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The Impact of a Carbon Price Floor on European Electricity Markets

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1 Introduction

Despite a recent price jump following reforms in early 2018, there is broad consensus that persistently low European Union Emissions Trading Scheme (EU ETS) allowances (EUAs) prices have failed to provide a long term price signal for investment in low carbon assets. Accelerated deployment of renewable energy, energy efficient and cleantech technologies will be required to achieve the ambitions of the Paris Climate Agreement[1]. The International Energy Agency (IEA) estimate that US$48 trillion of cumulative investment in energy supply and efficiency is required between 2014 and 2035 to have a chance of maintaining global temperature increases below 2°C, (IEA, 2016). Investment in low carbon assets is characterised by long lead times and high up-front capital costs relative to investing in fossil generation assets so a high carbon prices is required to provide a long term signal for investment in decarbonisation, (Hu et al., 2018). The energy sector is a major contributor to greenhouse gas emissions production so a reduction in emissions in this sector is critical, (Ambec and Crampes, 2012, Bassi, 2013). In many liberalised electricity markets where gas sets the marginal electricity price, investing in thermal generation is essentially a spread option on the difference between electricity prices less fuel and carbon emissions costs and can provide an attractive and stable return on investment. In order to incentivise investment in low carbon assets, a strong price signal for the externality of carbon emissions is required. The higher the carbon price, the more low-carbon technologies or options become competitive. While reforms to the EU ETS implemented in 2018 will improve its functioning, some have already noted that the reforms will not bring the price to the level needed to meet the Paris Agreement commitments and that

[1] 21st Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC).

further remedial action will be required, (Europe (2018), Hirst, 2018, Koch et al., 2016, Kollenberg and Taschini, 2016, Knopf et al., 2014, Clò et al., 2013). Commentators have suggested a carbon price well in excess of current prices are required to meet the Paris goals. For example, the European Commission analysis for the 2030 Climate and Energy Framework suggested that to meet a 43% emission reduction target in the ETS by 2030 cost-effectively, a carbon price of €40 tCO_2e would be required (EC, 2014). The World Bank's High Level Commission on Carbon prices suggests that "the explicit carbon price level consistent with achieving the Paris temperature target is at least US$40-80 / tCO_2e by 2020 and US$50-100/ tCO_2e by 2030", Prices (2017). The European Council for the Academies of Applied Sciences, Technologies and Engineering noted (2014) that in Europe,

"for 2015, the socially optimal CO_2 price paths … range from about 10 to €20/tCO_2, and for 2020 the optimal price range across models spans from 20 to €70/tCO_2, (Edenhofer, 2014). To date, the EU ETS has not encouraged adequate decarbonisation of electricity generation and industry. The EU's long-term climate targets are acutely at risk. Calls for a carbon price floor to be introduced via an auction reserve prices were rejected by the European Commissions on the basis that a carbon floor price would unduly interfere with the market when the scheme was being established.

In light of the low expectations for the EUA price, some EU Member States have or are planning to take national measures to support the carbon price signal in their respective ETS sectors. The UK has implemented a carbon floor price across its ETS industries since 2013. In 2013, the UK carbon floor price was set at £9/tCO_2e and rose to £18/tCO_2e in 2015 where it has since been held fixed with no plans for further increase. The UK carbon floor price has been credited as the main driver for the rapid reduction of coal fired power generation in the

UK, Hirst (2018). In 2017, a Dutch government coalition agreement included plans for the introduction of a carbon floor price for the power generation sector of €18/tCO_2e from 2020 rising to €43/tCO_2e by 2030.[2] The French government has also announced plans to continue to pursue a carbon floor price in the electricity sector and to implement a carbon tariff at Europe's external border for countries that don't sign up to the Paris Agreement, (Simon, 2018). The French government have committed to stop subsidising fossil fuels and under the Energy Transition for Green Growth[3] Act of Parliament the French carbon tax on fossil fuels will quadruple by 2020. Some Scandinavian countries expressed their determination to pursue national measures if the EU ETS did not sufficiently drive low carbon transformation, (Kirk (2017)). There are also reports that Germany is interested in such an initiative, (Witkop (2018)).

There has been much discussion in the literature on regulation of emissions (Brink et al., 2016, Tol, 2018, Wood and Jotzo, 2011, Brauneis et al., 2013) and the question of optimal carbon pricing mechanisms has long been debated, (Aldy and Stavins, 2012) . In the seminal paper on economics of regulation, Weitzman (1974) shows the optimal policy choice is to set the marginal cost of abatement (via fixed price) rather than the quantity of abatement.

Some economists have argued for a direct carbon tax while (Keohane (2009), Stavins, 2007, Holland and Moore (2013)) have advocated for a cap and trade system. Other researchers have argued that the two approaches amount to the same thing (Aldy (2010), de Mooij (2012)).

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[2] Netherlands (2017) https://www.government.nl/documents/publications/2017/10/10/coalition-agreementconfidence-in-the-future

[3] http://www2.developpement-durable.gouv.fr/IMG/pdf/16172-GB_loi-TE-les-actions_DEF_light.pdf

Wood and Jotzo (2011) suggest that while there has been much discussion in the literature on approaches that include a carbon price ceiling, the debate on carbon price floors is less developed. They suggest that carbon price floors can reduce risk and price volatility and that investment certainty would be improved with price floors. Stranlund et al. (2014) find that imposing a combined price ceiling and floor or price collar is a more direct and effective way of limiting price volatility. However, Stocking (2012) finds that combined floor and price ceilings can provide opportunities for strategic actions by firms which may lower government revenue and increase emissions. Newbery et al. (2018) suggest that recent reform of the EU ETS still leave the risk of a low short term carbon price and the 'missing market' of a longerterm carbon price. They propose a carbon price floor to resolve the price uncertainty.

Carbon price floors also lean on a relatively new area of economic theory known as tax salience. Rivers and Schaufele (2015) provide an overview of the emerging literature which emphasises that that the way in which taxes are displayed and presented can affect how they influence the economy and suggest that behaviour is more likely to change in response to highly visibly and highly salient taxes. Tax salience relies on the hypothesis that tax-induced price changes generate greater demand responses when compared with equivalent marketdetermined price movements. Carbon taxes impose a disincentive on fossil fuel consumption and are explicitly deigned to reduce environmental externalities. Rivers and Schaufele (2015) find that in British Columbia a carbon tax generated a demand response more than four times greater than an equivalent change in the carbon market price. A carbon price floor is a highly salient environmental tax which is particularly important given the long term price signal necessary for investment in low carbon technologies.

Prior research examines the impact of a carbon floor prices for electricity prices in individual countries, for example, (Egli and Lecuyer, 2017) find that with a German carbon floor price of €40 / tonne, median German electricity prices increase by €37/ MWhr. (Woo et al., 2017) find that California's carbon price affects electricity prices in four interconnected market hubs in Western USA. Yet, it is an open question in the literature what the competitiveness effects for implementing a carbon floor price for a coalition of EU member states would be for electricity prices and hence industrial competitiveness in individual countries. Electricity prices range from having only a minor role in production costs to making up to 20% of total production costs in the most energy intense industries[4]. In this paper, we present the impacts of implementing a carbon floor price for a coalition of EU member states including Ireland. Our findings have implications for all European countries and contributes to the academic literature on efficient regulation of environmental externalities. The paper proceeds as follows: Section 2 outlines the proposed reform of the EU ETS. Section 3 presents results and energy system modelling work. Section 4 concludes and highlights the broader policy considerations for a carbon price floor.

2 EU ETS Reform

The EU ETS is the world's largest market for emissions permits covering 45% of EU greenhouse gas emissions from 11,000 installations in power generation and heavy industry[5]. The EU ETS was established in January 2005 against the institutional backdrop of the Kyoto Protocol that required European countries to reduce greenhouse gas emissions on average by 8% to 2012 compared to 1990 levels, UNFCCC (1997). The scheme is a cap and trade scheme

[4] https://ec.europa.eu/energy/en/studies/prices-and-costs-eu-energy-%E2%80%93-ecofys-bv-study
[5] See https://ec.europa.eu/clima/policies/ets_en

which sets a cap on emissions where emissions are constrained to a level that requires decarbonisation by participants who are power generators and heavy industry. EUAs are traded among participants and the market price should provide a signal for investment in decarbonisation. A fundamental objective of the scheme is to initiate a structural change in power generation assets away from carbon-intense generation. The scheme is now in its third phase, which runs from January 1st, 2013 to December 31, 2020. Emissions permits are valid for the entire phase and surpluses can be carried forward or 'banked' beyond 2020. (Tol, 2018) notes this intertemporal fungibility to accommodate unpredictable emissions makes hedging much easier and reduces compliance risk.

Conscious of these failings in the EU ETS and wanting to provide a strong incentive for investment in low carbon technologies, following lengthy negotiation within and between the EU Council and European Parliament, a revised EU ETS directive came into force in April 2018 (Directive (EU) 2018/410 amending Directive 2003/87/EC) to intensify emission reductions in a cost-effective manner and facilitate investment in low-carbon technologies, as well as amending Decision (EU) 2015/1814 on the market stability reserve.

The amendments to the ETS Scheme will result in the total volume of emissions across the EU being reduced annually under the linear reduction factor by 2.2% from 2021 (compared to the current 1.74%). Each year from 2019 to 2023, the amount of allowances to be placed in the Market Stability Reserve instead of being auctioned, will be doubled: 24 % of the cumulative surplus of allowances will go to the Market Stability Reserve. From 2023, the allowances held in the reserve above the total number auctioned during the previous year will be cancelled. Allocation benchmarks will be updated and a more dynamic system of adjustments to align allocation with actual production will come into place. Member States may voluntarily cancel allowances (of the amount assigned to them for auction) to offset closure of electricity generation capacity in their territory resulting from additional national climate and energy policies. This is important if the ETS is to work most effectively. The intent of these reforms is to drive an increase in carbon prices. Notwithstanding these reforms, there have been criticisms that the measures will not go far enough to support a long term carbon price increase[6], Perino (2018). A carbon price floor may be the most cost effective way of establishing confidence in high prices for emissions and there is strong impetus for a coalition of EU-member countries to implement a carbon price floor, (Reuters, 2018).

1.1 Coal Phase Out in Europe

European countries, including Austria, Denmark, France, Germany, Italy, the Netherlands, Finland, Portugal, Sweden, Ireland and the UK have all recently announced the phase-out of all coal-fired capacity within the next decade while in Belgium the last coal-fired power plant was retired in 2016. At the same time, new coal fired capacity of 6.7GW[7] is either under construction, or expected to come online by 2025 in Poland, Germany, Greece and Croatia.

3 Scenario Modelling and Assumptions

To examine the impacts of a carbon price floor we simulate the full EU interconnected electricity market at hourly resolution considering both variable renewable and thermal generation plants for the year 2020 and 2030 under varying carbon price floor assumptions for

[6] Danish Council on Climate Change makes a similar criticism- https://www.klimaraadet.dk
[7] https://ec.europa.eu/jrc/en/publication/scenario-analysis-accelerated-coal-phase-out-2030-study-europeanpower-system-based-euco27-scenario

select member states. Power plant portfolios, fuel prices, electricity demand and interconnection capacities are based on the European Commission's Reference Scenario which is a projection of where current EU policies coupled with market trends are likely to lead

In all, total four scenarios are considered: A Reference Scenario (Ref) which assumes a unified ETS prices across all Member States and follows projections of the ETS price for 2020 and 2030 based on the EU Reference Scenario. Scenario 1 (S1) assumes a carbon price floor (CPF) is applied to the following countries Belgium, Denmark, Finland, France, Ireland, Luxembourg, Netherlands, Norway, Sweden and the United Kingdom. Scenario 2 (S2) assumes a CPF is applied to all S1 countries and Germany. A final scenario (S3), Power Past Coal Alliance[8] (PPCA) assumes a complete shutdown of coal fired plant in all S1 countries (as opposed to a carbon floor price reducing their output). This amounts to 26GW of coal fired generation out of a total of 144GW coal fired plant in the EU 2020 system and 13GW out of a total of 100GW in 2030.

Scenario 1 and PPCA countries capture 45% of Total EU electricity demand, 19% of total EU CO2 Emissions and 46% of EU GDP. Scenario 2 countries capture 62% of Total EU electricity demand, 43% of total EU CO2 Emissions and 66% of EU GDP.

[8] https://unfccc.int/news/more-than-20-countries-launch-global-alliance-to-phase-out-coal

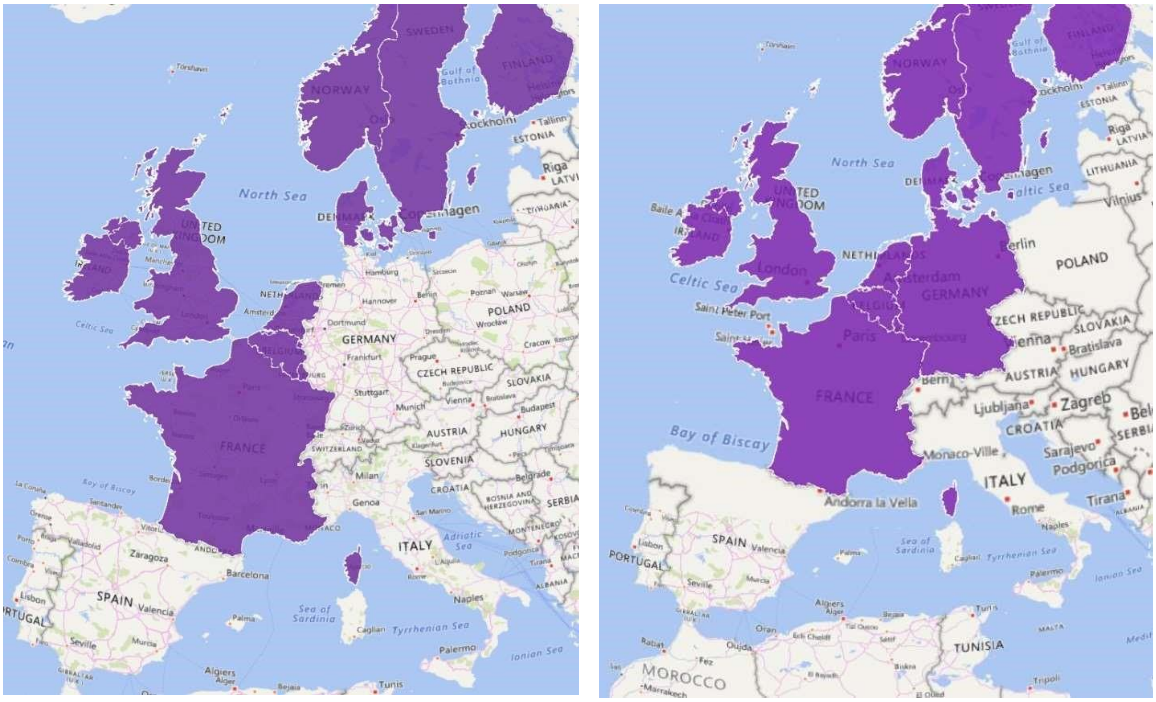

Figure 2: Carbon floor prices are applied to Scenario 1/PPCA (left) and Scenario 2 Groups (Right)

A series of reference carbon prices and assumed carbon price floors are examined for 2020 and 2030 as follows.

	REF Carbon Price (€/tonne)	S1 & S2 Carbon Price Floor (€/tonne)
2020	18	35
2030	35	50

Table 1: Carbon prices and carbon floor prices examined

Fuel prices used in this analysis are from the European Commission's Reference Scenario and have a significant impact on results.

Fuel	2020	2030
Coal Price (€/GJ)	2.0	3.1

Natural Gas (€/GJ)	8.1	9.7
Nuclear (€/GJ)	1.9	1.9
Oil (€/GJ)	11.5	15.8

Table 2: Fuel Prices from EU Reference Scenario

Note that power plant portfolios have important implication for understanding results. A carbon price floor (CPF) will affect emissions from existing plant in the short term; in the longer term, it will influence the choice of plant to construct and retire. This is a 'snapshot' analysis with fixed power plant portfolios in 2020 and 2030 and therefore portfolio capacity does not change in reaction to the carbon price floor (however generation does). In reality some level of portfolio adjustment would be expected if a CPF was implemented. In light of the assumption of fixed portfolios, results should be interpreted as short term impacts representative for the specific years and portfolios only. This is the same for the PPCA scenario which models the immediate shutdown of coal fired plant in S1 countries, we assume that these plant are not replaced in the modelled years.

The software used to model the EU electricity market is the PLEXOS Integrated Energy Model.[9]

The PLEXOS software is available from Energy Exemplar. PLEXOS is a tool used for electricity and gas market modelling and planning. In this analysis, the focus is limited to the electricity system, i.e. gas infrastructure and delivery is not considered. The methodology used to develop this European model is as presented in Collins et al. (2015). Model equations are

[9] http://energyexemplar.com/. The full model and data used are available via https://www.dropbox.com/sh/1xhjk3e19xc7xdq/AACS8ln_sjt3Aa_zSj7nzRYoa?dl=0

shown in Appendix B and Deane et al. (2014). In brief, the model optimises (using linear programming) the dispatch of thermal and renewable generation and pumped hydro storage. It does so subject to operational and technical constraints at hourly resolution while holding the installed capacity constant. The model seeks to minimise the overall generation cost across the EU to meet demand subject to mix of installed generation fleets and their technical characteristics such as interconnection, ramp rates, start costs, minimum up times etc. This includes operational costs, consisting of fuel costs and carbon costs; start-up costs consisting of a fuel offtake at start-up of a unit and a fixed unit start-up cost. In these simulations, a perfect market is assumed across the EU (i.e. no market power or bidding behaviour and power station bid their short-run marginal cost) and only a day ahead market is considered.

No inertia or detailed transmission constraints are imposed in the model.

Asking questions on the future EU power system requires assumptions to be made. These assumptions have an impact on how results should be interpreted; namely-

- Electricity demand is assumed to be constant across the scenarios in each member state and is non-elastic.
- Fixed power plant portfolios for 2020 and 2030 are assumed that do not change across the scenarios modelled i.e. the portfolio and associated investment in generation capacity does not respond to the addition of a carbon price floor or the closure of coal stations. In reality, we would expect electricity generators to react to a carbon price floor signal and therefore portfolios would be different. It is not possible to say with a degree of confidence, how this would change. Results should therefore be assumed to capture a snapshot of the impact for specific years.

- Perfect functioning markets and no market power within or across Member States is assumed
- The cancelation of ETS permits is not considered or its impact on ETS prices or EU emissions
- There are extensive data requirements for this analysis and it is not possible to show it all in tabular format. Readers are directed to the EU Reference Scenario web site where all input data and assumptions can be queried graphically.

3.1 Results

Results are examined in terms of CO_2 emissions, wholesale electricity prices, total generation costs[10] and net profits for generators for 2020 and 2030 for all scenarios. All results are presented relative to the Reference Scenario and are first presented for the year 2020 in Table 3 and for the year 2030 in Table 4.

Note that locational marginal pricing is assumed where all generators in a member state receive the system marginal price for electricity generated in each hour and all consumers pay the same system marginal price for electricity consumed in each hour in that member state. Generators do not receive the system marginal price in the member state they export to. The EU power system is a highly interconnected system and generators in a member state may generate more or less electricity than consumers require in that member state due to net imports or exports. This leads to a positive 'settlement surplus[11]' in a country with net imports of electricity and the opposite in countries with net exports. In practice the settlement surplus is distributed back

[10] Total Generation Cost = Generation Fuel Cost + Start & Shutdown Cost + Emissions Cost

[11] Settlement Surplus = (Price Paid × Customer Load)- (Price Received x Generation)

to generators via the system operator. Across the EU a small settlement Surplus (<0.1%) will remain due to varying efficiencies of power plant across the region. Full details on calculation and definition are in the technical appendix.

In general, the implementation of a carbon price floor will increase wholesale electricity prices in countries where it is applied but it will also impact neighbouring countries through interconnection. The impact of a carbon price floor will vary depending on a number of factors including the make-up of electricity portfolio in a country and the level of electricity interconnection. Countries with more thermal generation, especially coal and less renewable electricity generation are more exposed to increases in carbon pricing. Likewise, a country with limited interconnection is also more likely to be impacted by a wholesale electricity price increase. A €10/tonne increase in ETS price generally adds €4/MWh to gas fired generation and €10 to coal fired plant. In member states where either is the marginal plant the price increase is passed through to the wholesale price of electricity however it is also impacted by level of import and exports of electricity. Countries that export more electricity will generally experience higher prices than countries that import more electricity. Taken as a whole, countries where the CPF is applied change from a net exporter position to a net importer of power from across the EU.

3.2 2020 Carbon Price Floor Results

Summary results in terms of emission reduction, revenue raised from the CPF, impact on consumer costs, changes in total generation costs (fuels costs, carbon costs and start-up costs to generators) and changes in net profits[12] are presented in absolute and relative value terms compared to the Reference Scenario in table 3.

3.2.1 2020 System Dynamics

The addition of a carbon price floor in S1 countries leads to a 5% (80TWh) reduction in generation in these countries and an increase in generation and imports from Non CPF countries. An increase in thermal generation is seen in gas fired plant in Italy (12%), Germany (77%) and Spain (21%) and coal fired plant in Germany (3%), Czech Republic (16%) and Poland

(3%). The biggest reductions in generation are in coal fired generation in the UK (34%), France (73%), Finland (62%) and gas fired generation in Netherlands (74%), Belgium (46%) and France (82%). The biggest change (reduction) in electricity exchange is seen in the interconnectors from France to Italy and France to Spain with significant increases in flow from Germany to the Netherlands and France to the UK.

For S2, the addition of Germany to the CPF countries has a significant impact as Germany has a projected 50GW of installed coal capacity in 2020 and has 11 interconnections to neighbouring countries. The inclusion of a €35/tonne ETS price in Germany reduces coal fired generation (including lignite) by 15% relative to the Reference. Germany switches from a net exporter to a net importer of power resulting in a reduction in exports of electricity to Italy (via Switzerland) and Austria and increased imports of electricity from Czech Republic and Poland.

In the PPCA Scenario, 26GW of coal is removed from the system in 2020 in S1 countries.

The largest capacity reductions are in the UK (10GW), Netherlands (5GW) and Finland

[12] Net Profit = (Market Price Received x Volume of electricity sold) - (Total Generation Cost)

(3GW). We assume coal generation is not replaced with other capacity so the shortfall must be met from increased generation in that Member State or other Member States via exports in electricity. Two main impacts are observed; 1) an increase in gas fired electricity generation in all PPCA countries and a general increase in imports into PPCA countries. The reduced capacity puts a wider strain on the system with increased exports of power flowing from German, Spain and Czech Republic towards PPCA countries. Germany in particular increases exports to Denmark and the Netherlands.

3.2.2 2020 Carbon Emissions

For the given assumptions, a CPF in S1 countries reduces emissions in those countries by 74Mt and increases emissions in other countries by 51Mt. This results in a net reduction of 23Mt or 2% of total emissions across the EU.[13] The largest absolute reductions in emissions are seen in UK, France and Finland with increases in emissions in Germany, Czech Republic and Poland. Governments in CPF countries earn revenue from the Carbon price floor[14]. The revenue is a function of emissions produced and the difference between the ETS price and CPF. In 2020 this is €2.5b with the highest revenues in the UK (€1.3b) and the Netherlands (€0.5b). Overall, governments in S1 countries earn revenue from the carbon price floor amounting to 0.03% of GDP (express as % of GDP of S1 countries).

[13] The net reduction could be larger if CPF participant countries cancel any allowances under Article 12(4) of the revised EU ETS directive.

[14] Defined as the price difference between the CPF and the ETS price multiplied by the emissions quantity in each country

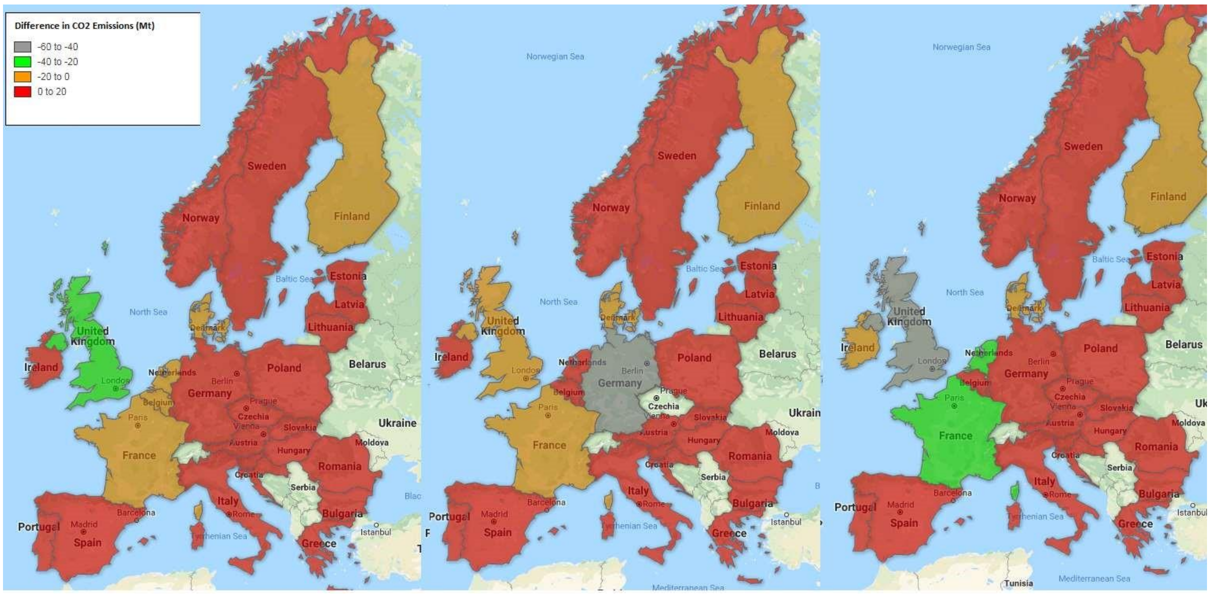

Figure 4: C02 Emissions impacts for 2020 Relative to Reference S1 (left), S2 (middle) and PPCA Scenario (right)

In Scenario 2, a stronger reduction in emissions is seen in the CPF countries (-104Mt) and the EU as a whole (-37Mt) but an increase in emissions in the non CPF countries (+67Mt). The largest reduction in emissions is in Germany (-57Mt) where coal plant reduce output by 47TWh. Increases in emissions are seen in Czech Republic, Italy and Poland where coal and gas fired generation increase output to provide exports to neighbouring countries. Governments in CPF countries earn revenue (€8.1b) from the Carbon Price floor with the largest revenue (€5.1b) going to Germany

In the PPCA scenario there is a strong reduction (-134Mt) in emissions in PPCA countries with the largest reduction seen in UK (-52Mt) and the Netherlands (-25Mt) while an increase is observed in non-PPCA countries with increases in Czech Republic (+11Mt) and Germany (+10Mt). This leads to an overall reduction in EU wide emissions of (-93Mt)[15].

3.2.3 2020 Consumer Impacts

The demand for electricity from consumers is the same and fixed across all scenarios so it is the resulting system marginal price (based on the generation technology mix) that determines overall costs to consumers. As a whole, overall consumer costs increase by €7.1b for S1 countries when a CPF is introduced. The largest increase in wholesale prices is seen in Finland, Ireland and the UK. These countries are impacted more by the CPF as they have limited or no interconnection to member states without a CPF and have a higher portion of fossil generation in the national mix. All CPF countries see a rise in consumer costs. While the wholesale price increase is generally less in Non CPF countries, there are increases in Germany and Estonia where both countries generate more electricity for export to neighbouring countries.

In Scenario 2 wholesale electricity prices increase by €14/MWh in Germany while Finland see the largest increases relative to the Reference Scenario (€11/MWh.) Finland's limited interconnection options and relatively high share of coal (16% of generation capacity) contribute to high wholesale price increases. Existing interconnection between Russia and Finland is small and is not modelled, however if included would reduce the impact on Finland. Overall the impact in CPF countries in Scenario 2 is larger than Scenario 1 due to higher prices and a greater volume of electricity demand that has to be met. Non CPF countries also see a rise in consumer costs due to moderately higher system marginal prices in countries that

[15] It is assumed that PPCA countries apply article 12(4) to cancel equivalent allowances for the plant closed.

increase generation of electrictity for export (Notably-Poland and Czech Republic). In the PPCA scenario without a carbon price floor, the shutdown of coal plant in PPCA (same as S1 countries) countries brings gas and more expensive plant (open cycle gas and distillate peakers) into the merit order. This capacity reduction has an impact on prices with large increases in wholesale price seen in Sweden, Finland and to a lesser extent the Netherlands. In general, across PPCA countries the increase in wholesale prices and associated consumer costs is moderately higher than the impact of a carbon price floor (S1 scenario) and lower in Non PPCA countries.

Figure 5: Increases in retail electricity prices relative to Baseline as a % of 2017 Eurostat Electricity prices for household consumers[16]. Shown in sequence Scenario 1, Scenario 2 and PPCA Scenario.

Table 3: Summary Results for 2020 Scenario 1, Scenario 2 and PPCA Relative to REF[17]

[16] Electricity prices for household consumers are defined as follows: Average national price in Euro per kWh including taxes and levies applicable for the first semester of each year for medium size

2020 (Absolute Values)	Scenario 1			Scenario 2			PPCA		
	CPF Group	NonCPF Group	EUWide	CPF Group	NonCPF Group	EUWide	PPCA Group	Non PPCA Group	EUWide
Environment: Change in Emissions/relative to REF (Mt)	-74	51	-23	-104	67	-37	-134	41	-93
Government: Revenue from CPF (€m)	2538	0	2538	8130	0	8130	0	0	-
Consumers: Change in Consumer Costs (€m)	7171	8052	15223	18848	6415	25263	8628	7039	15,667
Producers: Change in Energy Net Profits (€m)	442	9771	10213	-967	7779	6812	4383	8268	12,651
Total System Costs: Fuel, start-up and emissions costs	-1073	4497	3424	4274	5402	9676	615	2875	3,490
Settlement Surplus	5263	-6216	-953	7411	-6766	646	3630	-4104	-474
2020 (Relative Values)									
Environment: Change in Emissions/relative to REF (%)	-33	5	-2	-18	12	-3	-60	-14	-12
Government: Government Revenue from CPF (% GDP)	0.03	-	-	0.08					
Consumers: Change in	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1

household consumers (Consumption Band Dc with annual consumption between 2500 and 5000 kWh). Until 2007 the prices are referring to the status on 1st January of each year for medium size consumers (Standard Consumer Dc with annual consumption of 3500 kWh). http://ec.europa.eu/eurostat/web/energy/data/database

[17] Cost to Load (Customers) - Net Energy Profits (Generators) – Total Generation Costs (Generators) – Carbon Price Floor Revenue (Government) – Settlement Surplus (Market Operator) = 0

Consumer costs (% GDP)									
Producers: Change in Energy Net Profits for Electricity Generators (% of GDP)	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1

3.2.4 2020 Producer Impacts-Net energy profits and total generation costs

Net energy profits are a function of the quantity electricity producers sell at a given price in a member state and how much they pay for the fuel, start-up costs of plant and emission costs. An important consequence of locational marginal pricing is that generators in a country can generate electricity for export and trade to neighbouring countries but get paid the system marginal price in the member state where it is produced.

In scenario 1, for generators in CPF countries the overall level of electricity generated decreases by 5%. Consumers must pay more per unit of electricity generated (due to CPF), however the domestic overall total generating cost is lower (Fuel, start-up and emissions costs) than the Reference scenario. Generators in CPF countries see a small increase in net profits as the increase in the system marginal price (wholesale electricity price) increases revenue for electricity sold and compensates for increased costs of generation. The largest absolute reductions are seen in the UK and the Netherlands with modest increases in France (due to higher share of low carbon generation). Generators in non CPF countries see increased net profits as they benefit more from increased system marginal prices and increased generation than the increased costs of generation. A positive settlement surplus is seen in CPF countries as the total cost consumers pay to meet their electricity needs exceed what generators in those countries get paid for electricity produced because CPF countries are net importers. In practice this surplus is distributed by the system operator back to NonCPF countries where a negative settlement surplus is seen.

In Scenario 2, generators across the CPF and Non CPF countries face higher costs for generating electricity. This is due to the increase in carbon price and increase in gas fired generation (particularly in the UK, the Netherlands and Italy) and coal fired generation in the Czech Republic and Poland. Germany sees higher generation costs even though the volume of electricity generation in the country reduces. German producers are particularly exposed to the CPF due to higher share of coal and fossil generation and must pay more per unit of electricity produced due to the CPF. In Scenario 2, generators in CPF countries see reduced net profits as the increase in production cost and reduced volume of electricity generated is not enough to offset any gains from higher system marginal prices in countries where electricity is produced. The opposite is seen in non CPF countries where generators see increased net profits. Similar to S1 a positive settlement surplus is seen in CPF countries, as it is a net importer of electricity and the total costs consumers pay to meet their electricity needs exceed what generators in those countries get paid. Similar to Scenario 1, the PPCA scenario sees an increase in total generation costs across the EU. The increased cost is due to increased generation of electricity in the remaining more expensive plant. The distribution of net profits is more even in the PPCA scenario as all generators face the same carbon price and it is changes in merit order that mainly impacts net profits.

3.3 2030 Carbon Price Floor Results

Summary results for 2030 in terms of emission reduction, revenue raised from the CPF, impact on consumer costs, changes in total generation costs (fuels costs, carbon costs and start-up costs to generators) and changes in net profits are presented in absolute and relative values compared to the Reference Scenario. Detailed results are in Table 4.

3.3.1 2030 System dynamics:

The introduction of a carbon price floor in S1 countries leads to a 2% (31TWh) reduction in generation in those countries and an increase in generation and exports of electricty from Non CPF countries. An increase in generation is seen in gas fired plant in Italy (12%), Spain (10%) and Germany (16%) and coal fired plant in Germany (2%), Czech Republic (25%) and Estonia (42%). The biggest reductions are in coal fired generation in the Ireland (94%), France (82%), Denmark (29%) and gas fired generation in Netherlands (41%), UK (13%) and France (38%). The biggest change (reduction) in electricity exchange is again seen in the interconnector from France to Italy and France to Spain with significant increases in flow from Germany to the Netherlands and France to the UK.

For Scenario 2, the addition of Germany to the CPF countries has a significant impact as Germany has 36GW of installed coal capacity in 2030. The inclusion of a €50/tonne ETS price in Germany reduces coal fired generation (including lignite) by 17% (45TWh) relative to the Reference. Germany again switches from a being net exporter to a net importer of power resulting in a reduction in exports to Italy (via Switzerland) and increased imports from Czech Republic and Poland.

In the PPCA Scenario, 13GW (of a total of 100GW in the EU) of coal is removed from the EU system in 2030. The largest capacity reductions are in the Netherlands (4GW), Finland (2GW) and France (4GW). We again assume coal generation is not replaced with other capacity so the shortfall must be made up from increased generation in that Member State. An increase in gas fired electricity generation in all PPCA countries is observed, particularly Netherlands (+44%) and the UK (+9%) and a general increase in imports into PPCA countries.

3.3.2 2030 Carbon Emissions

For the given assumptions, a CPF in S1 countries reduces emission in those countries by 38Mt and increases emissions in other countries by 33Mt. This results in a net reduction of 4Mt across the EU. The largest absolute reduction in emissions are seen in UK (8Mt), France (8Mt) and the Netherlands (8Mt) with increases in emissions in Germany (10Mt), Czech Republic (4Mt) and Italy (7Mt). Governments in CPF countries earn revenue from the Carbon price floor. In 2030 this is €2.0b [0.03% of GDP express as % of GDP of S1 countries] with the highest revenue in the UK (€0.6b) and the Netherlands (€0.5b).

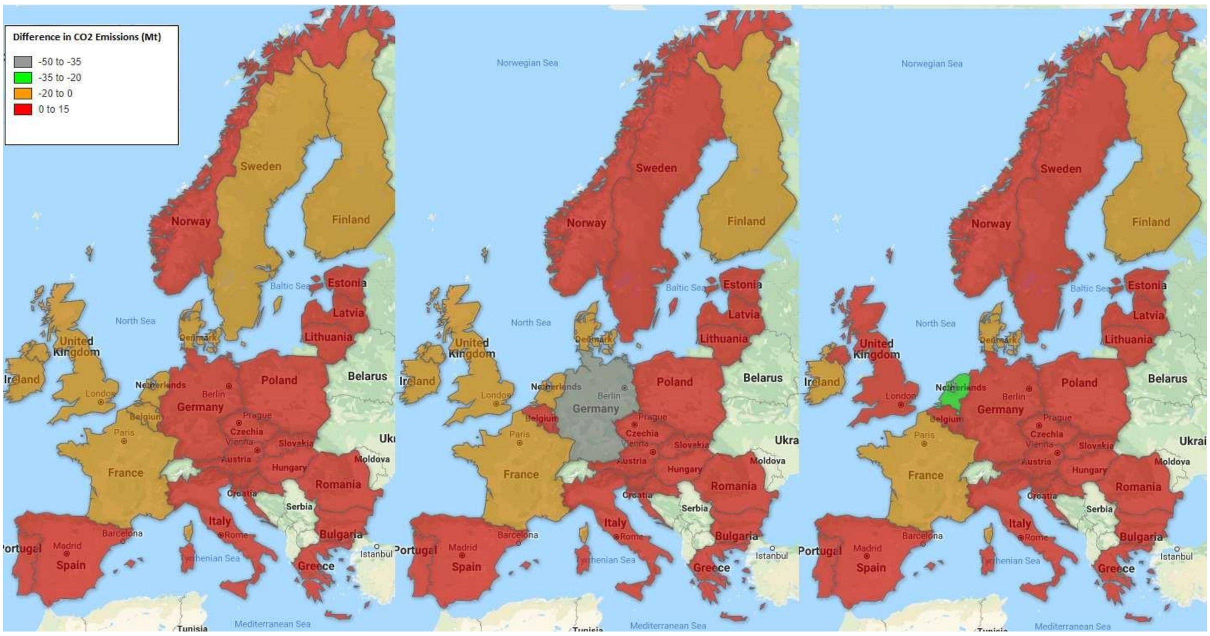

Figure 6: C02 Emissions impacts for 2030 Relative to Reference S1 (left), S2 (middle) and

PPCA Scenario (right)

In Scenario 2, a stronger reduction in emissions in seen in the CPF countries (-67Mt) and an increase in emissions in the non CPF countries (+47Mt) giving reductions across the EU as a whole (-20Mt). The largest reduction in emissions is in Germany (-46Mt) where coal plant reduce output by 17%. Increases in emissions are seen in the Czech Republic (13Mt), Italy (12Mt) and Poland (5Mt) where coal and gas fired generation increase output to meet demand for exports to neighbouring countries. Governments in CPF countries earn revenue (€6.1b) from the Carbon Price floor with the largest revenue (€3.7b) going to Germany.

In the PPCA scenario there is a reduction (-51Mt) in emissions in PPCA countries with the largest reductions seen in Denmark (-9Mt), Finland (-11Mt) and France (-8Mt) while an increase is observed in non-PPCA countries with increases in Czech Republic (+4Mt) and Germany (+5Mt). This leads to an overall reduction in EU wide emissions of (-31Mt).

3.3.3 2030 Consumer costs

In scenario 1, consumer costs increase by €10.8b for CPF countries when a CPF of €50/tonne is introduced. The largest increase in wholesale prices is seen in Sweden, Finland, Ireland and the UK (approx. €10/MWh). These countries are impacted more by the CPF as they have limited interconnection to member states without a CPF and have a high portion of fossil generation in the mix. All CPF countries see a rise in consumer costs. While the wholesale price increase is less in Non CPF countries.

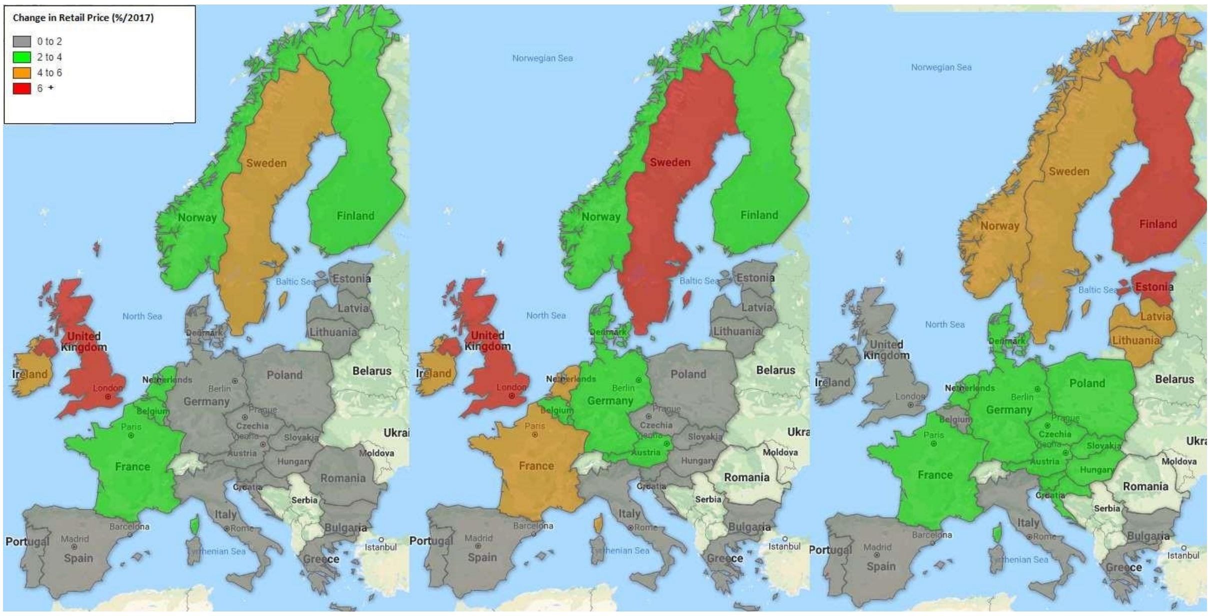

Figure 7: Increases in retail electricity prices relative to Baseline as a % of 2017 Eurostat Electricity prices for household consumers. Shown in sequence Scenario 1, Scenario 2 and PPCA Scenario.

In Scenario 2, wholesale electricity prices increase by €6/MWh in Germany, this is directly due to the CPF and Germany's high exposure to fossil generation; coal and gas fired plant are 30% of total generation capacity but 55% of total generation volume in 2030. Non CPF countries see a small rise in consumer costs but it is less pronounced than the 2020 impacts as the level of coal fired generation is lower across the EU and level of interconnection between member states has increased.

In the PPCA scenario without a carbon price floor, the shutdown of 13 GW of coal plant in PPCA countries brings gas and more expensive plant (open cycle gas and distillate peakers) into the merit order. This capacity reduction has an impact on prices and wholesale price increases are seen in Sweden (€7/MWh), Finland (€10/MWh) and Denmark (€8/MWh). In general, across PPCA countries the increase in wholesale price and associated consumer costs is lower than the impact of a carbon price floor (S1 scenario). However, the impact on Non PPCA countries is higher than the Carbon Price Floor Scenarios. As the consumer demand for electricity is the same in all the scenarios the impact is solely due to the resulting wholesale price increase. This impact is especially pronounced in Germany where peak-hour prices (17:00 to 19:00) increase by an average of €8/MWh as reduced availability of imports from Denmark and the Netherlands leads to more expensive peaking generation capacity coming online to meet demand.

Table 3: Summary Results for 2030 Scenario 1, Scenario 2 and PPCA Relative to REF

2030 (Absolute Values)	Scenario 1			Scenario 2			PPCA		
	CPF Group	NonCPF Group	EUWide	CPF Group	NonCPF Group	EUWide	PPCA Group	Non PPCA Group	EUWide
Environment: Change in Emissions/relative to REF (Mt)	-38	33	-4	-67	47	-20	-51	19	- 31
Government: Revenue from CPF (€m)	2093	0	2093	6084	0	6084	0	0	-
Consumers: Change in Consumer Costs (€m)	10824	982	11806	16753	625	17378	7195	6201	13,397
Producers: Change in Energy Net Profits (€m)	5586	1602	7188	3155	1260	4415	5120	6418	11,538
Total System Costs: Fuel, start-up and emissions costs	-2672	4986	2314	729	6175	6904	0	1051	1,051
Settlement Surplus	5816	-5605	211	6787	- 6811	-24	3198	-2391	807
2030 (Relative Values)									

Environment: Change in Emissions/relative to REF (%)	-21.2	4.7	-0.5	-14.1	11.2	-2.2	-28.5	-7.1	-5.7
Government: Government Revenue from CPF (% GDP)	0.03	-	-	0.06	-	-	0.00	0.00	0.00
Consumers: Change in Consumer costs (% GDP)	0.1	0.0	0.1	0.2	0.0	0.1	0.1	0.1	0.1
Producers: Change in Energy Net Profits for Electricity Generators (% of GDP)	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1

3.3.4 2030: Producers-Net energy profits and total generation costs

For generators in S1 countries the overall level of electricity generated decreases by 2% and while consumers must pay more per unit of electricity generated (due to the CPF) the overall total generating cost is lower (Fuel, start-up and emissions costs) than the Reference. Reduced generation costs are seen in the Netherlands, the UK and France as domestic generation volume decrease and imports of electrcity increase from Germany and Spain while exports of electricity from France to Italy reduce. Generators in the UK, Sweden and France are compensated by the increase in wholesale electricity price for electricity sold leading to an overall increase in Net profits in these member states while reduction are seen in Net profits in the Netherlands and Belgium. Generators in non CPF countries also see increased net profits as they benefit from increased system marginal prices and increased generation. A positive settlement surplus is seen again in CPF countries as the total costs consumers pay to meet their electricity needs exceed what generators in those countries get paid for electricity produced because CPF countries are net importers of electricity.

In Scenario 2, generators across CPF and Non CPF countries face higher costs for generating electricity. This is due to the increase in carbon price in CPF countries and increase in gas fired generation (particularly in the Italy, Spain and Poland) and coal fired generation in Czech Republic and Poland. Germany sees higher generation costs even though the volume of electricity generation in the country reduces as German producers, who are particularly exposed to the CPF due to higher share of coal and fossil generation) pay more per unit of electricity produced due to the CPF. In Scenario 2, generators as a whole across the EU see a moderate increase in net profits as the gains from electricity sold at higher system marginal prices offsets the extra cost of generation due to changes in merit order and the CPF.

Similar to Scenario 1, the PPCA scenario sees an increase in total generation costs across the EU albeit at a lower level than the CPF scenarios. The increased cost is due to more expensive plant coming online to meet demand.

4 Discussion and Conclusion

There is a rich body of literature on regulating environmental externalities, however, it is an open question in the literature what effects if any a carbon price floor would have for emissions reduction and how this would be transmitted to producer profitability and consumers via electricity prices. Equally, the potential emissions reductions and power price impact of a complete shutdown of coal power plant in Europe has not been addressed.

In this paper, we present a detailed model-based analysis to examine these scenarios. The analysis is developed using the EU Reference Scenario 2016, Energy, Transport and GHG Emissions, Trends to 2050 energy systems model using decarbonisation scenarios for two target years; 2020 and 2030.

In the 2020 scenario, the introduction of a carbon price floor has the biggest impact in terms of emissions reduction when Germany is included (emissions are reduced by 104Mt in the CPF Group and by 37Mt across the EU), however stronger emissions reduction is seen across the EU in both 2020 and 2030 in the Power Past Coal Alliance scenario (with emissions reductions of 134Mt in 2020 and 51Mt in 2030 in the PPCA Group with overall EU Wide emissions reductions of 93Mt and 31Mt respectively). This represents an overall 12% reduction in EU wide ETS power sector emissions in 2020 and 6% in 2030. While this is not a 'game changer' in terms of decarbonisation, it is a significant potential step. Emissions reduction in CPF scenarios are smaller and similar to the inter annual variation in emissions due to varying wind and solar years in Europe (Collins 2018).

Countries outside of PPCA are not immune from its impact and the direct closure of coal plant leads to capacity shortage resulting in increased peak prices in member states like Germany. In reality, the market would react by building new capacity somewhere; more coal capacity could be built in Poland or Czech Republic which would result in increased net emissions. Equally more gas fired plant could be built raising questions over security of EU gas supply.

It is also assumed that demand is non elastic and so increases in wholesale price do not lead to demand reduction or demand response. It is likely that consumers, particularly large consumers, with moveable loads would adapt a strategy to move consumption to lower priced periods of the day.

The burden on consumers in terms of increased electricity costs is most pronounced in Scenario 2 when Germany is included with similar and less pronounced impacts in PPCA and Scenario 1 results. Increases in retail costs of electricity are small and modest in most scenarios, suggesting minor impacts on competitiveness, with peripheral countries such as Finland, Ireland impacted the most in absolute terms. Increased interconnection to neighbouring countries may help price convergence but the benefits may be small if connecting to a country with a CPF. The increase in wholesale electricity prices will reduce the overall amount of revenue required for renewable support schemes where developers receive the difference between a strike price and wholesale electricity price. This impact in not assessed here.

We conclude that from an environmental perspective, a coalition of countries such as the PPC Alliance that implement the closure of coal power plant provides greater emissions reduction than implementing a carbon price floor in select countries. A carbon price floor is most effective when Germany is included as a participating country.

Acknowledgements

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Appendix-Data Inputs

The analysed power system is based on recent European Commission modelling of the EU Reference Scenario for the future European Energy system and we consider one fuel price scenario in our main analysis. This is one vision of what the European power system might look like in 2030 based on business-as-usual assumptions, including full implementation of

European climate and energy policies adopted by December 2014 to achieve a renewable electricity penetration of 42.5% in 2030 up from 27.5% in 2014.[17] This pathway can be interpreted as a lower bound on the emission reduction ambition within Europe, as we expect that further emission-abatement policies will be implemented prior to 2030. Approximately 2,220 individual thermal power plants are included in the model. The resulting market price is defined as the marginal price (note that this is often called the shadow price of electricity) at member state level and does not include any extra revenues from potential balancing, reserve or capacity markets or costs such as grid infrastructure cost, capital costs or taxes. These additional revenues or costs are not considered in this study. Hourly wind power generation for each Member States was taken from Aparicio et al. (2016). Localised hourly solar profiles for each Member State were developed using NREL's PVWatts® Calculator web application, which determines the electricity production of photovoltaic systems based on system location and basic system design parameters. Interconnection between Member States is modelled as net transfer capacities and no transmission lines within the same country are considered. The electricity network expansion is aligned with the latest reference capacities for the year 2030 from the 10 Year Network Development Plan from ENTSOE (2016), without making any judgement on the likelihood of certain projects materialising. Hourly demand for each member state was developed by taking the historical 2012 hourly demand reported in ENTSOE for the EU-28 plus Switzerland and Norway and scaling it to 2020 and 2030. We assume that peak increases by 10% in 2030, and we linearly scale the demand accordingly. In the Reference Scenario examined, electricity demand across the EU rises by 12% between 2012 and 2030.

[17] The generation mixes of Switzerland and Norway were developed based on ENTSOE (2016) and Energiewende (2015).

For the purpose of this study, demand is assumed inelastic with respect to price; as a result, we use the same demand independent of changes in price across all our scenarios.

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Definitions:

1) Cost to Load (Customers) - Net Energy Profits (Generators) – Total Generation Costs (Generators) – Carbon Price Floor Revenue (Government) – Settlement Surplus (Market Operator) = 0

2) <u>Cost to Load</u> is the total cost paid by loads for energy purchases, and is defined as:

Cost to Load = Price × Customer Load

3) <u>Total Generation Cost</u> is the total generation cost including fuel, variable operations and maintenance costs, start and shutdown costs and emissions costs and is defined as:

4) Total Generation Cost = Generation Cost + Start & Shutdown Cost + Emissions Cost

5) <u>Generator Pool Revenue</u> is the total payment made to Generators and is defined as:

Price Received x Generation Settlement Surplus is the surplus accruing to the Market Operator after all payments have been made to Generators and monies received from loads and is defined as:

6) Settlement Surplus = Cost to Load + Generator Pump Cost - Generator Pool Revenue