Real-Time Pricing in the Nordic Power Markets

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MOTIVATION

- Marginal cost of producing electricity varies significantly according to the time of the day
- The true cost of consuming electricity varies hour by hour but prices do not reflect this
- Retail electricity prices should reflect their true opportunity costs
- New technology has enabled hourly metering and so the technocal constraint is disappearing

LITERATURE

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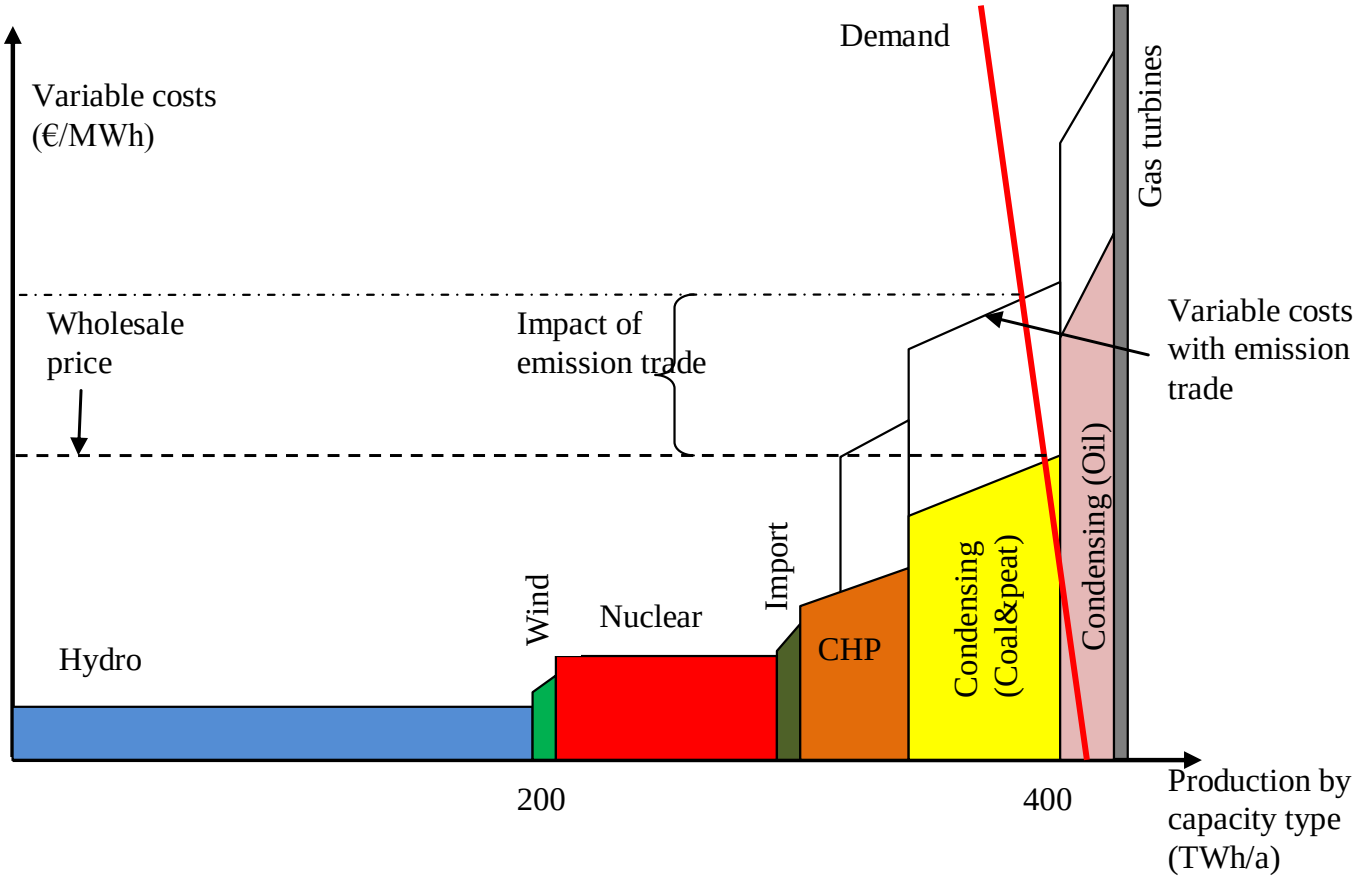
- Faruqui, A., Sergici, S. (2010)
- Saele, H., Grande, O. (2011)
- Borenstein, S., Holland S.P. (2005)
- Borenstein, S. (2005, 2007a, 2007b, 2009)
- Holland and Mansur (2008)
- Kauppi (2009)
- Kopsakangas-Savolainen and Svento (2012a, 2012b, 2013a,b,c)

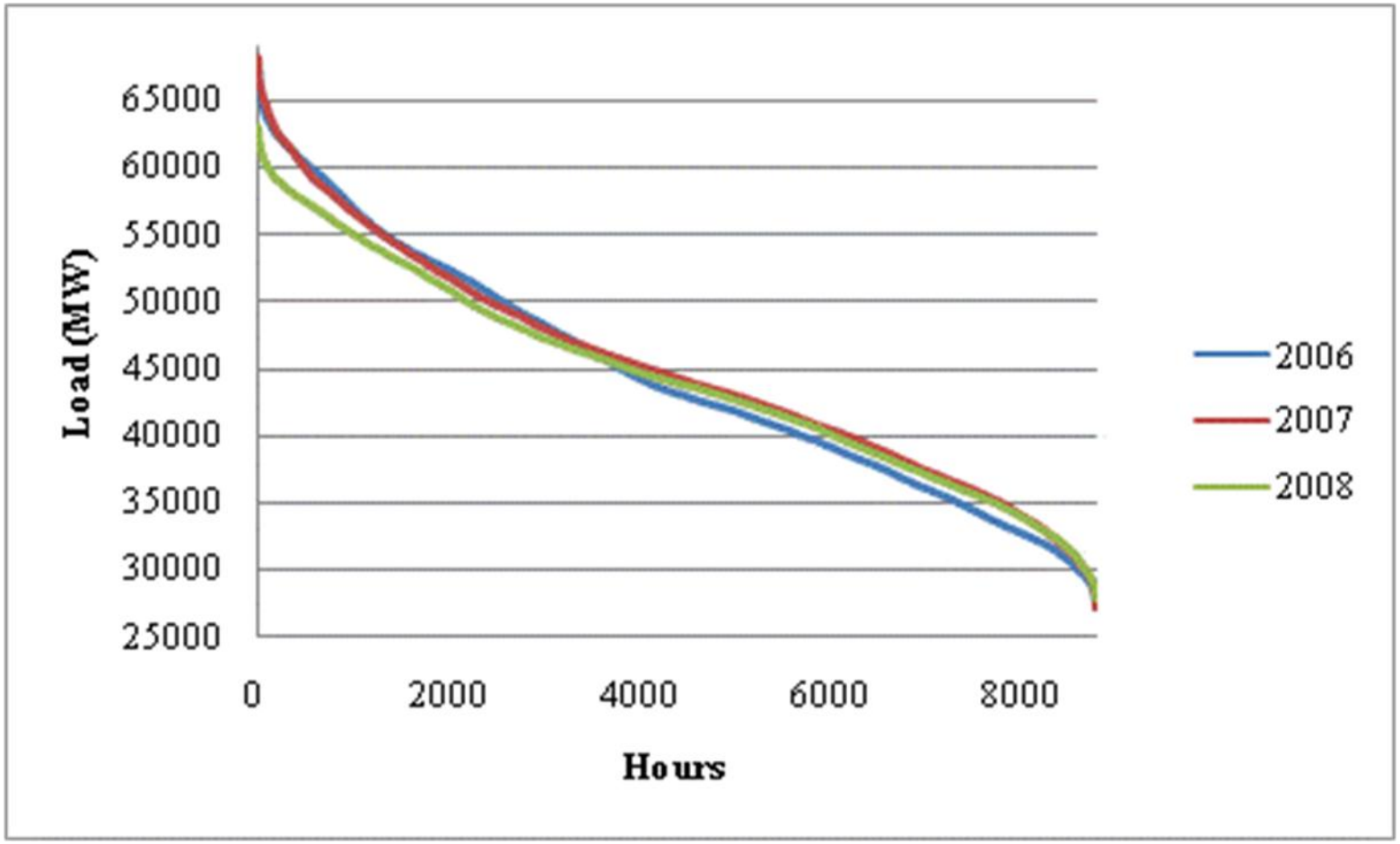
NORDIC POWER MARKETS

- Nord Pool organize the power trade among market participants (Sweden, Finland, Norway, Denmark, Estonia and Lithuania)
- Heterogeneous production structure leads to efficiency gains. Total production (2011) 378,6 TWh
  - 80,3 TWh nuclear power
  - 200,2 TWh on hydropower,
  - 55,2 conventional thermal power
  - 35,7 TWh renewables (other than hydro).
- Market participants make their quantity-price bids one day in advance to the hourly market
  - Market clearing price called system price
- Over 70% of total consumption of energy traded through Nord Pool in 2011

NORDIC POWER MARKETS



LOAD DURATION



CAPACITY AND GENERATION COSTS

Generation type	Specific investment cost (€/kW)	Economic lifetime (a)	Annual Capital Costs €/MW	Variable costs €/MWh
Wind power	1300	25	92238	11
Hydro power	2000	75	102643	4
Nuclear power (baseload)	3750	40	218543	23
Midmerit power	1370	25	99333	51
Peaker power	700	25	49667	87

SIMULATION MODEL

1. Identify load duration curve
2. Specify demand function:

$$D_h(p_r, p_f) = \left[\alpha p_r^{\varepsilon} + (1-\alpha) p_f^{\varepsilon}\right] A_h, h = 1, \ldots, 8760$$

3. Determine capacity structure technology by technology according to profit maximizing rule:

$$\pi_G = \sum_{h=1}^{8760} (w_h D_h - c D_h) - rK\,,$$

4. Determine flat rate such that retail market breaks through:

$$\pi_R = \sum_{h=1}^{8760} \left[(p_f - w_h)(1-\alpha) D_h(p_f) + (p_r - w_h)\alpha D_h(p_r)\right]$$

5. Simulate until the equilibrium for both market is reached

LOAD DURATION AND RTP SHARE

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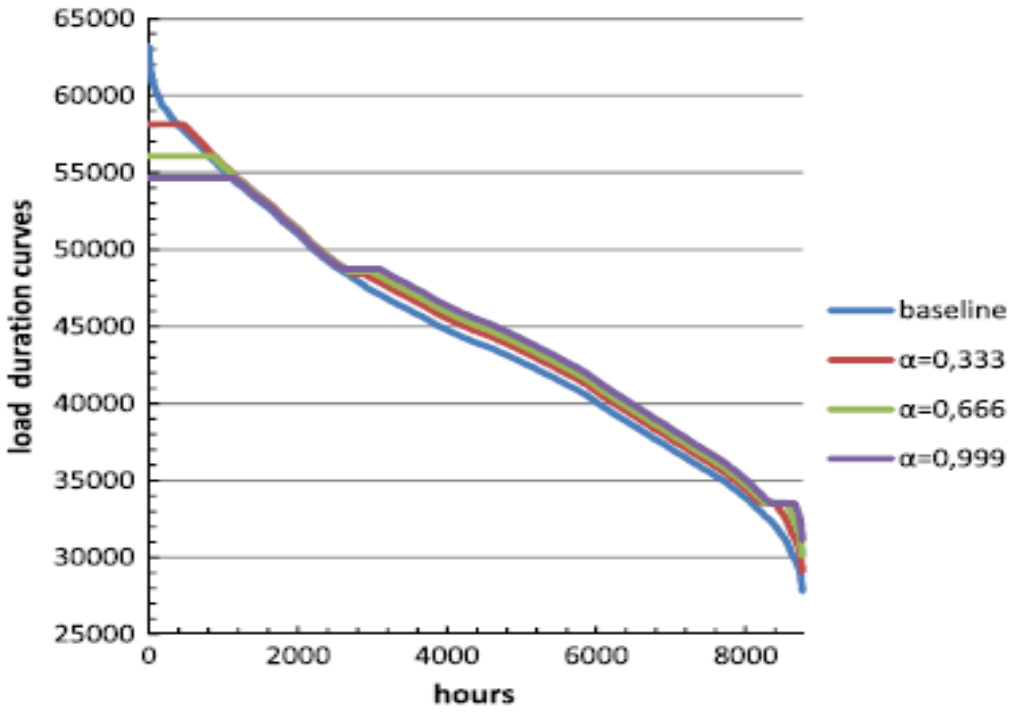

Fig. 4. Load duration with different share of the customers on the RTP, ε — —0.1, no emission trade.

LOAD DURATION AND ELASTICITY

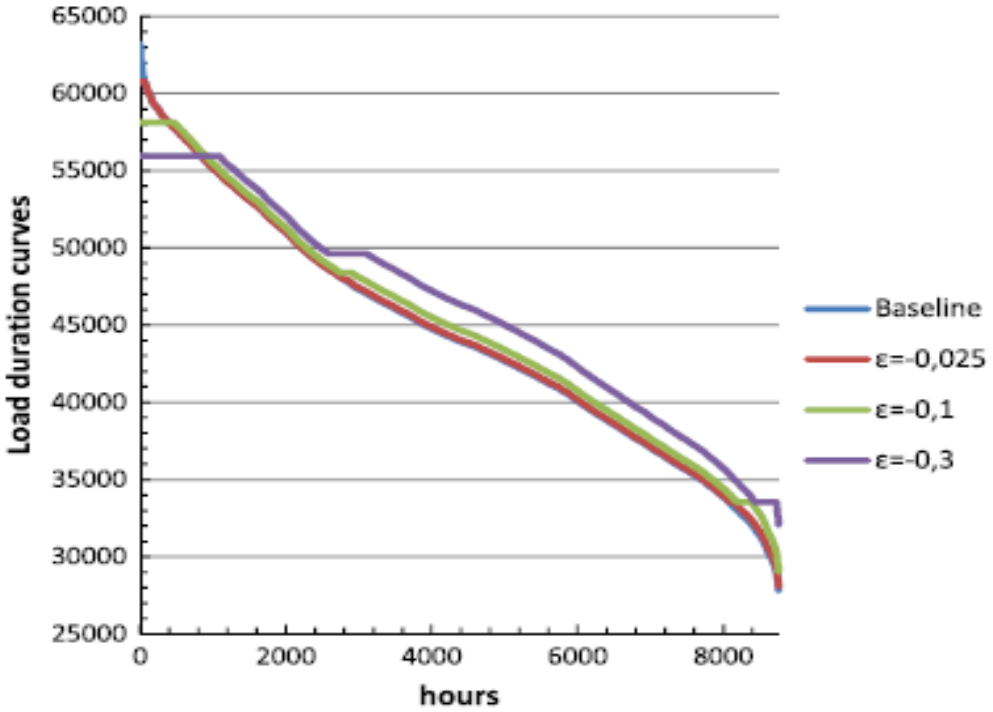

Fig. 5. Load duration with different values of elasticity, $\alpha = 0.333$, no emission trade.

EFFECTS OF RTP, NO EMISSION TRADE

Table 2
Effect of the Real Time Pricing, no emission trade.

Elasticity	Share on RTP	Total annual energy consumed, TWh	Flat rate €/MWh	Hydro power, MW	Nuclear power, MW	Midmerit power, MW (coal and peat)	Peaker power, MW	Total equilibrium capacity, MW	Peak rice €/MWh	Hours at peak quantity (at 8760)
Baseline scenario		389.38	43.67	21,899	11,636	14,351	15,318	63,204		
−0.025	0.333	390.08	43.09	21,899	11,636	14,419	12,799	60,753	6468.40	60
−0.025	0.666	390.51	43.06	21,899	11,636	14,451	11,277	59,263	2257.90	192
−0.025	0.999	390.83	43.05	21,899	11,636	14,486	10,260	58,281	1130.13	351
−0.1	0.333	393.90	43.16	21,899	11,636	14,869	9723	58,127	894.75	460
−0.1	0.666	394.79	43.20	21,899	11,636	15,033	7513	56,081	309.81	857
−0.1	0.999	395.49	43.27	21,899	11,636	15,213	5900	54,648	199.499	1148
−0.3	0.333	402.90	43.41	21,899	11,636	16,088	6329	55,952	249.69	1081
−0.3	0.666	404.97	43.43	21,899	11,636	16,679	2599	52,813	127.85	1775
−0.3	0.999	406.51	43.54	21,899	11,636	16,967	0	50,502	99.58	3780

LOAD DURATION AND RTP SHARE WITH EMISSION TRADE

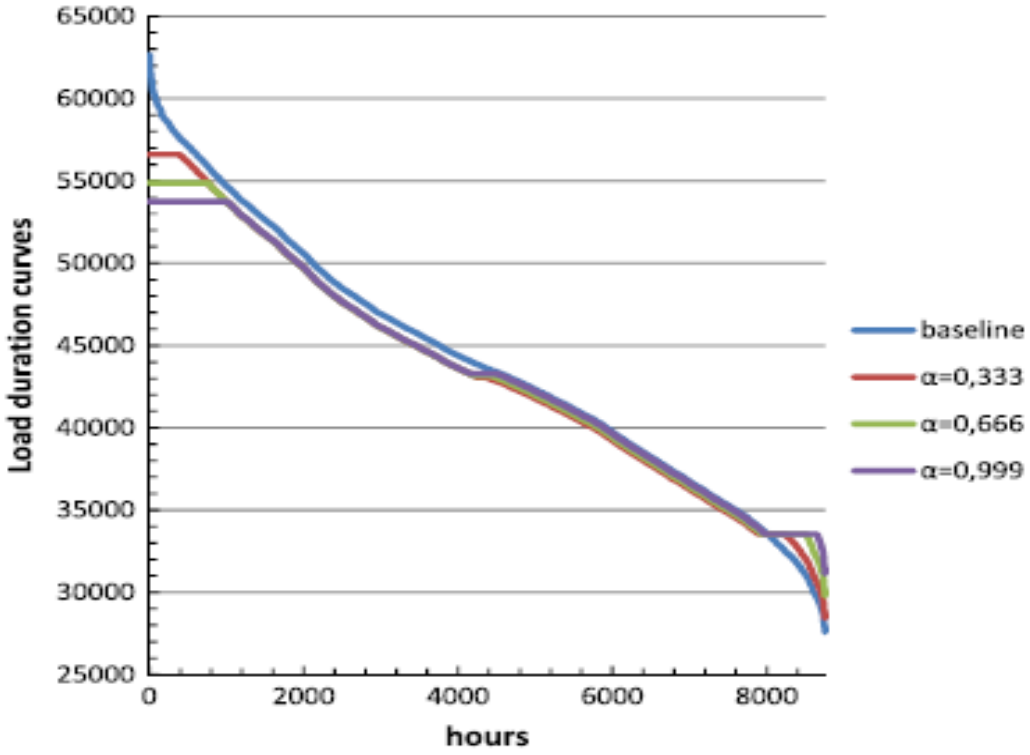

Fig. 6. Load duration curves with different share of the customers on the RTP, ε— —0.1, with emission trade.

LOAD DURATION AND ELASTICITY WITH EMISSION TRADE

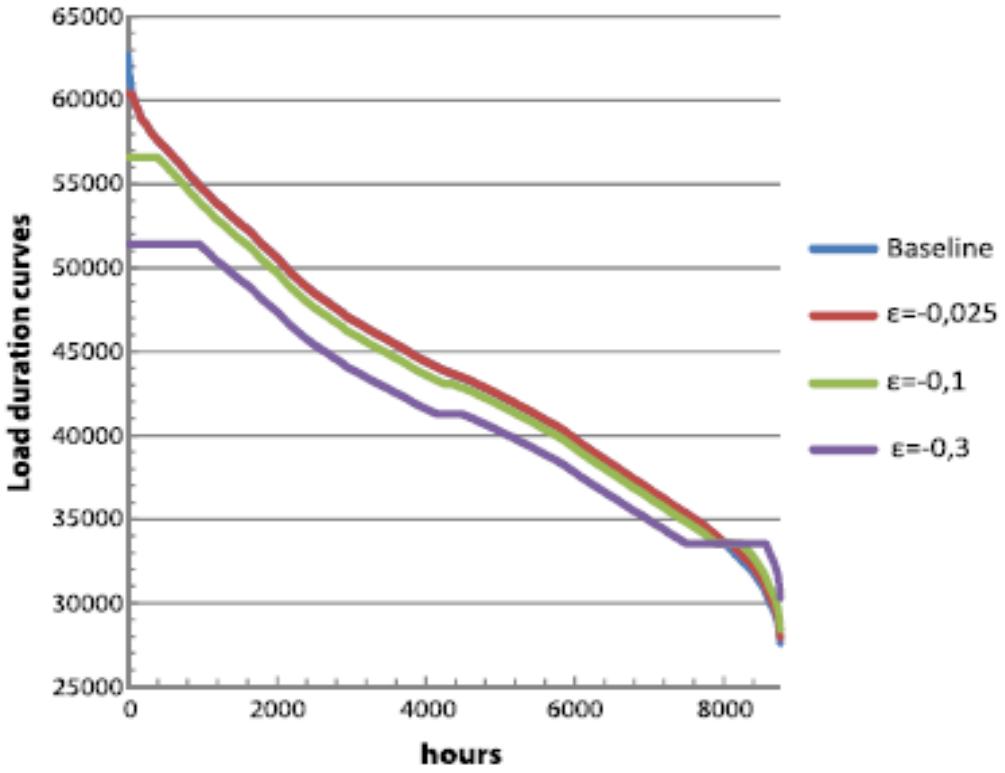

Fig. 7. Load duration with different values of elasticity, $\alpha = 0.333$, with emission trade.

EFFECTS OF RTP WITH EMISSION TRADE

Table 3
Effect of the Real Time Pricing with emission trade.

Elasticity	Share on RTP	Total annual energy consumed (TWh)	Flat rate €/MWh	Hydro power, MW	Nuclear power, MW	Midmerit power, MW (coal and peat)	Peak power, MW	Total equilibrium capacity, MW	Peak price €/MWh	Hours at peak quantity (at 8760)
Baseline scenario		386.11	61.22	21,899	11,636	10,206	18,932	62,673		
−0.025	0.333	386.60	60.88	21,899	11,636	10,246	16,604	60,385	6545.63	55
−0.025	0.666	386.90	60.92	21,899	11,636	10,289	15,210	59,034	2371.97	164
−0.025	0.999	387.11	60.97	21,899	11,636	10,316	14,306	58,157	1230.29	298
−0.1	0.333	380.44	60.63	21,899	11,636	9533	13,524	56,592	963.55	391
−0.1	0.666	380.72	61.00	21,899	11,636	9638	11,709	54,882	355.85	762
−0.1	0.999	380.81	61.31	21,899	11,636	9763	10,442	53,740	235.83	1001
−0.3	0.333	364.55	60.33	21,899	11,636	7728	10,165	51,428	282.39	952
−0.3	0.666	363.26	61.23	21,899	11,636	7992	7470	48,997	154.13	1581
−0.3	0.999	362.74	61.66	21,899	11,636	8371	5498	47,404	122.95	2008

EFFECTS OF RTP WITH EMISSION TRADE

Table 4
Effects of Real Time pricing with emission price 30€/tCO_2.

Share of RTP	Flat rate, €/MWh	Total annual energy consumed, TWh	Midmerit power, MW	Peaker power, MW	Total equilibrium capacity, MW	Peak price €/MWh	Hours at peak quantity (at 8760)
Baseline	66.53	385.31	8212	20,601	62,543		
0.333	66.07	385.80	8305	18,300	60,297	6580.39	53
0.666	66.18	386.07	8356	16,961	58,978	2403.89	159
0.999	66.29	386.27	8413	16,076	58,124	1258.46	285

EFFECTS OF EMISSION PERMIT PRICE

Table 5
Effects of emission permit price, $\alpha = 0.333$.

Emission permit price €/tCO2	Flat rate, €/MWh	Total annual energy consumed, TWh	Midmerit power, MW	Peaker power, MW	Total equilibrium capacity, MW	Peak price €/MWh	Hours at peak quantity (at 8760)
No emission trade	43.09	390.08	14,419	12,799	60,753	6468.40	60
23	60.88	386.60	10,246	16,604	60,385	6545.63	55
30	66.07	385.80	8305	18,300	60,297	6580.39	53
50	79.97	383.94	0	26,392	60,093	6657.61	48
100	109.85	380.92	0	26,037	59,753	6830.44	43

WELFARE EFFECTS OF RTP, NO EMISSION TRADE

Table 6
Welfare effects of the Real Time Pricing, no emission trade.

Elasticity	Share on RTP	Billing costs for RTP customers million €	Billing costs for flat rate customers, million €	Total billing costs, million €	Producers' profits hydro, million €	Producers' profits nuclear, million €	Total producers' profits, million €	Change in consumers' billing costs (from all in flat rate), million €	Change in producers' profits (from all in flat rate), million €
Baseline scenario			16988.89	16988.89	3673.20	1160.15	4833.35		
−0.025	0.333	5531.11	11190.67	16721.79	3689.47	1168.79	4858.26	−267.10	24.91
−0.025	0.666	11100.27	5591.19	16691.46	3703.50	1176.25	4879.74	−297.42	46.39
−0.025	0.999	16660.83	16.77	16677.60	3717.72	1183.80	4901.52	−311.28	68.16
−0.1	0.333	5549.88	11284.99	16834.87	3754.06	1203.12	4957.18	−154.02	123.82
−0.1	0.666	11180.92	5648.27	16829.20	3801.64	1228.40	5030.04	−159.69	196.69
−0.1	0.999	16808.97	16.97	16825.93	3836.56	1246.95	5083.51	−162.95	250.16
−0.3	0.333	5661.80	11545.09	17206.89	3869.05	1264.21	5133.26	218.01	299.91
−0.3	0.666	11391.67	5774.64	17166.31	3916.57	1289.46	5206.03	177.43	372.68
−0.3	0.999	17138.99	17.36	17156.35	3960.34	1312.72	5273.05	167.46	439.70

WELFARE EFFECTS OF RTP WITH EMISSION TRADE

Table 7
Welfare effects of the Real Time Pricing with emission trade.

Elasticity	Share on RTP	Billing costs for RTP customers million €	Billing costs for flat rate customers, million €	Total billing costs, million €	Producers' profits hydro, million €	Producers' profits nuclear, million €	Total producers' profits, million €	Change in consumers' billing costs (from all in flat rate), million €	Change in producers' profits (from all in flat rate), million €
Baseline scenario			23637.98	23637.98	7018.97	2937.92	9956.88		
−0.025	0.333	7776.76	15671.93	23448.69	7055.41	2957.28	10012.70	−189.29	55.81
−0.025	0.666	15606.88	7840.93	23447.81	7085.83	2973.45	10059.28	−190.18	102.40
−0.025	0.999	23439.00	23.54	23462.54	7117.06	2990.04	10107.09	−175.44	150.21
−0.1	0.333	7578.15	15325.48	22903.63	7039.56	2948.86	9988.42	−734.36	31.54
−0.1	0.666	15308.05	7703.76	23011.81	7164.10	3015.03	10179.13	−626.18	222.25
−0.1	0.999	23082.01	23.22	23105.23	7262.87	3067.51	10330.38	−532.76	373.50
−0.3	0.333	7168.48	14537.34	21705.82	7009.53	2932.90	9942.44	−1932.16	−14.45
−0.3	0.666	14572.84	7344.06	21916.90	7276.42	3074.71	10351.13	−1721.08	394.25
−0.3	0.999	21993.57	22.14	22015.71	7413.85	3147.74	10561.59	−1622.27	604.70

WIND POWER MARKET ENTRANCE

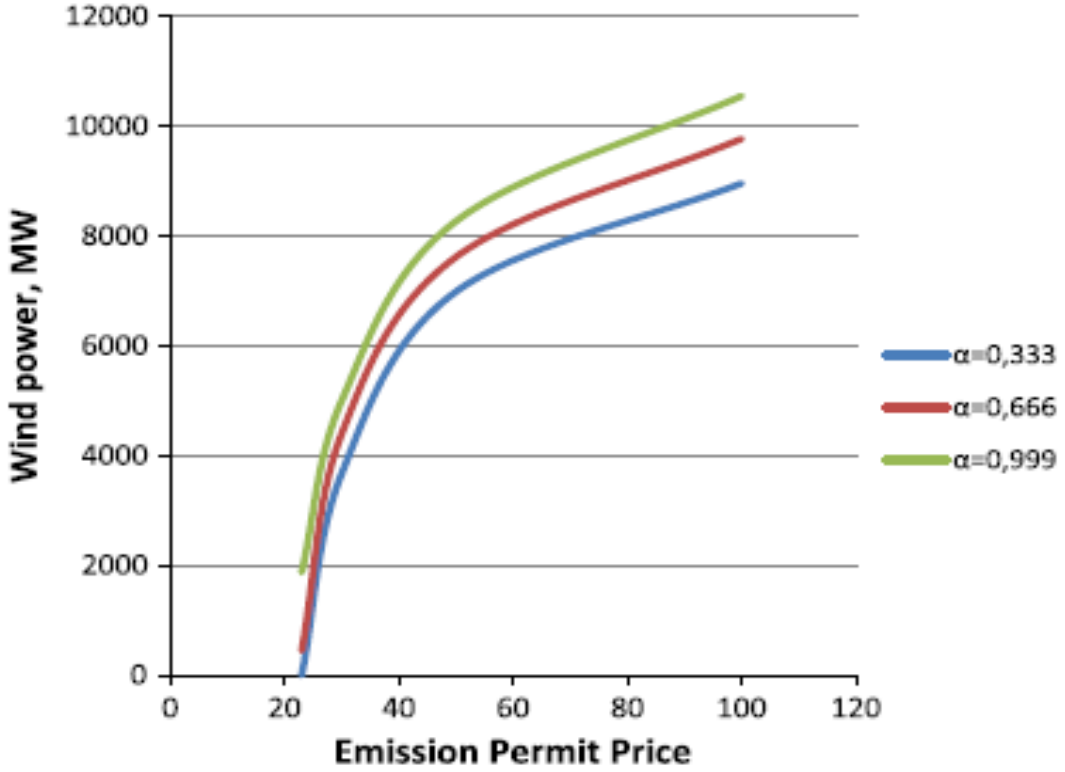

Fig. 8. Wind power with different emission permit prices and shares of customers on RTP.

EPP, RTP AND WIND POWER

Table 8
Emission permit price, Real Time Pricing and wind power.

Emission permit price €/tCO2	Share on RTP	Flat rate, €/MWh	Total annual energy consumed, TWh	Wind power, MW	Midmerit power, MW	Peaker power, MW	Total equilibrium capacity, MW	Peak price €/MWh	Hours at peak quantity (at 8760)
23	0.333	60.76	386.62	0	10,093	16,605	60,387	6545.78	55
23	0.666	60.79	386.93	442	10,121	15,211	59,035	2371.98	164
23	0.999	60.73	387.18	1874	9976	14,306	58,157	1230.29	298
30	0.333	65.36	385.94	3669	7607	18,291	60,308	6584.81	53
30	0.666	65.28	386.30	4397	7416	16,964	58,985	2404.23	159
30	0.999	65.22	386.59	5002	7262	16,076	58,124	1258.48	285
50	0.333	76.40	384.54	6983	0	24,383	60,140	6664.23	48
50	0.666	76.31	384.99	7618	0	23,254	58,868	2496.08	150
50	0.999	76.50	385.36	8271	0	21,955	58,037	1336.04	263
100	0.333	101.72	381.95	8956	0	23,236	59,831	6847.82	42
100	0.666	101.65	382.57	9773	0	21,862	58,640	2713.95	128
100	0.999	101.58	383.11	10,553	0	20,906	57,858	1511.50	208

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