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Eyes on the Price: Which Power Generation Technologies Set the Market Price? Price Setting in European Electricity Markets: An Application to the Proposed Dutch Carbon Price Floor

Eike Blume-Werry

Energy Economics Group (EEG), Institute of Energy Systems and Electric Drives TU Wien and Axpo Holding AG

Thomas Faber

Axpo Holding AG

Lion Hirth

Neon Neue Energieökonomik GmbH (Neon) and Hertie School of Governance

Claus Huber

Axpo Holding AG

Martin Everts

Axpo Holding AG

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By Eike Blume-Werry, Energy Economics Group (EEG), Institute of Energy Systems and Electric Drives TU Wien and Axpo Holding AG
Thomas Faber, Axpo Holding AG
Lion Hirth, Neon Neue Energieökonomik GmbH (Neon) and Hertie School of Governance
Claus Huber, Axpo Holding AG
Martin Everts, Axpo Holding AG

Summary

Upon discussion of price setting on electricity wholesale markets, many refer to the so-called merit order model. Conventional wisdom holds that during most hours of the year, coal- or natural gas-fired power plants set the price on European markets. In this context, this paper analyses price setting on European power markets. We use a fundamental electricity market model of interconnected bidding zones to determine hourly price-setting technologies for the year 2020. We find a price-setting pattern that is more complex and nuanced than the conventional wisdom suggests: across all researched countries, coal- and natural gas-fired power plants set the price for only 40 per cent of all hours. Other power generation technologies such as wind, biomass, hydro and nuclear power plants as well as lignite-fired plants set the price during the rest of the year. On some markets, the price setting is characterised by a high level of interconnectivity and thus foreign influence – as illustrated by the example of the Netherlands. During some 75 per cent of hours, foreign power plants set the price on the Dutch market, whilst price setting in other more isolated markets is barely affected by foreign markets. Hence, applying the price setting analysis to the proposed Dutch carbon price floor, we show that different carbon prices have little effect on the technological structure of the price-setting units. In this respect, the impacts of the unilateral initiative are limited. There are, however, considerable changes to be observed in wholesale power prices, import/export balances as well as production volumes and subsequent CO₂ outputs of lignite-, coal- and gas-fired power plants.

Keywords: Price Setting, Electricity Markets, Merit Order, Generation Technologies, Carbon Price Floor

JEL Classification: O13; Q41

Address for correspondence:

Eike Blume-Werry
Energy Economics Group (EEG), Institute of Energy Systems and Electric Drives TU
Wien Gusshausstrasse 25-29/370-3
A-1040 Vienna
Austria
E-mail: eike.blumewerry@gmail.com

Eyes on the price: Which power generation technologies set the market price?

Price setting in European electricity markets: An application to the proposed Dutch carbon price floor

Eike Blume-Werry^{ab}, Thomas Faber^b, Lion Hirth^{cd}, Claus Huber^b, Martin Everts^b

^a Energy Economics Group (EEG), Institute of Energy Systems and Electric Drives TU Wien, Gusshausstrasse 25-29/370-3, A-1040 Vienna, Austria, eike.blumewerry@gmail.com

^b Axpo Holding AG, Switzerland

^c Neon Neue Energieökonomik GmbH (Neon), Germany

^d Hertie School of Governance, Germany

Abstract

Upon discussion of price setting on electricity wholesale markets, many refer to the so-called merit order model. Conventional wisdom holds that during most hours of the year, coal- or natural gas-fired power plants set the price on European markets. In this context, this paper analyses price setting on European power markets. We use a fundamental electricity market model of interconnected bidding zones to determine hourly price-setting technologies for the year 2020. We find a price-setting pattern that is more complex and nuanced than the conventional wisdom suggests: across all researched countries, coal- and natural gas-fired power plants set the price for only 40 per cent of all hours. Other power generation technologies such as wind, biomass, hydro and nuclear power plants as well as lignite-fired plants set the price during the rest of the year. On some markets, the price setting is characterised by a high level of interconnectivity and thus foreign influence – as illustrated by the example of the Netherlands. During some 75 per cent of hours, foreign power plants set the price on the Dutch market, whilst price setting in other more isolated markets is barely affected by foreign markets. Hence, applying the price setting analysis to the proposed Dutch carbon price floor, we show that different carbon prices have little effect on the technological structure of the price-setting units. In this respect, the impacts of the unilateral initiative are limited. There are, however, considerable changes to be observed in wholesale power prices, import/export balances as well as production volumes and subsequent CO₂ outputs of lignite-, coal- and gas-fired power plants.

Key words: Price setting, electricity markets, merit order, generation technologies, carbon price floor

1. Introduction

Wholesale power markets follow the principle of short-run electricity markets where the market clearing price is determined by the intersection of supply and demand at any given hour. In theory, the resulting hourly day-ahead market price is equal to the marginal costs of the last (marginal) unit in the merit order necessary to satisfy the demand. Given that this marginal unit sets the price for all power generation units operating during that particular hour, one can refer to this as ‘price setting’.

It is frequently stated that in most central European markets, gas- and/or coal-fired power plants are usually the marginal price-setting units (Finon, 2013, pp. 133–134; Geiger, 2011, p. 20; Genoese et al., 2015, pp. 176–177; Pietroni, 2017, p. 1). Geiger, for instance, notes with respect to the German power market that “the price setting unit is often either a gas or a coal plant” (Geiger, 2011, p. 20). Also concerning the German market, Genoese and Egenhofer conclude that “it is safe to assume that gas was the price-setting technology in most hours” when analysing the comparably high prices of 2008 (Genoese et al., 2015, p. 177). Researching the British market, Roques et. al. state that “gas-fired plants were often the marginal price-setting plants in the British electricity market” (Roques et al., 2008, p. 1841). But is it safe to assume this? Is it still valid at present? And on what basis is this conventional wisdom accepted?

There are well founded reasons for this general idea. First, one can point towards the nature of European power plant portfolios with significant coal- and gas-fired generation capacities and their marginal pricing. Second, it should be noted that causal relationships between coal and/or gas prices and wholesale power prices have indeed been observed and documented (Emery and Liu, 2002; Ferkingstad et al., 2011; Mohammadi, 2009; Moutinho et al., 2011; Roques et al., 2008). Beyond this research on the relationship between fuel and power prices, there is to our knowledge no academic literature that looks in detail into the actual price setting on European markets and the question to what extent coal- and gas-fired power plants are indeed commonly price-setting.

This paper aims to fill this gap and investigate the price setting on European power wholesale markets using a fundamental electricity market model. From the hourly calculations of European power markets, one can derive the marginal price-setting technology for any given hour. Taking a whole year as a timeframe, it is possible to analyse how the hours of a year are structured and what share different generation technologies take in providing the marginal price-setting units. The core objective is to broaden the knowledge on the price setting on European power markets and get a more nuanced picture on what technologies set market prices. Given that the European power market is integrated and significant cross-border flows are taking place, the analysis is not limited to one country but looks at twenty integrated central European power markets¹. This will help to understand interdependencies and in what ways larger markets dominate price setting elsewhere.

This framework can then be used to research a whole range of developments to see how certain changes in the market affect the price setting. There are many possible ‘sensitivities’ one can employ here; such as fuel price changes, interconnector capacity changes, power plant portfolio changes, etc. In view of ongoing public debates on CO₂ price floors and the announcement of the Dutch government to introduce one, the authors have chosen to analyse how different CO₂ price floors affect the price setting on those markets. This will shed light on the question how carbon price floors influence marginal price setting and if a given price floor will cause in a shift from coal to gas as a dominant price-setting technology.

¹ The twenty modelled countries are: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

To this end, the paper first discusses the general approach to price setting on European power markets and the existing literature and research. This is followed by a description of the applied methodology with regards to the employed model and carbon price floors. Afterwards, the results are presented, analysed and discussed. First in the light of price setting across borders, second with respect to the different price-setting technologies and then sorted in three price level. Last but not least, the paper looks at the employed carbon price floors before concluding.

2. Price setting general approach

As aforementioned, conventional wisdom holds that gas- and/or coal-fired power plants are the price-setting marginal units in different central European countries for most hours of the year. This seems reasonable given the substantial capacities of gas- and/or coal-fired generation capacities in many countries and their marginal pricing. The marginal costs of coal- and gas-fired power plants fall within the commonly observed range of wholesale power prices. Other generation technologies such as nuclear power or renewable energy sources are characterised either by very low marginal costs or, in the case of peak generation units like oil or diesel generators, by very high marginal costs. Therefore, unless power prices are at any given moment extraordinary high or low, one can assume that these technologies do not provide the marginal price-setting units.

It should be noted at this point that European wholesale power prices have experienced a significant drop within the last several years, and that the number of hours in a year with very low prices increased significantly (Everts et al., 2016; Hirth, 2018). It therefore seems plausible that during those low-priced hours, inflexible low-marginal cost generation technologies such as lignite, nuclear power or must-run technologies are indeed providing the last marginal unit on the merit order to meet the load – and are thus price-setting.

A look at the merit order can help to take further the idea of substantial coal- and gas-fired power plant capacities and their marginal pricing. Figure 1 displays an approximated example of a merit order in Germany. The line shows the German residual load of the year 2017 in 1,000 Megawatt (MW) brackets. The residual load is commonly defined as the difference between actual power demand and the non-dispatchable stochastic power generation of photovoltaics and wind turbines (Schill, 2014, p. 65). Other generation technologies (in this case predominantly thermal ones) are therefore those covering the residual load. The distribution of the residual load over the merit order curve shows which generation technology should, in theory, set the price at a given residual load. Following this principle, lignite and hard coal power plants should be the price-setting units during most hours of the year, whilst gas-fired power plants alongside biomass and nuclear power plants take a smaller share.

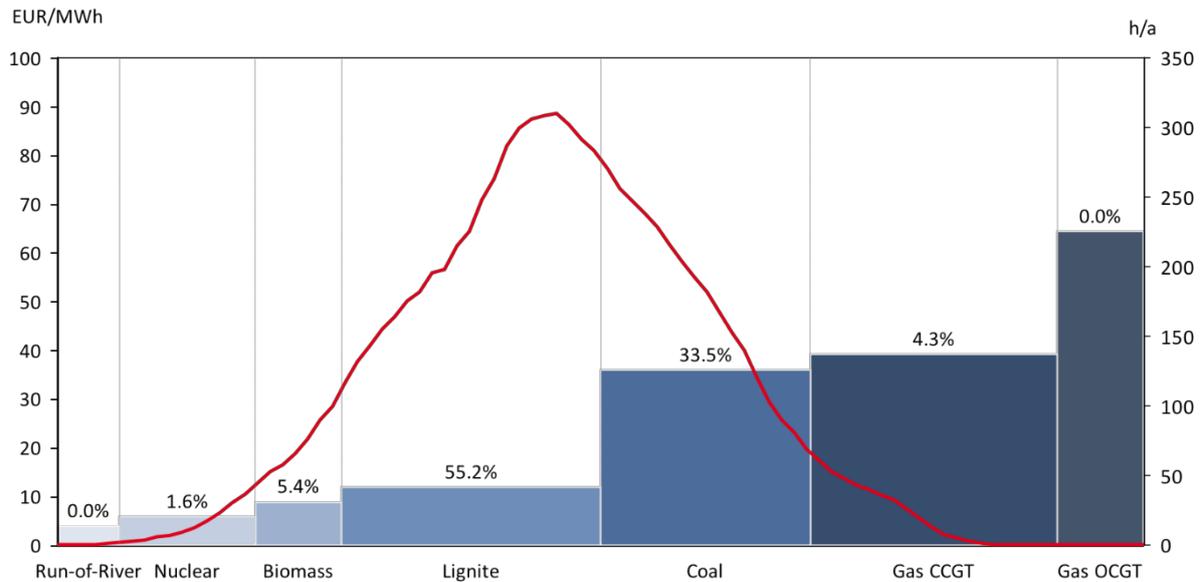


Figure 1: Approximated 2017 German merit-order and residual load (as probability density function)². At 100 per cent power plant availability, lignite- and coal-fired power plants seem to set the price for the majority of hours.

One should note at this point that the unavailability of power plants – for instance due to revisions, maintenance and naturally occurring lower capacity factors of run-of-river and biomass power plants – are disregarded in this visualisation. Taking these factors into account would shift the merit order curve to the left and increase the hours in a year during which gas-fired power plants should provide the marginal units. In addition to the unavailability of power plants, this merit order and residual load-based view of the price setting concept also disregards cross-border flows, i.e. electricity imports and exports. These drawbacks demonstrate why this approach is not the most accurate way of looking at the concept of marginal units and price-setting technologies, but it *can* help to understand where the conventional wisdom or usual narrative might originate from.

Numerous scholars have researched price dynamics between gas or coal prices and power prices in different countries. Emery and Liu analyse the relationship between electricity futures prices and gas futures prices and find that they are co-integrated (Emery and Liu, 2002). Mohammadi finds a stable long-run relation between real prices for power and coal and insignificant long-run relations between power and gas prices (Mohammadi, 2009). Ferkingstad et al. research the interplay of different fuel and electricity prices in the Nordic and German markets and find a strong connection between gas and electricity prices yet no significant connection between electricity and coal prices (Ferkingstad et al., 2011). Moutinho et al. observe inter alia a positive correlation between gas and electricity prices on the Spanish market (Moutinho et al., 2011, pp. 5905–5907). Roques et al. analyse the correlation between electricity and gas prices in Britain with respect to portfolio optimisation for generators and calls for further research in the area, especially in regard to effects of carbon emission allowances on the marginal technology in the market (Roques et al., 2008).

Even though the findings of scholars differ with different methodologies and research focuses, it can be noted that causal relationships between gas *and/or* coal prices and power

² Marginal costs are based on authors' estimations. Residual load and capacity data from Bundesnetzagentur | SMARD.de (Bundesnetzagentur, 2018).

prices exist, depending on the researched countries, time frames, applied methodologies and so forth.

In terms of price setting, reservoirs or storage plants, as well as pumped-hydro storage plants, serve a special role. Reservoirs and hydro-storage plants have effectively very low marginal costs and are, however, often the last marginal unit to satisfy demand. Given that those plants have only a limited amount of water that can be discharged within a year, the usage hours are optimised to serve the highest priced hours. Economists mention that the opportunity costs of releasing water are equal to the expected future value of electricity produced when referring to this non-marginal costs-based dispatch (Faria and Fleten, 2011, p. 83; Pikk and Viiding, 2013, p. 52). With regards to hydro-storage plants or pumped-hydro storage plants, the term ‘price setting’ can thus be misleading since *shadow prices* – reflecting the marginal costs of additional alternative (thermal) power plants – are used for the dispatch. The shadow prices thereby relate to the costs of a thermal reference power plant, and the historic monthly water levels of reservoirs are used for modelling the dispatch of reservoirs and pumped-hydro power plants.

3. Methodology

3.1 Model

The techno-economic model Green-X³ is used to model the European power market. The modelling process incorporates the dispatch and investment in power plants, minimisation of total investment costs as well as production and trade decisions, all with a range of technical constraints. In economic terms, the model is a partial equilibrium model of wholesale electricity markets, focussing on the supply side. It includes an up-to-date power plant database⁴ of all twenty countries including plants that are planned or set to be decommissioned, as well as an up-to-date database of all interconnectors among those countries.

Aside from the Green-X model power plant database – including planned plants and those under construction –, the model also adds further capacities endogenously. Although endogenous conventional capacity additions are limited given the relatively short time horizon of this research, they take an important role in longer-term modelling. The endogenous capacity additions are based on economic criteria with support schemes and political frameworks taken into account, which is especially important for renewable technologies, and first and foremost wind and photovoltaics.

³ Green-X is a fundamental power model covering the 28 Member States of the European Union (EU) and selected EU neighbouring countries. It allows for the investigation of future deployments in the power and renewable sector including accompanying costs and benefits. It enables the derivation of a detailed quantitative assessment of renewable electricity sources deployed in a real-world policy context on a national and European level for the power, heat and transport sectors. It has been successfully applied for the European Commission within several tenders and research projects to assess the feasibility of ‘20% renewable electricity sources by 2020’ and for assessments of its developments beyond that time horizon. In addition, Green-X can be used for a detailed quantitative assessment of the hourly market prices of the European power markets (Everts et al., 2016; Huber, 2004).

⁴ Small-scale plants and non-hydro renewables are grouped into clusters.

The actual modelling can be described as a three-level process. In a first step, the endogenous and exogenous capacity additions/deductions (the latter from the aforementioned power plant database) are determined. The second step consists of computing the hourly power plant dispatch based on the determined power plant portfolio (taking into consideration interconnector capacities, power plant availability and power demand). A marginal cost-based merit order curve determines the marginal power plants for every hour in addition to country-specific power prices. The third step examines the economic viability of new power plants and calculates final market prices. For the latter, the model also estimates incomes from ancillary services based on information provided by TSOs regarding historic ancillary services.

3.2 Price-setting technologies

The model was calibrated in a way to most accurately represent the current European power market and replicate hourly day ahead prices on the power exchanges. The year 2020 was chosen as a reference year as it is the year the Dutch carbon price is supposed to come into effect. This comparable near future horizon allows for using real future market prices for most primary energy sources that were taken from the Intercontinental Exchange (ICE) at the time of the modelling (Spring 2018).

Other primary energy sources such as lignite, uranium or biomass have no available and suitable real future market prices, which is why they had to be estimated based on available data and scientific studies. Lignite and biomass prices are therefore country specific and remain, just like uranium prices, constant within the analysed year of 2020.

For transfer capacities between countries, the model uses current data and planned additions from the European network of transmission system operators for electricity (ENTSO-E). Within countries the model assumes that no congestions exist. The power demand is determined first and foremost by gross domestic product (GDP) forecasts of the International Monetary Fund (IMF) and the individual countries' power consumption per unit of GDP. To model yearly power demand, historic GDP and power consumption data of different providers are used for an accurate calibration. The influence of energy policies on power consumption such as increases and reductions in demand through the deployment of electric vehicles or energy saving measures is taken into account, yet due to the short time horizon in question this influence is rather limited. For the modelling of the hourly demand, the model uses load profiles from the year 2009, whereby changes in consumption behaviour are considered. In order to simulate the production of renewable technologies such as hydro power plants, photovoltaics and wind turbines (that are heavily dependent on meteorological conditions), hydrological conditions, solar radiation and wind speeds from the same year (2009) were used (since 2009 represents a somewhat typical meteorological year).

3.3 Carbon price floors

Ceteris paribus, carbon prices were changed once to 18€/tCO₂ for the Netherlands to simulate the *announced* carbon price floor, and once to 30€/tCO₂ for Austria, the Benelux countries, France, Germany and Switzerland to simulate the concept of a common carbon price floor. The floor price of 18 or 30€/tCO₂ thereby includes the EU ETS allowance price and is not to be understood as a top-up or premium.

The corresponding CO₂ emissions of the different scenarios are derived from the calculated hourly power plant dispatch. The emissions of the different power plants are hereby limited to CO₂ emissions. Other greenhouse gas emissions such as methane (CH₄) or nitrous oxide (N₂O) are not taken into account.

4. Modelling results

4.1 Price setting across borders

There exists the key question of how the modelling results compare with the conventional wisdom. A first observation is that, with respect to the marginal price-setting units, the modelling results indicate a higher level of interconnectivity than one may assume. Large countries tend to dominate the price setting – presumably simply due to the large number of power plants and their differentiated marginal costs. Small countries such as Luxembourg only provide the price-setting marginal units for few hours a year and are to a great extent influenced by their neighbouring countries. Relative size, i.e. the size in relation to neighbours, also matters in this context. Hence, electricity markets and wholesale power prices of comparably small countries are significantly influenced by the energy policies of their larger neighbours. Indeed, the modelling results show that in terms of price setting, foreign energy policies can have a larger influence on a given state's electricity market than domestic policies.

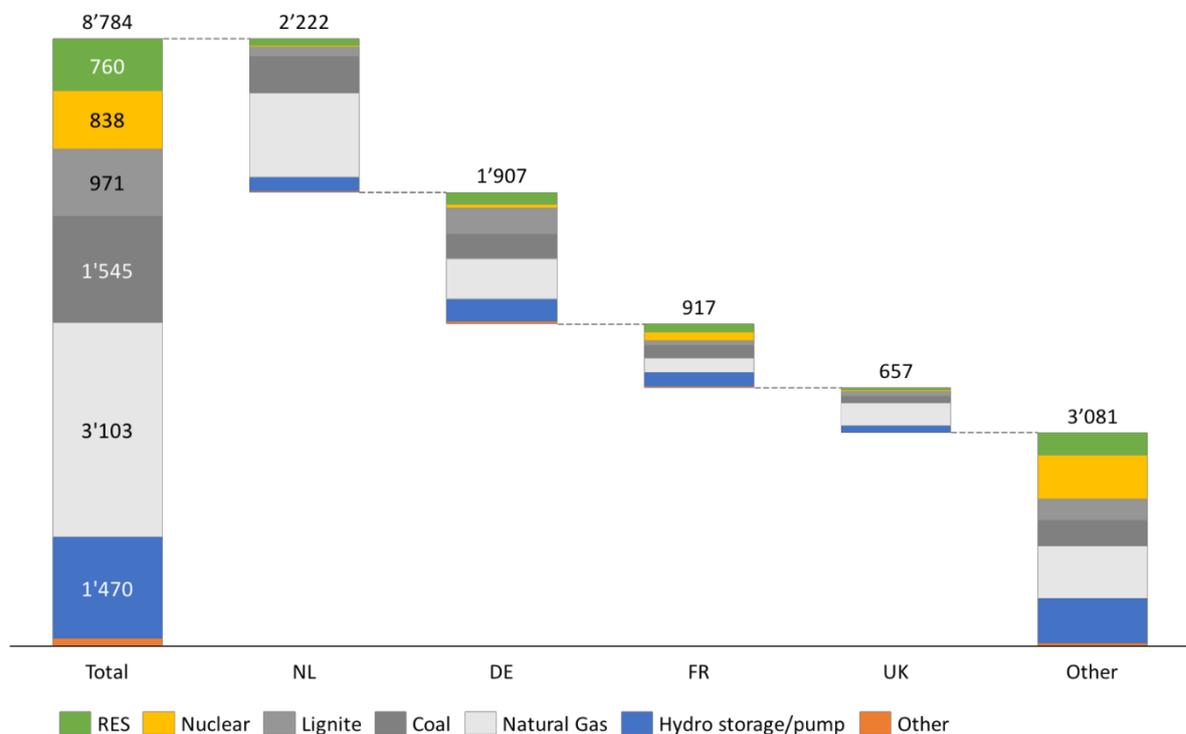


Figure 2: Price-setting technologies Netherlands 2020 in hours per year. Price setting in the Netherlands shows a substantial foreign influence.

Figure 2 shows the structure of the price-setting units in the Netherlands for the year 2020. The bar on the left illustrates the amount of hours different technologies provide the price-setting units. The other bars show the countries where those price-setting units are location (Netherlands, Germany, France, Great Britain and other countries combined). Gas-fired power plants represent the most dominant price-setting technology and for most hours of the year, foreign power plants set the price in the Netherlands. One can therefore surmise that foreign markets and thus foreign energy policies influence the Dutch power market considerably.

A closer look at the German price setting (Figure 3) reveals that this is not merely a Dutch or small-state phenomenon given that the German market represents the largest European market.

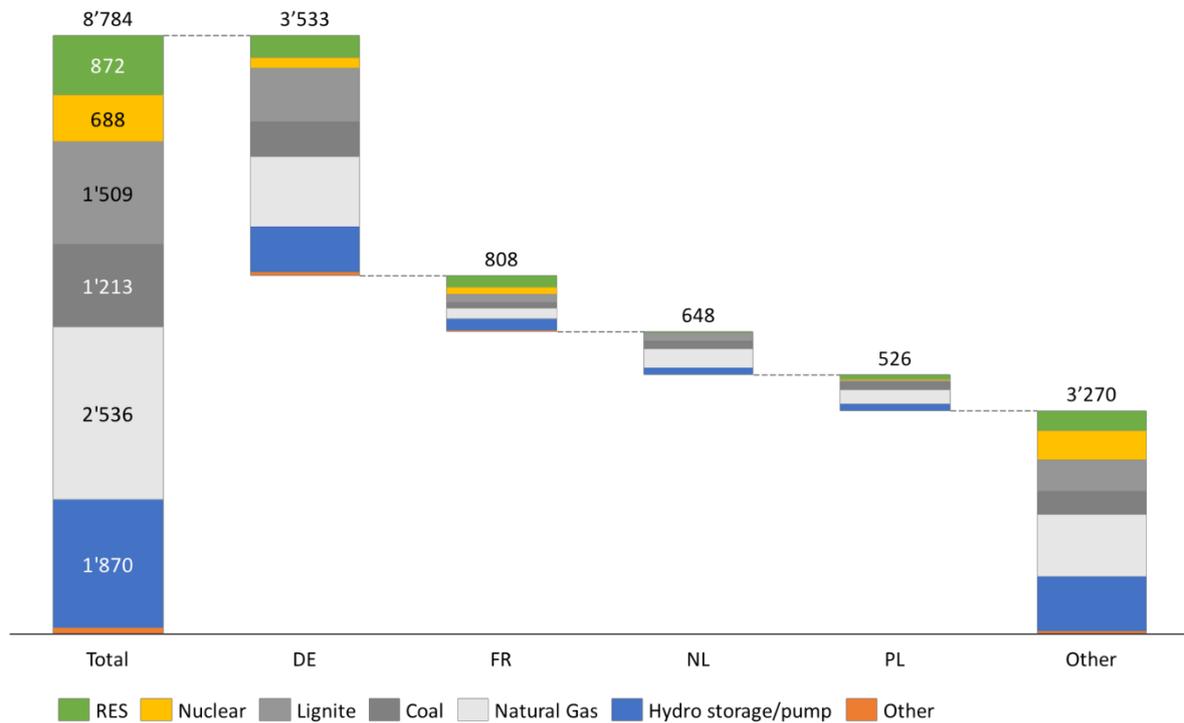


Figure 3: Price-setting technologies Germany 2020 in hours per year. Price setting in Germany is heavily linked with foreign markets despite the considerable size of the domestic market.

Other more isolated markets such as Great Britain are only marginally influenced by cross-border flows due to rather limited net transfer capacities. The Spanish and Portuguese markets on the Iberian Peninsula are also barely affected by outside markets in terms of price setting (see Figure 4).

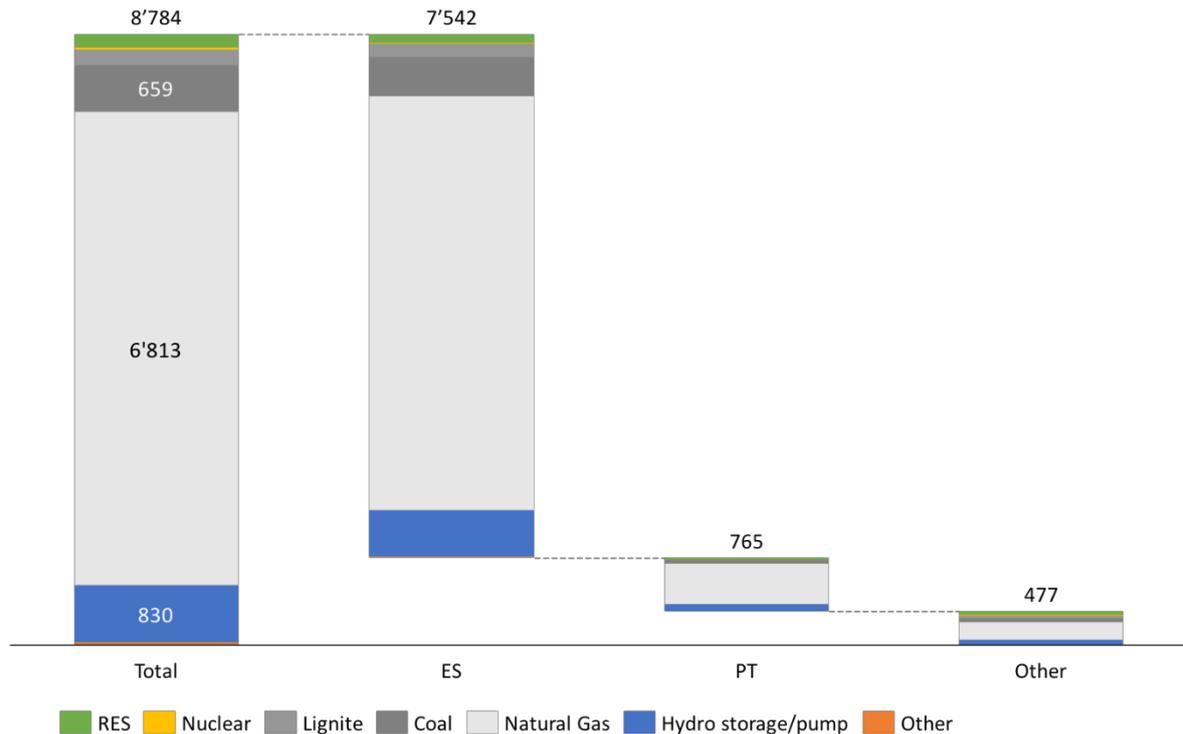


Figure 4: Price-setting technologies Spain 2020 in hours per year. Price setting in Spain shows little foreign influence.

As a general observation, the number of total hours power plants from a given country are price setting is highest in that given country, i.e. plants from country X do not provide as many price-setting hours in any other country as they do in country X.

4.2 Price-setting technologies

Looking at the technologies that provide the marginal price-setting units, one can confirm aforementioned presumptions. For the large majority (>90%) of total hours in all countries, reservoirs, pumped-hydro, nuclear, gas-, coal- and lignite-fired power plants provide the marginal price-setting units. Other technologies such as stochastic renewables or other fossil plants play an almost negligible role in terms of price setting. This seems plausible given the very low marginal cost of renewable energies and their subsequent position at the starting point of the merit order. During most hours, further power plants are necessary to satisfy the demand.

Altogether, the modelling results show that gas-fired power plants provide the price-setting units for almost a third of the total hours and thus for more hours than any other generation technology. Coal- and lignite-fired power plants follow, and together provide the price-setting units for over a quarter of the total hours (whereby lignite-fired power plants take a larger share than coal-fired ones). A notable point is that reservoirs and pumped-hydro power plants are also price setting for another quarter of the total hours. Nuclear power plants set the price for just below 10 percent of the hours, a share similar to that of renewables, including run-of-river power plants (see Figure 5).

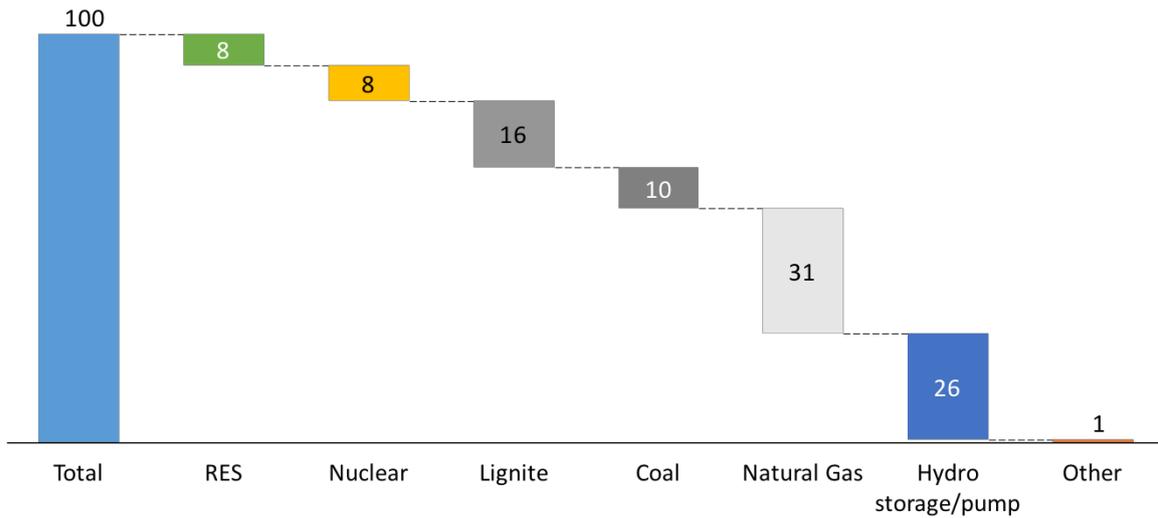


Figure 5: Price-setting technologies of all researched countries 2020 in per cent.

On an individual country basis, the picture of price-setting technologies can look very different depending on the countries' – and connected, surrounding countries' – generation portfolio(s). Here one can observe some expected outcomes. The price setting in Poland, for instance, is dominated by lignite- and coal-fired power plants whereas in Great Britain, Italy and on the Iberian Peninsula, gas-fired power plants provide the price-setting units for the most hours. Similarly, Norwegian reservoirs as well as Finnish and Swedish nuclear power plants share the price-setting hours in the three states, which generally have a similar picture in terms of the price-setting units. This can be seen as an indicator of similar production parks, a high level of interconnectivity, or indeed a combination of both.

4.3 High vs low priced hours

In order to evaluate the modelling results further, one can divide the hours in a year into different groups. Therefore, the 8,784 hours of the year 2020 were divided into the highest, medium and lowest priced hours per country.

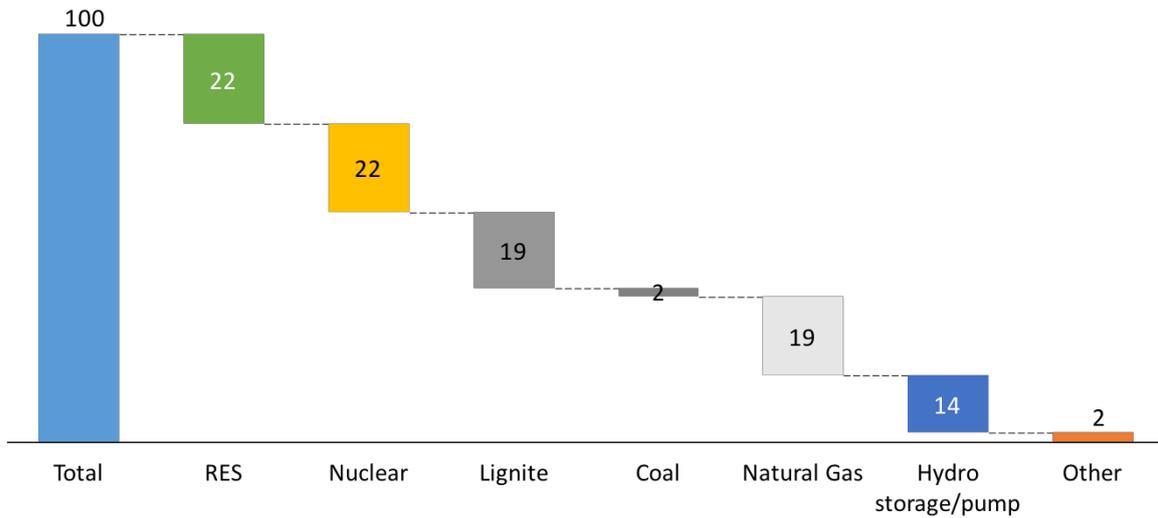


Figure 6: Price-setting technologies of the lowest priced tercile in per cent

The price setting of the lowest priced tercile is as one might expect; characterised by low marginal cost technologies. Hence, nuclear is the technology that sets the price for most hours in the lowest priced tercile with almost a quarter of the total hours. Indeed, the hours during which very low marginal cost technologies such as nuclear, stochastic renewables and run-of-river power plants set the price are almost exclusively found in the lowest priced third of the total hours. Of interest here is the observation that coal-fired power plants provide almost no price-setting units in this low-price segment. In contrast, lignite-fired power plants set the price for a fifth of the hours in this segment. It may come as a surprise that, according to the results of the model, gas-fired power plants also provide the price-setting units for a fifth of the hours in the lowest priced third. In fact, gas-fired power plants are price-setting in lowest priced tercile throughout all modelled countries⁵. For most countries, this share only comprises a small percentage of the hours, but they dominate the price setting in this price segment on the British, Spanish, Portuguese and, to a lesser extent, the Italian market. It should be noted at this point that those four markets also comprise the markets with the highest overall price-level by quite a margin. This is the consequence of price-setting gas-fired power plants.

⁵ In countries with little or no gas-fired generation capacity, foreign gas-fired power plants provide the price setting units during those hours.

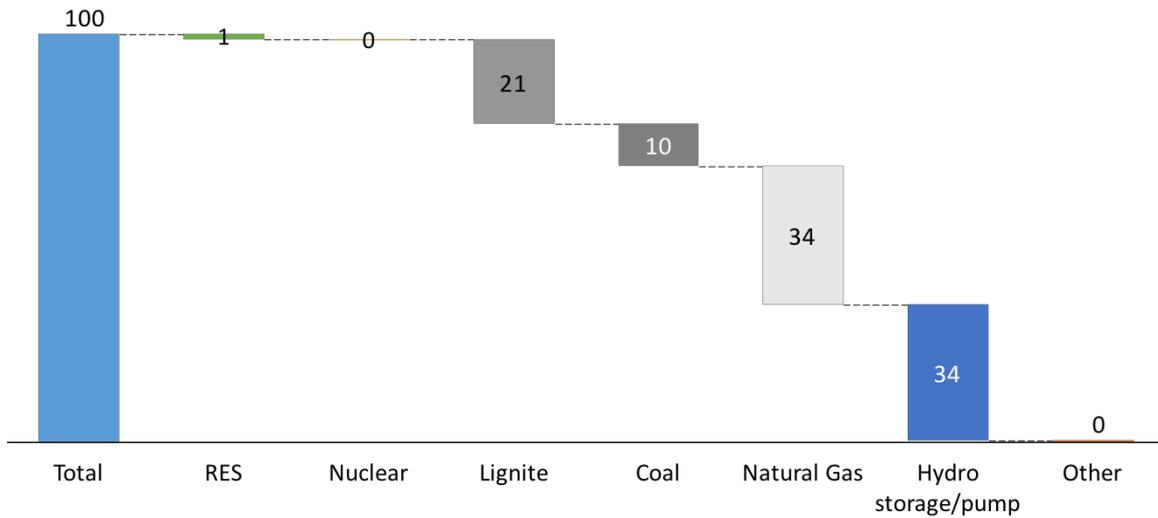


Figure 7: Price-setting technologies of the medium priced tercile in per cent

The picture of price-setting technologies changes significantly in the medium-priced segment (Figure 7). Renewable energies and nuclear power plants are no longer a relevant factor in terms of providing price-setting units. Gas-fired power plants, reservoirs & pumped-hydro plants as well as lignite- and coal-fired power plants each provide the price-setting units for about third of the hours. Again, the share of lignite-fired power plants is higher than that of coal-fired plants, and gas-fired units dominate the price setting on the British, Spanish, Portuguese and Italian market. Among Sweden, Finland and Norway it is Norwegian reservoirs that are setting the price for the great majority of hours.

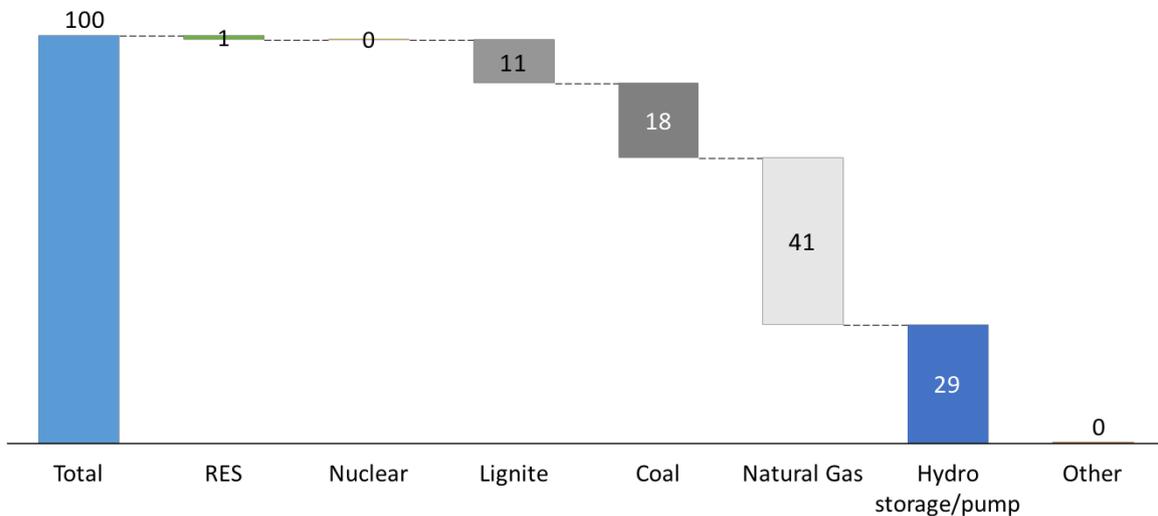


Figure 8: Price-setting technologies of the highest priced tercile in per cent

In the highest priced tercile, the share of gas-fired power plants as price-setting units increases further to two fifths of the hours, whilst the share of lignite-fired power plants is lower than in the other price segments (Figure 8). Only in Eastern Europe does the latter technology remain a relevant price-setting technology. Coal-fired power plants provide the price-setting units for one fifth of the hours. As a further point of interest, the share of reservoirs as price-setting units is slightly lower compared with the medium priced segment. It seems striking that their share as price-setting units in Sweden, Finland and Norway is lower than in the medium priced tercile. Furthermore, for some hours in the highest price segment

– albeit very few – there are lignite- and coal-fired power plants providing the price-setting units in the three countries, despite those technologies not playing a role there in the price setting in the medium and lowest priced thirds.

A look into prices reveals that Norway, Sweden and Finland represent the three countries with the lowest general price level and that prices during most hours, even in the highest priced segment, are not significantly above the marginal cost level of coal-fired power plants.

With respect to the price setting in the Nordic countries, analysts mention the relevance of German off-peak pricing for Nordic power prices (Loreck et al., 2013, pp. 27–33; Mollestad, 2016). The modelling results do not convey a *significant* relevance of German off-peak generation units as price-setting power plants in the Nordics. However, German off-peak generation may still be relevant in this context, even if it is not providing the price-setting units directly. During most hours in the Nordics, Norwegian reservoirs set the price as per the modelling results. However, the marginal costs of these reservoirs are not the decisive factor. Shadow prices used for the optimisation reflect the marginal costs of the next dispatchable power plant in the merit order, which in this case can be German coal- or lignite-fired power plants, once those in Finland and Denmark are exhausted. Hence, German off-peak generation may still have an influence on the price setting in the Nordic countries, without providing the actual price-setting units for a significant number of hours.

4.4 Conventional wisdom vs modelling results

Subsequently, there is the question of how the modelling results compare with the aforementioned conventional wisdom.

First, the modelling results indicate that gas-, lignite- and coal-fired power plants are indeed setting the price during most hours of year. This dominance is, however, not as clear cut as conventional wisdom might suggest. Whilst gas-, lignite- and coal-fired power plants provide the marginal price-setting units for most hours, their share lies below two thirds (Figure 5). Reservoirs and pumped-hydro power plants provide the last marginal unit for approximately a quarter of the hours of a year, predominantly in the medium- and high-priced segments. Nuclear power plants and renewable electricity sources – first and foremost run-of-river hydro power plants – also provide price-setting units, primarily during low-priced hours. Generally, the results reflect the merit order of a given country, but according to the results of the model, the level of interconnectivity in terms of price setting can be high (see Figure 2).

Altogether, the modelling results indicate that the price setting in Europe can be more complex than conventional wisdom might suggest. It is not incorrect to argue that coal-fired power plants set the price in times of low demand and gas-fired power plants when demand is high, but this can potentially disregard the heterogeneity of European power systems and the interconnectivity of markets.

5. Application to carbon price floors

Carbon price floors are currently subject to an ongoing debate in academia and the public sphere. The European Union Emissions Trading Scheme (EU ETS) is characterised by a comparably low allowances price level; a level scholars generally regard as too low to fulfil the intended functions of the scheme (Abrell et al., 2016, p. 2; European Commission, 2014; Rogge et al., 2011). There is an extensive body of literature on the weak performance of the EU ETS and possible paths to reform, yet policy makers have increasingly looked towards setting a carbon floor price.

In this vein, the recently formed Dutch government under Mark Rutte (the third Rutte cabinet) announced its plans to introduce a national carbon price floor for the power sector starting at 18 EUR/tCO₂ in 2020 (Van Veldhoven in Franke, 2017)⁶. And since becoming French president, Emmanuel Macron has reiterated his campaign call for a pan-European carbon price floor (Macron, 2017a). When presenting his oft-reported 'Initiative for Europe', President Macron stated that any price floor below 25-30 Euros per ton of CO₂ would not be effective (Macron, 2017b).

The German approach is far more cautious. The coalition agreement of the new government (the fourth Merkel cabinet) did call for a CO₂ pricing system that was globally oriented; to at least include the G20 states (Christlich Demokratische Union et al., 2018, p. 143). This call – deemed unrealistic – was followed by a statement advocating to follow the momentum of the recent common Franco-German resolution marking the 55th anniversary of the Élysée treaty, and co-operate in the framework of Franco-German partnership for the implementation of the Paris climate agreement and the commitments of the “One Planet Summit” (Christlich Demokratische Union et al., 2018, p. 148).

The common resolution of the German and French parliaments includes a proposal to suggest common initiatives regarding a CO₂ price (Assemblée nationale and Deutscher Bundestag, 2018, p. 10). Nevertheless, the fact that the German coalition agreement fails to mention the prospect of a national, European or Franco-German CO₂ pricing initiative is telling. Optimists may point towards the subsequent mentioning of the common resolution and argue that it could be construed as a signal to France that the door might not be fully shut.

Regardless, and despite its comparably slim chances of coming into fruition, this paper will entertain the idea of a common Pentalateral Energy Forum⁷ CO₂ price floor, next to a sober analysis of the announced Dutch price floor. Even though the Pentalateral Forum has been primarily a platform for regional integration towards electricity market integration (i.e. market coupling) and security of supply, it is assumed in this scenario that the energy ministers in question would follow Macron's proposal and take the step for a common CO₂ price floor for the power sector.

⁶ Final details are yet to be disclosed, but Member of Parliament van Veldhoven from the liberal D66 party announced a starting price of 18EUR/tCO₂ which will rise to 43EUR/tCO₂ in 2030 (in Franke, 2017).

⁷ The Pentalateral Energy Forum is an intergovernmental initiative and a framework for regional co-operation in central Western Europe towards improved electricity market integration and security of supply. It was created in 2005 by energy ministers from Austria, the Benelux, France, Germany, and Switzerland as permanent observer (European Commission, 2015; Umpfenbach et al., 2015, p. 9)

Aside from the potential aforementioned initiatives, there is currently only one active carbon price floor scheme in the EU that applies to the power sector, which is the British Carbon Price Floor established in 2013. An issue common to carbon price initiatives is the question of how to handle electricity imports and exports. In legal terms, any scheme ought to be compatible with relevant legislation and in particular with WTO law, EU Law and other trade agreements. Thus far, the only established system (i.e. the British system) disregards electricity imports, which means power imports from abroad are not charged the carbon price support⁸. Whilst subsequent competitive disadvantages for domestic power producers are somewhat limited in Great Britain due to the comparably low interconnection capacity, the picture might look different on the continent. Details on the forthcoming Dutch carbon price floor are yet to be published, yet analysts expect it to follow the British model (Carbon Pulse, 2017; Tijs, 2017). In this analysis it is therefore assumed that the Dutch carbon price floor as well as the theoretical Austrian-Benelux-Franco-German-Swiss (Pentalateral Forum) price floor would function in this manner.

5.1 A Dutch CO₂ floor price of 18EUR/tCO₂

Market analysts and traders expect the Dutch CO₂ price floor to cause production shifts from the Netherlands to the neighbouring countries. Following the introduction of the price floor in 2020, Dutch fossil fuel generators will face higher marginal costs and thus have a competitive disadvantage over their Belgian and German counterparts. This rests of course upon the assumption that the Dutch price floor will indeed follow the British model in handling imports (see above). Consequently, analysts expect rising prices in the Netherlands and increased imports from Germany, Belgium and Great Britain depending on British carbon policy post Brexit⁹ (Franke, 2017; Tijs, 2017; Witkop, 2018).

The modelling results confirms this view. Even though the Dutch CO₂ price floor of 18 Euros per ton of CO₂ is only a couple of euros higher than the EU ETS future prices at the time of the modelling, the results show noteworthy developments. Dutch net power imports rise by almost a quarter. As a result, one notes rising exports from Germany and reduced British imports from the Netherlands. Average wholesale baseload power prices in the Netherlands and its neighbours rise marginally; about 30 cents per megawatt hour (MWh) in the Netherlands, 20 cents in Belgium and 10 cents in France and Germany.

A higher price mark-up than the proposed price floor shows amplified effects. Whilst Dutch coal- and gas-fired generation decreases by approximately ten and five per cent respectively at a Dutch carbon floor price of 18 Euros per ton of CO₂ compared to the reference scenario, these numbers do rise to approximately 45 and 15 per cent respectively when a higher carbon price floor of 30 Euros per ton of CO₂ is applied in the Netherlands. In a similar fashion, such a higher carbon price floor would also result in higher wholesale baseload prices in the Netherlands and neighbouring countries, as well as considerably larger changes in the import and export balances. In this case, Dutch power imports would approximately double as Dutch

⁸ Carbon taxation models looking to charge electricity imports a minimum carbon price are subject to an extensive legal debate. It is questionable whether border tax adjustments or other measures could be successfully and legally employed for this purpose (Blume-Werry et al., 2017, p. 12; Holzer et al., 2017, p. 373; Kreiser et al., 2015, p. 167).

⁹ In the computations it was assumed that Great Britain will continue to participate in EU ETS.

coal- and gas-fired generation is replaced: primarily by German, British, Belgian and even Italian gas-fired generation.

In terms of the price-setting technologies, the effects are negligible. On a country-to-country basis, the number of hours during which Dutch power plants are price-setting rise due to the carbon price floor and the subsequently, slightly higher price level. In turn, German and Belgian plants have slightly less hours during which they provide price-setting units. Of more significance are the effects of the price floor on carbon emissions. The CO₂ emissions of the conventional Dutch power plant fleet shrink by approximately five per cent as Dutch coal and gas-fired power plants produce less electricity than in the reference scenario. On a European level, this reduction is, however, offset by increased emissions elsewhere – in particular in Belgium, Germany and Poland.

Altogether, the modelling results back the prevailing view. The Dutch carbon price floor would lead to rising Dutch imports and ergo reduced Dutch emissions, but with little to no emission reductions on a wider European level (as in most cases Dutch power plants are substituted with power plants of the same technology elsewhere). With respect to the price-setting technologies, the general price setting picture stays virtually unaffected by the Dutch carbon price floor and there are no major shifts taking place.

5.2 The Pentalateral Energy Forum CO₂ price floor of 30EUR/tCO₂

In a second scenario it is assumed that the countries of the Pentalateral Energy Forum (Austria, Benelux, France, Germany and Switzerland) introduce a common carbon price floor of 30 Euros per ton of CO₂. The research year remains the same (2020) as in the reference and Dutch price floor scenario. Given the significantly higher carbon price and the larger pool of countries introducing the price floor, one would expect considerably more substantial effects.

The modelling results show that such an initiative would cause wholesale power prices to rise. Prices in the Benelux and Germany are approximately 2.5€/MWh higher in this scenario compared with the reference scenario. In the less carbon-intensive power markets of Austria, France and Switzerland, prices rise by approximately 1.7€/MWh. With regards to the import/export balance, one can observe notable shifts with Dutch power imports nearly doubling and Germany turning from a net exporter into a net importer.

Carbon price floors serve the declared target of emission reductions and the modelling results confirm that the carbon price floor analysed leads to lower emissions in the countries introducing it and, in this case, also overall at a wider European level. In absolute terms, emission reductions are most significant in Germany and the Netherlands whilst British, Polish and Czech power plants increase their output and subsequently their CO₂ emissions. Altogether, the clear emission reductions in the countries of the Pentalateral Energy Forum - of whom Belgium, Germany and the Netherlands experience emission reductions of 15-20 per cent – are, unlike in the scenario of the Dutch carbon price floor of 18EUR/tCO₂, not fully offset by rising emissions elsewhere even though emissions in Eastern Europe and in Great Britain rise significantly.

It is important to note at this point that the modelling computations disregard EU ETS price developments originating from the introduction of the carbon price floor. It has been argued that emission reduction measures in one area or facility will depress demand which in turn puts downwards pressure on prices and results in subsequent emission increases in another area or facility (Burtraw et al., 2017, p. 4). One can refer to this as the so-called ‘waterbed effect’¹⁰.

Be that as it may, the carbon price floor leads to a fuel switch in Germany, with running hours of gas-fired power plants increasing and those of coal- and lignite-fired power plants decreasing. The modelling results further indicate reduced production volumes of all fossil generation technologies in the Netherlands and increased outputs of British gas-fired power plants following the introduction of the carbon price floor in the countries of the Pentalateral Energy Forum.

With respect to the price-setting technologies, the effects of the carbon price floor are again small scale or indeed negligible. The results of the model show minimal changes compared with the reference scenario. It is thus a key finding that even though the marginal costs of fossil plants, general price level and import and export balances change, the structure of the price-setting technologies remains very similar. Even though coal-fired power plants, for instance, provide the price-setting units for slightly less hours in this carbon price floor scenario than in the reference scenario, the scale of change is too insufficient to observe important changes.

6. Conclusion

The conventional wisdom holds that in many central European countries, coal- and/or gas-fired power plants provide the marginal price-setting units for most hours of the year. The modelling results confirm that in the countries researched, coal-, lignite- and gas-fired power plants are indeed price-setting for most hours of the year. Their dominance is, however, not as clear cut as the conventional wisdom might suggest. The analysis with a fundamental electricity market model has shown that during hours of low demand, nuclear power plants and renewables are providing price-setting units for a considerable number of hours alongside lignite- and gas-fired power plants. Throughout all price segments yet especially

¹⁰ Emission reduction measures outside or independent of the EU ETS often face critique related to the ‘waterbed effect’. The coining of the term ‘waterbed effect’ is commonly credited to British economist Paul Geroski, who described that if prices are pushed up or down on one side of a two-sided market, it can result in a rebalancing at the other side – just like a waterbed (Genakos and Valletti, 2008, p. 1). As regards the EU ETS, it has been argued that emission reduction measures in one area or country do not reduce total emissions as they are set by a fixed cap. To what extent the waterbed effect is actually applicable to the EU ETS and potential carbon price floors within it is disputed; as is the question of whether total long-term supply of allowances is fixed and capped or set by future policy decisions (Burtraw et al., 2017; Edenhofer et al., 2017; Perino and Willner, 2016; Whitmore, 2016). The most recent EU ETS reform enables EU Member States to voluntarily cancel allowance units following national energy policies that lead to a reduction of their electricity generation capacity (European Parliament and European Council, 2018). In theory, this paves the way for national or regional carbon price floors and coal-fired power plant phase-outs as envisaged by some Member States without risk of the waterbed effect. However, experts remain very sceptical of the (large-scale) use of this new measure that enables Member States to cancel allowances to counteract the impact of capacity closures (Edenhofer et al., 2017, p. 9; Ferdinand in Evans, 2017).

during mid- to high-priced hours, reservoirs and pumped-hydro power stations play a substantial role in the price setting process. However, one should keep in mind that their marginal pricing does not reflect the marginal costs, as shadow prices or water values – reflecting the marginal costs of an additional alternative (thermal) power plants – are used for the dispatch (see above). In the highest priced segment, gas-fired power plants provide the price-setting units for the largest share of hours.

Large countries tend to have a strong influence on the price setting in smaller neighbouring countries, as long as there are sizeable interconnector capacities. More generally, one can observe a high level of interconnectivity between the countries researched. The price-setting technologies per country vary significantly depending on the generation portfolio of a given country and the connected surrounding countries. In Southern Europe (Italy, Portugal and Spain) and Great Britain, gas-fired power plants dominate the price setting, whilst lignite- and coal-fired power plants tend to do so in Eastern Europe. Hydro-storage and pumped-hydro plants provide the price-setting units during most hours in Northern Europe. The most balanced picture with respect to the price-setting technologies is to be found in central Europe and the price setting ergo reflects the general generation portfolio.

Two scenarios with different carbon price floors have shown that the general structure of the price setting remains largely unaffected by the researched carbon price changes. A Dutch carbon price of 18EUR/tCO₂ would lead to reduced Dutch coal- and gas-fired generation and CO₂ output, and subsequently higher electricity imports. Despite these observations, the changes in the price-setting technologies as a result of the Dutch carbon price are found to be limited.

One can draw conclusions regarding the scenario of a wider European carbon price floor encompassing the countries of the Pentalateral Energy Forum in a similar fashion. The carbon price floor would have a substantial impact on wholesale power prices, fuel switching, CO₂ emissions and import/export balances, whilst the general structure of price-setting technology remains largely the same as in the reference scenario. For Austria, the Benelux, France, Germany and Switzerland the results show rising power prices, production shifts to surrounding countries with lower carbon prices and subsequently lower emissions.

Altogether, the analysis contributes to fill the identified gap in the literature. It shows that price-setting patterns are more complex and nuanced than the conventional wisdom suggests and that other power generation technologies than coal- and gas-fired power plants provide more often than one may assume the last marginal price-setting units. In this light, further research can help to establish a more detailed view on the price setting on European power markets and how this may change as the decarbonisation of the power sector progresses.

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Fondazione Eni Enrico Mattei

Corso Magenta 63, Milano - Italia

Tel. +39 02.520.36934

Fax. +39.02.520.36946

E-mail: letter@feem.it

www.feem.it

