Regulatory coal phase-out and EU-Climate Energy Package targets: impact on the fundamentals of EU-ETS CO2 price

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Abstract

The EU-ETS has been facing persistent issues since its phase II was launched in 2008. In 2016-2017, ETS reform process succeeded in reaching a compromise in the Trilogue leading to a reform, notably of the Market Stability Reserve (MSR). In order to quantify interactions between the EU-ETS and the Climate Energy Package targets or other possible national regulatory measures such as coal phase-out, and their impacts on the fundamentals of EU-ETS CO2 price over the 2018-2030 period, a TIMES-based modelling study was carried out. This study simulates the 2018-2030 fundamentals of the EU-ETS CO2 price but without explicitly modelling the Market Stability Reserve and other dynamic constraints such as banking/borrowing or hedging constraints.

It shows that a large part of RES technical potential (corresponding to a ≈53-54% share in EU 28 electricity generation) close to EU implicit RES target for electricity (≈55%-60%) could be competitive without subsidies with a substantial, but reasonable, EU-ETS CO2 price (≈35-44€/tCO2). However, a 60% share of RES in EU 28 electricity generation in 2030 cannot be reached without subsidies.

But the possible regulatory coal phase-out in some countries would depress the CO2 price low enough to allow the utilization of remaining coal power plants to be competitive in comparison with CCGTs: a -5700 Mt CO2 2018-2030 carbon budget tightening/withdrawal would then be needed in order to restore CO2 price high enough to allow coal/gas fuel switch. Yet, external studies, along with our own evaluations, show that such level of carbon budget withdrawal might not be reached with the recent EU-ETS reform (Market Stability Reserve implementation: between 3400 and 4300 of MEUA which could be transferred into the reserve until 2030).

An additional EU-ETS reform leading to an at least ≈-5700 MtCO2 2018-2030 carbon budget tightening/withdrawal would deliver robust price incentive (notably to drive coal-to-gas switch) in the case of not only the possible national regulatory coal phase-out in some countries, but also of a subsidized 60% RES target for 2030 which, when combined, would otherwise drive the price close to zero.

Thus, considering the impact on the EU-ETS CO2 price of, on the one hand, the coal phase-out and, on the other hand, of the uncertainties on electricity consumption and of the fuel prices, additional measures will be needed to secure cost-efficient (market-driven) decarbonization of the power sector.

Keywords: EU-ETS, CO2 price, electricity generation, renewables, coal phase-out, Climate Energy Package

European energy-climate policies and other drivers behind the EU-ETS CO2 market price evolution

EU-ETS has been facing persistent issues since its phase II was launched in 2008

Since the adoption of the 2020 Climate Energy Package (CEP) in 2008, Europe has decided to implement simultaneous targets by adding Renewable Energy Sources (RES) and Energy Efficiency (EE) targets to Greenhouse Gases (GHG) commitment.
Applying a similar approach, the European Council adopted on 2014/10/24 the 2030 CEP which defines among other things three targets:

- 40% reduction of GHG emissions compared with 1990 levels (binding target);
- at least 27% of renewable energy in final energy consumption (EU-level binding target), which, according to the Impact Assessment study issued by the EC on 2014/01/22, would lead to 45% of RES and 29% of variable RES ("VRES") in net power generation in 2030;

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- at least 27% of EE (indicative target), meaning 27% reduction of energy consumption in 2030 compared with the 2007 PRIMES scenario energy consumption projections (pre-crisis scenario).

On the 14th of June 2018, Trilogue finally adopted the definitive 2030 binding targets for RES and EE:

- Concerning Renewables, their share must be 32% in 2030. And, even if, at this step, the text does not explicitly specify, the ratio is to be understood as the share in final consumption.
- Energy Efficiency target (which is actually, as the 2020 target, an energy cap target) is 32,5% meaning that the level of consumption is limited to this value compared to the level anticipated for 2030, in the 2007 Reference Scenario. Once again, the text of the agreement does not clearly define if the ratio concerns Primary Consumption and/or Final Consumption [EC Council 26/06/2018j- EE Directive proposal][1]

Presented by EC as the flagship of European climate policy, the EU-ETS has seen much lower prices than expected. Since the start of its second phase in 2008, EU-ETS emissions have been lower than allocations every year, with the exception of 2008. The 2009-2011 economic crisis and an accelerated RES development led to a large surplus of permits that weakened the ETS price.

Figure 1: 2005-2017 EU-ETS three successive phase CO2 price evolution (data from: ICE,EEX,ECX)

In 2016-2017, ETS reform process succeeded in reaching a compromise in the Trilogue. The main provisions impacting the ETS Market were:

- The increase of the Market Stability Reserve (MSR) intake rate to 24% in the first five years (2019-2023) with 2 thresholds: when the Total Number of Allowances in Circulation (TNAC) is greater than 833 Mt CO2 then 24% of it is transferred in the MSR. When TNAC is inferior to 400 Mt CO2 then 100 Mt of Allowances are put back in the Market from the MSR.
- From 2024 the cancellation from the reserve of allowances if the volume of the reserve is larger than the auctioned EUA volume from the previous year

[1][EC Council 26/06/2018j- EE Directive proposal]: " (4) *The need for the Union to achieve its energy efficiency targets at EU level, expressed in primary and/or final energy consumption, in [ ]2030 should be clearly set out in the form of a target of at least 32.5% for 2030. This target, which is of the same nature as the Union's 2020 target, should be assessed by the Commission in order to revise it upwards by 2023 at the latest in case of substantial cost reductions or where needed to meet the Union's international commitments for decarbonisation. There are no binding targets at national level in the 2030 perspective, and Member States' freedom should not be restricted to set their national contributions based on either primary or final energy consumption, primary or final energy savings, or energy intensity. Member States should set their national indicative energy efficiency contributions taking into account that the Union's 2030 energy consumption has to be no more than 1 273 Mtoe of primary energy and/or no more than 956 Mtoe of final energy. This means that in the Union primary energy consumption should be reduced by 26%, and final energy consumption should be reduced by 20%, compared to 2005 levels. A regular evaluation of progress towards the achievement of the Union 2030 target is necessary and is provided for in the [Governance Regulation].*"

- The possibility for member States to voluntarily cancel allowances to be auctioned to compensate with the effects of domestic policies or emissions.

In parallel some Member States consider the regulatory phase-out of coal generation capacities. Table 1 summarizes the up to date political announcements of coal phase-out in Europe.

Planned year of coal phase-out	**Country**	**Coal power plant capacity at the end of 2017 (GW)**
2021	France	3
2022	Sweden	0.8
2025	UK	13.6
	Italy	10.4
	Austria	0.6
2029	Finland	3.3
2030	Denmark	1.9
	Netherlands	6.4
	Portugal	1.8
Total		**41.8**
Note: In EU28, at the end of 2017, a total existing coal plants capacity of 156.9 GW		

Table 1: Up to date coal phase-out political announcements in Europe and corresponding capacities (sources: [ICIS 04/2018][IHS Markit 04/2018])

Up to now, Germany did not announce an official anticipated withdrawal of coal power plants but a high-level commission was mandated (see [BMU 2018]) this year to study the question and to produce a coal phase-out roadmap before the end of 2018. That is the reason why we built up a scenario which takes into account a significant decrease of coal power plant in this country until 2030 (see Table 2). Figure 2 shows the coal phase-out trajectory scenario we simulated for Germany.

Year	**Installed capacity in hard coal and lignite power plant (*) for Germany in the anticipated coal phase-out scenario (GW)**
2016	40.1
2018	33.3
2020	28.7
2025	15.9
2030	9.7
2040	0.0

(*) capacity figures do not take into account supercritical coal capacities

Table 2: Installed capacity in hard coal and lignite power plant for Germany in the anticipated coal phase-out scenario

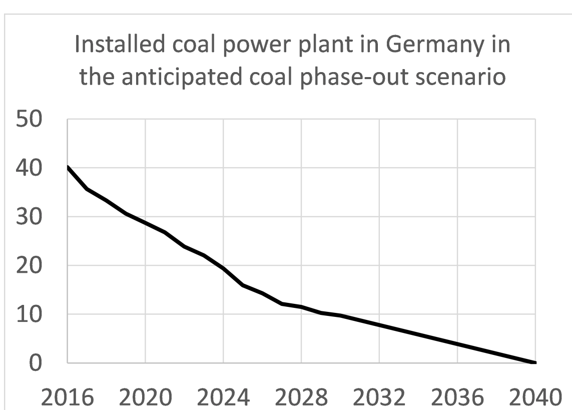

Figure 2: German hard coal and lignite phase-out trajectory according to Table 2 (excluding supercritical coal power plants)

Note concerning the assessment of TNAC as defined in the official texts:
The Aviation sector's demand for EUAs is not taken into account for computation of TNAC (because it only considers the emissions of stationary installations) while the aviation net demand for EUAs totalled 65.8 Mt on 2013-2016, because the emissions of the sector are growing fast: +4.5% per year in average for 2013-2016. This means that the actual surplus will be lower than the official one. The MSR thresholds of 833 Mt and 400 Mt will then be activated when the actual surplus on the market will be lower than the threshold.

Recent increase in EU-ETS CO2 price: the weight of the recent positions taken by financial funds along with the hedging policies of utilities

Since mid-January 2018, the CO2 price is increasing rapidly reaching levels not met during the past 6 years:

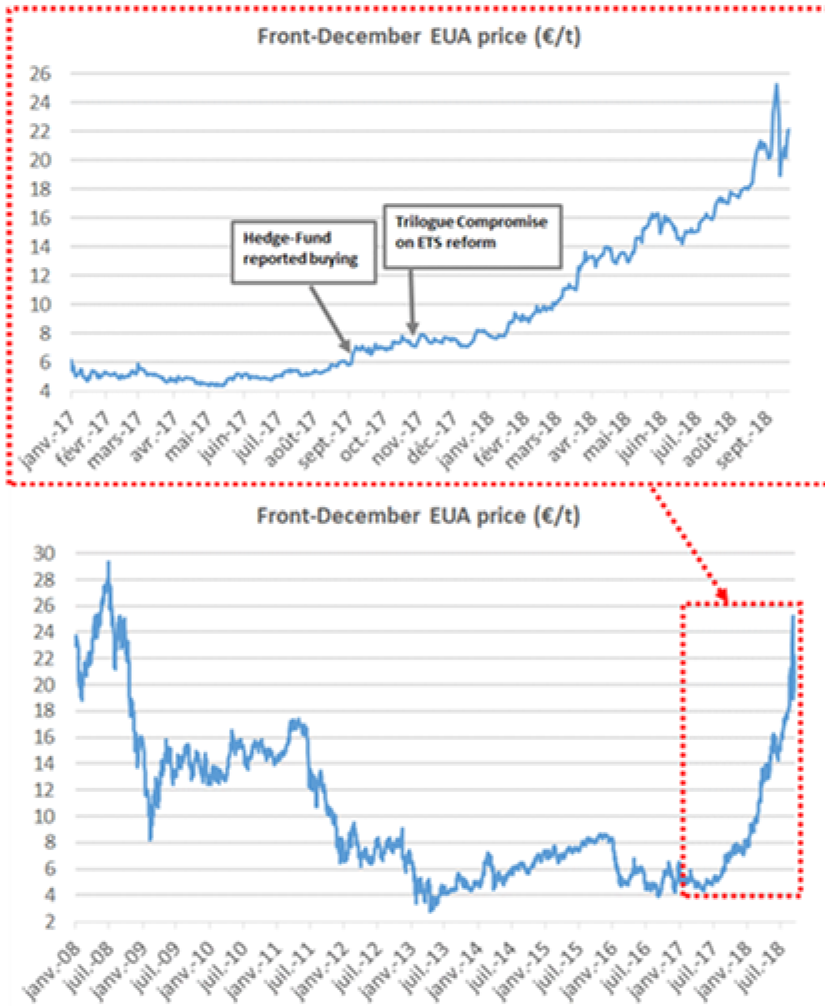

Figure 3: EU-ETS EUA price 2008-2018 evolution with a focus on January 2017-September 2018 sharp increase (data from: ICE,EEX)

This sharp price increase happened and is continuing while paradoxically EUAs surplus could still appear to be important (≈1686 Mt at the end of 2017 according to our estimations) without taking into account the effect of hedging.

The weight of the recent positions taken by financial funds along with the hedging policies of utilities

One important driver of this recent increase has been the positions taken by hedge-funds and investment banks betting on a tightening of the market for the 2019-2023 period. Their analysis is that the MSR, along with the measures concerning unallocated phase 3 allowances, such as the direct transfer in the reserve by the end of phase

3 decided at the end of Trilogue process, will create a sufficient shortage of permits for the price to reach much higher levels than today. Evidences of this activity has been reported by Carbon-Pulse and by the Financial Times. On 2017/09/17, Carbon-Pulse mentionned that Lansdowne Partners, one of the biggest hedge fund of the London Financial Center, have started buying permits since mid-2017. Its CO2 portfolio is managed by a veteran of the EU-ETS previously at Barclays, Per Lekander, who has been explaining his strategy in an August 2017 conference. In January 2018, Carbon-Pulse mentioned that Morgan Stanley and Marex Spectron (a broker) have reopened previously closed carbon desks. Further names have been added by the Financial Times (2018/09/07), such as JP Morgan and Goldman Sachs, the journalist reporting important profits realized by the different funds having taken long positions on the EU-ETS. The return of financial actors on this market has been pointed by some consultancies (ICIS, Redshaw Advisors and Thomson-Reuters) as the main factor behind the EUA price strong recovery.

But the impact of utilities hedging has also been pointed by some analysts as the fundamental explanation underpinning the financial actors strategy. In order to keep the volatility of their revenues low, utilities sell forward their production 3 years in advance, thus obtaining guaranteed electricity prices. They buy forward the production inputs, commodities and emissions permits, and are able to secure their margins as a result. Since those operations are mainly done through futures markets, for every emission permit future bought, there is a counterparty which has taken the opposite position (selling forward). No actor on the EU-ETS is a net seller (besides the regulator). As a consequence counterparties will buy spot permits thus locking in a certain return (the cost-of-carry), equivalent to an interest rate. This implies that utilities forward hedging immobilizes a part of the permits available a given year for compliance in future years. A part of the surplus is thus not an excess of supply. Estimation of the volumes of hedging has traditionally been the Open-Interest on futures markets. On the 10th September 2018, the total number of contracts opened on EEX and ICE was around 1800 Mt. A part of that number may be linked to financial funds positions, but no reliable estimates exist. A lower estimate, based on average hedging ratios reported by utilities, would represent 1400 Mt-1600 Mt.

A tightening of the market during the 2019-2023 period?

The case for an important tightening of the market in 2019-2023 can be made by remarking that the MSR, when it will absorb 24 % of the TNAC (the official expression for surplus), will greatly lower the supply of permits during those four years. If the amount of undistributed allowances was to be the same as for the 2013-2017 period (560 Mt), the present surplus (around 1650 Mt at the end of 2017) would shrink and could eventually fall below the MSR threshold (833 Mt) as soon as 2021, even in a case where emissions continue to decrease at the same pace than in previous years (- 2.9% per year in average in 2013-2016).

The Figure 4 bellow shows EDF R&D estimation of this possible shrinking of EU-ETS surplus along with the mid-march 2018 open-interest (OI) volume on EUAs forwards contracts on ICE and EEX (1400 Mt on the 16th of March 2018):

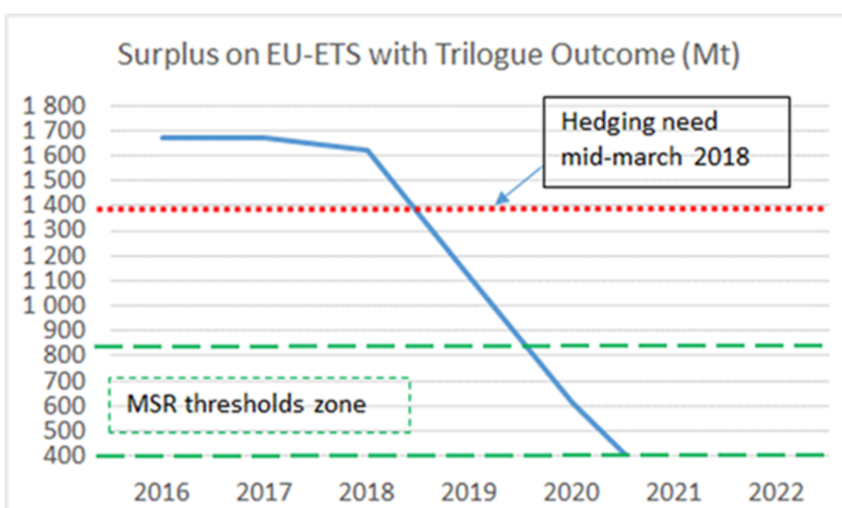

Figure 4: EDF R&D simulation of the impact of Trilogue Outcome on the EU-ETS surplus compared to mid-March 2018 Open-Interest on EUA forwards contracts volume on ICE and EEX

If the amount of available permits is lower than what is needed for forward hedging, then some fuel-switch from coal to gas would be needed in the electricity sector. Recent Carbon-Tracker report by Mark Lewis ([Carbon Tracker 08/2018]) alleges this is the case, and forecasts a level of 35€/t in 2019 and 40€/t in 2020.

But the recent reform impacts are still highly uncertain even for the 2019-2023 period, and most of all, for beyond 2025.

Nevertheless, the CO2 price level necessary for fuel-switch is hugely dependent on the prices of coal and gas. Commodity prices are very volatile, as the last two years have shown. Thus, any forecast of high CO2 prices rests on some assumptions about their uncertain future levels. Possible coal power plants phase-out plans, announced by some EU countries would have an impact as well. Current high prices cannot thus be taken as indicators of the level of prices beyond a short-term horizon: when it comes to considering the 2020-2030 horizon, the impact of interactions between the EU-ETS and the Climate Energy Package targets (EE and RES target) or other national regulatory measures such as coal phase-out along with the uncertainty on fuel prices need to be quantified which is the aim of the study.

EDF R&D TIMES-elec model for assessing the fundamentals of EU-ETS CO2 price: a focus on the power generation system including technical RES production potentials and a 2018-2030 CO2 budget constraint for the electricity sector

In order to quantify interactions between the EU-ETS and the 2030 Climate Energy Package targets or other national regulatory measures such as coal phase out, and their impacts on both the EU-ETS CO2 price and the European electricity sector, a TIMES-based[2] modelling study was carried out with the EDF R&D TIMES-elec model. We limited the simulations to the electricity sector and the permits supply to quantities auctioned for the sector, as a first-pass for the whole of ETS.

EDF R&D TIMES-elec model:

The EDF R&D TIMES-elec model is a deterministic European generation capacity expansion model coupled with national data about wind and solar production potentials. The model represents 29 European interconnected[3] countries: these are the EU28 countries with the exception of Croatia but with taking into consideration Switzerland and Norway. The objective of the model is the minimization of the total discounted system costs (investment as well as production costs), while satisfying an exogenous electricity demand, taking into account already existing generation capacities. Simulations provide yearly results based on 288 time steps per year.

A 2018-2030 carbon budget constraint which embeds the fraction of the ETS carbon budget remaining for the electricity sector according to different regulatory scenarios (Market Stability reserve and other ETS actual or future reforms) is applied which shadow value represents the market fundamental of the ETS price.

Market Stability Reserve and all other dynamic constraints effects relative to hedging or banking/borrowing mechanisms are not modelled.

The impact of the Clean Energy Package targets on the EU-ETS can be simulated as follows:

- Renewables: a constraint on share (the volume) of intermittent renewable (wind, solar) can be applied (RES target to be met eventually with subsidies) or not (RES economic development without subsidies)
- Energy Efficiency target: simulated through different levels (scenarios) of electricity demand.

[2]The TIMES (The Integrated MARKAL-EFOM System) model generator was developed as part of the IEA-ETSAP's methodology for energy scenarios to conduct in-depth energy and environmental analyses. The TIMES model generator combines two different, and complementary, approaches to modelling energy: a technical engineering approach and an economic approach. In a nutshell, TIMES is used for, "the exploration of possible energy futures based on contrasted scenarios" (Loulou et al., 2005): https://iea-etsap.org/index.php/etsap-tools/model-generators/times

[3]assumptions taken for interconnection capacities: ENTSO-E Ten Year Network Development Plan 2016 (see [ENTSO-E TYNDP 2016])

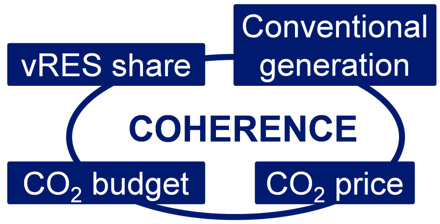

Figure 5: Principal constraints and coherence principe of the EDF R&D TIMES-based model for electricity

Fossil-fuel prices assumptions:

Two scenarios, taken from [UK BEIS 2017] fossil-fuel prices central and high scenarios[4], are simulated (see Table 3 below). They are both anchored to long-term 2030 values, with prices growing from 2017-19 low points, but to different 2030 levels.

2030 fossil fuel prices	median	high
Oil ($16/bl)	78.6	117.9
Coal ($16/ton)	86.4	113
Gas ($16/MMBtu)	8.6	10.7

Table 3: 2030 projected fossil fuel prices in the "median" and "high" BEIS 2017 scenarios

2018-2030 carbon budget for the electricity sector assumptions:

Until now, the Industry has had a surplus of free allocated permits. The free allocations will be maintained after 2020 even if decreasing. We assumed that Industry will keep its free allocated permits. If the EU-ETS price is not high enough, there will be no financial incentive to sell them. On the contrary, if EU-ETS price is expected to increase in the future, Industry could also decide not to sell its allowances considering banking possibilities. For those reasons, we considered that the ETS could be restricted to the Power sector only which is exposed to EUA auctioning.

The so-called banking of permits is allowed under the EU-ETS, that is, using permits auctioned on a given year can be used for compliance in the future, without restriction. This implies that the effective constraint on emissions is given by the sum of annual caps from 2018 to 2030, minus sum of free allowances for Industry on the same period. This sum is called **a carbon budget.**

Initial 2018-2030 carbon budget for the electricity sector before the adjustment of the MSR:

- The surplus calculated at the end of 2017 is 1673 MEUA. This surplus is actually used by the market to cover utilities's hedging. Therefore, we considered that the surplus is affected to power sector's dedicated carbon budget.

- According the EC's data [5](EU28+Norway+Liechtenstein+Iceland), 2 899 MEUA will be auctioned in 2018, 2019, and 2020, **without taking into account the effects of the MSR.**

- For the Phase 4 (2021-2030), the carbon budget for Power sector is 8 837 MEUA considering that 57% of the cap will be auctioned.

- The Aviation sector will need to use EUA, to complement its EUAA allocations that will not be sufficient to cover its growing emissions until 2030. According to the Carbon Tracker Initiative's study [Carbon Tracker 04/2018], the demand for EUA will be 507 MEUA over 2018-2030. The carbon budget dedicated to Power sector will be decreased by this volume because the Aviation sector will buy the needed EUA on the market.

Before the adjustment of MSR, the 2018-2030 carbon budget for Power sector taken into account in the calculations is : 1 673 + 2 899 + 8 837 − 507 = **12 902 MEUA**.

[4]Euro-dollar exchange-rate is a simple interpolation between the 2017 market average and the OECD 2015 PPP value. We use this last number as a projection for 2030, making the assumption that there will be on average no inflation differential between the USA and the Eurozone on 2015-2030.

[5]see [EC 2018 data]

Minimum volume of the reserve of the MSR by the end of 2020:

From 2021, the MSR reserve will have a minimum volume of around 1700 MEUA, whatever the effects triggered by the TNAC will be. Indeed, a part of the allowances will be directly transferred in the reserve:

- 900 MEUA from the Back-loading;
- the volume of phase 3 allowances which have not been allocated by the end of 2017 is 786 MEUA according to EC's data (see [EC 2018 carbon market report]).

By the end of 2020, whatever the effect of the MSR could have been in 2019 and 2020, the reserve of the MSR will contain at least 1 686 MEUA (900+786). But this value appears to be a minimum volume since some other EUA are likely not to be allocated until 2020. In the most recent Carbon Tracker analysis (see [Carbon Tracker 08/2018]), the total volume of phase 3 unallocated EUAs is estimated at 851 MEUA (327 EUA from the NER Phase 3 and 524 EUA from other sources). Thomson Reuters estimated this volume to 740 MEUA in February 2018.

5 levels of 2018-2030 carbon budget simulated in this study:

In the present study, the MSR effects are not explicitly modelled. Instead, we consider **5 different levels of 2018-2030 carbon budget withdrawal** simulating the effect of lower carbon budget on the power sector: along with a "minimal reserve" further withdrawals of -1 000 MEUA, -2 000 MEUA, -3 000 MEUA and -4 000 MEUA were introduced in order to simulate different levels of permits in the MSR in 2030[6] .

Considering that the MSR will absorb "by default" 1 686 MEUA, the present total volume of allowances which will have been absorbed by the MSR until 2030 will be:

	Minimal reserve	-1000 MEUA	-2000 MEUA	-3000 MEUA	-4000 MEUA
Minimum volume of EUA transferred in the reserve until 2030 (*)	1686	2686	3686	4686	5686

* *in 2030, a part of the EUA will have actually been cancelled on the 2024-2030 time period.*

Table 4: Correspondance between carbon budget simulation cases and minimum volumes of EUA transferred in the reserve until 2030 (in Millions of EUA)

But the -3000 MEUA and -4000 MEUA withdrawal cases could not be reached with the present MSR parameters

According to different studies, it appears that **the -3 000 and -4 000 MEUA withdrawal cases**, respectively **corresponding to a reserve of 4 686 and 5 686 MEUA** absorbed until 2030, **could not be reached with the present MSR parameters**.

- I4CE ([I4CE 06/2018] and see figure 6 below) estimated that the total volume of the EUA which could be absorbed by the MSR would be **hardly 3 500 MEUA in 2030** (including the permits which will be cancelled from 2023).
- Thomson Reuters [Thomson Reuters 09/2017] assessed the volume of EUA which could be absorbed by the MSR until 2030: **between 2 900 and a maximum of 4 300 MEUA** (in a coal phase out scenario).

Both analysis show that the MSR can hardly absorb 4 300 MEUA until 2030, which part of them will be cancelled from 2024. Nevertheless, in order to identify the effects of possible higher adjustments, the -3 000 and -4 000 cases were maintained in our assumptions (respectively corresponding to 4 686 and 5 686 MEUA absorbed until 2030).

[6]Actually, those decreased budgets could be produced by other potential ETS reform (lower LRF from a -2.2% to a -2.5% annual decrease for example) or other policies leading to the same level of CO2 prices associated with this carbon constraint

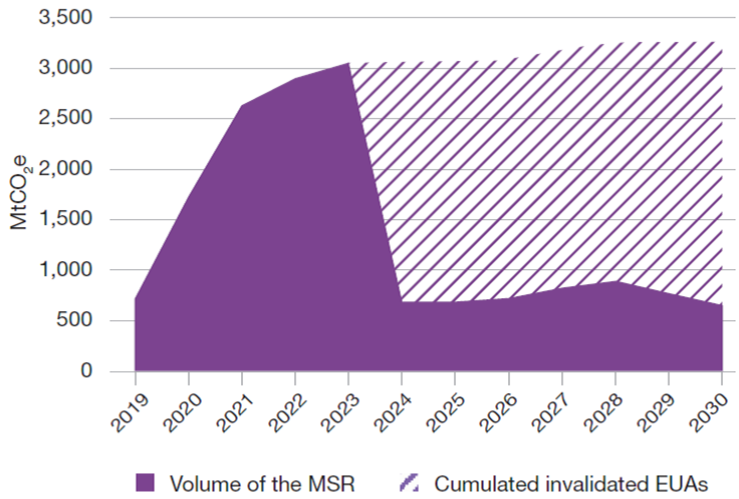

Figure 6: source: [I4CE 06/2018] (according to ENERDATA 2017)

Note: With the present parameters of the MSR, one can assume that, if the CO2 price increases, i.e. if TNAC is low enough, possibly lower than 400 MEUA, the MSR would release some EUAs (100 MEUA/y) from the reserve to the market, tending to drive down the CO2 price. Nevertheless, whatever the choice that could be done to reach these lower budgets (higher LRF, change of MSR intake parameters...), it is likely that the MSR release tuning would be also adjusted modifying the behaviour of MSR which maybe would release a smaller volume of EUAs, with a possible weaker impact on ETS price. As explained above, the MSR was not explicitly modelled in our calculations, making it impossible to simulate the response of the MSR in the different cases.

EU28 Electricity demand assumptions:

According to the latest International Energy Agency's World Energy Outlook (2017) ([AIE WEO 2017]), the European power demand will increase by 0.26% between 2020 and 2030 (0,41% over 2016-2030). This evolution is considered in the AIE WEO 2017 New Policy Scenario in which 2030 RES and EE targets were both defined at 27%. Since then, the 2030 European targets were raised to 32% and 32,5%. Based on EC's Non Paper released by Euractiv in March 2018 ([Euractiv 03/2018]), increasing the RES/EE targets from 27/30% to 33/33% would drive up the electricity demand by 0,2% over 2020-2030. In order to have a range wide enough to represent possible demand's evolutions, two different scenarios were assumed:

- The high case considers an increasing power demand (+0,5%/year) depicting a situation where the implementation of the 2030 EE target triggers an accelerated penetration of electricity uses, globally coherent with the WEO anticipation (+0.26%/year) but corrected by the effect of enhanced RES/EE targets (additional +0,2%/year).
- The low one is based on a flat demand corresponding to a case where activity could be lower than expected and EE targets could be reached without increasing the share of electricity in final consumption.

The level of electricty consumption of our two scenarios are the following:

- **baseline 0.5% per year growth rate** of electricity consumption on EU28 for the 2018-2030 period: 3366 TWh in 2030 on EU29 (EU27 + Norway and Switzerland), 3161 TWh on EU27 (ie EU28 minus Croatia):
- 0% per year growth on 2018-2030 scenario : flat demand of 3118 TWh on EU29 (EU27 + Norway and Switzerland); 2924 TWh on EU27 (ie EU28 minus Croatia).

Thermal power plants assumptions:

Two trajectories of coal (lignite as well as hard coal) power plants installed capacities were constructed and simulated for this study:

- **A baseline trajectory** with power plants shut down according to the technical end of life .

- **An anticipated coal phase-out trajectory** that concerns particularly the following countries : Germany, Italy, Netherlands, Spain, Sweden, UK, France, Austria, Finland, Denmark, Portugal according to the Table 1 announcements but with also Germany.

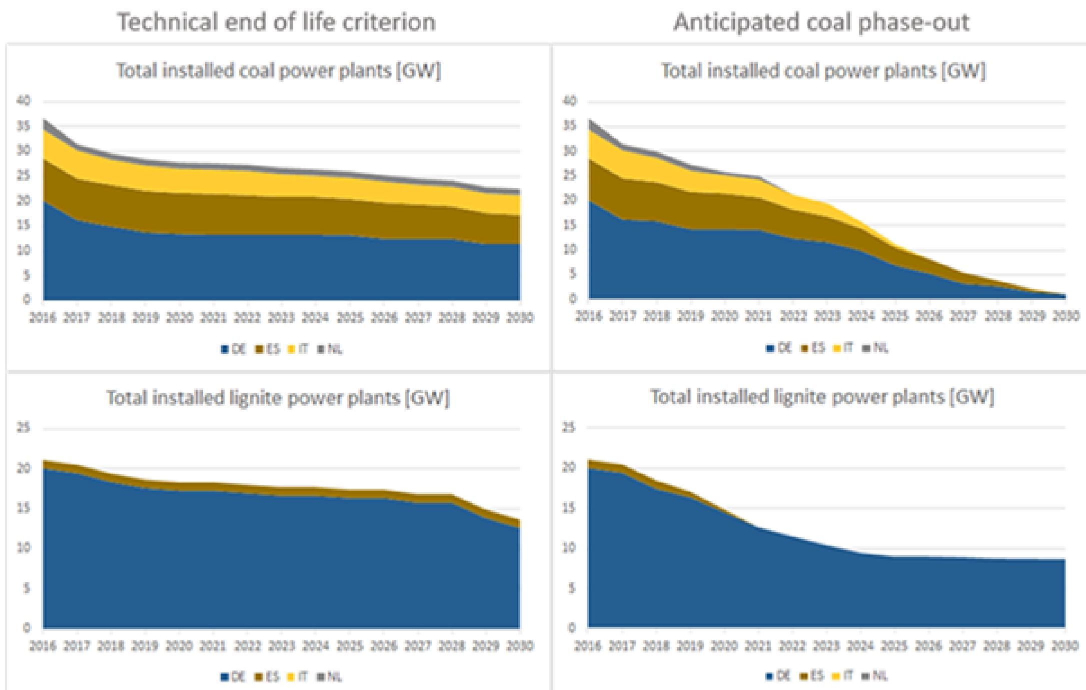

Figure 7: Total installed power plant capacities for hard coal and lignite in the baseline trajectory and in the anticipated coal phase-out scenarios (note: supercritical coal capacities not represented)

In the model, thermal power plants are represented according to two categories: existing technologies and new (to be built) technologies. They mainly differ in terms of efficiency and costs. Table 5 below summarizes the main characteristics of the existing thermal capacities that are represented in the modelling

Existing technologies	Efficiency	CAPEX	OPEX	life duration	WACC
	[%] (*)	[€/kW]	[€/kW.year]	[years]	[%]
Nuclear life extension	100%	1030	144	10	8%
Subcritical lignite steam turbine	32.2%	1917	34	40	8%
Subcritical coal steam turbine	32.5%	1686	28	40	8%
Oil steam turbine	38.2%	1588	28	40	8%
Gas steam turbine	37.8%	873	20	40	8%
Combined Cycle Gas Turbine (CCGT)	52.2%	995	27	30	8%
Open Cycle Oil Turbine	35.5%	669	18	20	8%
Open Cycle Gas Turbine (OCGT)	35.1%	661	18	20	8%

(*) Low heating Value

Table 5: Main characteristics of the existing power plants

Variable renewables: costs and technical potentials

Onshore wind, offshore wind and solar PV (residential, commercial as well as utility scale) are the variable renewable technologies taken into consideration in our modelling[7].

[7]Other variable renewable technologies like Concentrated Solar Power (CSP) were not considered in our study because its development in Europe seems to remain marginal

Costs assumptions:

To represent the variable RES adequately, we made use of different sources of data which are shortly described below.

- The IRENA dataset ([IRENA 2016]), which is summarized in Table 6, provided recent past (2015) as well as projected (2025) investment costs and performances of the technologies

	CAPEX [€2016/kW]		**Capacity factor**	
years	**2015**	**2025**	**2015**	**2025**
Onshore wind	1392	1222	0.27	0.3
Offshorewind	4149	3524	0.43	0.45
Solar PV	1615	705	0.18	0.19

Table 6: CAPEX and capacity factor of variable RES according to [IRENA 2016]

- To be more accurate with the present costs of the variable RES capacities, we used a recent published study by Fraunhofer ISE ([Fraunhofer ISE 2018]) which provides range of CAPEX and OPEX values for investments occurring this year (2018). On top of that, data concerning the WACC of the project, the technical lifetime and its degradation rate was available. Table 7 summarizes this dataset.

		CAPEX [€/kW] - Investment 2018		**Lifetime [years]**	**WACC [%]**		**fixed OPEX [€/kW]**	**OPEX variable [€/kWh]**	**Degradation**
		low	**high**		**nominal**	**real**			
PV rooftop	**small (5-15 kWp)**	1200	1400	25	3.80%	1.80%	2.5% of CAPEX	0	0.0025
	large (100-1000	800	1000	25	4.10%	2.10%	2.5% of CAPEX	0	0.0025
PV ground-mounted	**utility-scale (> 2 MWp)**	600	800	25	4.10%	2.10%	2.5% of CAPEX	0	0.0025
Wind	**onshore**	1500	2000	25	4.60%	2.50%	30	0.005	0
	offshore	3100	4700	25	6.90%	4.80%	100	0.005	0

Table 7: present CAPEX range and OPEX values for variable RES according to [Fraunhofer ISE 2018]

- For the long term data (2030), [NREL 2017] (Annual Technology Baseline summarized in Table 8) was taken as reference.

		CAPEX Range [€2016/kW]		**Fixed O&&M [€2016/kW year]**
		Min	Max	
Wind	Land-based	1117	1769	41
	Off-shore	2225	5231	113
Photovoltaic	Residential	1338	1338	9
	Commercial	1005	1005	7
	utility	822	822	9

Table 8: CAPEX and fixed O&M for variable RES from [NREL 2017]

As the previous data are not fully compatible each other, we had to adapt some of them according to EDF R&D own knowledge[8].

[8] And taking the following assumptions for WACC: residential photovoltaic: 4%; commercial & utility photovoltaic:5,5%; onshore winf: 5.5%; offshore wind: 8%

Technical potentials assumptions

The potentials in GW of each type of variable RES technology in each simulated country are determined with help of GIS software in analysing Corine Land Cover data.

The **potentials caluclated for each country** are **theoretical**: on the one hand, only areas where it is technically possible to value a vRES resource are considered and on the other hand, a "social acceptance ratio" is applied on the previous selected surfaces. Table 9 shows the assumptions that we took according to EDF R&D own knowledge.

	surfaces	**% of surface equipped**	**density**	**productible**
PV-ground	all "surfaces without apparent use" (Corin Land Cover nomenclature & surfaces)	4%	4.3%	12 sunshine classes
PV-residential	all well-oriented residential	75%	15% of each roof	
On-shore wind	all "favourable areas" (Corin Land Cover nomenclature & surfaces)	100%	225 kW /km2 (*)	9 wind speed class, 3 electricity grid connexion distances class
Off-shore wind	marine space within 40-100 km from the coast	2.5% of marine space	6 MW/km2	9 wind speed class, 2 depths (<30m & [30m-60m]) + floating
	marine space within 0-40 km from the coast	23% of marine space		

(*) present average on shore wind density in Schleswig-Holstein länder (the highest density in Europe)

Table 9: Data for the calculation of technical and acceptable potentials of vRES technologies [EDF R&D own assumptions]

Result: EU29 vRES cumulated technical potential (TWh) according to the corresponding LCOE

The Figure 8 shows the resulting aggregated EU29 2030 vRES LCOE/cumulated technical potential curve resulting from the assumptions mentionned above:

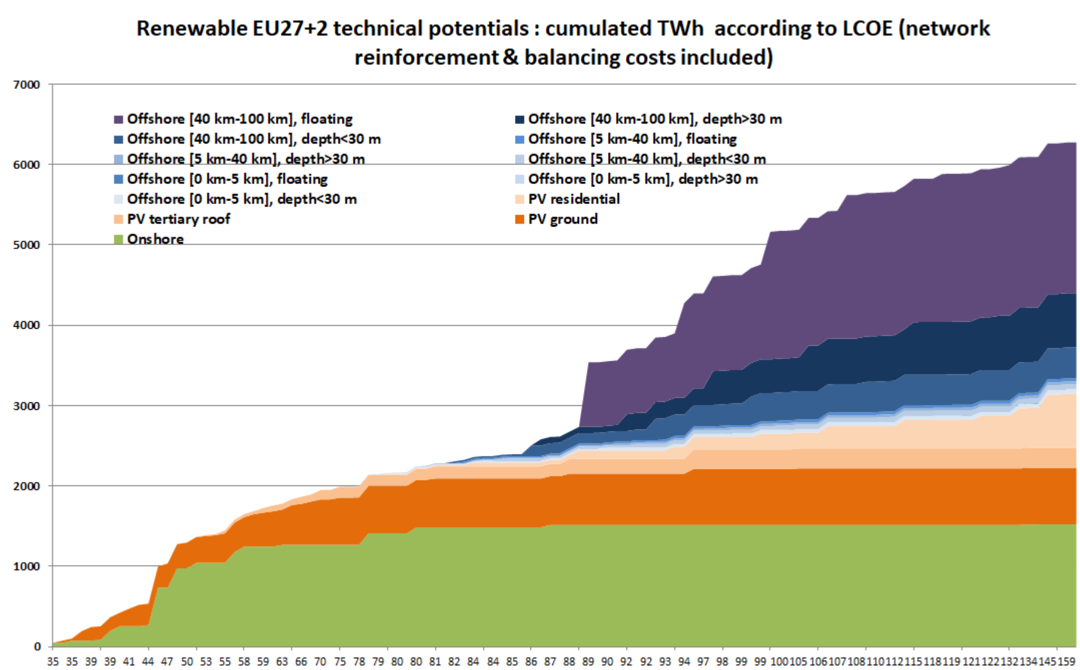

Figure 8: 2030 EU29 vRES cumulated technical potential (TWh) according to the corresponding LCOE ((€/MWh) [EDF R&D]

Nuclear power plants:

In this study a conservative view envisaging a stagnation (63GW) of the nuclear power capacity in France until 2030 has been taken. In other European countries official up to date announcements of nuclear capacity development or withdrawal have been taken into consideration. The resulting installed capacity for each country is indicated in Table 10.

Country\Year Capacity [GW]	2016	2020	2025	2030
Belgium	5.9	5.9	3.5	0
Bulgaria	2	2	2	2
Switzerland	3.3	2.6	2.2	1.2
Czech Republic	3.9	3.9	3.9	3.9
Germany	10.8	8.1	0	0
Spain	7.1	5.1	0	0
Finland	2.8	3.4	3.4	3.4
France	63.1	63.0	63.0	63.0
Hungary	2.0	2.0	3.2	4.4
Netherlands	0.5	0.5	0.5	0.5
Romania	1.3	1.3	1.3	1.3
Sweden	10.2	10.2	10.2	10.2
Slovenia	0.7	0.7	0.7	0.7
Slovakia	1.8	2.8	1.8	1.8
United Kingdom	8.9	8.9	4.7	11.5

Table 10: : Nuclear installed capacity in Europe [GW] (Non listed countries do not have installed nuclear power plants throughout the scenario duration)

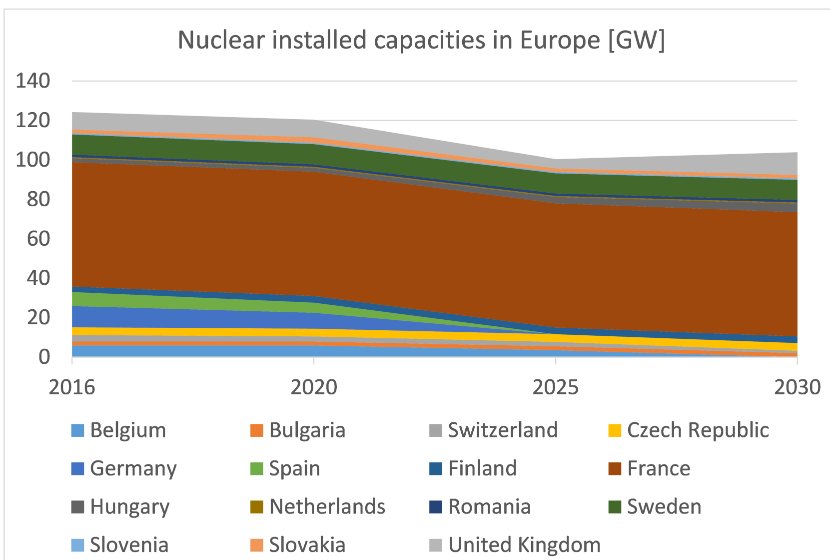

Figure 9: Evolution of nuclear installed capacities across Europe according to Table 5 assumptions

Hydro power:

Existing hydro power plants are taken into account in the model/simulations. The evolution of the installed capacities depends on the technical life duration of the assets. No significant increase in terms of hydro power plant capacity is foreseen in Europe for the scenario framework as the main potentials are well exploited until now in Europe.

Simulation results

A large part of RES technical potential (corresponding to a ≈53-54% share in EU 28 electricity generation) close to EU implicit 2030 RES target for electricity (≈55%-60%) is competitive without subsidies with a substantial but reasonable EU-ETS CO2 price (≈35-44€/tCO2)

According to external studies and our own calculations, the 2030 European Energy Package target of a **32% renewables in final energy consumption would imply a 55%-60% share of renewables in electricity generation**, which, after subtracting dispatchable RES production (mainly hydropower and biomass), results in a 39%-44% share for variable renewables (wind, PV).

The forecasted decrease in RES investment costs makes it possible to have an important share of renewable developing economically without subsidies.

As shown in Table 11, before considering any policy overlaps effects on the ETS such as coal phase-out decisions or a flat electricity demand, a large part of RES **technical** potential corresponding to a ≈53-54% share in EU 28 electricity generation close to EU RES implicit target for electricity (≈55%-60%) is competitive without subsidies with an EU-ETS CO2 price between 35 and 44 €/tCO2.

(electricity demand annual growh rate: 0.5%)	2030					
	median fossil fuel price			high fossil fuel price		
	% of VRES	% of RES	CO2 price (€/tCO2)	% of VRES	% of RES	CO2 price (€/tCO2)
2016	14%	32%				
minimal reserve case for 2018-2030 carbon budget	30%	49%	22	29%	47%	2
-1 000 MEUA further	33%	52%	37	34%	53%	30
-2 000 MEUA further	34%	53%	43	36%	54%	44

Table 11: RES economic development (without subsidies) according to EU-ETS CO2 price and fossil fuels prices scenarios

Indeed, in our simulations, a large technical potential of onshore wind (see Figure 8 on RES technical potentials and Figure 10 on vRES economic development) is competitive without subsidies, allowing the electricity sector to reach a high share of RES in production when the CO2 price is high enough.

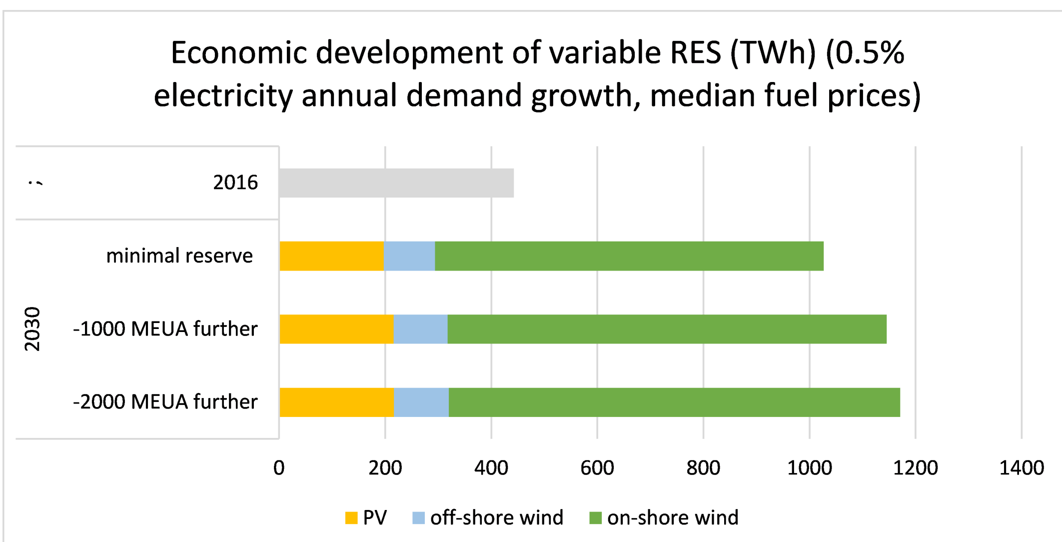

Figure 10: economic development (without subsidies) of variable renewables (onshore and offshore wind, residential & ground PV in the 0.5% annual rate of growth for electricity demand, median fossil fuels BEIS 2017 price scenarios

But a 60% RES target in 2030 would not be met without subsidies

Even in the constrained case of a strong tightening of the 2018-2030 carbon budget (-3000 MEUA case) with a 0.5% annual growth of electricity demand and no national regulatory coal phase-out, the EU-ETS CO2 price doesn't drive a further development of the renewables beyond a 53%-55% share of RES in generation (34%-36% share of variable RES) (see Table 12). The combination of several factors explain this. While the EU29 aggregated vRES cost/potentials curve displayed in Figure 8 could suggest a large technical potential of vRES with a reasonable LCOE, still those potentials are not equally distributed among countries: interconnections capacities limit their development. And also, above a certain level of variable renewable penetration, the adequacy between demand shape and renewable production shape might not be met without further and costly system adaptation or the mobilization of the most expensive but better located vRES potentials which is not possible, without subsidies, considering the CO2 price obtained in our simulations.

(electricity demand annual growh rate: 0.5%)	2030					
	median fossil fuel price			high fossil fuel price		
	% of VRES	% of RES	CO2 price (€/tCO2)	% of VRES	% of RES	CO2 price (€/tCO2)
2016	14%	32%				
minimal reserve case for 2018-2030 carbon budget	30%	49%	22	29%	47%	2
-1 000 MEUA further	33%	52%	37	34%	53%	30
-2 000 MEUA further	34%	53%	43	36%	54%	44
-3 000 MEUA further	**34%**	**53%**	**46**	**36%**	**55%**	**54**

Table 12: shares of variable and overall renewable in EU28 2030 electricity generation according to different 2018-2030 carbon budget withdrawals and thus different CO2 prices (0.5% annual rate of growth for electricity demand, median and high fossil fuels BEIS 2017 price scenarios).

The EU-ETS CO2 price signal could be enough to trigger coal to gas switch in most cases if there is no regulatory coal phase-out

Fuel switch between old hard-coal power plants and old CCGTs needs a high enough CO2 price. The evolution of the average load factor[9] of existing coal and gas power plants in both the high and median fossil fuel prices scenarios, as represented in the Figures 11 and 12, illustrates this phenomenon.

Without national regulatory coal phase-out, the EU-ETS CO2 price signal would be enough to trigger coal to gas switch in most cases of demand and fuel prices assumptions in the - 2000 MEUA case[10] (see Figure 12).

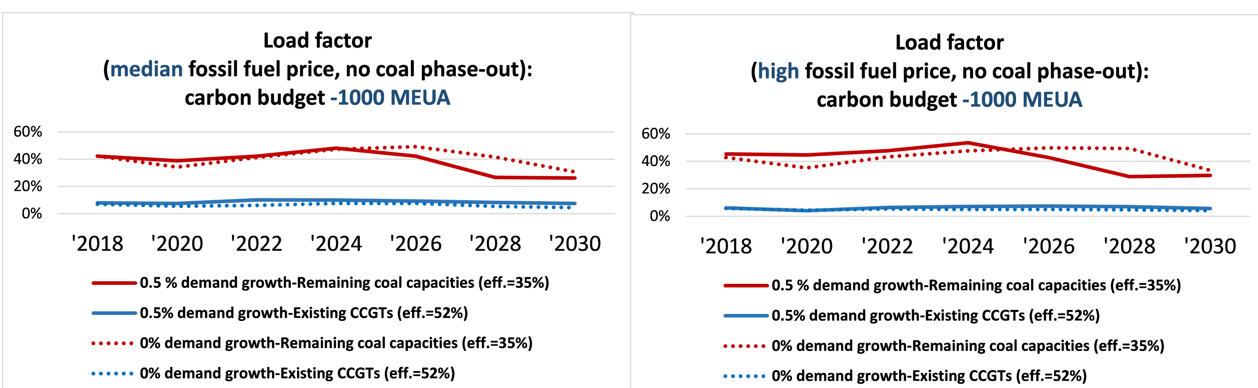

Figure 11: remaining coal and existing CCGTs capacities annual load factor: -2686 MEUA transferred into the reserve until 2030, no regulatory coal phase-out

[9]The load factor (LF) is the number of hours in operation (full power equivalent) divided by the number of hours in a year (8760) : the higher LF, the longer the annual time of operation for the considered plant.
[10]-2000 MEUA case =a minimum of 3686 MEUA transferred into the reserve until 2030.

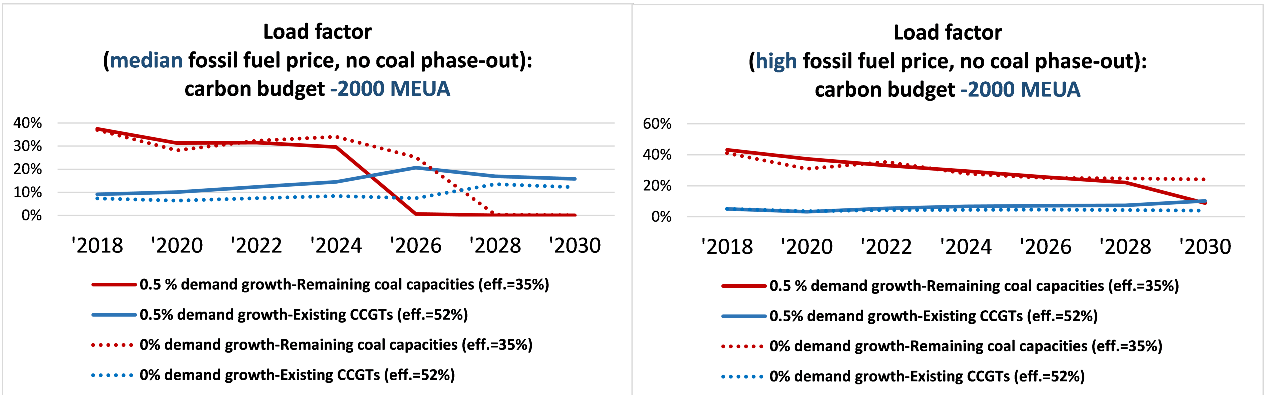

Figure 12: remaining coal and existing CCGTs capacities annual load factor: -3686 MEUA transferred into the reserve until 2030, no regulatory coal phase-out

But the possible regulatory coal phase-out in some countries would depress the CO2 long-term fundamental price

But the possible regulatory coal phase-out in some countries would lower the carbon price. For our base case for the carbon budget[11] the CO2 fundamental price falls to zero in both cases of fuel prices (see Figure 13). Only the cases with a higher emissions constraint see a recovery of the CO2 price: a withdrawal of a further -1000 to -2000 MEUA is needed in the baseline scenario (0.5% annual growth of electricity demand) in order to have a 2030 CO2 fundamental price ranging between 20 and 40€/tCO2 (see Figure 13 with median (left) and high (right) fossil fuels prices scenario).

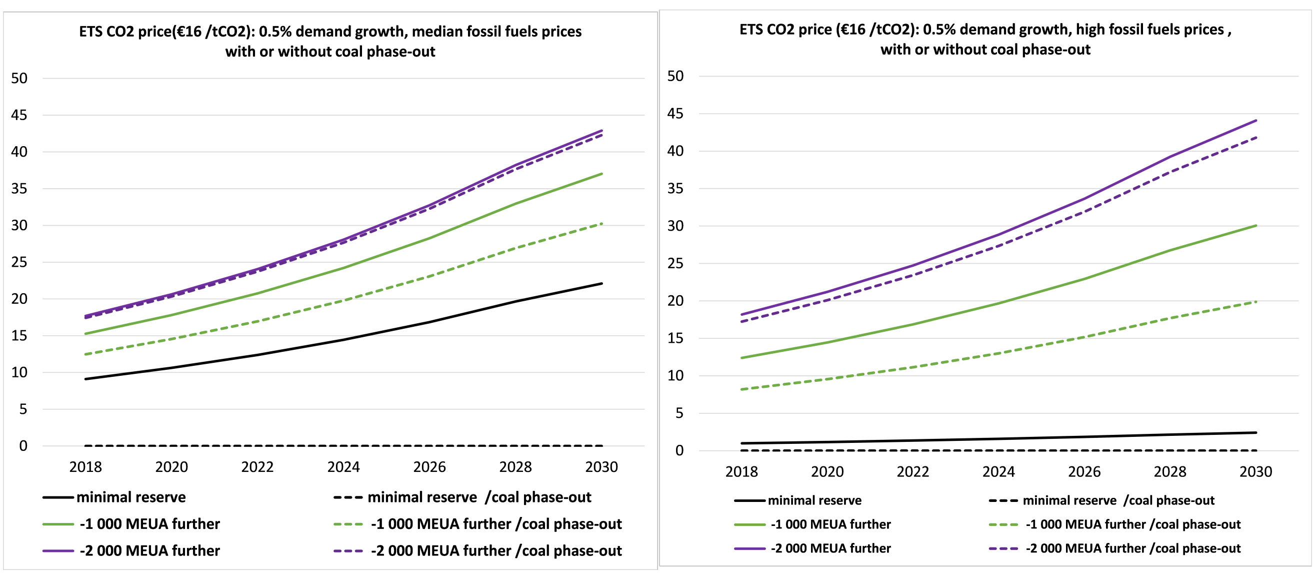

Figure 13: Comparison of the impact of coal phase-out on ETS CO2 price according to different 2018-2030 carbon budget withdrawals in the BEIS 2017 median fossil fuel price scenario (0.5% annual growth rate for electricity demand case)

National regulatory coal phase-out would depress the CO2 price low enough to allow remaining coal power plants to be competitive in comparison with CCGTs

Fuel switch between existing hard-coal power plants and existing CCGTs needs a high enough CO2 price. The evolution of the average load factor of existing coal and gas power plants in both the median and high fossil fuel prices scenarios, as represented in the Figures 14, 15 and 16, illustrates this phenomenon.

[11]initial carbon budget of 12902 MtCO2 minus the minimum volume of 1686 EUA transferred into the reserve until 2030

With national regulatory coal phase-out, such a level is only attained, in our study, in the case of an electricity demand annual growth rate of 0.5%, of an economic development of renewables (without subsidies) and in the **-3000 MEUA/-4000 MEUA cases** (depending on the fossil fuel prices assumptions))[12] from the 2018-2030 carbon budget (see Figure 15 and Figure 16).

But with a 0% annual growth rate for electricity demand, the -4000 MEUA case is a bit short to make existing flexible CCGTs competitive in case of a high fossil fuel price scenario (see Figure 17).

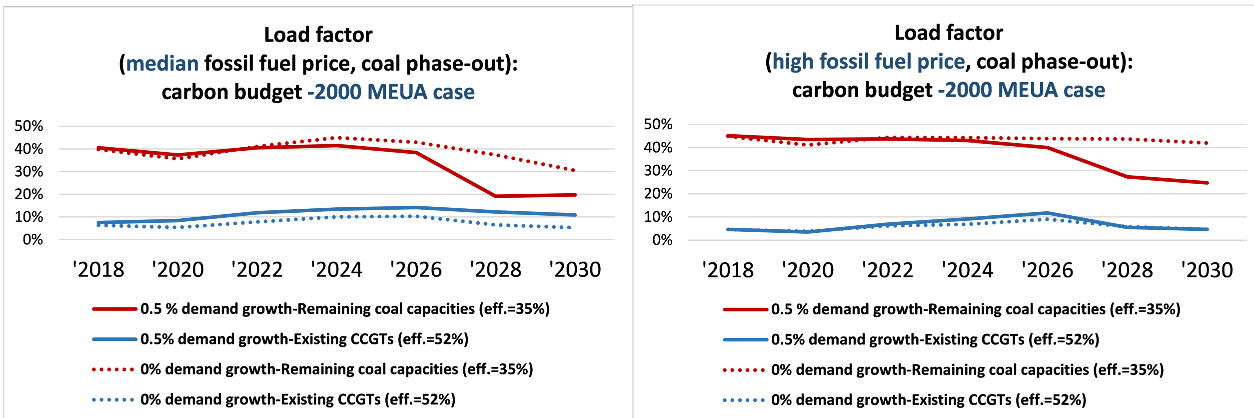

Figure 14: remaining coal and existing CCGTs capacities annual load factor: -3686 MEUA transferred into the reserve until 2030

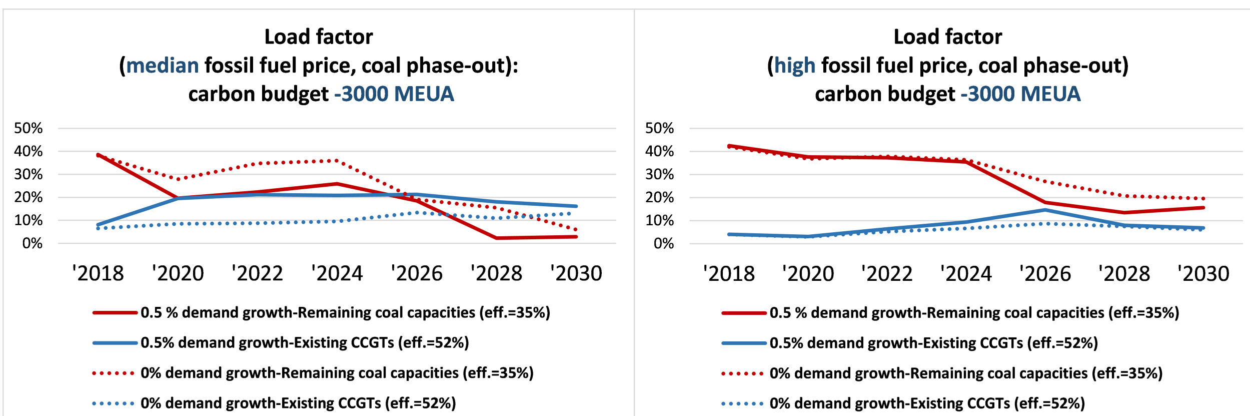

Figure 15: remaining coal and existing CCGTs capacities annual load factor: -4686 MEUA transferred into the reserve until 2030

[12] A -3000 Mt CO2 -/4000 Mt CO2 further decrease of the 2018-2030 carbon budget besides the already taken into account minimum volume of 1686 EUA transferred into the reserve until 2030 (see Table 4 for correspondance)

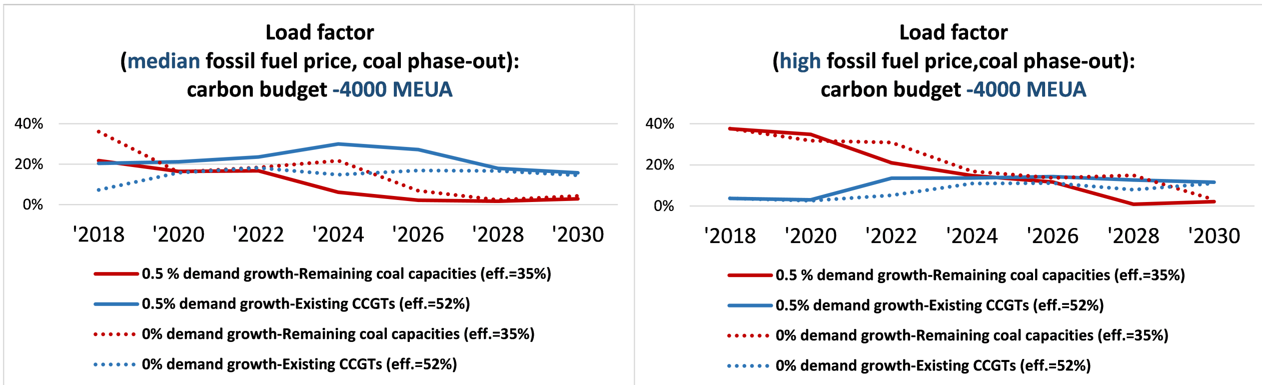

Figure 16: remaining coal and existing CCGTs capacities annual load factor: -5686 MEUA transferred into the reserve until 2030

When combined, the effects of a subsidized 60% RES 2030 target, of coal phase-out would drive the CO2 price close to zero

If the subsidized 60% RES target (44% subsidized variable RES share) for electricity is met and coal phase-out decisions become effective then **the 2030 CO2 price will be close to zero in the -1000 MEUA and – 2000 MEUA cases** (see Figure 17)**: an additional EU-ETS reform leading to** an at least -4700 (-3000 MEU case) but rather **a -5700 MEUA (-4000 MEUA case) withdrawal is necessary to restore a reasonable but substantial enough CO2 price allowing coal/gas fuel switch for the remaining thermal capacities** (see Figure 18 and Figure 19).

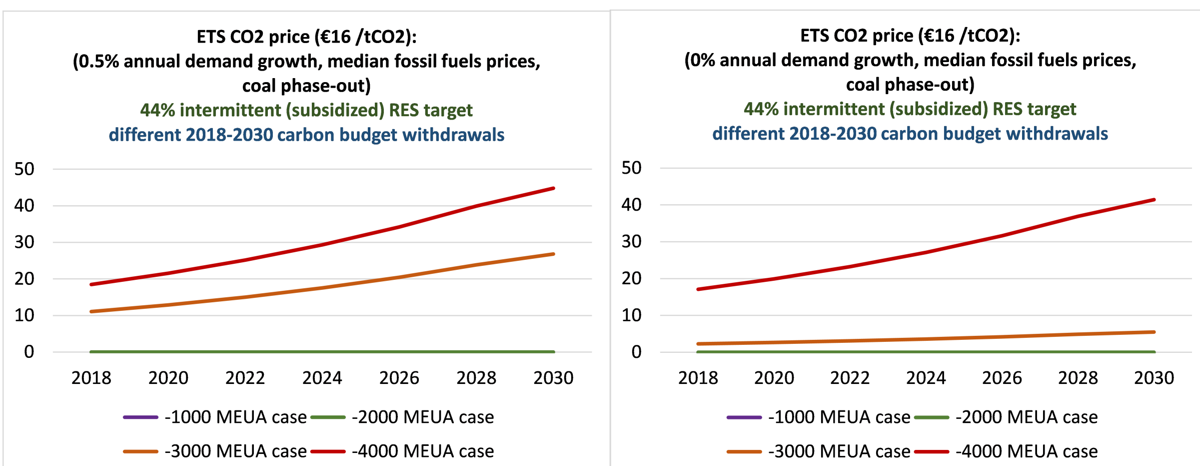

Figure 17: impact on ETS CO2 price according to different 2018-2030 carbon budget withdrawals of a scenario combining a 44% variable RES (subsidized) target plus regulatory coal phase-out in some countries

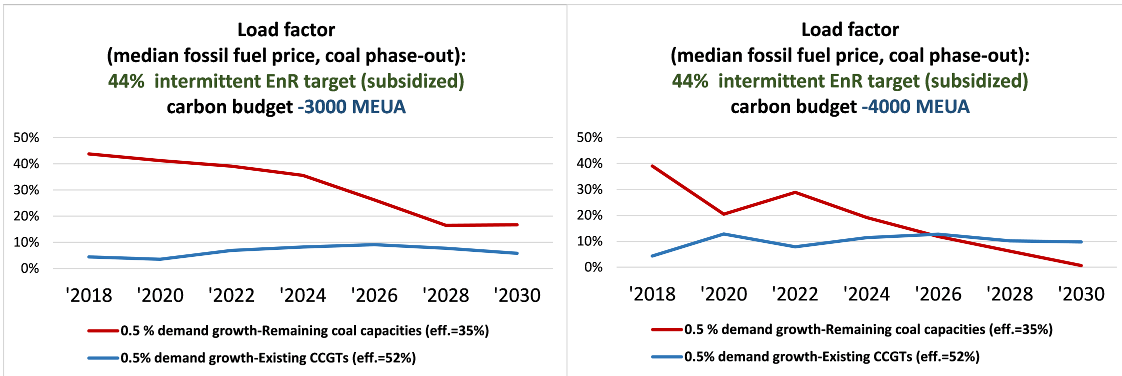

Figure 18: Impact, on the remaining coal and existing CCGTs capacities annual load factor, of a scenario combining a 0.5% annual growth rate for electricity, a 44% variable RES target plus regulatory coal phase-out in some countries (BEIS 2017 median fossil fuel prices) : -3000 MEUA & -4000 MEUA cases

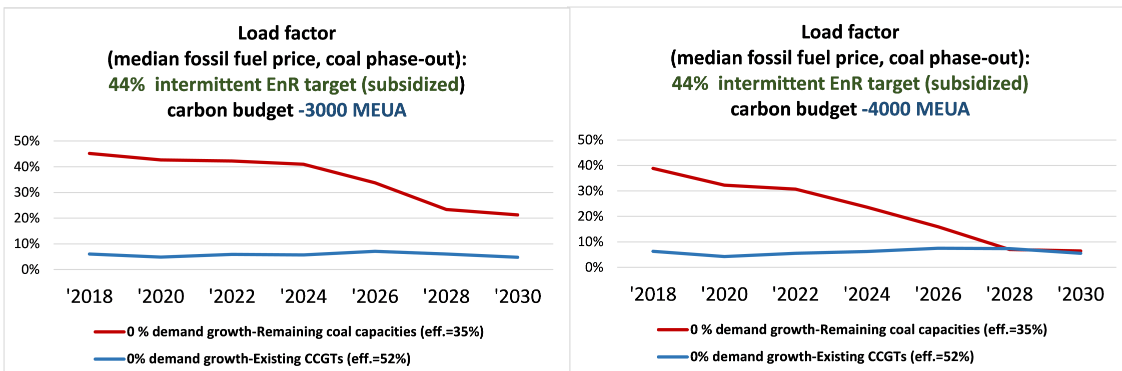

Figure 19: Impact, on the remaining coal and existing CCGTs capacities annual load factor, of a scenario combining a 0% annual growth rate for electricity, a 44% variable RES target plus regulatory coal phase-out in some countries (BEIS 2017 median fossil fuel prices) : -3000 MEUA & -4000 MEUA cases

Conclusion: the need of new measures in order to minimize the cost of the energy transition for the electricity sector

If a 60% share of RES in EU 28 electricity generation in 2030 cannot be reached without subsidies, still a large part of RES technical potential (corresponding to a ≈53-54% share in EU 28 electricity generation in 2030) close to the 2030 EU implicit RES target for electricity (≈55%-60%) is competitive without subsidies with a substantial but reasonable EU-ETS CO2 price (≈35-44€/tCO2).

But the possible regulatory coal phase-out in some countries would depress the CO2 price low enough to allow the utilization of remaining coal power plants to be competitive in comparison to CCGTs: a -5700 Mt CO2 2018-2030 carbon budget tightening/withdrawal would then be needed in order to restore CO2 price high enough to allow coal/gas fuel switch. But external studies, along with our own evaluations, show that such level of carbon budget withdrawal might not be reached with the recent EU-ETS reform (Market Stability Reserve implementation: between 3400 and 4300 of MEUA which could be transferred into the reserve until 2030).

An additional EU-ETS reform leading to an at least ≈-5700 MtCO2 2018-2030 carbon budget tightening/withdrawal would deliver robust price incentive (notably to drive coal-to-gas switch) in the case of not only the possible national regulatory coal phase-out in some countries, but also of a subsidized 60% RES target for 2030 which, when combined, would otherwise drive the price close to zero.

Thus, considering the impact on the EU-ETS CO2 price of, on the one hand, the coal phase-out and, on the other hand, of the uncertainties on electricity consumption and on the fuel prices, additional measures will be needed to secure cost-efficient (market-driven) decarbonization of the power sector.

Nomenclature

CEP: Climate Energy package

CAPEX: Capital expenditure

EC: European Commission

ECX: European Climate Exchange

EE: Energy Efficiency

EEX: European Energy Exchange

EUA: EU-ETS Allowance

EUAA: EUA aviation

EU: European union

EU-ETS: European Union Emission Trading Scheme

GHG: GreenHouse Gases

ICE: Intercontinental Exchange

MEUA: Million of EU-ETS Allowances

MSR: Market Stability Reserve

NER: New Entrants'Reserve

OI: Open Interest

OPEX: Operational expenditure

RES: Renewables Energy Sources

TNAC: Total Number of Allowances in Circulation

VRES: Variable Renewables Energy Sources

WACC: Weighted Average Cost of Capital

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