Interactions Renewables-CO2-Electricity prices

+

Two issues at stake: quantities

+ 1MWh of renewable energy = -1MWh of fossil energy?

- *Potential* substitution effect, in particular in the case of electricity generation

+ 1MWh of renewable energy = - 1tCO_2 emissions?

- *Potential* consequence of the substitution effect

Two issues at stake: pricing

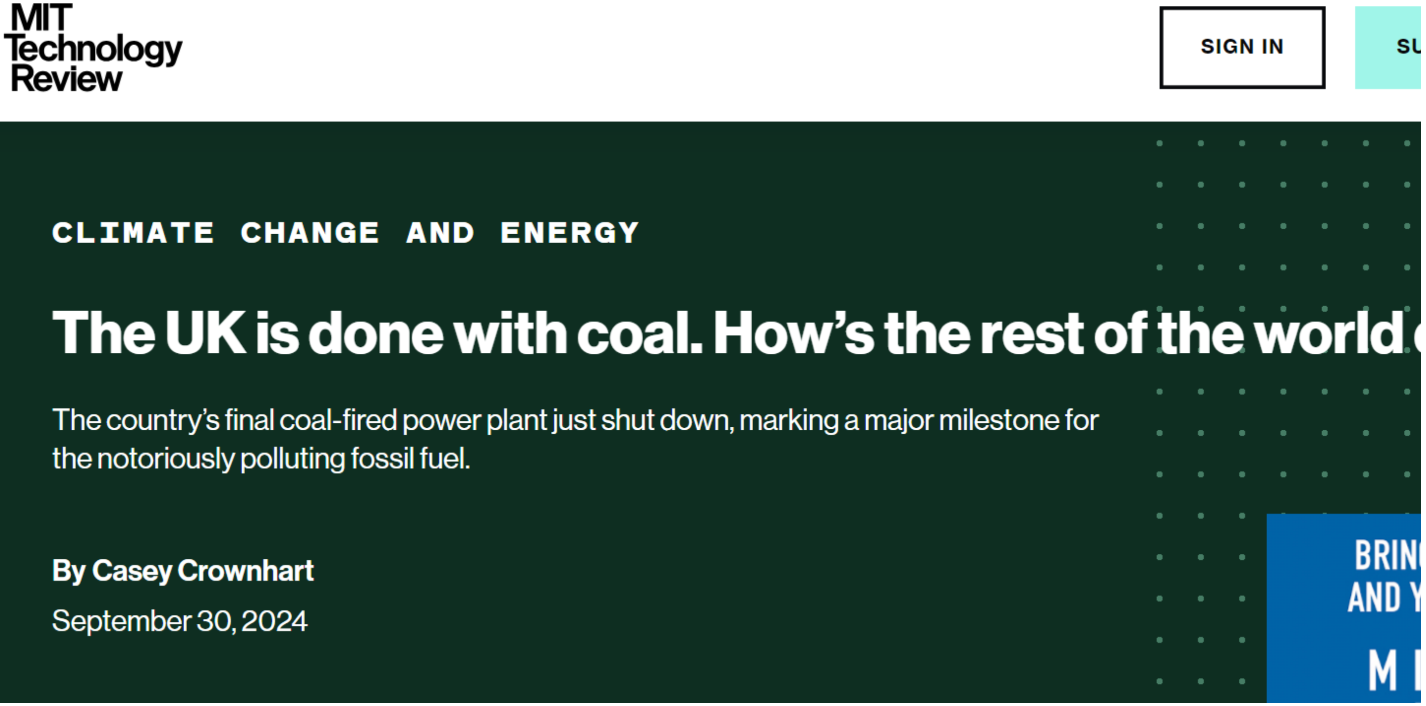
+ 1MWh of renewable energy = -1MWh of fossil energy?

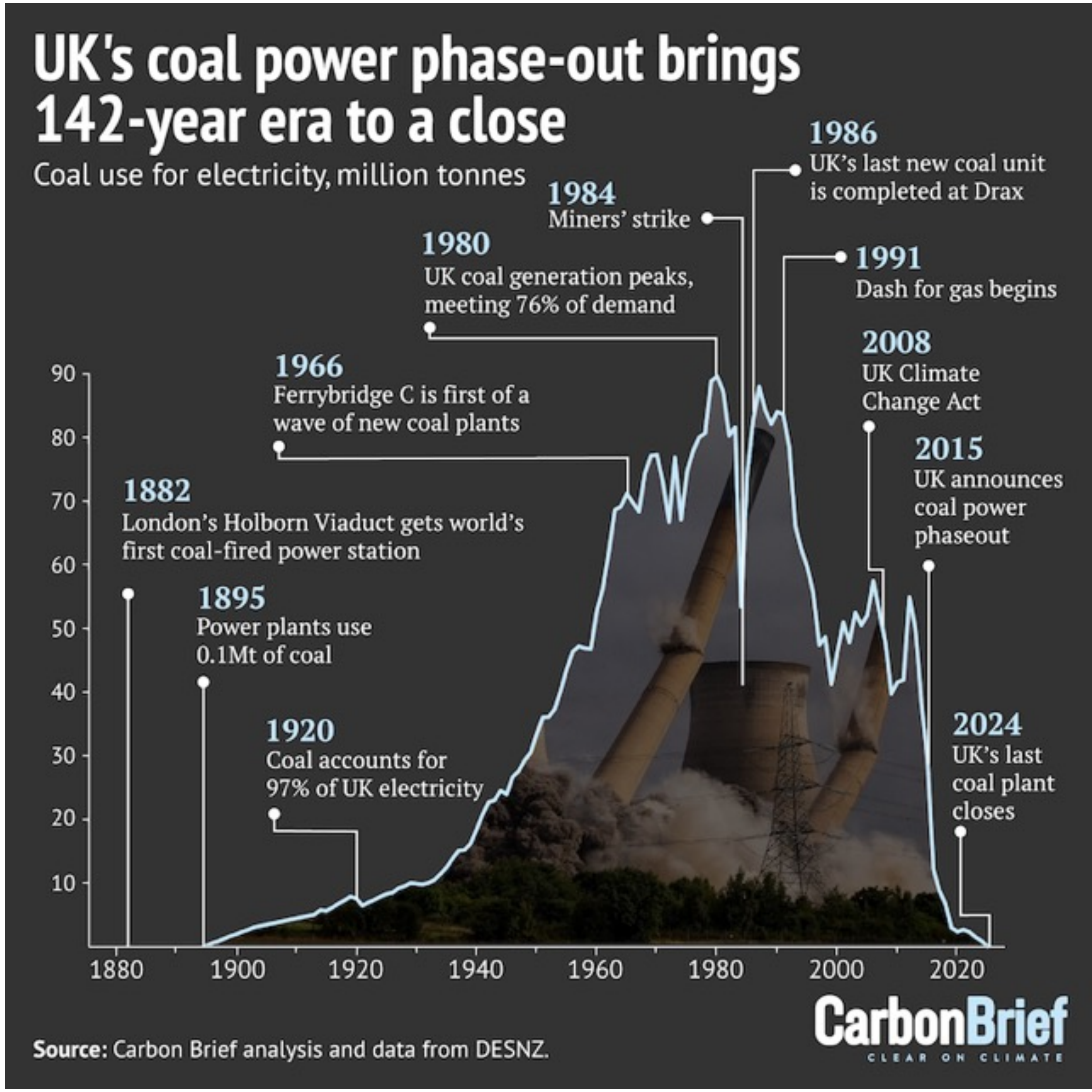
+ 1MWh of renewable energy = - 1tCO2 emissions?

- *Potential* impact on electricity pricing

- *Potential* consequences of CO2 pricing

[The UK is done with coal. How's the rest of the world doing? | MIT Technology Review]



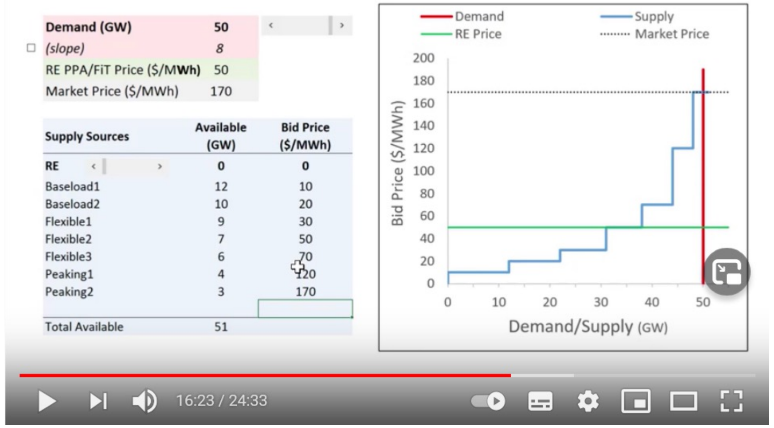


Key concepts

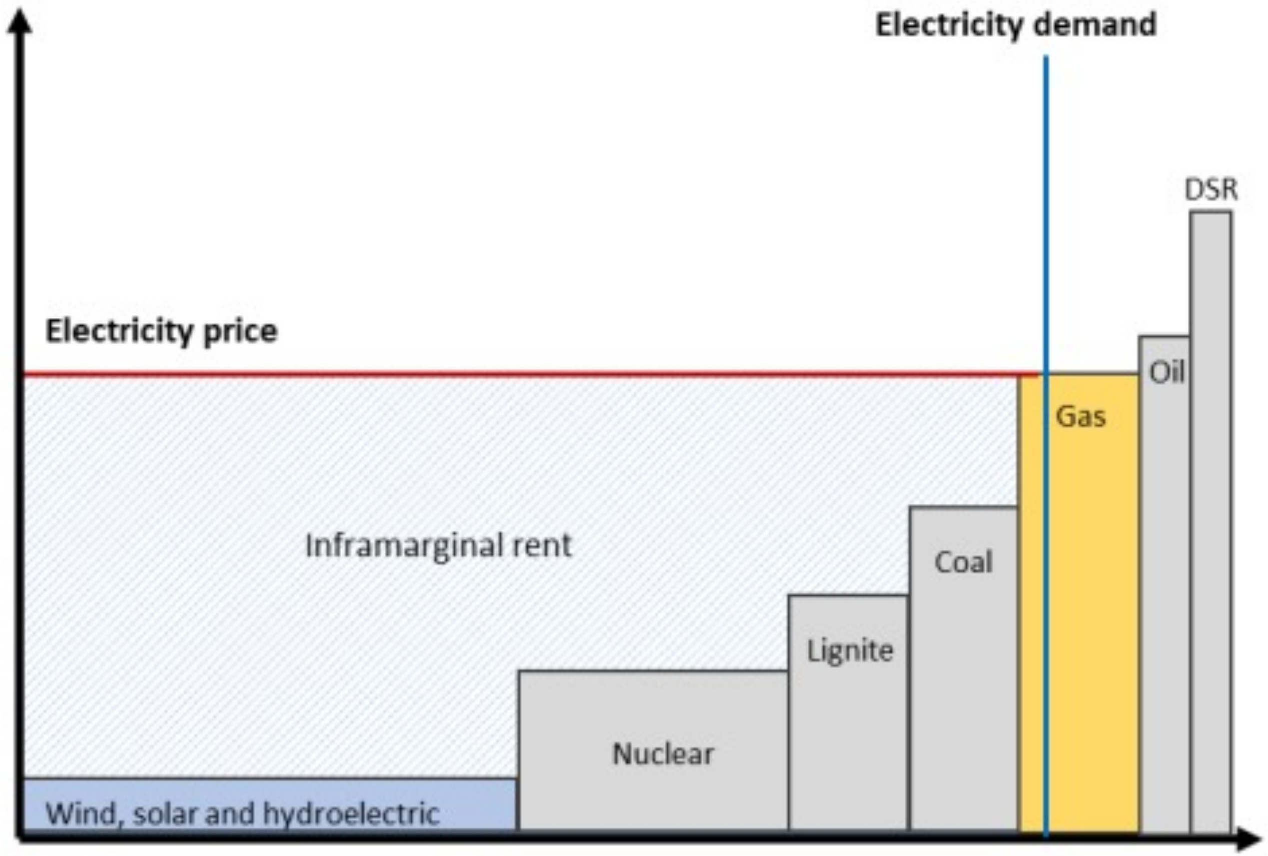
- Merit order effect
- Windfall profits
- Carbon pass-trough
- Efficiency of policy instruments to curb emissions (mostly in electricity markets)

The merit order effect (MOE)

- An example
- https://youtu.be/q-ZCS2epHuA



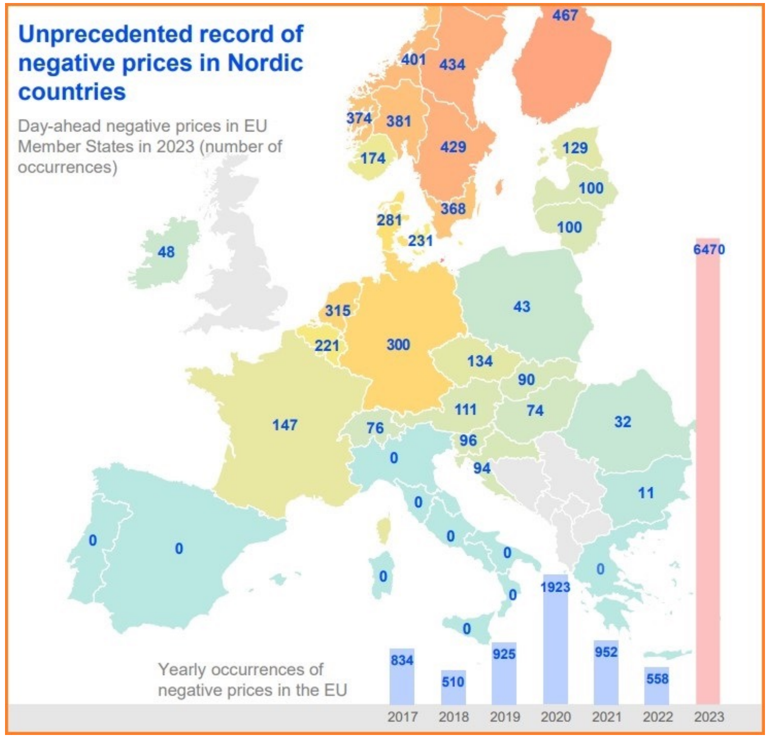
Simplified merit order supply stack



Source: EC JRC

The paradox of negative prices

London 14 September 2024, Financial Times



- In some instances, according to consultancy ICIS, prices fell below -€20 per megawatt hour.
- Solar energy has driven the negative pricing, the *FT* says, as it tends to be more consistent, leading to negative prices in particular in spring and summer, and during late mornings and afternoon.
- Batteries and long-term energy storage such as hydrogen could help address the issue of negative pricing.

Are RE responsible for theses negative prices?

- In thermal power plants, the chosen production for one given hour does not solely depend on the market conditions during that hour. The production status during the previous hours and the forecasts for the following hours also play an essential role.
- If, for example, the operator of a thermal power plant thinks it will have to produce a lot of energy between 7am and 8am and if, to meet this demand, they must start to increase production as of 4am, they need to be sure that their power plant will be called by the market operator at each hour between 4am and 7am.
- The economic cost of MWh produced during the night is, therefore, lower than the immediate marginal cost, as we need to deduct the expected gains at peak hours thanks to the ramp-up during the night.
- This deduction can be so significant that the economic cost of night-time hours becomes negative. It is this value – lower than the immediate marginal cost, and possibly negative – which will be presented as a bid by the operator of the thermal power plant. **We can therefore interpret the negative price offered during off-peak night-time hours as an option intended to increase gains during peak morning hours.**

The merit order effect: charateristics

- The impact of the RE on the system marginal price depends on five important factors: (Hirth, 2012; IEA, 2014; Sjim 2017):
  - the RE penetration rate;
  - the slope of the merit-order curve;
  - the type of RE technology (wind or solar);
  - the geographical size of the market area;
  - the flexibility of the power system.

The merit order effect: charateristics

- The first factor is the volume effect: **a larger RE output has a larger impact on prices.**
- The impact on the SMP rises as the slope of the merit-order curve increases since **a steeper curve leads to a stronger price drop** when REs are available.
- At higher RE generation rates, **the wholesale price effect is usually higher for solar than for wind** as solar generation generally fluctuates more significantly during the day.

+

The merit order effect: charateristics

- If **a larger geographical area** is integrated into one uniform price area, it **helps to smooth the wind-generation profile**, alleviating transmission constraints and reducing the wholesale price effect at higher penetration rates.

- Flexibility resulting from large-scale hydro reserves or generation plants that have quick cycling has a similar effect, absorbing the fluctuations of RE generation over time (IEA 2014).

+

The merit order effect: charateristics

- There is a long tradition of quantifying market effects of RE, emerging in the 1980s. This empirical literature is quite heterogeneous with respect to methodology and focus.
- An interesting survey of the empirical literature on the impact of RE on the SMP has been undertaken by Hirth (2013) who has compared the calculations of more than thirty studies on several countries worldwide.
- These results are expressed in relative terms, i.e. as a percentage or ratio – called *"**value factor**""*– between an annual base price (the annual average of SMP price) and a relative average price earned by RE (the SMP price weighted by the volume of RE production).

+

The merit order effect: some figures

- If the relative average price of RE was €49/MWh for wind power, and the average, reference price over a certain period was estimated at €70/MWh, the value factor of wind power would be 0.7 (or 70 percent).

- The complement of the value factor is the wholesale price effect. In this example, it would be 0.3 (30 percent) in relative terms and €21/MWh in absolute terms.

+

The merit order effect: some figures

- Hirth (2013) finds that, on average, at low penetration rates, RE value factors are generally close to unity: all the impact on SMP, if any, is due to the volume of VER injected into the wholesale market.
- Wind value factors are estimated to drop to 0.7 at 30 percent wind penetration, while solar value factors are reported to drop faster, i.e. they reach 0.7 already at 10–15 percent solar penetration
- Based on these findings and **assuming a normalized, system-base price of €70/MWh in all studies surveyed, Hirth estimates that the wholesale price effect, in absolute terms, varies between €15–35/MWh at 30 percent wind penetration**.
- **Hirth (2018)** estimates the wholesale price reduction caused by RE expansion as 20.10 €/MWh for Sweden (between 2010 and 2015) and 15.50 €/MWh in Germany (between 2008 and 2015).

+

The merit order effect: some figures

- Detailed figures depend on local specificities, such as grid structure and capacity, plant characteristics and costs, the existence and amount of interconnection, and load profile.
- Increasing RE deployment also has important impacts on dispatchable plants. All conventional power plants could be affected by the RE-induced wholesale price effect (i.e. by lower electricity prices and, hence, lower revenues).
- This applies in particular for active gas plants during the hours in which RE plants produce substantial amounts of output.
- Depending on the RE penetration rate, some conventional plants are also affected by reduced capacity factors, resulting in higher average production cost.

A brief literature review on the MOE

- Existing studies of the MOE can mostly be classified as either simulation-based studies that use both hypothetical and real data or empirical studies that use ex-post data and are generally conducted using econometric models.
- Most of these earlier studies used simulation-based approaches:
  - Sensfuß et al. (2008) show that electricity generation from RE has a considerable impact on the German market prices, with an average electricity price reduction of 7.8 €/MWh in 2006.
  - Weigth(2009) also modeled the German electricity market and reported an average price reduction effect for wind generation of approximately 10 €/MWh between January 2006 and June 2008. The study also showed that the price effect of wind generation increased over time during the study period.

Cont.d (simulation models)

- Sáenz de Miera et al. (2008): wind generation reduced Spanish electricity prices considerably by −7.08 €/ MWh to −12.44 €/MWh between 2005 and 2007.
- Holttinen et al. (2001) on Nordpool: wind data ranging from 1961 to 1990 to calibrate the model; evidence of price reductions of 2 €/MWh for each 10 TWh of additional annual wind generation in a 2010 forecast scenario

MOE effect: econometric approach

- Neubarth et al. (2006) used a univariate regression model to investigate the MOE of wind generation on spot prices during the period from 2004 to 2005 and showed that for each additional GW of wind power generated, the spot market price fell by 1.89 €/MWh.
- Würzburg et al. (2013) used a multivariate regression model along with daily averaged data on electricity prices to investigate the MOE of RE (solar and wind power). Their study showed that between 2010 and 2012, RE reduced the electricity spot price on average by 7.6 €/MWh.
- Cludius et al. (2014) performed a time-series regression analysis using hourly data on the spot market price, wind and solar generation, and the load: electricity from wind and solar energy sources caused reductions in the German/Austrian day-ahead spot electricity price of 6 €/MWh in 2010 and 10 €/MWh in 2012.

Cont.d

- Gelabert et al. (2011) focused on the Spanish spot market price, and their ordinary least squares (OLS) estimation results showed that a marginal increase of 1 GWh of electricity from RE is associated with a reduction of approximately 1.9 €/MWh in the wholesale prices during the period studied between 2005 and 2010.
- Clò et al. (2015) also performed a time-series regression analysis that focused on the impact of wind and solar generation on the Italian spot market price. Their study showed that between 2005 and 2013, wind and solar generation reduced the wholesale electricity prices on average by 4.2 €/MWh and 2.3 €/MWh, respectively.
- Quint and Dahlke (2019) investigated the MOE of wind generation while focusing on the Midcontinent Independent System Operator (MISO), which is the largest wholesale electricity market by geographical area worldwide: each 1 GWh of additional wind generation reduced the wholesale prices in MISO by $1.4/MWh to $3.4/MWh.

Cont.d

- Bublitz et al. (2017) provide a good summary of some empirical and modelling studies that estimated quantitatively the merit-order effect. The effect ranges from Euro-15/MWh to Euro-0.55/MWh depending on modelling assumptions, RES technology (wind, solar, biomass,etc.),location (Germany, Spain, Ireland) and methodology (simulation, time series analysis).

- Tselika et al. (2024) suggest that an increase in renewable energy cannot lead to price reductions of the same magnitude as the price increases caused by a decrease in wind.

Some key references

- • The role of capital costs in decarbonizing the electricity sector (https://iopscience.iop.org/article/10...)
- System LCOE: What are the costs of variable renewables? (https://www.sciencedirect.com/science...)
- • Why Wind Is Not Coal: On the Economics of Electricity Generation (https://www.iaee.org/en/publications/...)
- The Optimal Share of Variable Renewables (https://www.iaee.org/en/publications/...)
- Market value of solar power: Is photovoltaics cost-competitive? (https://ieeexplore.ieee.org/document/...)
- The market value of variable renewables: The effect of solar wind power variability on their relative price (https://www.sciencedirect.com/science...)

Electricity and Co2 pricing
Fuel Switching and Windfall profits

Co2 pricing and electricity markets

- When there is environmental regulation to reduce carbon emission in the form of a carbon price, it is possible that firms make some arbitrage in production and emissions in order to pass carbon costs through to final consumers.
- This issue has been extensively discussed in Europe, where a carbon market has existed since 2005, namely, the European Emission Trading Scheme or EU ETS (Ellerman and Joskow, 2008). Around 5,000 operators with approximately 12,000 production units participate in this attempt to reduce CO_2 emissions from four broad sectors:
  - energy (electric power production, oil refineries, etc.);
  - production and processing of ferrous metals (iron and steel);
  - minerals (cement, glass, ceramics);
  - pulp and paper.

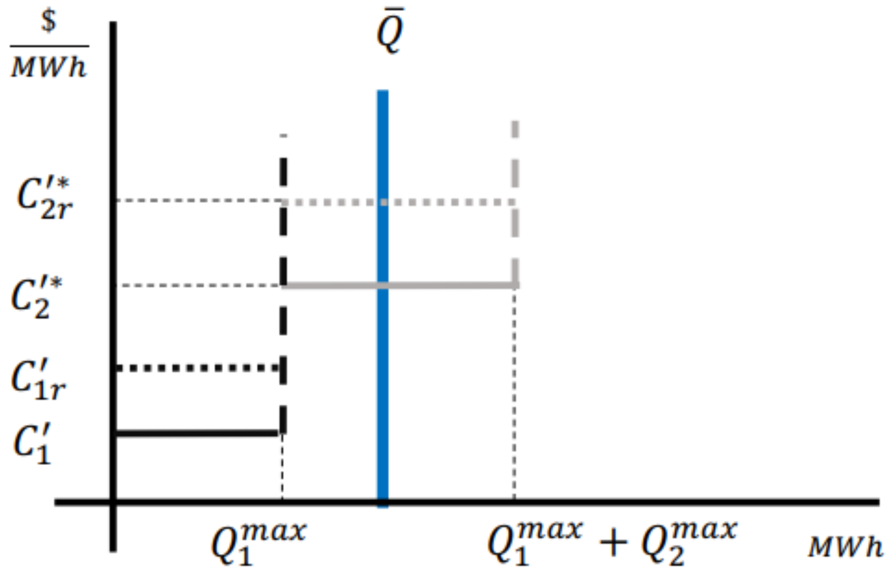
Fuel switching and Co2 pricing

- Given the functioning of wholesale electricity markets, the effect on electricity prices of the emission trading costs, and more generally of the cost of CO_2 emissions relating to power production are complex, since one must consider the impact on the marginal technology that determines the system marginal price (SMP).

- Consider the case of two technologies ($i = 1,2$)

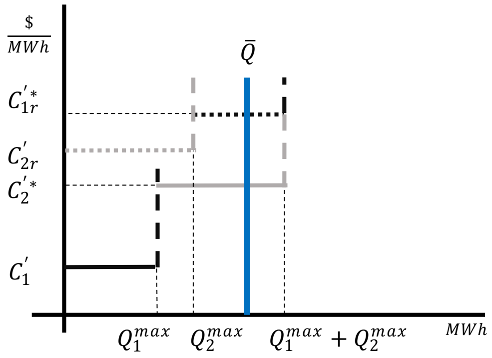
- After carbon trading, the technology i has to cover the CO_2 costs entailed by its usage, at the unit permit price p, proportionally to its emission factor e_i. Every units of power costs $C'_{ir} = C'_i + e_i p$.

No price switch



The merit order is unchanged; power plant 2 is still the marginal technology, and the equilibrium SMP after the introduction of pollution regulation is ${C_{2r}'}^{*}$ (the uppercase * denotes equilibrium). The electricity price difference is equal to the increase of marginal costs of the technology 2, that is ${C_{2r}'}^{*} - {C_2'}^{*}$.

Price switch



- The carbon costs make technology 1 less competitive than technology 2. The SMP becomes ${C'_{1r}}^*$. See that the carbon costs of the "new" marginal technology is higher than the electricity price increase $({C'_{1r}}^* - C'_1 > {C'_{1r}}^* - {C'_2}^*)$.

- Plant 1 is able to to consumers only a fraction of the increase in the cost due to the emissions. There is an imperfect pass-through. Moreover, there is also an implicit cross-subsidization across plants, since plant 1 becomes now the marginal plant, while plant 2 sees an increase in its profits due to higher prices.

Windfall Profits

Windfall profits

- The issue of the interaction between carbon prices and electricity prices was discussed in particular at the outset of EU ETS trading, since in the period 2005–2007 electricity prices hit very high levels in several European markets.
- It has been argued that when the initial permit allocation is given for free, called **grandfathering**, instead of using an auction, windfall profits arise because producers pass on the market value of the emission rights to consumers via a markup on energy prices.
- As of 2013, in the European emissions market, the power sector no longer receives free allowances; industrial sectors, such as cement and steel may receive free allowances of up to 100 percent of their requirements; and other sectors receive a free allocation of 80 percent of their share of the pollution cap, which will be reduced by 10 percentage points each year, **phasing out free allocation by 2020**.

Windfall profits

- Instead of using the free allowances, firms can sell them at the current market price. A company that receives free permits can always choose to cut production instead of using the allowances, and thus sell them in the market.

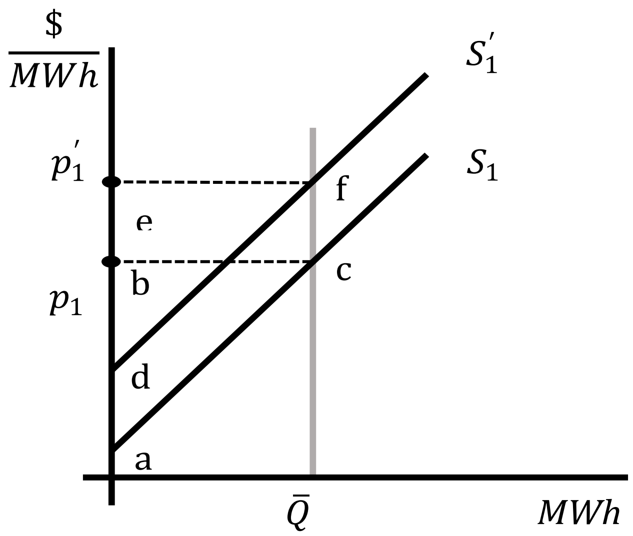
- There is an opportunity cost of electricity production accruing from the decision to generate power and thus consuming the allowances instead of selling them in the market.

Windfall profits

- When producing electricity, the firm needs to recover this foregone opportunity cost in the electricity price.
  - Although a power plant does not have to pay for emission rights, it uses them to cover emissions when producing. It tries to pass on the extra opportunity cost arising from this forgone possibility of selling allowances to the final product price (Woerdman et al. 2009).
  - Instead, *when power producers buy allowances*, costs rise due to the increase in producers' expenditures to generate. Thus, even if they pass these extra costs to the buyers of electricity, *they do not experience any windfall profit*.

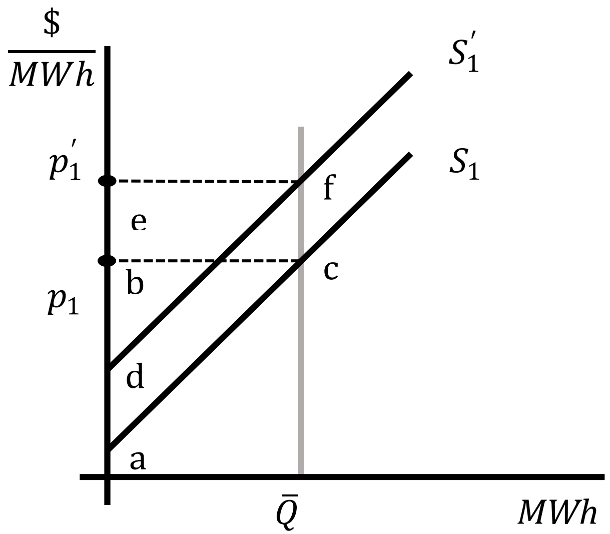
+

Windfall profits



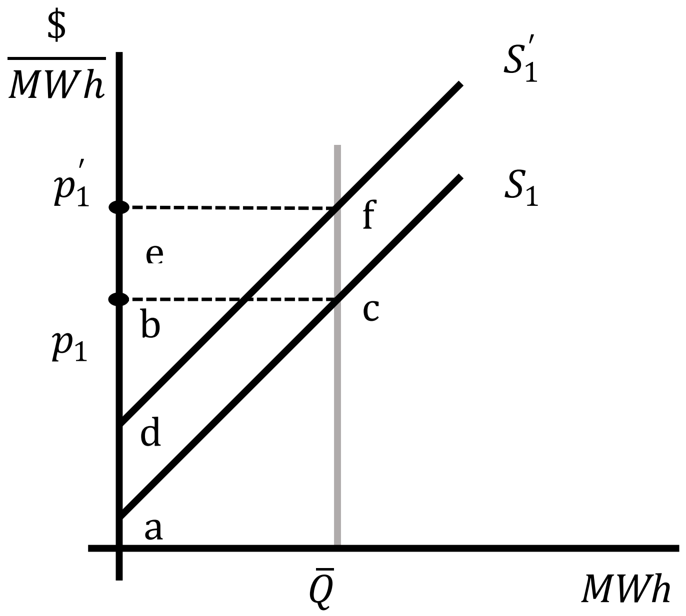
- The curve S_1 represents the reference case of either auctioning or free allocation, assuming perfect competition.
- Absent carbon costs, the equilibrium price is P_1 where the inelastic load $\bar{Q}$ meets the supply S_1.
- When emissions trading is introduced, the opportunity costs of carbon allowances are included into the other variable production costs, reducing the supply curve S_1' and rising the equilibrium price P_1'.

Windfall Profits



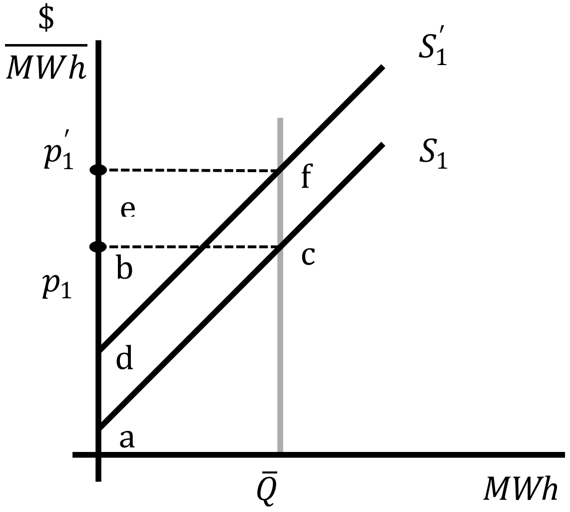
- The power price increases from P_1 to P_1' : the pass-through rate is 100% as the change in power price is equal to the change in marginal production costs.
- The producer surplus before emissions trading is equal to the triangle **abc**. In a competitive situation this surplus covers the fixed (investment) costs of power production, including some fair plants' profits.
- After emissions trading, ***in the case of auctioning***, when the power producers have to pay for the emission permits, the producer surplus is equal to **def**. The producer will gain after the increase of variable costs due to emissions if the area **def** is bigger than the area **abc**.

Windfall profits



- The total emission costs are equal to the area **adfc**, which are fully passed on to consumers by means of higher prices, resulting in a similar consumer surplus loss.

Windfall profits



- ***In the case of free allocation***, producers get the allowances for free. Even if their opportunity cost is increased, which justifies the shift from S_1 to S_1', they are not charged for allowances, while still passing on the opportunity cost to the consumers.

- This results in an increase in their producer surplus by the area **adfc**.

- This increase in producer surplus due to emissions trading are the **"windfall profits" resulting from grandfathering.**

+

Windfall profits in practice

- Evidence on the effects of free permit allocations and windfall profits has come from three sources:
  - ***quantitative simulations*** of expected windfall profits (Sijm et al. (2006) and Chen et al. (2008)): for example, in the Netherlands at a CO_2 price of €20/tonne windfall profits are expected to be €3–5 per MWh
  - ***theoretical work*** on permit allocations (i.e Nicolaï and Zamorano, 2018 is the most recent one)
  - ***estimates of carbon cost pass-through*** for the power sector frequently find close to 100% pass-through rates (Hintermann, 2016, Fabra and Reguant, 2014, Leslie, 2018))
  - ***direct empirical estimates of windfall profits are limited*** and more recent (Frasaer et al. 2023 for Australia US$614 million per year, Japan with huge regional variations Ding 2022 , China with low pass through rates, Wang et al 2023)

Factors affecting the pass-through

- In general, with several plants, and different marginal impacts on plants' costs of the carbon pricing, the computation of windfall profits is challenging.
- There can be other factors that affect cost pass-through rates, such as market power, elasticity of electricity demand and domestic supply.
- Trade intensity, transport costs, tariff barriers and product substitutability, as well as indicators of market concentration and pricing power have an impact
- Clearly, the exact extent at which costs are estimated to be passed through is highly dependent on the methods chosen and the data used.

Factors affecting the pass-through

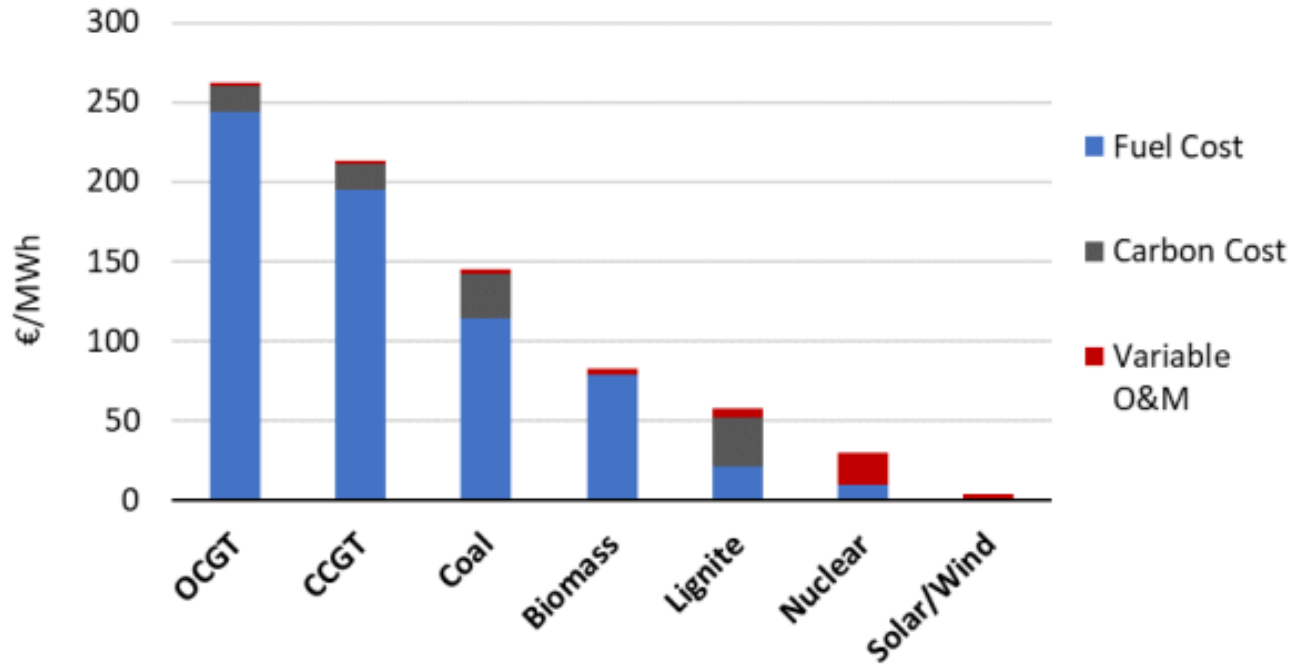
- Higher fuel prices play a role in electricity price increases, and some plants' profits reflected their ownership of low-cost nuclear or coal generation in areas where the market electricity price was set by higher-cost natural gas plants (Ellerman and Buchner, 2007; European Commission, 2015)

- This debate has been fueled by the recent energy crisis

- The 2022 Council Regulation 1854 introduced two fiscal measures: A "temporary solidarity contribution" imposed on the oil, gas, coal, and refinery sector to recover surplus profits generated during the fossil fuel crisis and a "cap on market revenues" for electricity producers. The regulation also outlines the use of these revenues in the Member States of the European Union to support its transition to renewable resources.

Takeaways

And finally, how technologies compare?



Source: EC JRC, based on external data providers (among others S&P)

Note: 1- OCGT (open combustion gas turbine) are more flexible gas plants while CCGT (combined combustion gas turbine) are generally more efficient

And finally how technologies compare?

- All the effect we have described overlap in practice, depending on contingent factors as well

- An example of these complex interaction is illustrated by Hobbie et al, 2019 Windfall profits in the power sector during phase III of the EU ETS: Interplay and effects of renewables and carbon prices - ScienceDirect