Evidence of Flexibility and its Economic Implications on the Day-ahead Electricity Market

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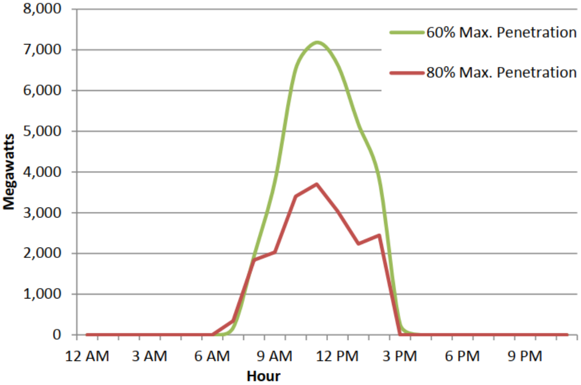
Strommarkttreffen PhD Seminar
January 29, 2021

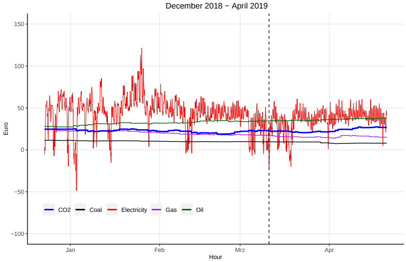
Westfälische
Wilhelms-Universität
Münster

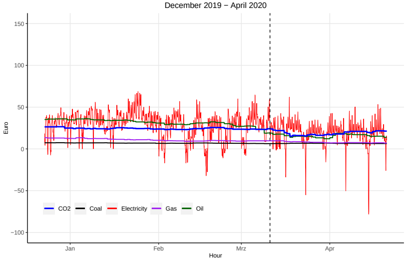
Curtailment of renewables, overgeneration



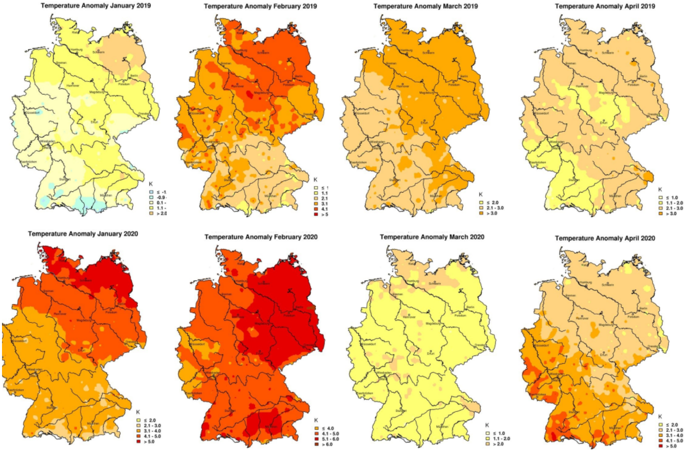
Source: NREL, 2015

Higher frequency of negative prices

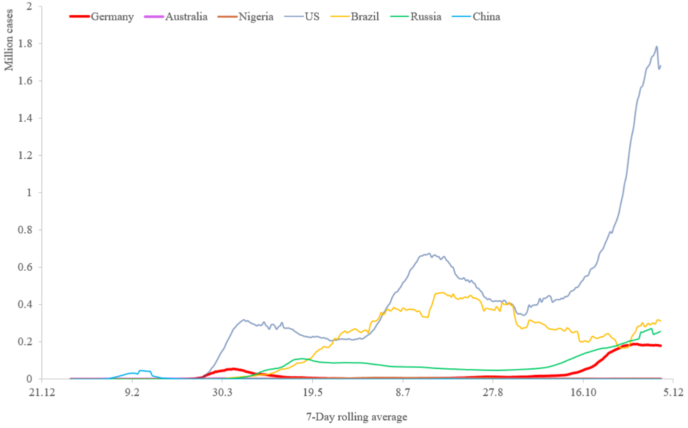




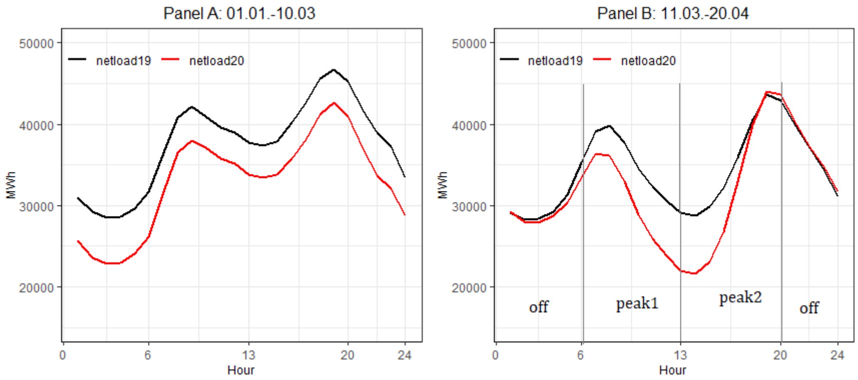
Weather anomalies + 44% renewable shares vs 36%



COVID-19 exogenous shock



Net load


Panel A: 01.01.-10.03
netload19
netload20
50000
40000
30000
20000
MWh
0
6
13
20
24
Hour
Panel B: 11.03.-20.04
netload19
netload20
50000
40000
30000
20000
MWh
off
peak1
peak2
off
0
6
13
20
24
Hour

- Curtailment: ↑ costs, ↑ GHG emissions?
- RPS + EU ETS + flexibility rules?

Do flexibility solutions alter the allocative efficiency between producers and consumers in electricity systems under RPS and ETS?

- ↓ net load both lose
- ↑ net load consumers a little better than producers in the afternoon 13-20:00
- The gap reduced, but both ended up worst off
- Post-COVID-19 pass-through fuel costs ≈ 1 / CO_2 costs rigid

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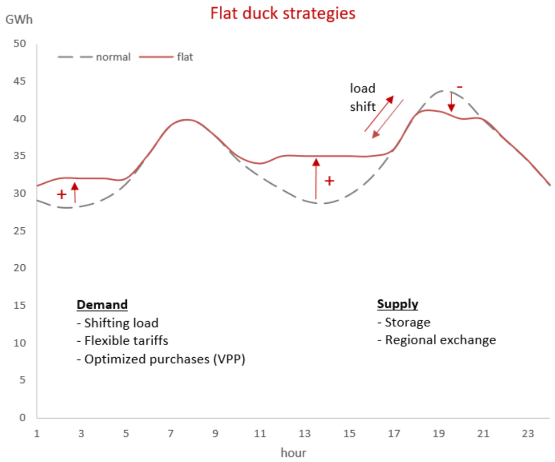
Flat duck strategies
GWh
50
45
40
35
30
25
20
15
10
5
0
normal
flat
load
shift
+
+
-
Demand
- Shifting load
- Flexible tariffs
- Optimized purchases (VPP)
Supply
- Storage
- Regional exchange
1
3
5
7
9
11
13
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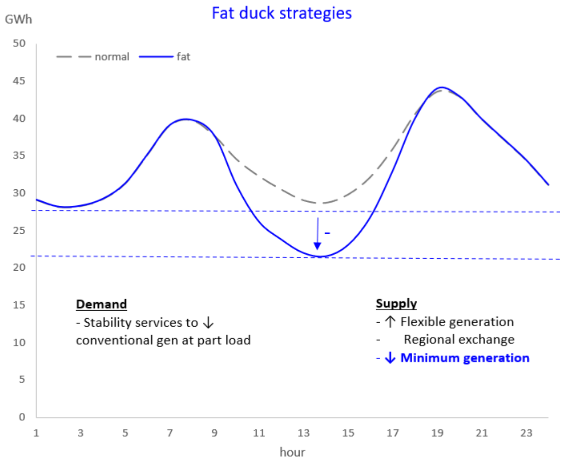
17
19
21
23
hour


Fat duck strategies
GWh
50
45
40
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normal
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Demand
- Stability services to ↓
conventional gen at part load
Supply
- ↑ Flexible generation
- Regional exchange
- ↓ Minimum generation
1
3
5
7
9
11
13
15
17
19
21
23
hour

Literature

- Stochastic-discrete choices: Doraszelski et al (2018), Conlon and Gortmaker (2019)
  → COVID-19 exogenous shock affecting intermittent endogenous price formation
  → Technology as source of product differentiation Quality differentiation
  → It does not requires bid data
  → One step supply and demand equilibrium estimation, GMM
- Pass through and welfare: Ganapati, Shapiro & Walker (2017), Cludius et al (2014), Weyl & Fabinger (2013), Hirth & Ueckerdt (2013)
  → Theory and drivers of the incidence of carbon taxes, RPS
  → Application to minimum wages, generation
- Flexibility solutions: NREL (2008, 2015), Elkasrawy & Venkatesh (2020), Wohlfarth et al (2020), Hou et al (2019)
  → Demand and supply sides

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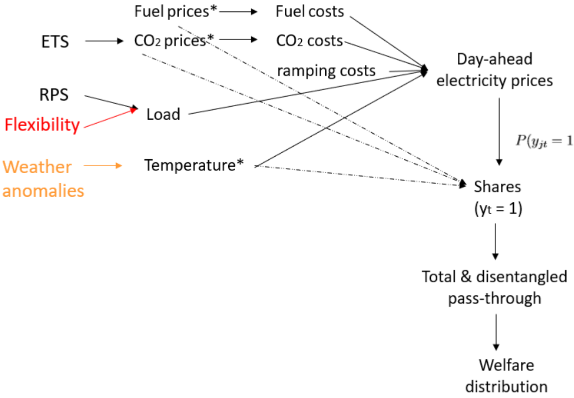


$$\max_{P_t} \prod_{it} = (p_t - c_j) M_t s_{jt}(p_t, X_{jt}, \varepsilon_{jt}; \theta)$$

$$P(y_{jt} = 1 | \alpha p_t, \beta, X_{jt}) = \int \frac{exp(\alpha p_t + \beta X_{jt})}{1 + \sum_{j=1}^{J} exp(\alpha p_t + \beta X_{jt})} f(\epsilon_{zt}|\theta) d\epsilon_{zt}$$

$$\varpi_{jt} = p_t - \eta_{jt} - \gamma V_{jt}$$

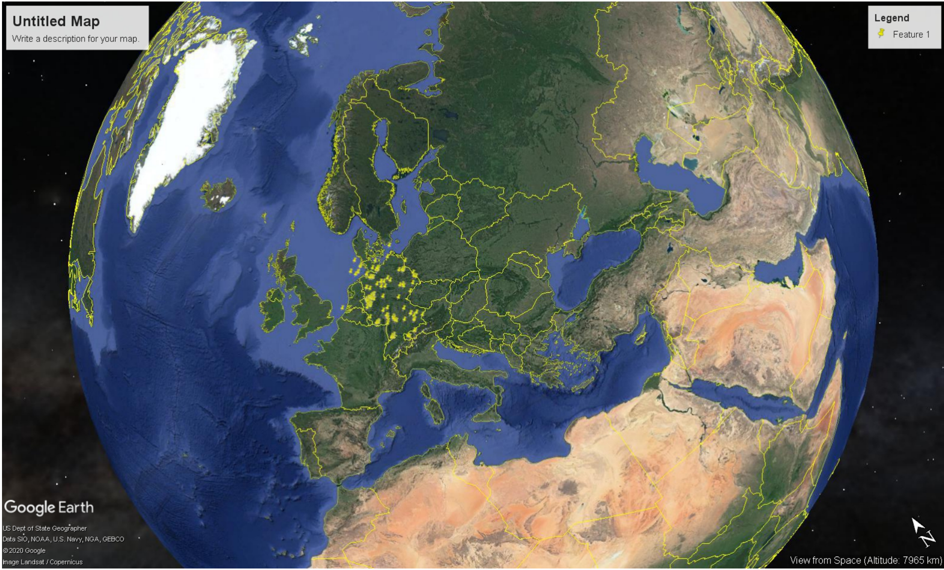
$$\varepsilon_{jt} = \delta_{jt} - \beta X_{jt} + \alpha p_t$$

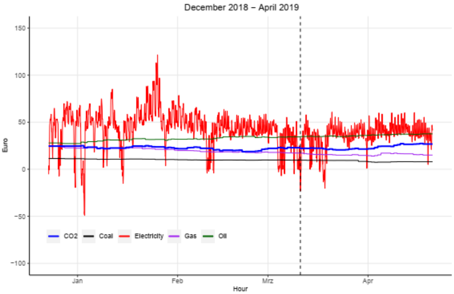
$$g(\sigma) = \begin{bmatrix} 1/N \sum_{jt} \varepsilon_{jt} Z^D_{jt} \\ 1/N \sum_{jt} \varpi_{jt} Z^S_{jt} \end{bmatrix}$$

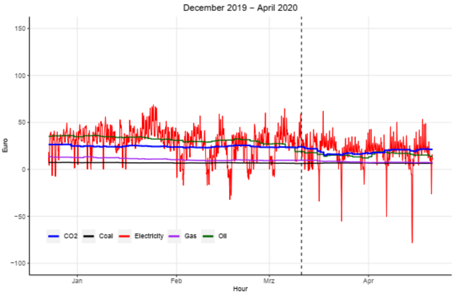
$$\min_{\sigma} q(\sigma) \equiv N^2 g(\sigma)' W g(\sigma)$$

$$PS = \sum_{j,t} p_{jt} - c_{jt} s_{jt}$$

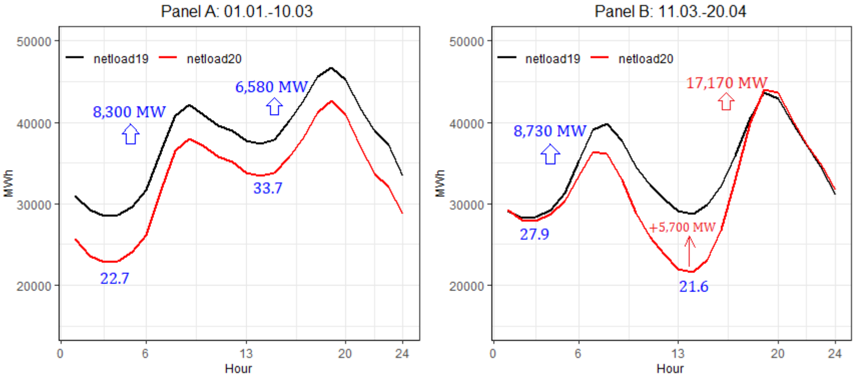
$$CS = \sum_{t,i} = w_i \frac{log(1 + \sum_j exp[-\beta X_{jt} + \alpha p_t + \varepsilon_{jti}])}{\alpha_i}$$


Untitled Map
Write a description for your map.
Legend
Feature 1
Google Earth
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
©2020 Google
Image Landsat / Copernicus
View from Space (Altitude: 7965 km)





	19a	19b
Electricity	47	34
	-48/121	-23/61
CO2	10	9
Coal	5	4
Gas	10	6
Temp	3	6
	20a	**20b**
Electricity	31	21
	-32/68	-78/62
CO2	11	8
Coal	3	3
Gas	5	3
Temp	4	8



Elasticity: Post-COVID-19, 2.4 times more elastic during the day
Max. -0.13 off peak 2019, -0.16 morning 2020 post

fuelpt co2pt disc lim

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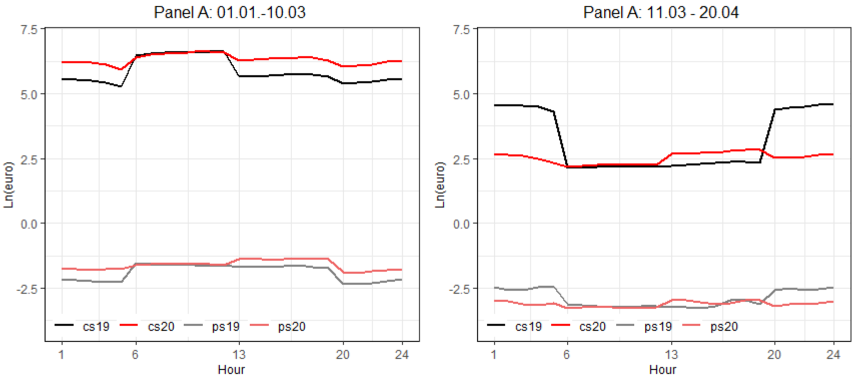
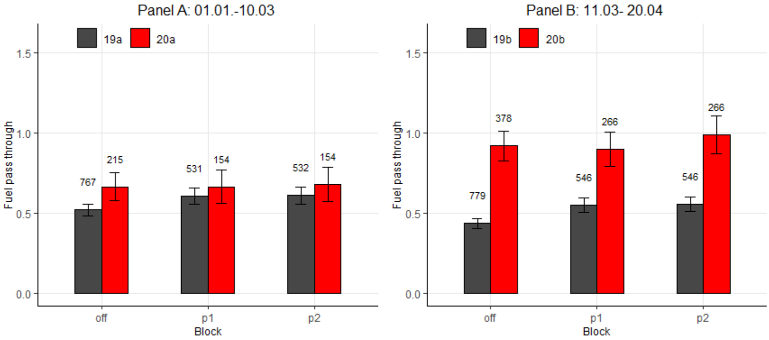
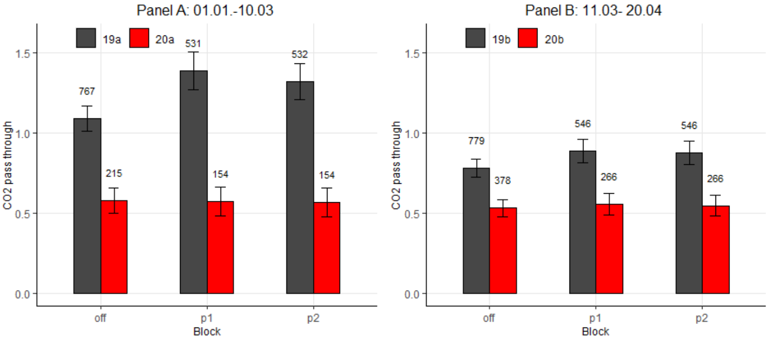


Post-COVID-19 pass-through fuel costs ≈ 1



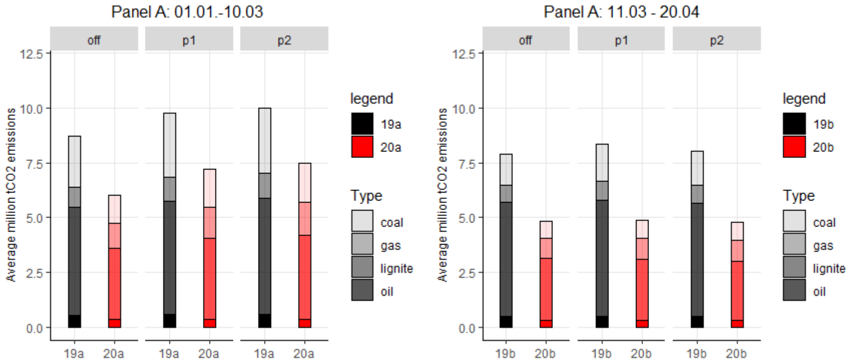
Duck

Post-COVID-19 pass-through CO_2 costs rigid



Duck

$\downarrow$ 31% GHG emissions, lignite share $\approx$ 56%



- ETS + RPS + Fat duck via reduction in minimum generation
- The lowest point of the valley, pre- and post-COVID-19 is associated with ↓ of pass-through of fuel costs, ↓ welfare for producers and consumers, ↑ price elasticity of demand.
- Post-COVID-19, a - net load is associated with the lowest value of pass-through of fuel costs and lower or equal welfare levels for producers and consumers.
- Post-COVID-19, a + net load is associated with and higher values of pass-through of fuel costs higher welfare levels, more so for consumers than producers.
- CO_2 pass-through not sensitive to this type of flexibility
- Positive effects overridden by negative effects

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- CO_2 rigidity due to expectations on the market stability reserve?
- With storage, trivial marginal unit costs if off-peak = peak?
- Persistent pattern?
- Daily routines changed ↑ residential consumption, ↓ industrial consumption dropped (Cicala, 2020)
- 22% of all full work days after COVID-19 at home, 2.4% higher productivity (Bloom, 2020)
- Consumption patterns in demand similar in Germany similar to the US

Limitations

- Min conventional generation not precisely quantifiable (variety of ancillary services, BNetzA 2019)
- Benefits from reduction of CO_2 emissions not assessed
- small vs. big consumers/producers

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Thank you!

https://gloriacolmenares.netlify.app/

- Investment / variable cost ratio → different markups per technology
- Efficiency / heat rates → heterogeneously affected by input cost shocks
- Flexibility in terms of ramping gradients → lignite when solar kicks in / drops out? (e.g. 41GW solar for roughly 20GW lignite and 30GW hard coal, gas 25GW, nuclear will leave the market)
- Must-run restrictions (minimum operating time, combined heat & power)
- Revision intervals back

Ramping assumptions

Table 4: Assumptions for ramping-costs regressions

Technology	Start-up condition $8 < h < 50$	$h < 8$	% ramp-up	hot ramping costs €$/MWh$
Coal	4.0	1.5	66.67	19.60
Gas	1.5	0.5	100.00	9.44
Gas CCGT	3.0	1.0	100.00	11.96
Lignite	5.0	2.0	50.00	15.92
Oil	3.0	1.0	100.00	9.44

Size and coverage

118 plants and capacities <100MW

55% of total demand on average, rest outside good

Table 1: Plants analyzed in this study with capacities higher than 100 MW

Technology	Plant
CHP must-run	1
Coal	37
Gas steam turbine	4
Gas OCGT	1
Gas CCGT	24
Hydro	4
Nuclear	7
Lignite	9
Oil steam turbine	2
Oil OCGT	1
Other fossil fuel	2
Other renewables	2
Pump storage	13
Wind offshore	10
Wind onshore	1
Total plants	118

In all cases we also include an artificial CHP plant operating at 1 €/MWh to reflect market conditions in Germany

Bertrand Equilibrium

$$\max_{P_t} \prod_{it} = (p_t - c_j) M_t s_{jt}(p_t, X_{jt}, \varepsilon_{jt}; \theta)$$

$$M_t s_{jt}(p_t, X_{jt}, \varepsilon_{jt}; \theta) + \frac{\partial M_t s_{kt}(p_t, X_{kt}, \varepsilon_{kt}; \theta)}{\partial p_t}(p_t - c_k) = 0$$

$$s_{jt}/(s'_{jt} p_t) = 1/\eta_{jt}$$

$$c_{jt} = p_t - \eta_{jt}$$

$$c_{jt} = \gamma V_{jt} + \varpi_{jt}$$

$$\varpi_{jt} = p_t - \eta_{jt} - \gamma V_{jt}$$

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Supply side: linear function including fuel, CO_2, and ramping costs

Table 2: Descriptive statistics for Dec 23, 2018 to March 10, 2019

	Mean	Standard deviation	Min.	Max.
Market share	0.011	0.016	0.000	0.136
Day-ahead price (€/MWh)	46.548	18.984	-48.930	121.460
Load factor	0.564	0.309	0.000	1.000
Temperature	2.671	4.980	-22.400	20.600
Fuel costs (€/MWh)	19.625	19.139	0.000	98.005
CO_2 costs (€/MWh)	9.945	9.351	0.000	30.457
Coal prices (€/MWh)	4.773	5.146	0.000	11.410
Gas prices (€/MWh)	9.490	10.300	0.000	24.870
CO_2 prices (€/MWh)	10.385	11.236	0.000	25.020
Observations	110,825			

Table 4: Descriptive statistics for Dec 23, 2019 to March 10, 2020

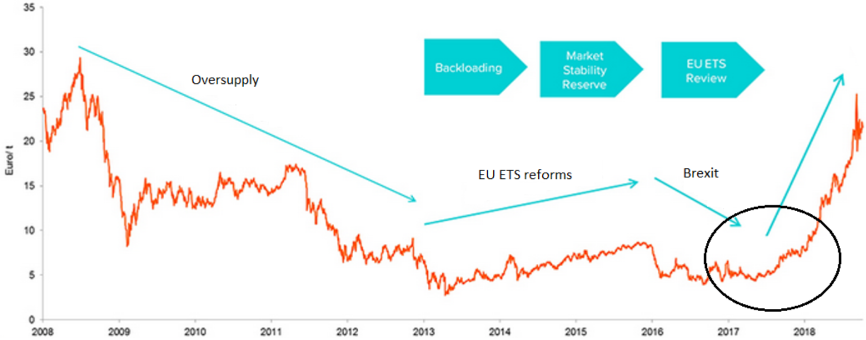
	Mean	Standard deviation	Min.	Max.
Market share	0.013	0.018	0.000	0.119
Day-ahead price (€/MWh)	31.304	13.169	-32.140	68.64
Load factor	0.501	0.311	0.000	1.000
Temperature	4.255	3.900	-18.700	20.400
Fuel costs (€/MWh)	14.947	14.563	0.000	102.051
CO_2 costs (€/MWh)	10.480	9.870	0.000	32.331
Coal prices (€/MWh)	3.246	3.461	0.000	7.390
Gas prices (€/MWh)	5.065	5.461	0.000	13.430
CO_2 prices (€/MWh)	11.397	12.150	0.000	26.560
Observations	95,443			

Table 3: Descriptive statistics for March 11 to April 20, 2019

	Mean	Standard deviation	Min.	Max.
Market share	0.014	0.022	0.000	0.165
Day-ahead price (€/MWh)	33.537	13.979	-23.040	60.730
Load factor	0.503	0.302	0.000	1.000
Temperature	6.059	4.958	-17.900	20.400
Fuel costs (€/MWh)	16.895	18.035	0.000	101.545
CO_2 costs (€/MWh)	8.864	9.031	0.000	27.523
Coal prices (€/MWh)	3.805	4.550	0.000	9.630
Gas prices (€/MWh)	6.324	7.556	0.000	17.130
CO_2 prices (€/MWh)	8.835	10.554	0.000	22.610
Observations	25,123			

Table 5: Descriptive statistics for March 11 to April 20, 2020

	Mean	Standard deviation	Min.	Max.
Market share	0.015	0.021	0.000	0.134
Day-ahead price (€/MWh)	21.486	10.719	-78.150	61.960
Load factor	0.426	0.288	0.000	1.000
Temperature	8.319	5.889	-11.100	25.200
Fuel costs (€/MWh)	11.442	9.720	0.000	53.554
CO_2 costs (€/MWh)	7.852	8.103	0.000	29.288
Coal prices (€/MWh)	2.716	3.246	0.000	7.030
Gas prices (€/MWh)	3.300	3.978	0.000	9.690
CO_2 prices (€/MWh)	8.010	9.682	0.000	24.060
Observations	47,188			



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Source: The financial and risk business, Thomson Reuters (REFINITIV)