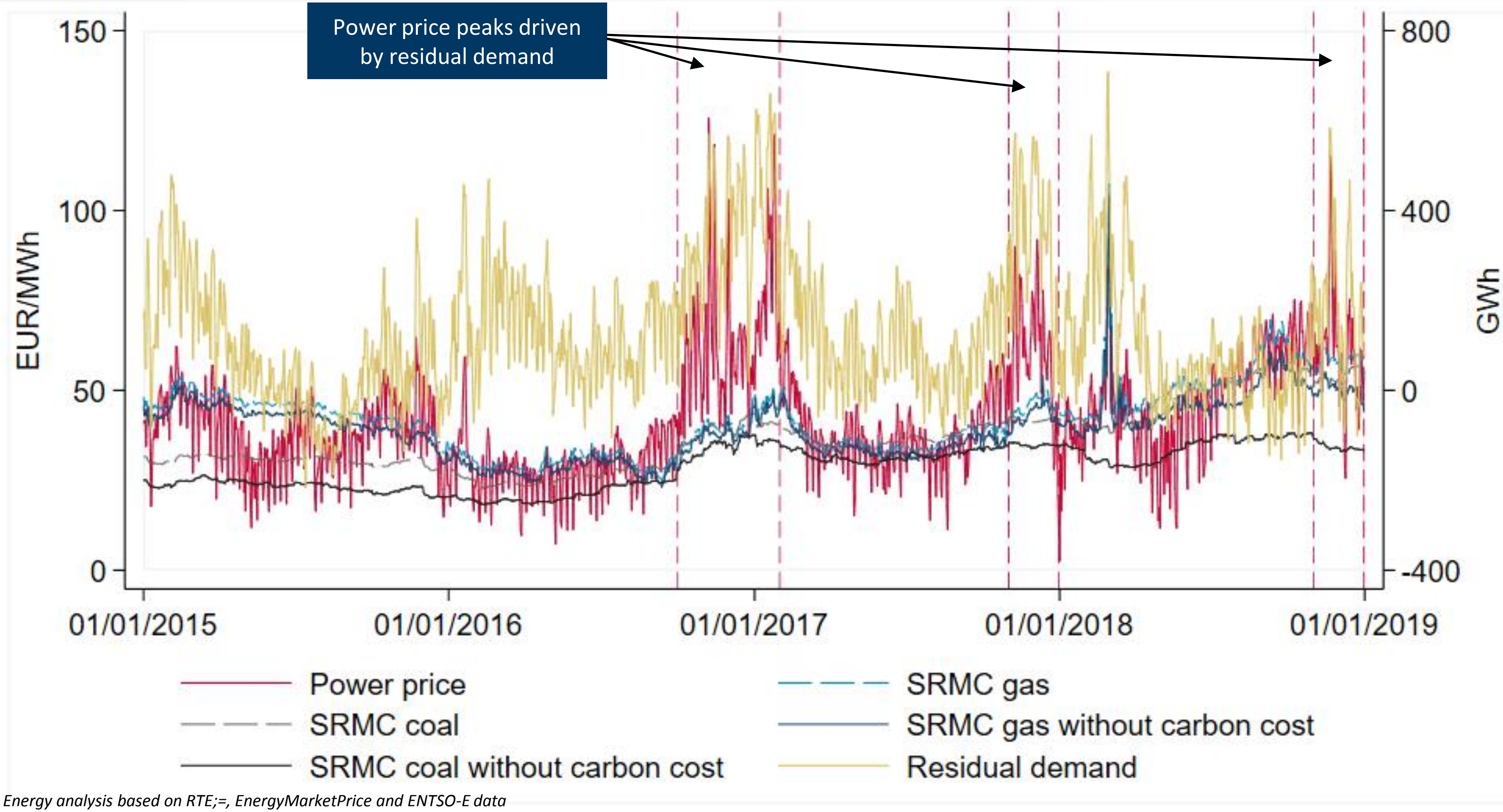
2. The EU ETS market has gone through different periods with completely different price trends – market clasped between 2011 and 2012 and carbon price started to slowly pick up from 2015, followed by a significant increase in 2017-2018. **Estimation on such a non-stationary price series would result in different coefficients of pass-through depending on selected periods**.

3. Our estimation over different periods confirms the point above – the coefficient could vary between a negative number (when carbon price went all the way downwards) and a positive number above 1 (when power price spikes). We perform an **econometric analysis based on daily data over the period of 2015-2018**.

The French electricity market features a large share of nuclear generation, leaving a small share of residual demand for thermal plants. We therefore control in our econometric model for residual demand in France, which is measured by the difference between the demand and the sum of generation from nuclear, wind and solar units.

Fundamental drivers of the spot French power price – Commodity prices and residual demand

Evolution of power price, thermal SRMC and residual demand 2015-2018



Source: FTI-CL Energy analysis based on RTE;=, EnergyMarketPrice and ENTSO-E data

Note: SRMC is the short-run marginal cost for a given type of generation

French power prices are driven by commodity prices and residual demand. We estimate the carbon pass-through rate in France over the period of 2015-2018 accounting for residual demand, which explains to a large extent variations of the power price.

Empirical spot regression results of carbon pass-through over the period of 2015-2018

Empirical regression results 2015-2018

Variable	2015-2018
Price Gas PEG	1.038***
	(0.102)
Price Coal	1.847***
	(0.120)
Price CO2	0.591***
	(0.0721)
Residual Load	0.0623***
	(0.00207)
Constant	-7.340***
	(1.337)
Observations	1,461
R-squared	0.742

*Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Source: FTI-CL Energy based on RTE, EnergyMarketPrice and ENTSO-E data

The carbon pass-through rate (t/MWh) is estimated by a linear equation for the *i*th observation as follows:

$$Price_{ElecSpot,i} = Constant_i + \beta_{PriceGasPEG} \times Price_{GasPEG,i} + \beta_{PriceCoal} \times Price_{Coal,i} + \beta_{PriceCO2} \times Price_{CO2,i} + \beta_{ResidualLoad} \times ResidualLoad_i + \varepsilon_i$$

- **Over the period 2015-2018 using daily data, we obtain an average pass-through rate of 0.59, meaning that 1€/tCO2 increase is translated to an increase of 0.59€/MWh in French electricity price**
  - This estimate is statistically significant and it ranges between 0.45 to 0.73 at 95% confidence level.

- **The goodness of the regression is demonstrated by:**
  - Overall, the model yields an overall fit of 0.74 (statistics of R-square), meaning that our model explains 74% of price formation in the French market;
  - We control the heterogeneity of the variance and use robust estimators;
  - The overall significance of fuel prices, consistent with plant characteristics.

Our econometric model provides an estimate the carbon pass-through rate in France over the period of 2015-2018 of 0.59t/MWh.

Comparison of our spot model with similar studies

Comparison of empirical results

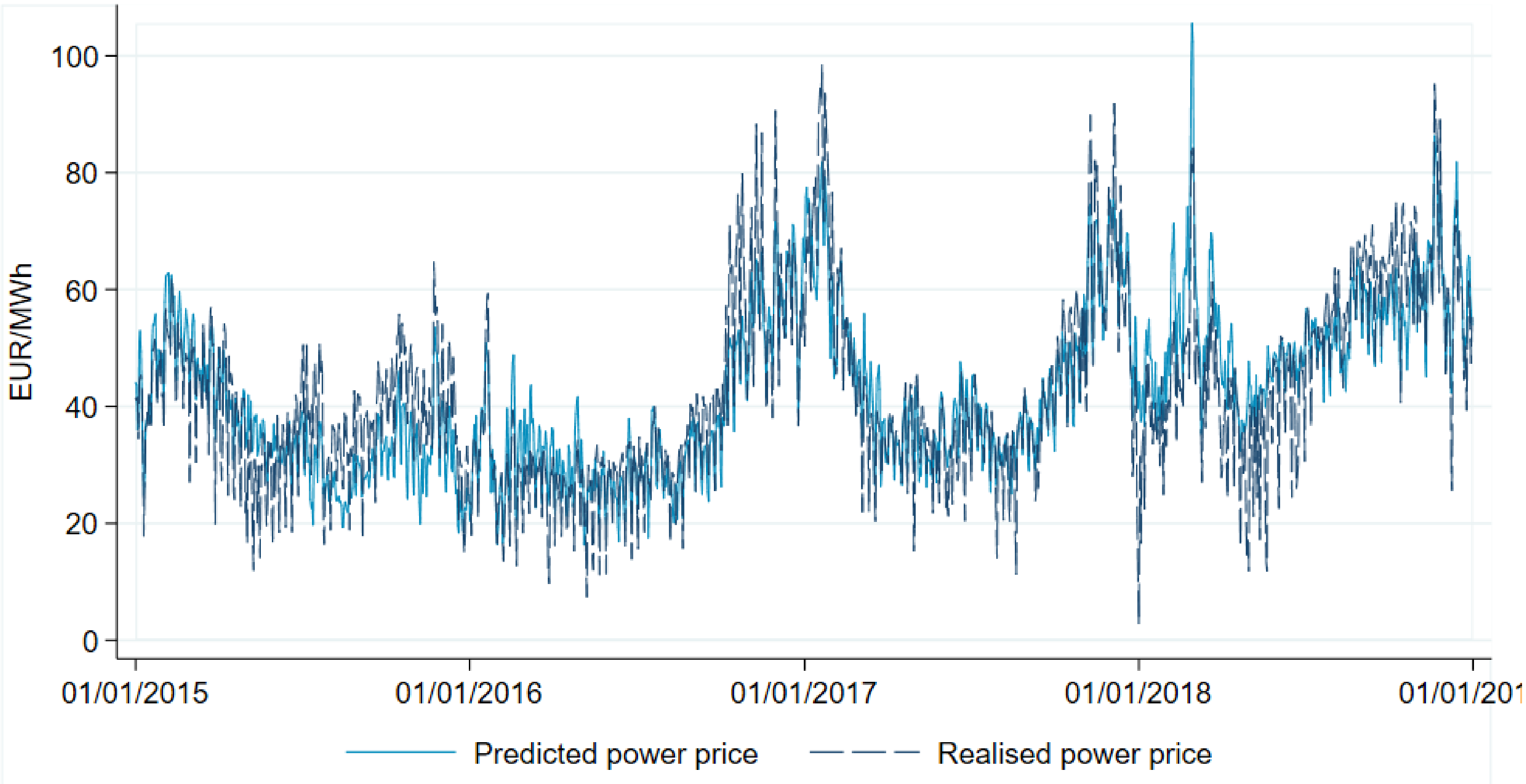
Studies	Results
CL regression results	0.59 (France)
Hintermann (2014)	0.98-1.06 (Germany)
Bariss et al. (2016)	0.55 (Nordic) 0.67 Baltic (Poland)
Keppler and Mansanet-Bataller (2010)	1% increase in carbon price, 0.44% in electricity price (France)
Jouvet and Solier (2013)	1.7 (peak period for French forwards in 2006)
Sijm et al. (2006)	117% at the peak, 60% off-peak for Germany, and 78% peak (gas at the margin) and 80% off-peak (coal at the margin) for the Netherlands
Sijm et al. (2008)	Forward estimate 0.66 for peak periods, 0.4 off-peak for France Spot estimate 1.96 at peak, 0.98 off-peak for France

- **Our approach is consistent with the study from Bariss et al. (2016) taking into account market-specific fundamentals with an OLS regression**
  - Bariss et al. (2016) controls for hydro production in the Nordic countries;
  - We opt for residual demand to control the feed-in of nuclear and renewable generation in France
- **Our estimation results are in line with the majority of empirical studies**
  - Existing empirical studies demonstrat that the estimated coefficient is very sensitive to estimating periods and sometimes is not consistent with economic sense
  - Our estimation is performed over the most recent period of 2015-2018

Our estimate is in line with the results of the majority of empirical studies leveraging a similar method.

Back casting result of the French spot price against the historic power price using estimated coefficients

Predicted power price vs. realised power price 2015-2018



Source: FTI-CL Energy analysis based on RTE, EnergyMarketPrice and ENTSO-E data

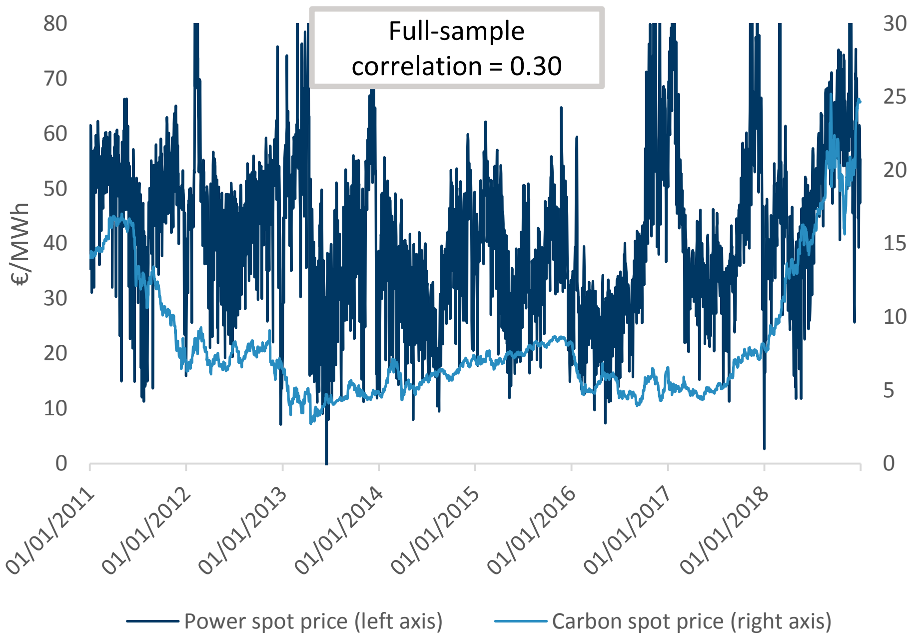
The estimates yield fairly good fit in terms of price prediction, which follows closely the realized historical power price.

We further search for a robust estimate with forward data

- As demonstrated by academic literature, **estimates of CO2 pass-through rates based on spot prices often appear to be unstable and counter intuitive in terms of economic sense** due to high noises in spot prices that cannot be captured by econometric models using spot series.
- The solution for this is to use **forward series instead spot series in order to avoid the influence of high price volatility** that masks the relationship between electricity and CO2 prices and to obtain more robust results.

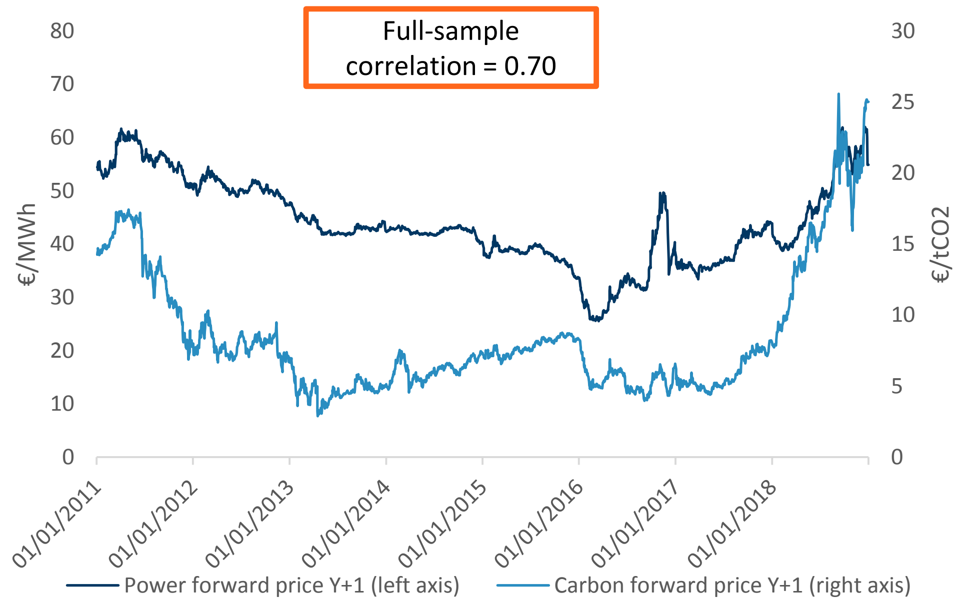
Spot electricity and CO2 price series

High volatility of spot prices leaves a large amount of variations unexplained by CO2 price and other fundamentals. Aggregating highly volatile daily series into weekly or monthly form would further reduce the model fit and introduce bias in the estimation



Forward base electricity and CO2 Y+1 price series

In contrast, the relationship between electricity and CO2 prices can be clearly observed in forward series, meaning that estimation of the CO2 pass-through rate would be more robust if it is based on forward series

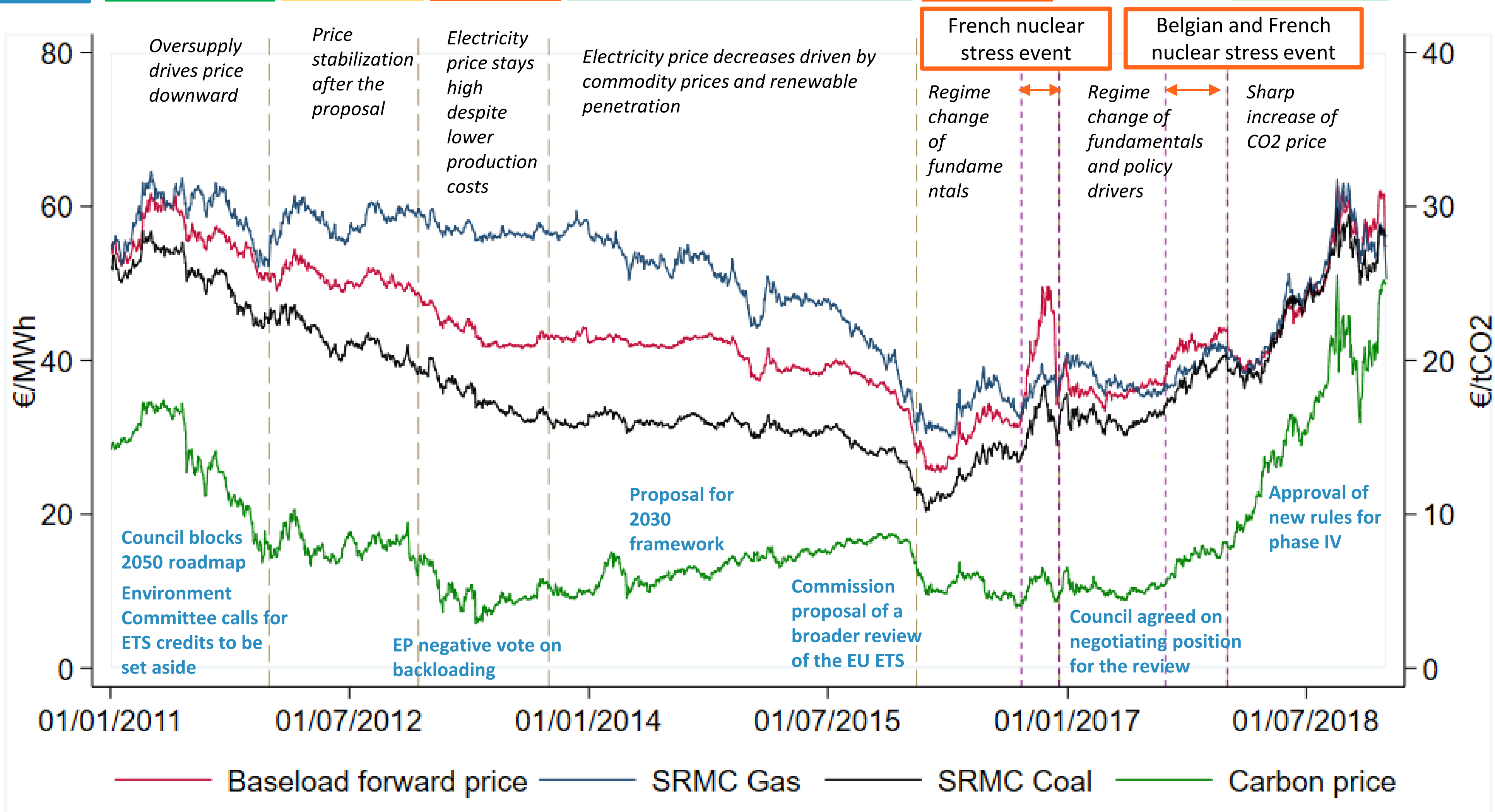


Source: FTI-CL Energy analysis based on EnergyMarketPrice data

Correlation between CO2 and electricity price can be clearly observed in forward price series which are less affected by short term noise than spot prices. Therefore, using forward prices instead of spot prices in our econometric model allows for more robust estimates of the CO2 pass-through rate.

Fundamental drivers of the forward French power price – Structural breaks identified by policy drivers, market fundamentals and shocks

	01/01/11-29/12/11	30/12/11-05/12/12	06/12/12-30/09/13	01/10/13-19/01/16	20/01/16-11/12/16	12/12/16-31/12/17	01/01/18-31/12/18
Emission factor	0.63	0.53	1.23	0.63	0.87	0.89	0.76



Source: FTI-CL Energy analysis based on EnergyMarketPrice data

Note: SRMC is the short-run marginal cost for a given type of generation.

We model the historical CO2 pass-through rate using year-ahead forward data while accounting for structural breaks and market shocks

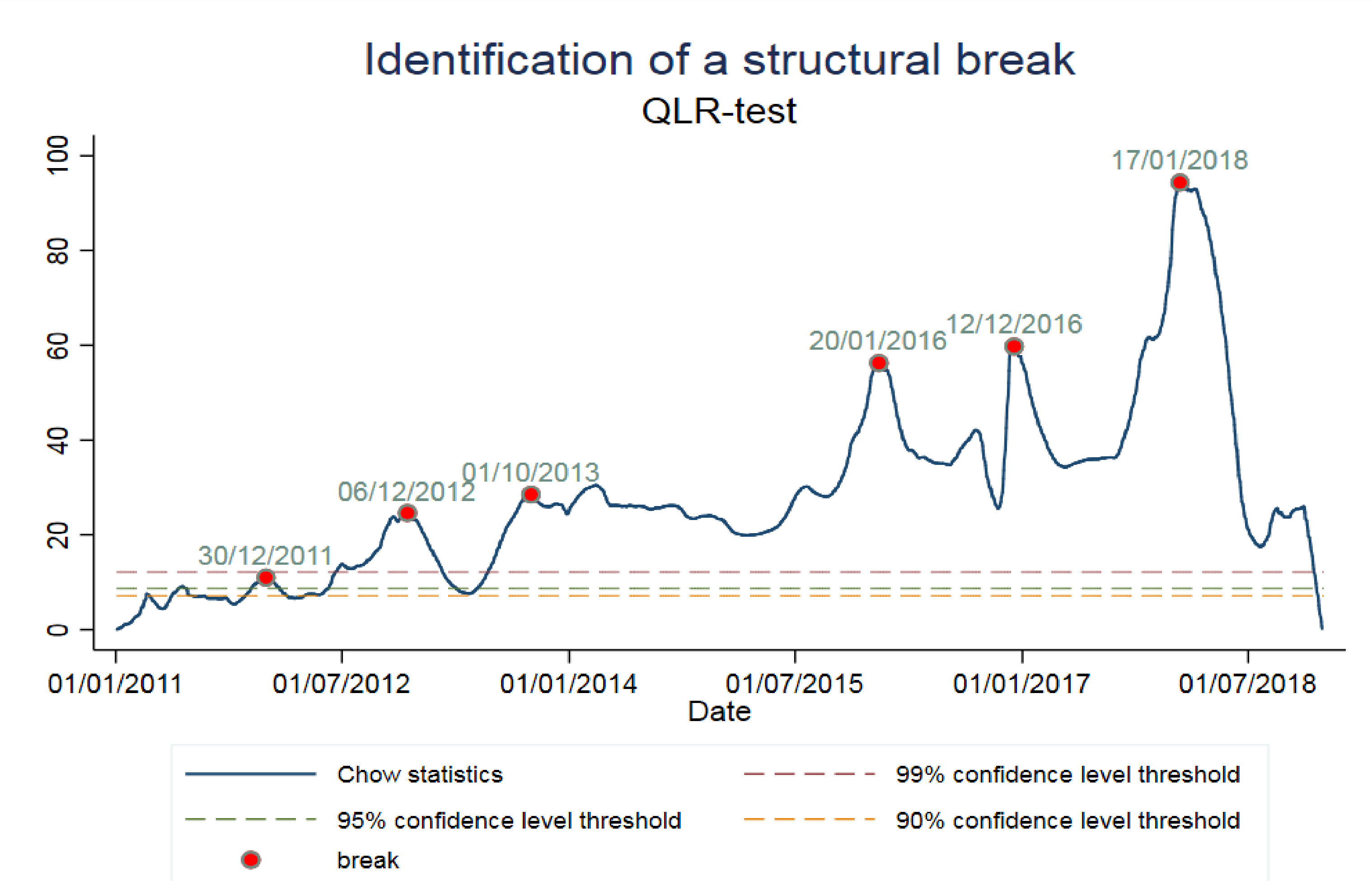
- **We estimate the historical CO2 pass-through rate using daily data over the period of 2011-2018 including:**
  - Y+1 forward base electricity price as dependent variable
  - Y+1 EU ETS CO2 price
  - Y+1 PEG gas price
  - Y+1 ARA Coal price

- **We identify structural breaks in order to construct relevant estimation periods and ensure robust and stable relationships between Y+1 electricity price and Y+1 CO2 price**
  - We use data available up to one year ahead to estimate the market view of carbon, commodity and electricity market dynamics
  - Since the market view is continuous, each regression period is not necessarily on an annual basis but rather regrouped based on structural breaks following important changes of policy drivers or market fundamentals
  - We further verify these identified structural breaks using a statistic Chow test by rolling regressions with a break for each day over the period of 2011-2018
  - Both analytic analysis and statistic test lead to the same identification of structural breaks

- **We additionally account for particular market shocks, namely unavailability of the French and Belgian nuclear power generation, which created price spikes in 2016 and 2017**
  - The unavailability of French nuclear generation in 2016 lead to persistent price spikes in the French market from mid-September onwards
  - The unavailability of Belgian and French nuclear generation in 2017 lead to a sharp price increase from mid-August onwards

Using daily year-ahead forward prices instead of spot prices for the econometric model allowed us to avoid some of the noise that characterizes spot prices, and to obtain more robust and stable estimates of the CO2 pass through rate over time.

We perform a statistical Chow tests to identify structural breaks in the econometric forward model



Notes: we test the possibility of structural breaks for each date using a F statistics of chow test and identify the potential structural breaks with highest probabilities. These identified structural breaks are used as regression periods in the econometric forward model. We keep the full year of 2018 as a period because price trends are consistent.

Source: FTI-CL Energy analysis based on RTE, EnergyMarketPrice and ENTSO-E data

The identified regression periods are further confirmed by a statistic Quandt Likelihood Ratio (QLR) test for structural breaks.

Empirical forward regression results of carbon pass-through over the period of 2011-2018

Empirical regression results on forward Y+1 electricity base price

The carbon pass-through rate (t/MWh) estimated by a full set of variables is specified as follows:

$$Price_{ElecForward,i} = Constant_i + \beta_{PriceCO2} \times Price_{CO2,i} + \beta_{PriceGas} \times Price_{Gas,i} + \beta_{Coal} \times Price_{Coal,i} + \gamma_{2016} \times D_{2016} + \gamma_{2017} \times D_{2017} + \varepsilon_i$$

Variables	01/01/11-29/12/11	30/12/11-05/12/12	06/12/12-30/09/13	01/10/13-19/01/16	20/01/16-11/12/16	12/12/16-31/12/17	01/01/18-31/12/18
CO2 EU ETS	0.63***	0.53***	1.23***	0.63***	0.87***	0.89***	0.76***
Gas PEG	1.03***	0.67***		0.72***	2.55***		1.40***
Coal ARA		1.20***	1.75***	1.14***		1.51***	
D_2016					8.59***		
D_2017						2.10***	
Constant	20.78***	14.64***	20.42***	10.67***	-13.39***	18.20***	7.46***
Observations	259	244	213	601	233	275	261
Adjusted R2	0.86	0.81	0.93	0.93	0.9	0.95	0.96

*Note (1): Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

Source: FTI-CL Energy analysis based on EnergyMarketPrice data

Note (2): Nuclear stress events are controled for the period of Sep 16, 2016-December 11, 2016, and August 12, 2017-December 31, 2017

Note (3): We keep both gas and coal forward prices in the regression when their coefficients are statistically significant, contributing to the robustness of the pass-through rate, and overall model fit is superior with both variables included. We drop one of the fundamental prices when there is a sign of multicollinearity, that significantly bias estimated coefficient and its variance.

- **Most of the estimates of CO2 coefficients are below 1. The CO2 pass-through for 2018 is estimated to be 0.76, meaning that an increase of 1€/tCO2 in CO2 price would translate into an increase of 0.76€/MWh in electricity price (view for 2019)**
  - The estimated pass-through rate stays between 0.53-0.63 until the end of 2012, but peaks at 1.23 between end 2012 and end 2013 due to the collapse of the carbon market in contrast to a relatively stable electricity price level
  - The estimated pass-through rate increases from end 2016, following a series of announces regarding the EU ETS reform that boost CO2 price

Using year-ahead forward data allowed us to obtain a robust estimate of CO2 pass-through rate for different periods.

We obtain a CO2 pass-through rate varying between 0.53-1.23 over the period of 2011-2018, varying in the different periods according to structural breaks.

Conclusions

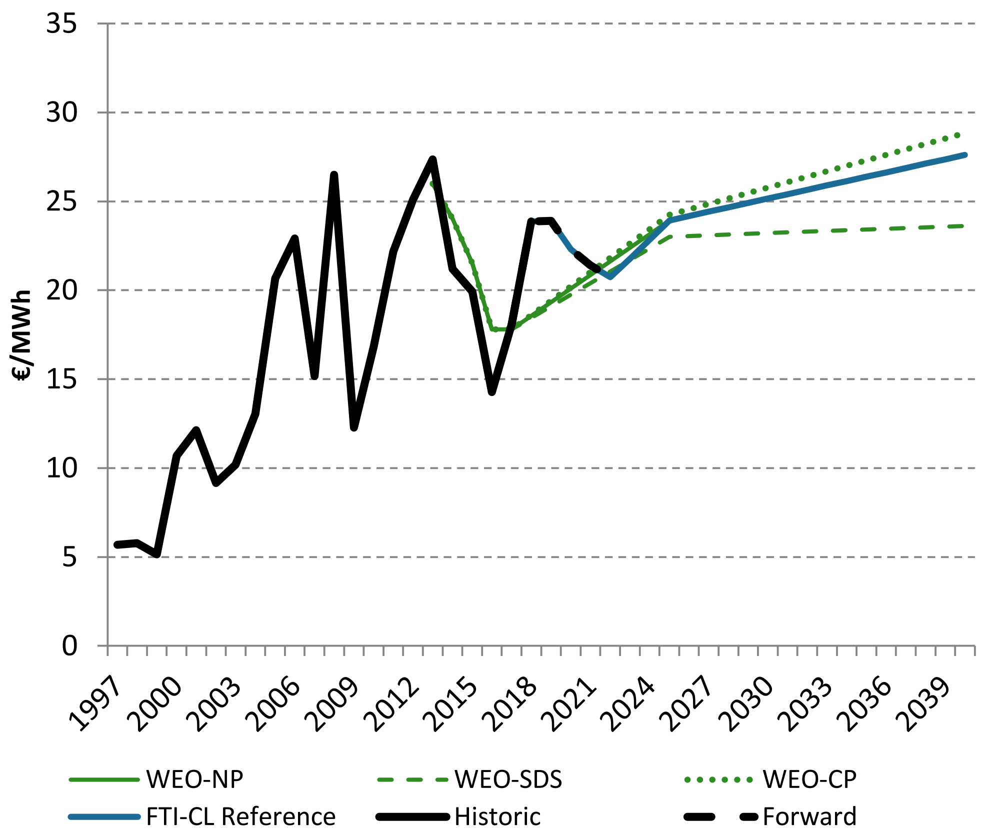
- **Our work on the spot econometric model suggests that :**
  - The specificities of French power spot market need to be taken into account in the regression, therefore we use residual load as a one control factor;
  - The results show a coefficient at 0.59t/MWh for the period 2015-18.

- **Our analysis on the forward econometric model shows that :**
  - The period 2011-18 can be split into seven sub-periods with identified structural breaks;
  - The regression provides one coefficient for each structural break: emissions factors vary between 0.53 and 1.23 depending on the period considered;
  - For the year 2018, the regression provides 0.76 as emission factor. In periods characterised by and increase in carbon prices, the econometric model leads to similar results to the other two approaches.

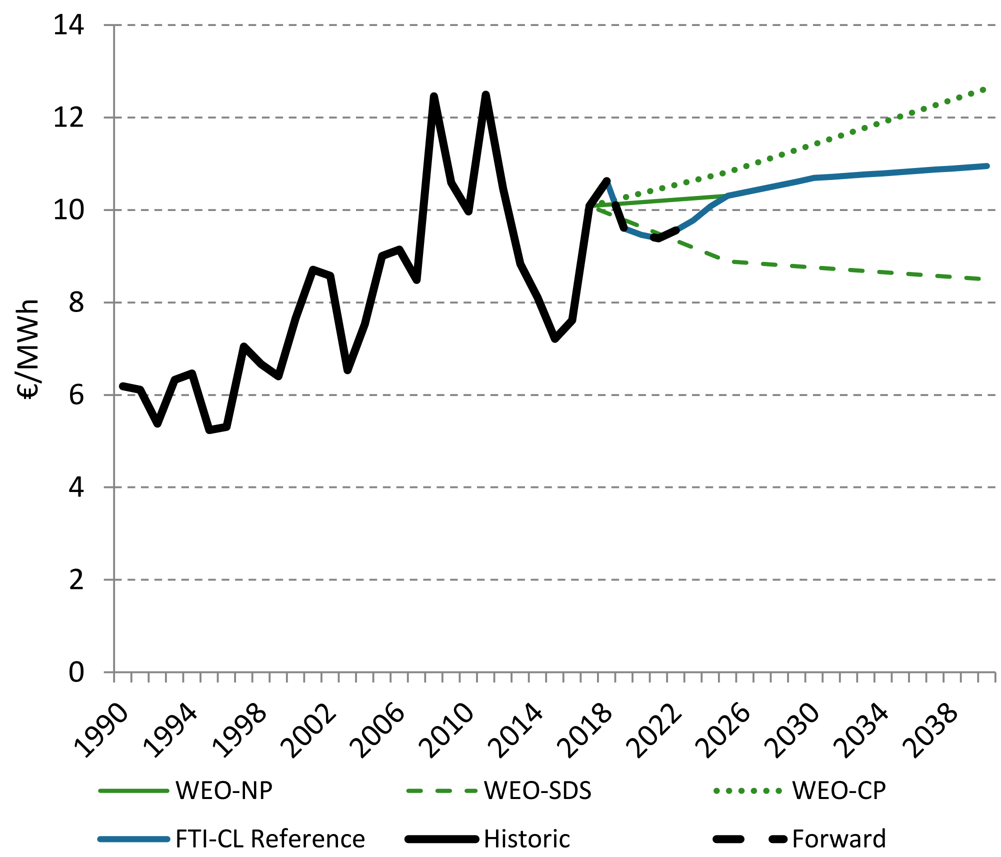
- **Both econometric models confirm that the results from the existing and counterfactual approaches are aligned with historical trends, especially during periods with growing carbon prices.**

We use the WEO NP scenario for fuel prices

Gas prices



Coal prices



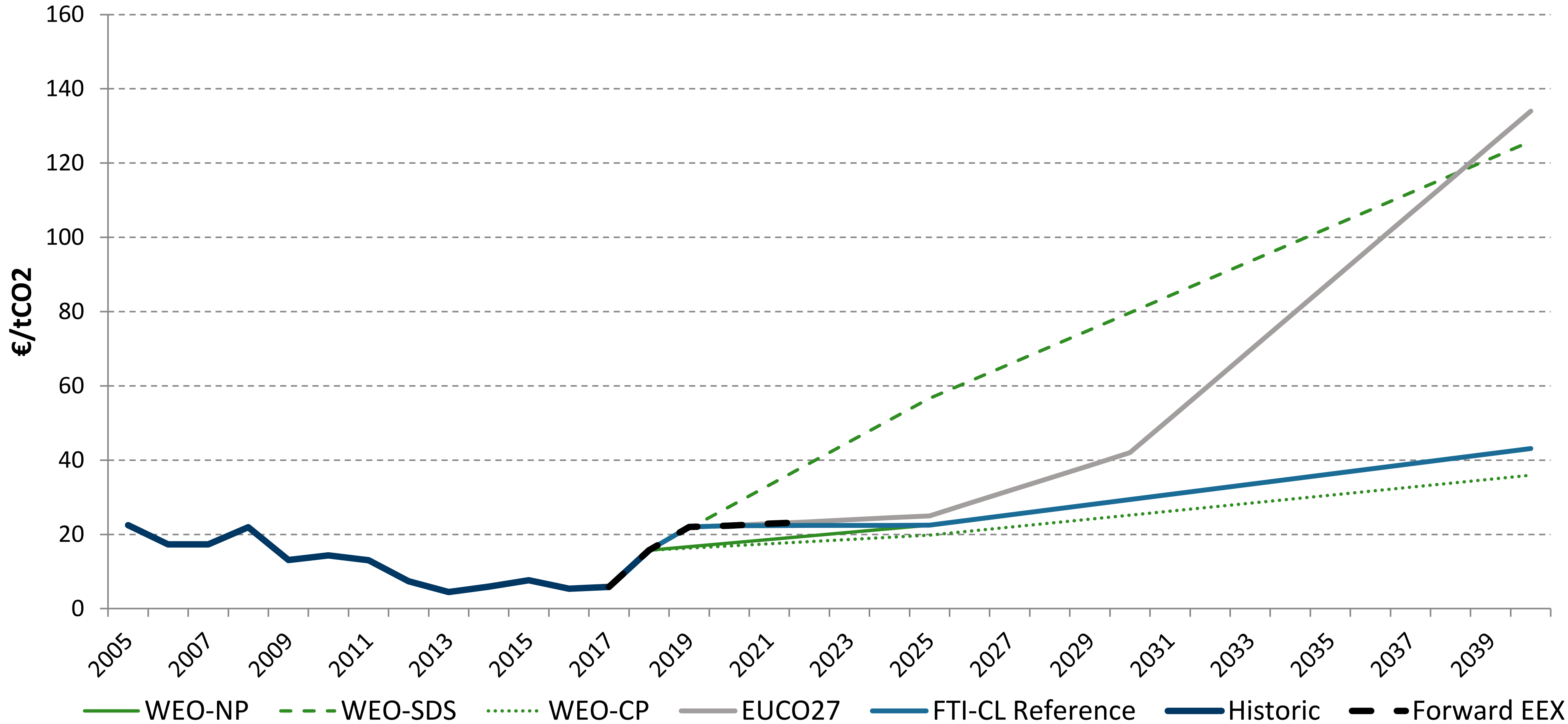
Notes: NP: New Policies, CP : Current Policies , SDS :Sustainable Development Scenario

Source : FTI-CL Energy analysis based on IEA and EEX

The WEO New Policy scenario is the IEA central scenario for fuel prices. This scenario incorporates existing energy policies as well as an assessment of the results that are likely to stem from the implementation of announced policy intentions. We use the forward prices until 2021 (average over the last 3 months) and interpolations to 2025 WEO NP.

We use forward prices and WEO NP for carbon prices

Carbon prices

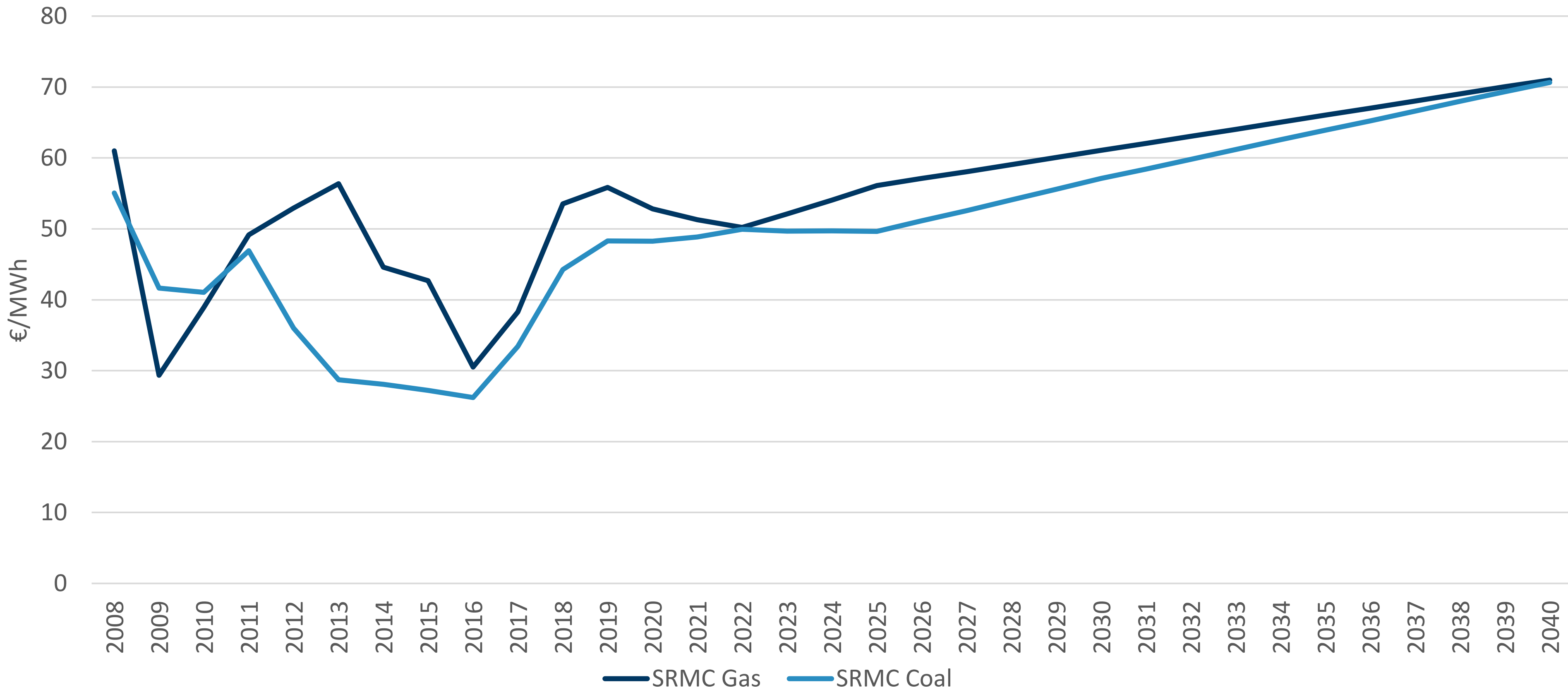


Source : FTI-CL Energy analysis based on IEA and EEX

Using the same scenario for fuel and carbon prices is key for consistency. Despite low prices in the long term, the WEO NP carbon price is aligned with the scenario EU CO27 in the short term (consistent with our modelling horizon).

Forecast of SRMC for coal and gas units

SRMC for coal and gas units



Note: SRMC : Short run marginal cost

Source : FTI-CL Energy analysis based on IEA and EEX

In our scenario, the coal units will be more cost-competitive than gas units in Europe on a SRMC basis.
We also perform a sensitivity replicating an opposite situation to test the impact of coal/gas competition on the results.

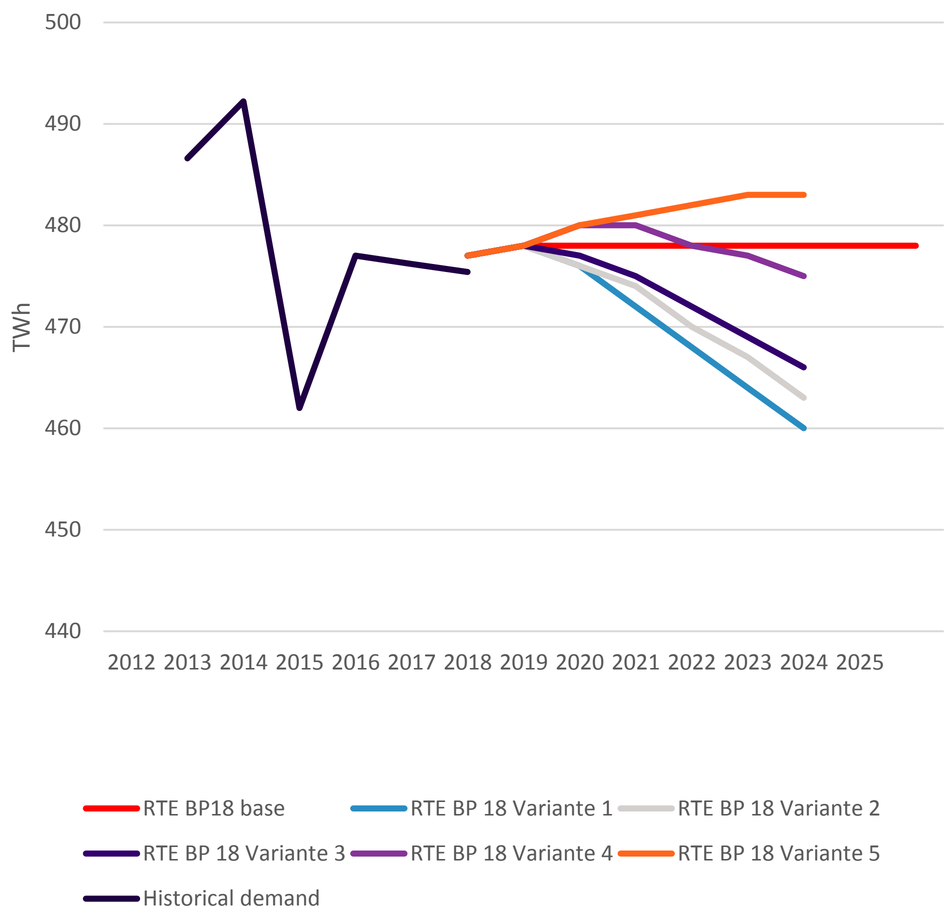
French demand outlook

- The latest RTE BP projects a flat demand until 2023 as base case. This trajectory is aligned with the historical trend seen over the last years.

- We base our analysis on this demand outlook and consider a flat demand until 2025.

- This flat trend can be explained by the two opposite drivers:
  - **Negative drivers**: A continuous increase of efficiency in residential and tertiary buildings and in industrial processes maintain a downward trend on power demand.
  - **Positive drivers**: Electrification of road transport and Heating & Cooling in buildings and industrial processes combined with positive macroeconomic drivers.

French demand



Source : FTI-CL Energy analysis based on RTE

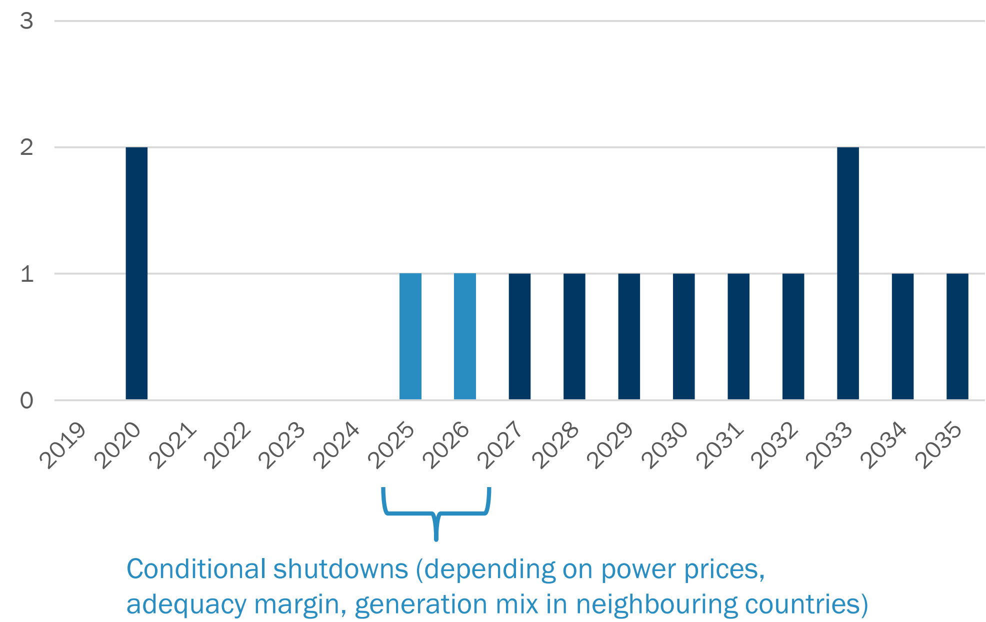
Evolution of nuclear capacity in France

- The new PPE was released in 2018. The PPE targets to reduce the share of nuclear generation to 50% by 2035.

- The PPE provides a detailed planning about the closures :
  - The first closures will happen in 2020 with the of the two Fessenheim units' retirements.
  - The Flamanville unit will reach its full capacity only by 2022
  - No nuclear closures are planned before 2027.

- The PPE mentions that anticipated closures could happen in 2025-26 under some conditions.

Number of decommissioned nuclear reactors

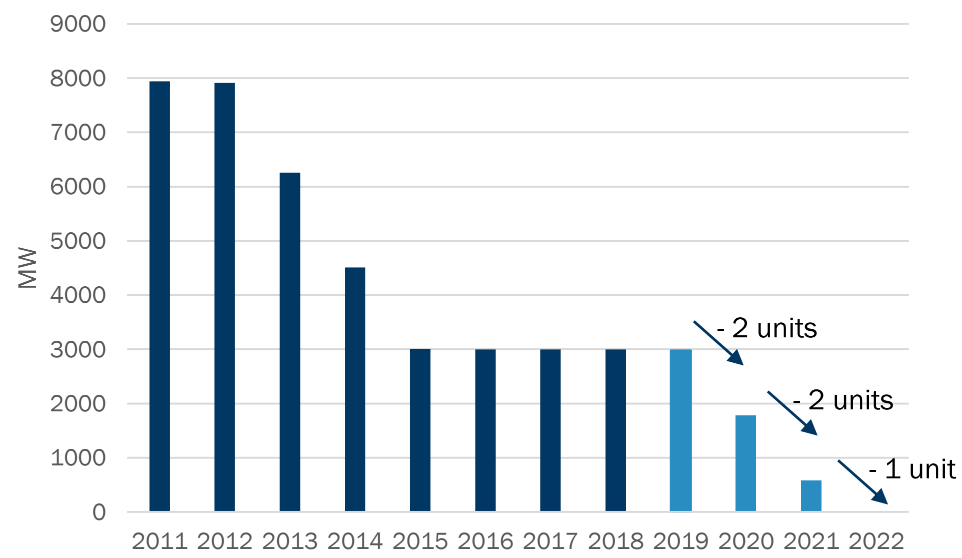


Source: FTI-CL Energy analysis based on PPE 2018

Evolution of installed thermal plants in France

- Newly published PPE 2018 confirms the closures of coal units by 2022.
- RTE BP provides a specific planning for this phase out (see graph). We use this schedule in our model. We don't expect any conversion to biomass for these units.
- RTE BP expects the CCGT Landivisiau to be commissioned by the end of the year 2021. This assumption needs to be aligned with the closures of coal units in Brittany for congestion issues.
- RTE BP doesn't expect any other thermal plant to come online in France as recommended by the PPE.
- RTE BP expects the small oil and gas units (TAC) to stay online in the short term as the market is expected to remain tight.

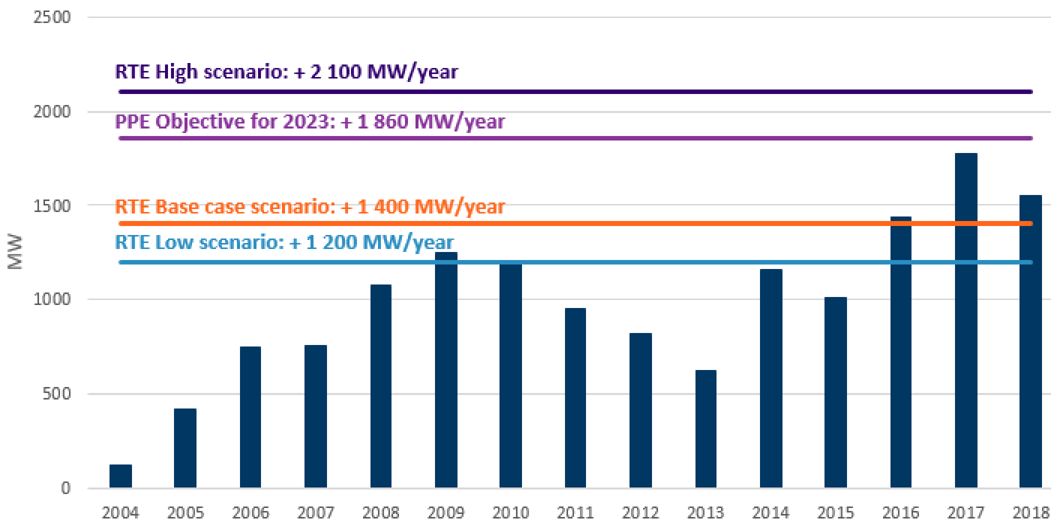
Evolution of installed coal capacity in France



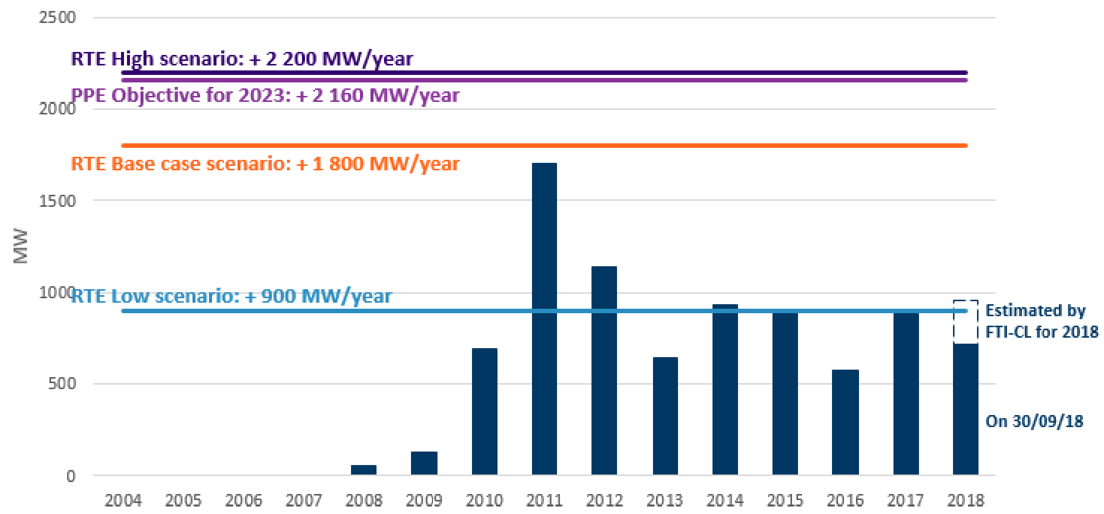
Source : FTI-CL Energy analysis based on RTE

Historical and forecast capacity additions for onshore wind and solar

Onshore wind capacity additions



Solar capacity additions



Source : FTI-CL Energy analysis based on RTE and PPE 2018

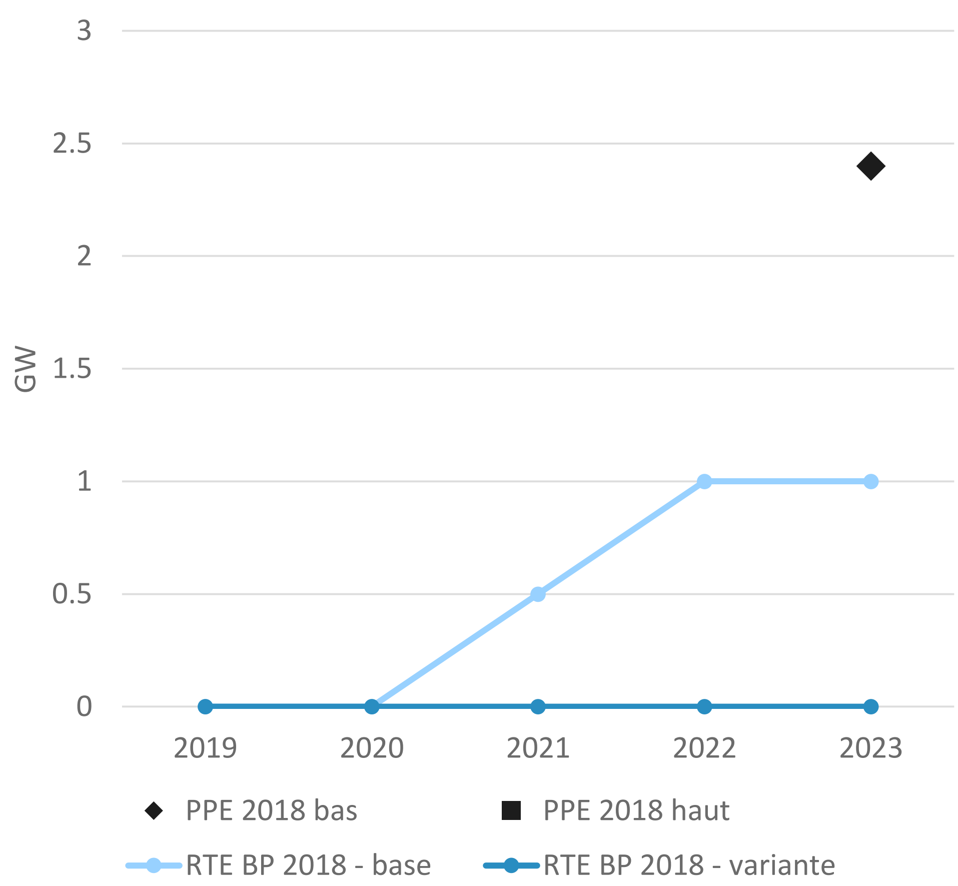
- The PPE 2018 sets high objectives for annual additions compared to historical data. These annual additions are aligned with RTE's high scenario.
- Owing to current delays in France for the commissioning of wind and solar units, the outlook of the medium RTE outlook is more aligned with historical trends. We use this outlook in our model.

Source : RTE, PPE

Forecast installed capacity for French offshore wind

- The first tenders were renegotiated in the summer 2018 creating further delays in the commissioning of the first offshore wind units in France.
- The first offshore plants are expected to come online in 2021 with a total installed capacity equal to 1 GW in 2023 in the BP RTE.
- We expect the planned additions to come online to have a total installed capacity at 3 GW in 2025.

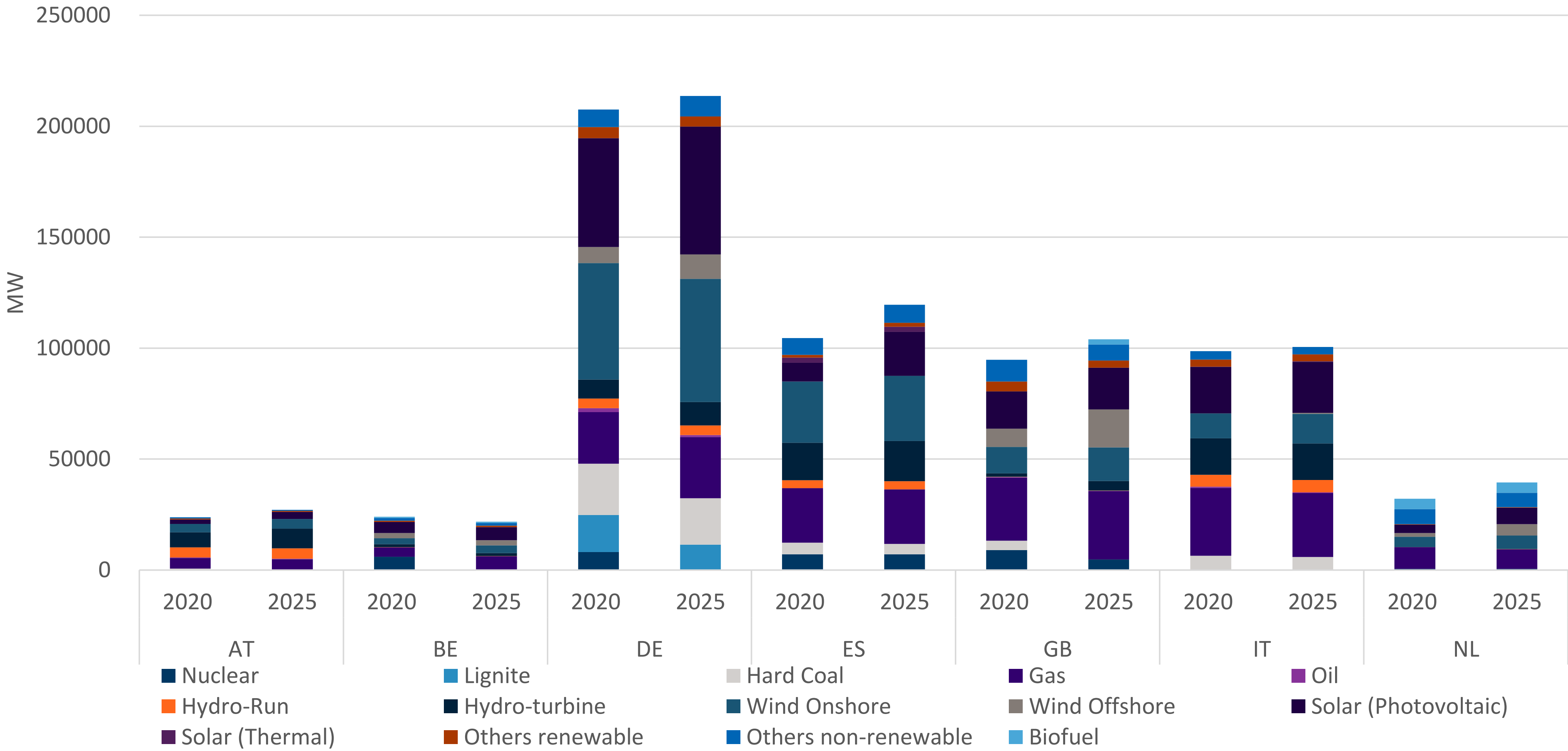
Offshore wind capacity additions



Source : FTI-CL Energy analysis based on RTE and PPE 2018

ENTSOE capacity outlook is used for neighbouring markets

Net installed capacity



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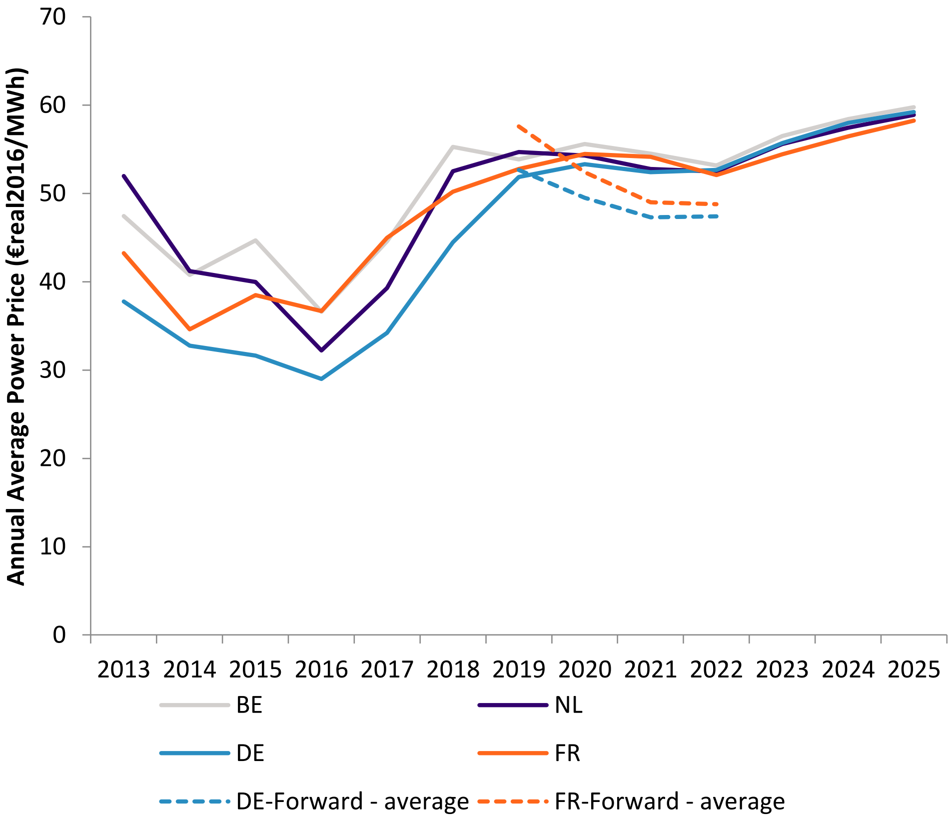
Source : FTI-CL Energy analysis based on ENTSOE

Modelling results - power prices for CWE zone

Power prices in CWE region including carbon prices



Source : FTI-CL Energy modelling results, FTI-CL Energy analysis based on EnergyMarketPrice data

- Based on the assumptions previously presented, we run our power model to estimate future power prices over the period 2019-2025.

- **Power prices are expected to remain flat until 2022**:
  - The gas prices and renewable deployment will have a downward impact on power prices; whereas
  - The closures (Fessenheim and German nuclear closures) will push power prices at higher levels.
- **Post 2022, power prices are expected to slightly increase** driven by:
  - An increase in commodity prices
  - The nuclear phase out in Germany and Belgium
  - Coal and lignite closures in Germany

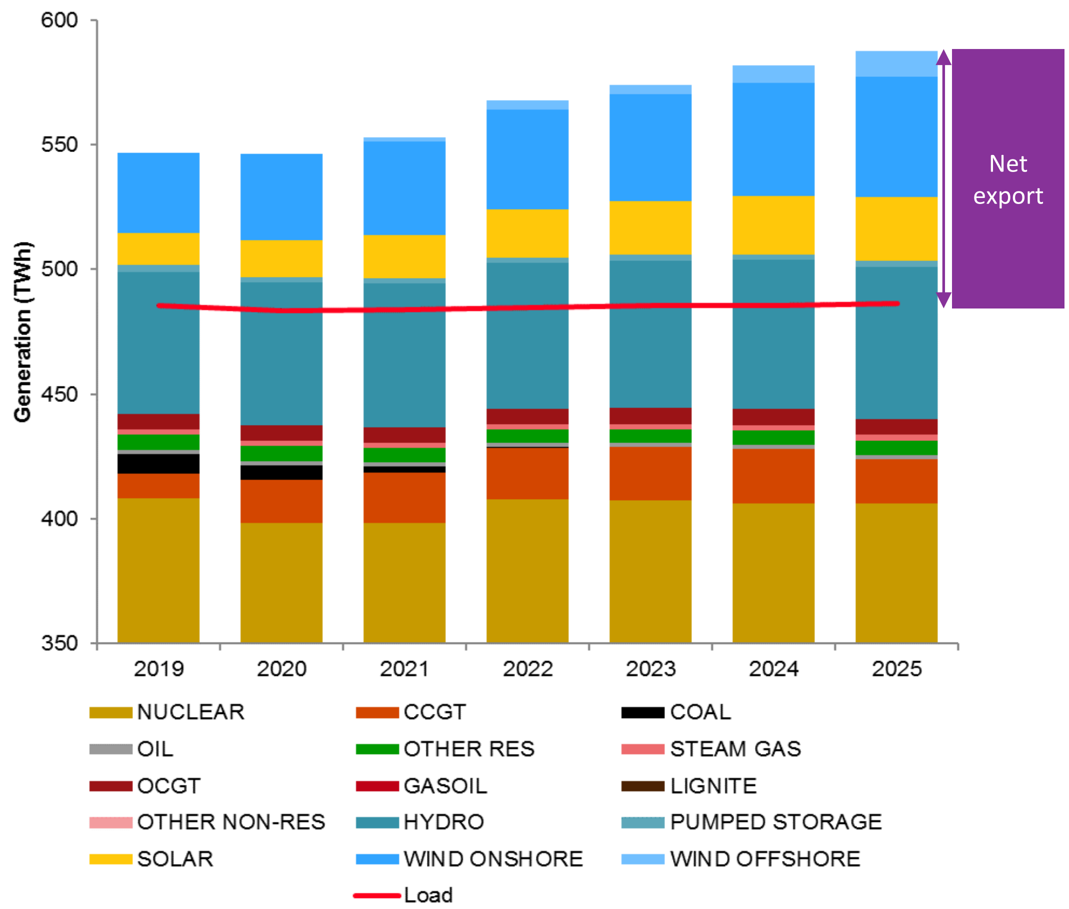
- French power prices are expected to remain slightly below neighbouring markets from 2022 owing to large share of nuclear generation in the mix. This point is subject to a correct nuclear availability.

- Forward prices seem to reflect a different view of fuel and CO2 price evolutions and/or underestimate the impact of closures in the CWE zone as they are lower than our projected prices from 2021.

Modelling results - French power generation mix

- French nuclear generation is expected to change over the period 2019-2022 driven by :
  - The decommissioning of Fessenheim units in 2020
  - The commissioning of the new Flamanville unit in 2022
- Generation from coal plants decreases from 2019 onwards, down to 0 in 2023 owing to the total coal phase out in France.
- The CCGT generation doubles between 2019 and 2024 to offset the lower generation from coal and nuclear plants and thanks to the high efficiency of the Landivisiau plant which comes online in 2022
- The generation from wind and solar increases up to almost 85 TWh in 2025, from 45 TWh in 2019
- France’s net export situation is intensifying from year to year.

Forecast Generation in France by type of technologies



Source : FTI-CL Energy modelling results

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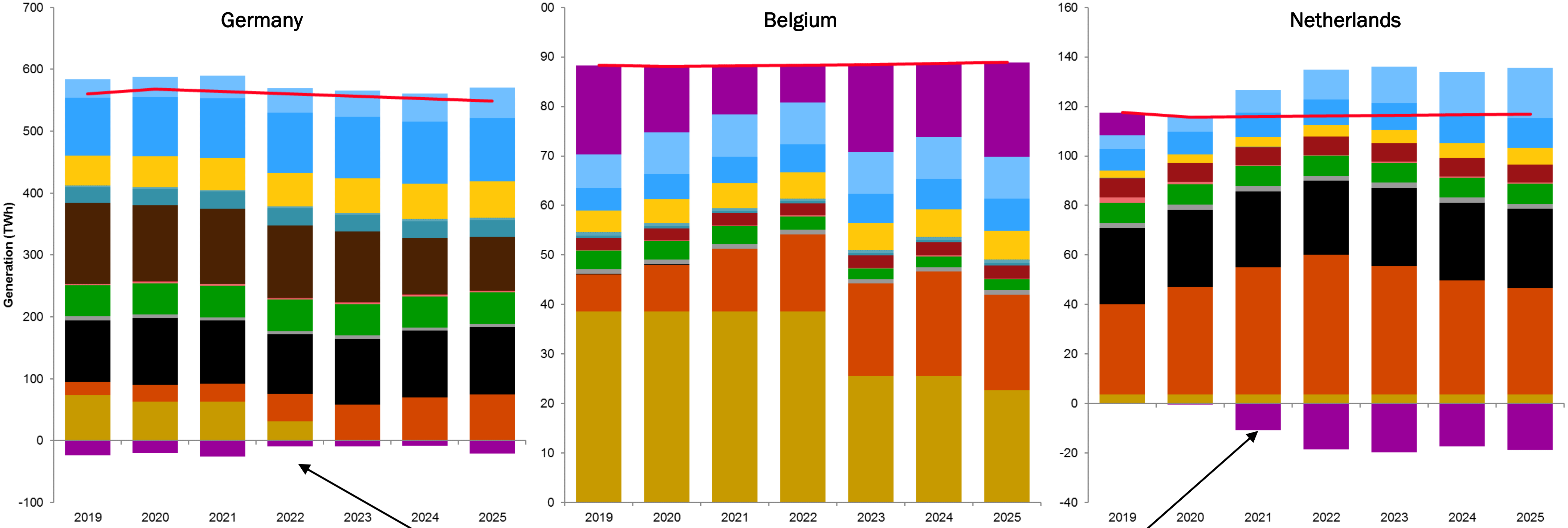
Modelling results - Neighbouring countries' power generation mix

Forecast Generation in the CWE zone by type of technologies



- Nuclear phase out in Germany associated with an increase in cross border capacity will modify flows between countries in the CWE zone.

Source : FTI-CL Energy modelling results

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