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Influence of Environmental Policy and Market Forces on Coal-fired Power Plants: Evidence on the Dutch market over 2006-2014

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ABSTRACT

Many governments aim to reduce the dependence on coal-fired generation to decrease carbon emissions. At the same time power markets have been created leaving the actual decisions concerning electricity production to power firms. This paper analyzes the interaction between environmental policies and policies to foster energy markets. Using hourly plant-level data on the Dutch power market over 2006-2014, we find that the dispatch of fossil-fuel power plants is strongly influenced by relative fuel prices, despite the existence of several environmental policy measures. Coal-fired power plants have become more important in the Dutch market since 2006, not only in share of total production, but also as provider of flexibility. Examining the short-term dispatch decisions and the past volatility in relative fuel prices, a CO_2 *price above approximately 40 euro/ton is required to provide robust incentives for power producers to dispatch a gas-fired plant instead of a coal-fired plant. We conclude that internalizing the external (*CO_2*) costs by raising the* CO_2 *price is the appropriate measure to align the principles of a market-based power industry and the wish to implement effective climate-policy measures at relatively low costs.*

Keywords: coal-fired power plants, electricity market, dispatch, environmental policy

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1. INTRODUCTION

Because of climate concerns, governments aim to reduce carbon emissions in the power sector by a range of measures varying from pollution-control measures for coal-fired power plants to stimulating renewable electricity generation (Jaraitė and Di Maria 2012). Governments in large emitting regions such as the European Union, the United States and China have formulated targets to strongly reduce carbon emissions in the near future. In order to reach these ambitious targets, the portfolio of generation techniques within power markets needs to change. More specifically, governments are stimulating renewable energy, while discouraging the role of coal-fired power plants. The realization of these objectives, however, is seriously challenged by the transformation of the electricity systems. Preceding the 1990s, the dispatch of power plants was primarily characterized by centrally coordinated decision-making. Since then, energy markets have been created, resulting in a decentralized process of decision making based on competition (Pollitt 2012). Yet, the liberalization of energy markets implies that individual electricity producers themselves decide to what extent particular types of power plants are utilized. This firm-level decision-making process regarding the electricity portfolio on the one hand and the societal policy ambitions regarding the generation mix on the other, creates challenges for government policies. The interaction between environmental policies and policies to promote competition is the topic of this paper.

Despite intensified environmental policies, electricity generation by coal-fired power plants exhibits continuous growth and has remained the dominant source of electricity generation worldwide. Coal-fired power plants accounted for approximately 40% of the total supply of electricity in 2013 (IEA 2014c). Moreover, worldwide demand for coal is expected to increase in the near future (IEA 2014c). An essential factor that recently hampers the effectiveness of environmental policies is the worldwide declining trend in coal prices (Burnham et al. 2012; Haftendorn, Kemfert, and Holz 2012; Lior 2008). Therefore, in order to realize the transition of the power sector towards less-polluting generation techniques, effective environmental policies are needed which are directed at reducing carbon emissions by discouraging the incentives for power firms to use coal-fired power plants (Newbery 2016).

This paper analyzes the tension between the environmental policy objectives and the policies to foster competition in energy markets, using hourly plant-level data on the Dutch power market over 2006-2014. We focus on the Dutch market since this market has faced many changes in the economic and policy environment over the past decade. The Dutch electricity supply is heavily based on thermal electricity generation. The Dutch supply of electricity moved from a centralized system, with coordinated decisions on investments, dispatch and prices, to a market system at the end of 1990s (Tanrisever, Derinkuyu, and Jongen 2015). Over the past decade, the Dutch government has implemented a number of environmental policy measures to influence the decisions of energy producers and consumers, such as stringent regulations on air pollution, taxes on energy consumption, subsidies promoting renewable energy generation, and making the electricity industry subject to the EU Emission Trading System (ETS). In 2013, the Dutch government and a large number of societal stakeholders, including the electricity producers, concluded the so-called Energy Deal, which is an agreement to foster energy efficiency, renewable-energy and emission reduction (Social Economic Council 2013). More recently, the Dutch government announced plans to close all coal-fired power plants by 2025 (EZ 2015). Using a unique data set containing hourly plant-level data on the Dutch electricity market, we examine whether these measures based on climate policy objectives s have affected the utilization of coal-fired power plants over 2006-2014. In this paper, we do not discuss the effectiveness of environmental policy measures to reduce the emissions of other contaminants (such as sulfur dioxide, nitrogen oxides and mercury).

We find that the dispatch of power plants was strongly influenced by relative fuel prices. Despite its low levels in the past, the price of CO_2 in the European Emissions Trading scheme had a negative effect on the dispatch of coal-fired power plants and a positive effect on the dispatch of gas-fired power plants. In spite of the implementation of a number of environmental policy measures, coal-fired power plants have become more important in the Dutch market since 2006, not only in share in total production, but also as provider of flexibility. While the government wanted to reduce the use of coal-fired power plants in order to reduce carbon emissions, market forces have been more powerful resulting in a larger role of these plants in the Dutch supply of electricity. An alternative policy currently considered in several countries is a forced closure of coal-fired power plants, but such a policy is at odds with the idea to have decentralized decision making in the power industry. A policy which is more in line with the existence of power markets is raising the CO_2 price. Examining the short-term dispatch decisions and the past volatility in relative fuel prices, a CO_2 price above approximately 40 euro/ton appears to be sufficient to provide robust incentives for power producers to dispatch a gas-fired plant instead of a coal-fired plant.

The rest of this paper is structured as follows. Section 2 starts by briefly describing power markets and environmental policies regarding the power market in a number of OECD countries. In Section 3, indicators are presented that measure the role of coal-fired power plants in the electricity market from different angles. Section 4 presents the results, while Section 5 offers the conclusions.

2 METHOD

2.1 Power markets and environmental policy

In many countries over the past decades, the electricity industry has been restructured from systems characterized by monopolies and coordinated decisions on investments, dispatch and prices towards liberalized markets where independent decision making units (i.e. firms) make their own decisions based on information coming from market prices (Pollitt 2012). In addition, national markets have been integrated into regional markets. Within the EU, the policies have been directed at fostering market efficiency and cross-border trade through removing barriers for international trade, resulting in a number of regional European markets. A similar process has occurred in the US where the electricity market now consists of eight regions with three nation-wide interconnected networks, namely the Eastern, Western and Texas Interconnected System.

Various environmental policies have been developed around the globe to reduce the environmental burden of electricity generation. In 2007, the European Union decided to counter climate change by adopting EU-wide objectives for 2020, namely their '2020 climate and energy package' (IEA 2014a). Relative to 1990, GHG emission ought to be decreased by 20%, while the share of renewable energy consumption as a proportion of gross energy consumption should increase up to 20%. Also, relative to 2007, total primary energy consumption ought to be cut down by 20%. Currently, however, coal is still the primary source of total electricity generation.

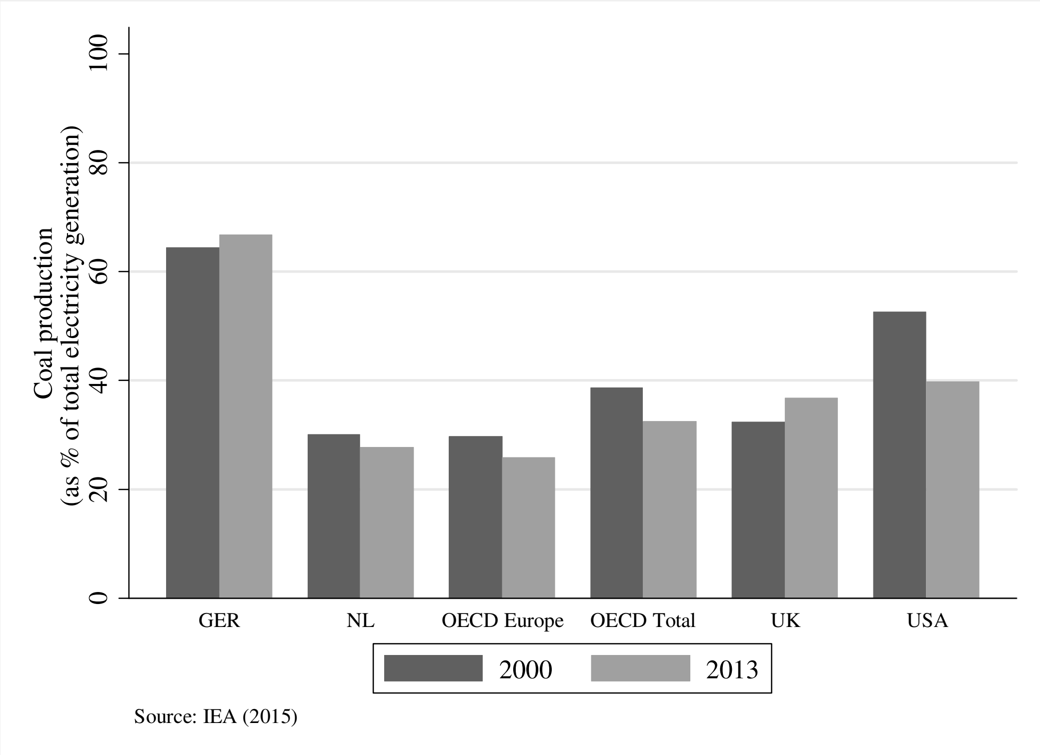

FIGURE 1

Share of coal-fired power generation, per country/region, 2000 and 2013

In the United States, the 'Blueprint for a Secure Energy Future' was developed in 2011 as an integral part of the US energy policy (IEA 2014b). Its main objectives included fostering domestic energy supplies, decreasing dependence on fossil fuels and funding research to develop innovative clean technologies. In 2013, the US launched the Climate Action Plan in 2013, meant to, amongst others, reduce domestic emissions by enforcing stricter emission regulation on new and existing power plants. Currently, coal is the primary input for electricity generation in the US, accounting for approximately 40% of total electricity generation (Figure 1). Nonetheless, a transition is taking place towards more natural gas as a result of the relatively low gas prices, while the role of renewable energy has become more prevalent. In response to the environmental regulations, it is expected that about 60 gigawatts of coal-fired capacity will retire before 2020 (EIA 2014).

In the United Kingdom, a Climate Change Act was implemented in 2008, stating environmental targets for the year of 2050 (UK Government 2008). By 2020, the United Kingdom aims to reduce their carbon account by at least 26 %, while the ultimate goal is to reduce GHG emissions by 80% relative to 1990 levels. The share of coal-fired generation in the UK, however, increased over the past years to 36% (Figure 1). The Energy and Climate Change Secretary has proposed to shut down all coal-fired power plants in the United Kingdom and to rely more on electricity generation by gas-fired power plants (DECC 2015). To achieve the 2050 targets, the Act imposes carbon budgets for succeeding periods of five years.

Germany started policies to stimulate renewable energy in 1991, by implementing feed-in-tariffs for wind power in 1991 (Hitaj 2013). More recently, the policies towards the power sector were considerably intensified by facing out nuclear power plants, strongly increasing the share of renewables and setting GHG emissions targets (Hirschhausen 2014). The objectives are to increase the share of renewables to 50% in 2030 and 80% in 2050. In 2014, about 25% of total electricity production came from renewable energy sources (mainly wind, biomass and solar), while this share was no more than 7% in 2000. The share of nuclear power has reduced to about 15% in 2014. However, the share of coal-fired generation is still above 60% (Figure 1).

In line with the EU '2020 climate and energy package', the Netherlands has committed to the objectives to decrease their GHG emission by 16%, to increase energy efficiency savings by 1.5% per year while renewable energy need to constitute 14% of total electricity generation by 2020. The Netherlands charges relatively high environmental taxes, accounting for approximately 9% of total government tax revenues. The use of fossil fuels in energy-intensive industries, however, is not taxed. The Dutch electricity generation portfolio is still predominantly characterized by the use of fossil fuel resources, namely natural gas and coal (Table 1). The share of coal-fired generation is comparable to the OECD level (Figure 1). A specific policy measure regarding coal-fired power plants is the reduction of tax burden on coal use by electricity producers. In addition, five coal-fired power plants will be shut down with capacity ranges from approximately 400 MW to 650 MW. Although recently a number of new power plants have been added to the installed capacity, the Dutch government is considering to implement measures to close all coal-fired power plants (EZ 2015). In this paper, we focus on how the role of coal-fired power plants has evolved in the Dutch market in response to market developments and environmental policies.

2.2 Indicators, model and data

To analyze the influence of markets forces and environmental policy on coal-fired power plants in the Netherlands over 2006-2014, we use a number of indicators. In order to quantify these indicators we use a unique data set containing hourly plant-level data regarding production levels and available capacity for each generation unit above 50 MW. This data is obtained from the Authority for Consumers and Markets (ACM).[3] In addition, data from Bloomberg on market prices is used.

First of all, we analyze aggregate numbers on the annual contribution of coal and gas-fired power plants to the Dutch market. Next, we analyze to what extent coal-fired power plants were dispatched compared to gas-fired power plants. Using hourly plant-level data, we examine how often coal and gas-fired power plants were yearly dispatched.[4] Furthermore, we investigate how coal-fired power plants are used in terms of providers of base load and flexibility. As a result of the increase of intermittent supply by renewable sources, more supply of flexibility is needed. We use duration curves of the annual production by coal and

[3] Electricity firms in the Dutch market are legally obliged to submit data on the hourly production and available capacity per power plant to the ACM. For an extensive description of this data set, see Mulder (2015) (Mulder 2015).

[4] By dispatch we mean that the hourly production is above zero.

gas-fired power plants to analyze which role these two types of plants play and whether these respective roles have changed since 2006. Duration curves are generally used as indicators to measure the degree of flexibility of power supply (de Jonghe et al. 2011; Korpaas, Holen, and Hildrum 2003). We test whether a change in the supply of flexibility can be observed between coal and gas-fired power plants in 2006, 2010 and 2014.

As the dispatch of power plants is strongly related to the marginal costs of production, we calculate these costs for all plants on a daily basis, using information on the technical characteristics per plant and daily data on gas, coal and CO_2 prices. In addition, we conduct a panel regression on the hourly dispatch of gas-fired and coal-fired power plants to explain the hourly dispatch levels. We hypothesize that the hourly dispatch of a power plant depends on the marginal generation costs as well as factors determining the total load (McGuinness and Ellerman 2008). Regarding the former, we include the prices of gas, coal and CO_2 in the regression model. As variables measuring the impact of changes in load, we include the hourly weather temperature and the supply of electricity by renewable sources. The latter is assumed to be related to environmental policy: the more effective this policy is, the higher the supply by renewable sources. We also include renewable supply in Germany since the Dutch market is closely connected to the German market, while the surge in the supply of renewable energy in this neighbouring country has strongly affected the German market (Mulder 2015). Note that the price of CO_2 is also related to the impact of climate policies, as this price originates from the European ETS. We test whether the price of CO_2 as well as the supply of renewable energy affects the production by coal and gas-fired power plants. Hence, the regression model to be tested is the following:

$$G_{i,t} = \beta_{i,o} + \beta_1 G_{i,t-1} + \beta_2 P_{g,t} + \beta_3 P_{c,t} + \beta_4 P_{CO_{2,t}} + \beta_5 L_t + \beta_6 T_t + \beta_7 RES_{NL_t} + \beta_8 W_{GER_t} + \varepsilon_t \, , \quad (1)$$

where $G_{i,t}$ is generation per plant t per hour t, P_g is the price of gas, P_c is the price of coal, P_{CO_2} is the price of CO_2, L is total load served by the centralized power plants, T is the average daily temperature, RES_{NL} is the supply of renewable energy in the Netherlands and $W_{GER}$is the supply of renewable energy in Germany.

Next, we examine a scenario in which coal-fired power plants are non-existent and how this absence of coal-fired power plants may influence the electricity price. We use the actual merit-order in the Dutch market to examine the effect on system-marginal costs if coal-fired power plants would be excluded from supplying power as is currently subject to debate in the Netherlands as well as in several other countries.

Finally, we go more into depth in the role of the price of CO_2. We calculate the break-even price of CO_2, which is the price of CO_2 where electricity producers are indifferent between dispatching a coal-fired or gas-fired plant.[5] This break-even price of CO_2 is a short-term price which is predominantly influenced by relative gas and coal prices, given the current technical efficiencies of coal and gas-fired power plants. To determine the annual break-even price of CO_2, the average marginal costs of coal-fired plants are set equal to the average marginal costs of gas-fired plants.[6] The marginal costs per type of plant are calculated as follows:

$$MC_f = \left(\frac{1}{e_f}\right)(P_f + P_{CO_2}CO_2rate_f) + VC_f \qquad (2)$$

where MC_f is marginal costs (euro/MWh) per type of generation plant (*f*), e_f is the technical

[5] See also Newbery (2016) (Newbery 2016) who calculates the break-even CO2 price for gas-fired power plants versus renewable generation techniques.
[6] For the sake of simplicity, we ignore the fixed start-up costs. Furthermore, we assume that the power producers cannot pass on an increase in the CO_2 price into the electricity price, implying that this price is treated as a fully exogenous cost driver (see also Delarue et al., 2008) (Delarue, Voorspools, and D'haeseleer 2008).

efficiency per type of generation plant, P_f is the fuel price, CO_2rate is the content of CO_2 per kWh electricity generated per type of plant and VC_f are the remaining variable costs per type of plant. Equating the marginal costs for gas-fired and coal-fired power plants, we find the following equation for the break-even value of the CO_2 price ($P_{CO_2}^{BE}$), where g stands for gas and c for coal:

$$P_{CO_2}^{BE} = \frac{\left(\frac{P_g}{e_g} - \frac{P_c}{e_c}\right) + (VC_g - VC_c)}{\left(\frac{1}{e_c} CO_2 rate_c\right) - \left(\frac{1}{e_g} CO_2 rate_g\right)} \quad (3)$$

Eq. (3) shows that the minimum CO_2 price needed to replace coal-fired electricity by gas-fired electricity strongly depends on the relative prices of gas and coal. Therefore, we calculate the break-even price of CO_2 for each year since 2006, a period in which the relative fuel prices changed significantly.

3. RESULTS AND DISCUSSION

The centralized domestic production within the Dutch market is primarily characterized by relatively high levels of production by coal-fired and gas-fired power plants (Figure 2). The production by gas-fired power plants largely dominated coal-fired power plants production in 2006, while the levels of production of these two types of power plants have reached rather similar levels in 2014. From the figure we clearly observe seasonal trends as total domestic centralized production during the summer is lower than during the winter. This is related to the fact that in the Netherlands electricity is relatively strongly used for lighting and less for heating (such as in the Scandinavian countries) or cooling (such as in France).

The generation capacity in the Dutch electricity market has increased significantly since 2006. The aggregated size of installed centralized capacity increased from approximately 17

GWh in 2006 to 24 GWh in 2014 (Table 1). The number of gas-fired power plants decreased, whereas the number of coal-fired power plants increased by 25%. The contribution of total domestic production to serving total load, however, declined whereas the share of import increased. This increase in cross-border flows was enabled by the increase in the import capacity from 3.6 GW in 2006 to 5.2 GW in 2014. Based on these aggregate numbers, we observe that the coal-fired power plants have become more important to the Dutch market over the past decade.

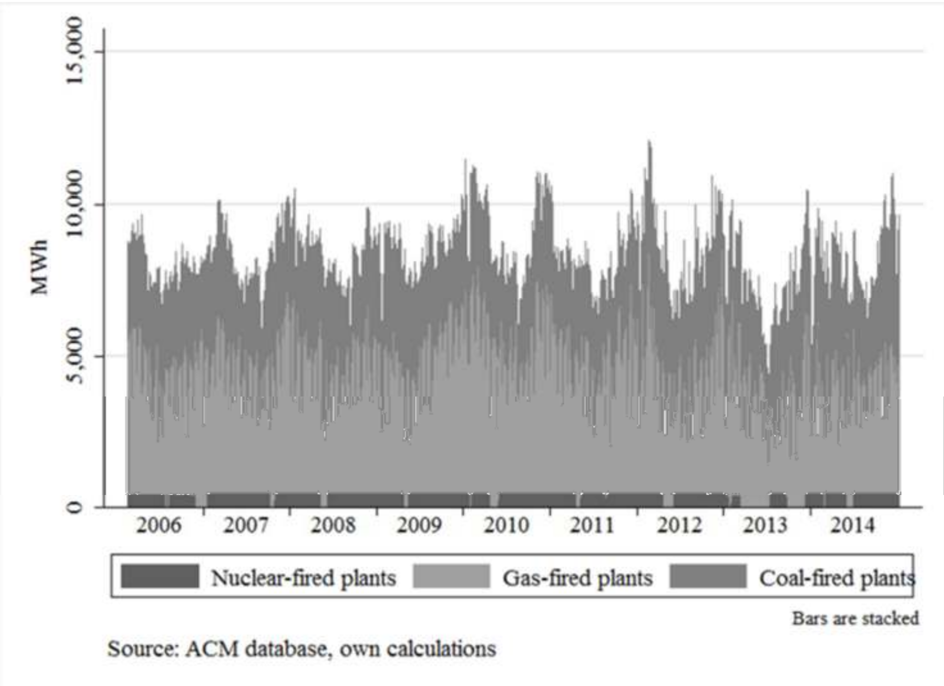

FIGURE 2

Aggregated hourly centralized production in the Dutch market by type of plant, 2006-2014

TABLE 1

Key Indicators of the Dutch power market in 2006-2014 (annual averages)

	2006	2010	2014
Number of power plants			
total	95	96	98
gas-fired	83	82	80
coal-fired	8	8	10
biomassa	1	2	2
nuclear	1	1	1
waste	2	3	5
Installed capacity of power plants (GW)			
centralized total	16.7	18.5	23.9
gas-fired	12.2	13.7	16.9
coal-fired	4.2	4.2	6.2
biomassa	0.0	0.0	0.0
nuclear	0.4	0.5	0.5
waste	0.1	0.0	0.2
Domestic Production (TWh)			
total	91.6	109.6	93.2
gas-fired	57.1	73.6	51.4
coal-fired	23.1	21.9	28.8
biomassa	5.2	7.1	5.9*
nuclear	3.5	4.0	4.1
waste	2.8	3.1	3.0*
Import (TWh)	27	16	33
Export (TWh)	6	13	18
Domestic consumption (TWh)	120	121	118
Import capacity (GW)	3.6	4.3	5.2

Sources: Number and size of power plants, RSI, HHI: ACM database; Production, import, export, domestic consumption and installed capacity: CBS; Import capacity: TenneT; Note: *due to unavailable data in 2014, data for 2013 have been used

Figure 3 shows the annual number of hours of dispatch of all plants ranked from the lowest number to the highest number of hours for three different years. [7] For gas-fired power plants, it can be seen that the hours of dispatch curve in 2014 is well below that of 2006 and

[7] By dispatch we mean that the hourly production is above zero.

2010, indicating that most plants were used less intensively. For approximately 2000 MW, gas-fired power plants were not dispatched at all in 2014. Also for coal-fired power plants, it can be observed that the number of hours of dispatch declined between 2006 and 2014, yet to a lesser degree than gas-fired power plants. For most coal-fired plants, the number of hours of dispatch in 2014 is comparable to those in 2006.

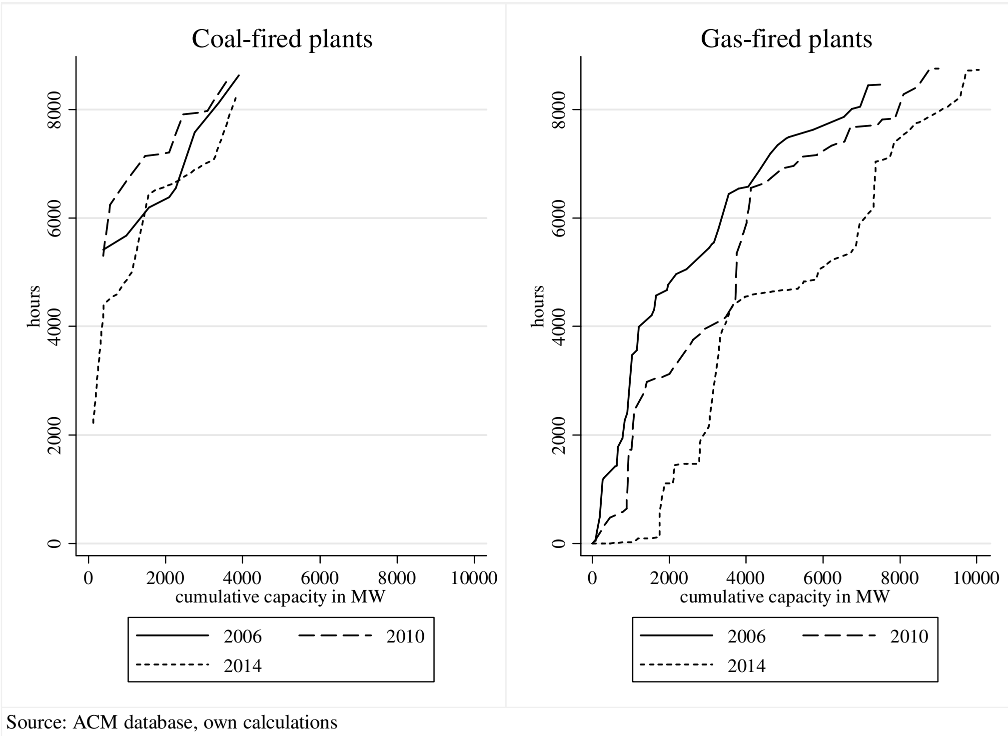

FIGURE 3

Number of hours of dispatch of coal and gas-fired power plants in the Dutch power market, 2006, 2010 and 2014

To examine the role of coal-fired power plants as providers of flexibility, we investigate the duration curves of production by coal and gas-fired plants (Figure 4). We observe that the coal-fired power plants increasingly provide flexibility as the duration curve in 2014 is much steeper than in the previous years. We also see that the production by gas-fired power plants decreased over the past decade, which is indicated by a leftward shift of the curve. Yet, the flexibility of gas production has remained rather similar.

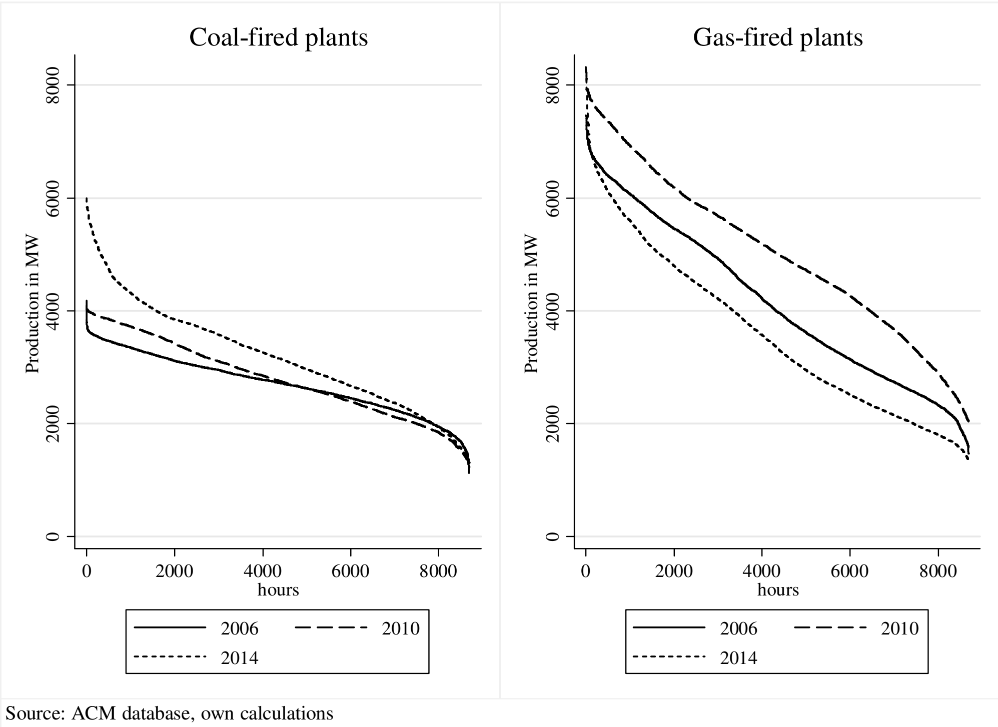

FIGURE 4

Duration curves of aggregated production by coal and gas-fired power plants in the Dutch power market, 2006, 2010 and 2014

Closely examining the average daily marginal costs of coal and gas-fired power plants in the Dutch electricity market, Figure 5 shows that their marginal costs hovered around similar levels until 2010, but afterwards they show a larger spread. Since 2010, coal-fired power plants operated at significantly lower marginal costs, whereas the marginal costs of gas-fired power plants were characterized by an increasing trend from 2010 onwards.

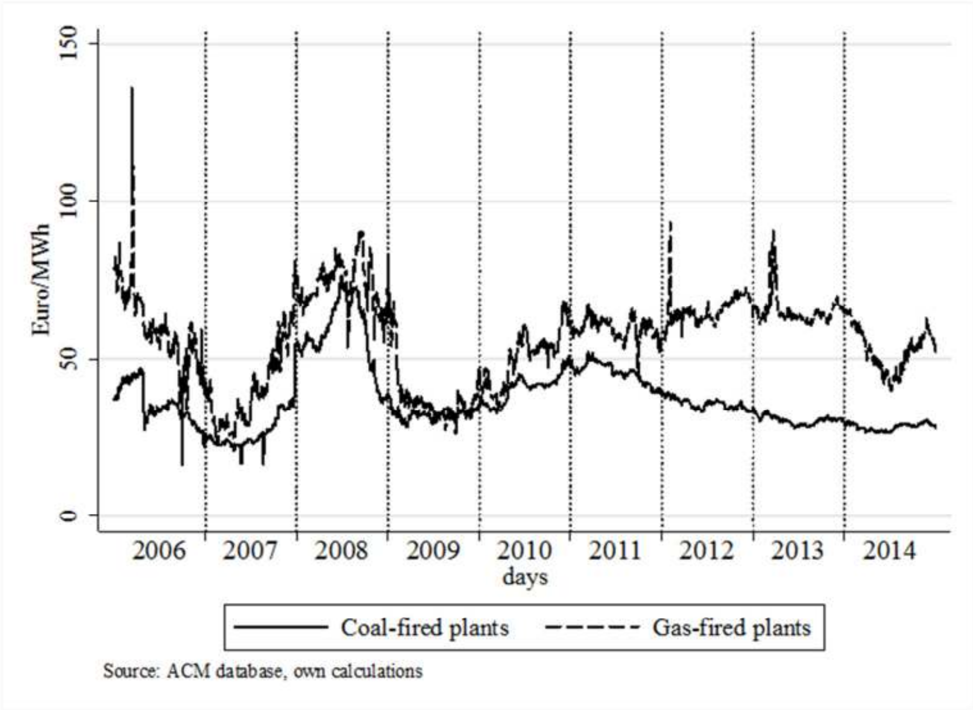

FIGURE 5

Marginal costs of coal and gas-fired power plants in the Dutch power market, 2006-2014

(average per plant type per day)

Conducting a panel analysis[8], it appears that the hourly dispatch of the gas and coal-fired plants is significantly related to the fuel prices, but in the opposite direction (Table 2). The higher the gas price, the lower the production by gas-fired plants and the higher the production of coal-fired plants, and vice versa for the coal price. It appears that the dispatch of the coal-fired power plants is sensitive to both fuel prices.[9] The price of CO_2 in the ETS also has an opposite effect on the production of both types of plants: the higher this price, the

[8] The panel regression is conducted on those plants which were running during the full period 2006-2014. See Appendix A for the results of the statistical tests on serial correlation, multicollinearity, stationarity and fixed/random effects. Based on these results we include the lag of the dependent variable in order to control for serial correlation. In addition, we take the first difference of the (annual) Dutch supply of renewable energy because of the presence of a unit root in this time series. Moreover, we estimate the model in fixed effects. Finally, we include hourly, daily and quarterly dummies to control for time patterns in the data. The full results of the regression model are presented in table A.7.

[9] A change in the price of gas by 1 standard deviation results in a decline of the (average) production of gas-fired plants by 0.29 MWh and increase in the production of coal-fired plants by 0.21 MWh, while a similar change in the price of coal results in an increase of the production of gas-fired plants by only 0.04 MWh and a decrease in the production of coal-fired plants of 0.17 MWh.

more gas-fired plants are dispatched, while the coal-fired plants are less dispatched. Hence, the price of CO_2 triggers substitution from coal-fired to gas-fired generation.

Both types of plants respond positively to an increase in the total domestic load. We also observe that the outside temperature has a significant impact on the level of production. Note that this variable also covers the influence of daylight because of the close relationship between these environmental variables.

The Dutch power plants, both gas and coal-fired, positively respond to the level of production by German wind turbines. The more wind electricity is produced in Germany, the more the Dutch conventional plants produce. This effect is related to the impact of German wind electricity on loop flows within the European network and the availability of cross-border capacity. German wind appears to reduce the size of the cross-border capacity which is allocated to the market by the TSO, as more capacity is needed to deal with the loop flows (TenneT 2014). As a result of the reduced availability of cross-border capacity and lower imports, domestic producers need to produce more.

The production of the conventional power plants shows strong time patterns (see Table A.7). The regression results show that coal-fired power plants are also used for short-term (i.e. within-day) flexibility.

TABLE 2

Results of the panel regression analysis on the hourly production of gas and coal-fired power plants in the Dutch power market, 2006-2014

Production per hour	**Gas-fired plants**	**Coal-fired plants**
constant	-9.005*** (0.119)	-20.46*** (0.344)

G_{t-1}	0.973***	0.988***
	(0.000145)	(0.000197)
P_{gas}	-0.0511***	0.0364***
	(0.00274)	(0.00779)
P_{coal}	0.0139**	-0.0646***
	(0.00621)	(0.0176)
P_{CO2}	0.0461***	-0.00919
	(0.00205)	(0.00577)
L	0.000679***	0.000514***
	(1.22e-05)	(3.52e-05)
T_{NL}	-0.0151***	-0.0275***
	(0.00327)	(0.00940)
1^{st} diff. RES_{NL}	0.00771	-0.0574*
	(0.0111)	(0.0320)
W_{GER}	0.00724**	0.0398***
	(0.00319)	(0.00928)
R^2	0.96	0.98
Observations	2,472,274	617,827
Number of plants	32	8

Note: Standard errors in parentheses

*; **; *** refer to 10%, 5% and 1% significance levels, respectively.

See Table A.1 for the full overview of the results.

Closing coal-fired power plants, a policy option that is currently considered in the Netherlands (EZ 2015) would have a significant effect on the merit order and, hence, the system-marginal costs. At a demand level of 9,000 MWh, the average system-marginal costs in 2014 increase from 45 euros to about 65 euros if coal-fired power plants were taken out of power supply. As a consequence of an increase in domestic system-marginal costs, import flows will also increase, since it will become relatively cheaper to import rather than generating electricity at home. Yet, as shown in table 1, the import capacity is constrained, namely 3.6 GW in 2014, which means that import will only be partly able to reduce the price effect of a forced closure of all power plants.

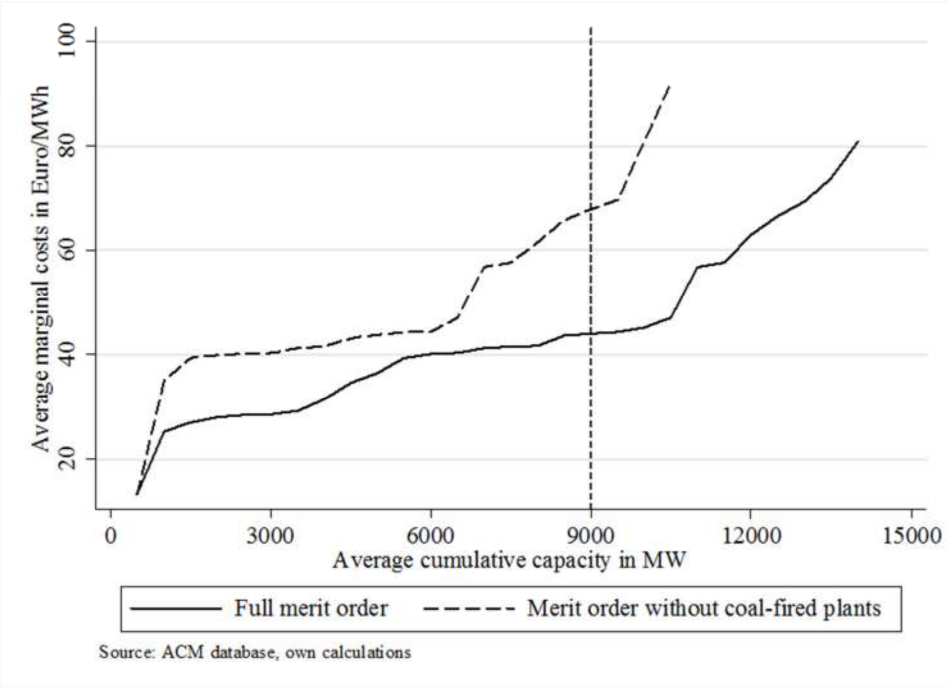

FIGURE 6

Merit order in Dutch power market, with and without coal-fired power plants, 2014 (average per year)

The final indicator regarding the role of coal-fired power plants is the short-term break-even price of CO_2, which is the price at which electricity producers are indifferent between dispatching coal or gas-fired power plants. The break-even price appears to be volatile from year to year, which is caused by the fluctuating gas and coal prices (Figure 7). The maximum value of the break-even price since 2006 is approximately 40 euros/MWh, whereas its minimum value was approximately 5 euros/MWh. A positive relationship exists between this break-even price and the spread between the gas price and the coal price. After all, the more expensive gas is compared to coal, the higher the price of CO2 which is needed to make both types of plant break even. This relationship is, however, weakened, because of the increase in the technical efficiency of gas-fired power plants from 2006 to 2014 (Figure 8). Gas-fired power plants have, on average, become more efficient, which means that a lower CO_2 price is needed to arrive at the break-even level of marginal generation costs.

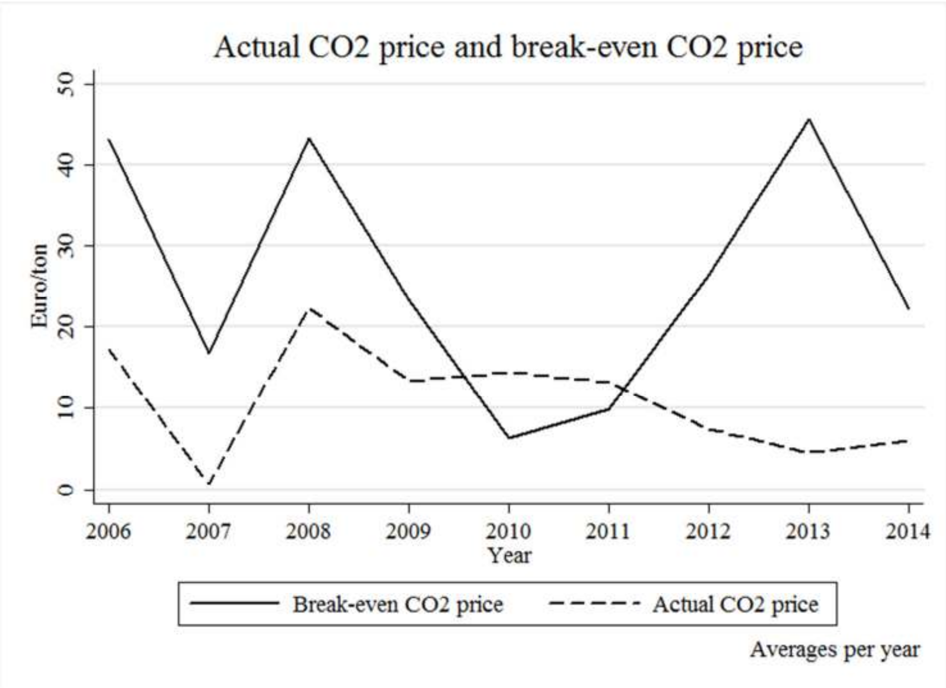

FIGURE 7

Actual CO_2 price and break-even CO_2 price between dispatching coal and gas-fired power plants, 2006-2014 (average per year)

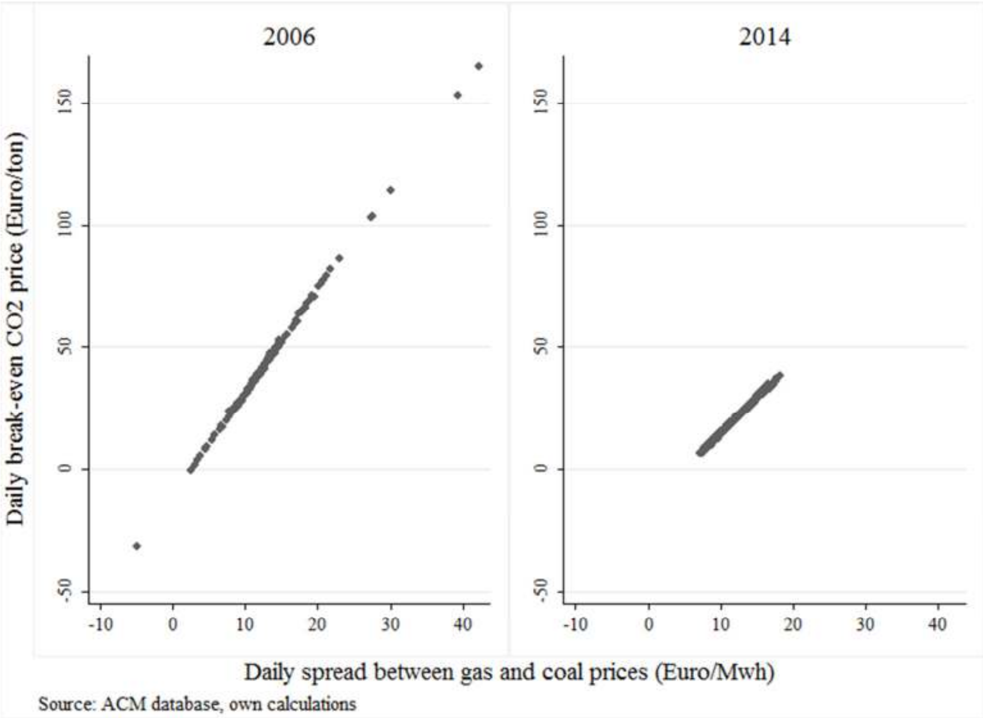

FIGURE 8

Relationship between break-even price of CO_2 and the spread between the gas price and the coal price, 2006 and 2014 (daily data)

4. CONCLUSION AND POLICY IMPLICATIONS

The fundamental challenge for governments aiming to reduce carbon emissions is how to align this target with decentralized decision making in power markets. Using a unique dataset of hourly plant-level data, we find that the decentralized decisions regarding the dispatch of power plants by electricity producers is strongly influenced by relative fuel prices of coal and gas, despite the existence of environmental policies. However, despite its low levels in the past, the price of CO_2 in the ETS had a negative effect on the dispatch of coal-fired power plants and a positive effect on the dispatch of gas-fired power plants. Hence, the price of CO_2 triggers the substitution of coal-fired plants by gas-fired plants. These results are in line with what was found by (McGuinness and Ellerman 2008) for the UK power market during the earlier years of the ETS.

We also find a small negative impact of the presence of renewable-electricity production in the Netherlands on the production by coal-fired plants. Contrary to what might be expected, we find that an increase in German renewable-electricity production raises production by the Dutch conventional power plants (both gas and coal). This phenomenon is related to the impact of renewable energy on cross-border loop flows which reduces the size of the available cross-border capacity between Germany and the Netherlands (Hulshof, van der Maat, and Mulder 2016; TenneT 2014). Hence, we have the paradox that more renewable-energy production in one country stimulates fossil-fuel production in a neighbouring country, although both countries are closely connected. Apparently, the current magnitude of this connection is not sufficient to control for the cross-border loop-flow effect reducing the available capacity for traders.

In spite of the implementation of a number of environmental measures meant to foster the transition of the energy system, coal-fired power plants have become more important in the Dutch market since 2006. The increase in their contribution to total production could be expected given the changes in the relative fuel prices, but coal-fired power plants also became more important for providing flexibility. Although gas-fired plants are technically better equipped to offer flexibility, it is important to acknowledge that coal-fired plants also appear to be able to supply this service to a significant extent to the market.

A measure to reduce the share of coal-fired generation which is currently considered in a number of countries is to force power firms to close these plants. Such a policy measure is at odds with the idea to have decentralized decision making in the power industry. Given the current constraints on cross-border capacity, such an intervention in the power market likely results in considerably higher prices for consumers as well as costs for societies compared to a market-based intervention directed at changing the incentives for power producers. Moreover, such a policy measure is not effective to reduce the overall level of CO_2 emissions because of the existence of the ETS, as any reduction in emissions will reduce the carbon price and, hence, raise emissions in other industries.

From the Dutch experiences, we learn that an increase in CO_2 price levels gives an incentive to electricity producers to use gas-fired power plants instead of coal-fired plants. Looking at the short-term dispatch decisions as well as the realized volatility in relative fuel prices since 2006, we conclude that a CO_2 price above 40 euro/ton provides fairly robust incentives for power producers to dispatch a gas plant instead of a coal plant. Hence, internalizing the external (CO_2) costs by raising the CO_2 price, for instance by reducing the cap in the ETS, is the appropriate measure to align the principles of a market-based power industry and the wish to implement effective climate-policy measures at relatively low costs.

REFERENCES

Burnham, A, J Han, C E Clark, M Wang, J B Dunn, and I Palou-Rivera. 2012. "Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum." *Environmental Science & Technology* 46 (2): 619–27. doi:10.1021/es201942m.

DECC. 2015. "Government Announces Plans to Close Coal Power Stations by 2025." *UK Government*. https://www.gov.uk/government/news/government-announces-plans-to-close-coal-power-stations-by-2025.

de Jonghe, C, E Delarue, R Belmans, and W D'haeseleer. 2011. "Determining Optimal Electricity Technology Mix with High Level of Wind Power Penetration." *Applied Energy* 88 (6): 2231–38. doi:http://dx.doi.org/10.1016/j.apenergy.2010.12.046.

Delarue, E, Kris Voorspools, and William D'haeseleer. 2008. "Fuel Switching in the Electricity Sector under the EU ETS: Review and Prospective." *Journal of Energy Engineering* 134 (2): 40–46. doi:http://dx.doi.org/10.1061/(ASCE)0733-9402(2008)134:2(40).

EIA. 2014. "Planned Coal-Fired Power Plant Retirements Continue to Increase." *US Energy Information Administration*. https://www.eia.gov/todayinenergy/detail.cfm?id=15491.

EZ. 2015. "Kamerbrief over Het Uitfaseren van de Kolencentrales in Nederland." https://www.rijksoverheid.nl/documenten/kamerstukken/2015/12/18/kamerbrief-over-het-uitfaseren-van-de-kolencentrales-in-nederland.

Haftendorn, C, C Kemfert, and F Holz. 2012. "What about Coal? Interactions between Climate Policies and the Global Steam Coal Market until 2030." *Energy Policy* 48: 274–83. doi:http://dx.doi.org/10.1016/j.enpol.2012.05.032.

Hirschhausen, C von. 2014. "The German' Energiewende'—An Introduction." *Economics of Energy & Environmental Policy* 3 (2): 1–12.

Hitaj, C. 2013. "Wind Power Development in the United States." *Journal of Environmental Economics and Management* 65 (3): 394–410. doi:http://dx.doi.org/10.1016/j.jeem.2012.10.003.

Hulshof, D, J-P van der Maat, and M Mulder. 2016. "Market Fundamentals, Competition and Natural-Gas Prices." *Energy Policy*. doi:http://dx.doi.org/10.1016/j.enpol.2015.12.016.

IEA. 2014a. "Energy Policies of IEA Countries: European Union 2014 Review." IEA. https://www.iea.org/Textbase/npsum/EU2014SUM.pdf.

———. 2014b. "Energy Policies of IEA Countries: The United States 2014." Paris: IEA. http://www.iea.org/Textbase/npsum/US2014sum.pdf.

———. 2014c. "Global Coal Demand to Reach 9 Billion Tonnes per Year by 2019." *International Energy Agency*. http://www.iea.org/newsroomandevents/pressreleases/2014/december/global-coal-demand-to-reach-9-billion-tonnes-per-year-by-2019.html.

Jaraitė, J, and C Di Maria. 2012. "Efficiency, Productivity and Environmental Policy: A Case Study of Power Generation in the EU." *Energy Economics* 34 (5): 1557–68. doi:http://dx.doi.org/10.1016/j.eneco.2011.11.017.

Korpaas, M, A T Holen, and R Hildrum. 2003. "Operation and Sizing of Energy Storage for Wind Power Plants in a Market System." *Journal of Electrical Power & Energy Systems* 25 (8): 599–606. doi:http://dx.doi.org/10.1016/S0142-0615(03)00016-4.

Lior, N. 2008. "Energy Resources and Use: The Present Situation and Possible Paths to the Future." *Energy* 33 (6): 842–57. doi:http://dx.doi.org/10.1016/j.energy.2007.09.009.

McGuinness, M, and A D Ellerman. 2008. "CO2 Abatement in the UK Power Sector: Evidence from the EU ETS Trial Period." *CEEPR Massachusetts Institute of Technology*, 1–16. doi:http://hdl.handle.net/1721.1/45654.

Mulder, M. 2015. "Competition in the Dutch Electricity Wholesale Market: An Empirical Analysis over 2006-2011." *The Energy Journal* 36 (2): 1–28.

Newbery, D. 2016. "Policies for Decarbonizing a Liberalized Power Sector." *EPRG Working Paper 1607 University of Cambridge*, 1–34. doi:https://www.repository.cam.ac.uk/handle/1810/255194.

Pollitt, M G. 2012. "The Role of Policy in Energy Transitions: Lessons from the Energy Liberalisation Era." *Energy Policy* 50: 128–37. doi:http://dx.doi.org/10.1016/j.enpol.2012.03.004.

Social Economic Council. 2013. "Energy Agreement for Sustainable Growth." http://www.ser.nl/~/media/files/internet/talen/engels/2013/energy-agreement-sustainable-growth-summary.ashx.

Tanrisever, F, K Derinkuyu, and G Jongen. 2015. "Organization and Functioning of Liberalized Electricity Markets: An Overview of the Dutch Market." *Renewable and Sustainable Energy Reviews* 51: 1363–

74. doi:http://dx.doi.org/10.1016/j.rser.2015.07.019.
TenneT. 2014. "Transportmogelijkheden 2014. SO-SOC 14-008." http://www.tennet.org/controls/DownloadDocument.ashx?documentID=1.
UK Government. 2008. "Climate Change Act 2008." The National Archives on behalf of HM Government. http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf.

Appendix

Table A.1 Table of descriptive statistics, 2006-2014 (per hour)

Variables	Mean	Standard deviation	Minimum	Maximum
G (in MW)	139.5	178.4	0.0	1598.1
P_{gas} (in Euro/Kwh)	20.6	5.8	2.5	50.0
P_{coal} (in Euro/Kwh)	9.8	2.6	5.4	20.0
P_{CO2} (in Euro/Kwh)	11.0	7.1	.01	30.0
L (in MW)	6993.4	1942.3	1068.31	13237.5
T_{NL} (in degrees Celsius)	10.7	6.6	-17.8	33.4
RES_{NL} (in MW)	1211.5	207.3	835844.7	1427.6
W_{GER} (in GW)	4.7	4.3	.02875	29.5

Table A.2 Correlation Matrix of Variables in Panel Regression Analysis excluding dummies, 2006–2014 (per hour)

Variables	G	P_{gas}	P_{coal}	P_{CO2}	L	T_{NL}	RES_{NL}
P_{gas}	-0.0478						
P_{coal}	-0.0122	0.4988					
P_{CO2}	0.0567	0.1166	0.3859				
L	0.1973	-0.0630	-0.0134	0.0386			
T_{NL}	-0.0554	-0.1895	0.0266	-0.0117	-0.2211		
RES_{NL}	-0.0854	0.3197	0.1084	-0.1039	-0.0347	-0.0500	
W_{GER}	-0.0138	0.0622	0.0168	-0.1144	-0.0337	-0.1330	0.1010

Table A.3 Unit root test results – Fisher type test, augmented Dickey-Fuller

Variables	P-value
P_{gas}	0.0000
P_{coal}	0.0000
P_{CO2}	0.0000
L	0.0000
T_{NL}	0.0000
RES_{NL}	0.9998
1st diff. RES_{NL}	0.0000
W_{GER}	0.0000

Note: a lag of 1 has been applied

H0: All panels contain unit roots

Ha: At least one panel is stationary

Table A.4 Multicollinearity test results, R-squared of regression estimates with explanatory variables taken as the dependent variable

Variables	Gas-fired plants	Coal-fired plants
P_{gas}	0.36	0.35
P_{coal}	0.39	0.38
P_{CO2}	0.21	0.19
L	0.70	0.71
T_{NL}	0.65	0.65
RES_{NL}	0.14	0.14
W_{GER}	0.14	0.14

Note: multicollinearity if R-squared > 0,80

Table A.5 Autocorrelation test results, Wooldridge test

Variables	P-value
G	0.00

H0: no first-order autocorrelation

Ha: first-order autocorrelation exists

Note: a lagged term of production has been included to account for first-order autocorrelation

Table A.6 Test for fixed versus random effects, Hausman test

Variables	P-value
All power plants	0.00

H0: difference in coefficients not systematic

Ha: difference in coefficients is systematic

Table A.7 Results of the panel regression analysis on the hourly production of gas and coal-fired power plants, 2006-2014

Production per hour	Gas-fired plants	Coal-fired plants
constant	-9.005***	-20.46***
	(0.119)	(0.344)
G_{t-1}	0.973***	0.988***
	(0.000145)	(0.000197)
P_{gas}	-0.0511***	0.0364***
	(0.00274)	(0.00779)
P_{coal}	0.0139**	-0.0646***
	(0.00621)	(0.0176)
P_{CO2}	0.0461***	-0.00919
	(0.00205)	(0.00577)
G_{total}	0.000679***	0.000514***
	(1.22e-05)	(3.52e-05)
T_{NL}	-0.0151***	-0.0275***
	(0.00327)	(0.00940)
1^{st} diff. RES_{NL}	0.00771	-0.0574*
	(0.0111)	(0.0320)
W_{GER}	0.00724**	0.0398***
	(0.00319)	(0.00928)
h_dum2	2.576***	3.321***
	(0.0889)	(0.256)
h_dum3	4.704***	8.384***
	(0.0892)	(0.257)
h_dum4	6.519***	13.61***
	(0.0893)	(0.257)
h_dum5	8.642***	21.64***
	(0.0892)	(0.257)
h_dum6	11.22***	31.55***
	(0.0888)	(0.256)

h_dum7	15.79***	42.29***
	(0.0886)	(0.256)
h_dum8	19.62***	44.94***
	(0.0896)	(0.259)
h_dum9	16.33***	39.40***
	(0.0913)	(0.263)
h_dum10	11.24***	31.48***
	(0.0926)	(0.267)
h_dum11	8.582***	26.11***
	(0.0934)	(0.269)
h_dum12	7.679***	23.63***
	(0.0939)	(0.271)
h_dum13	6.245***	20.59***
	(0.0939)	(0.271)
h_dum14	6.650***	20.07***
	(0.0938)	(0.270)
h_dum15	6.003***	19.37***
	(0.0934)	(0.269)
h_dum16	6.084***	18.76***
	(0.0928)	(0.268)
h_dum17	6.506***	20.62***
	(0.0924)	(0.266)
h_dum18	8.256***	25.57***
	(0.0924)	(0.267)
h_dum19	6.808***	23.39***
	(0.0922)	(0.266)
h_dum20	6.633***	22.48***
	(0.0920)	(0.265)
h_dum21	3.325***	18.90***
	(0.0912)	(0.263)
h_dum22	2.444***	17.21***
	(0.0904)	(0.261)
h_dum23	1.921***	15.67***
	(0.0897)	(0.258)
h_dum24	-1.062***	7.216***
	(0.0887)	(0.256)
d_dum2	0.644***	0.471***
	(0.0539)	(0.155)
d_dum3	-0.382***	-0.242

	(0.0560)	(0.161)
d_dum4	-0.412***	-0.580***
	(0.0561)	(0.162)
d_dum5	-0.425***	-0.720***
	(0.0560)	(0.161)
d_dum6	-0.529***	-0.705***
	(0.0544)	(0.157)
d_dum7	-0.637***	-0.538***
	(0.0486)	(0.140)
q_dum2	0.515***	0.0500
	(0.0472)	(0.137)
q_dum3	0.432***	0.359**
	(0.0546)	(0.158)
q_dum4	0.0127	-0.0780
	(0.0384)	(0.111)
R^2	0.96	0.98
Observations	2,472,274	617,827
Number of plants	32	8

Note: standard errors in parentheses

*; **; *** refer to 10%, 5% and 1% significance levels, respectively.

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