

Toward a Fully Renewable European Electric Energy System

2050 - The electricity market design of the future

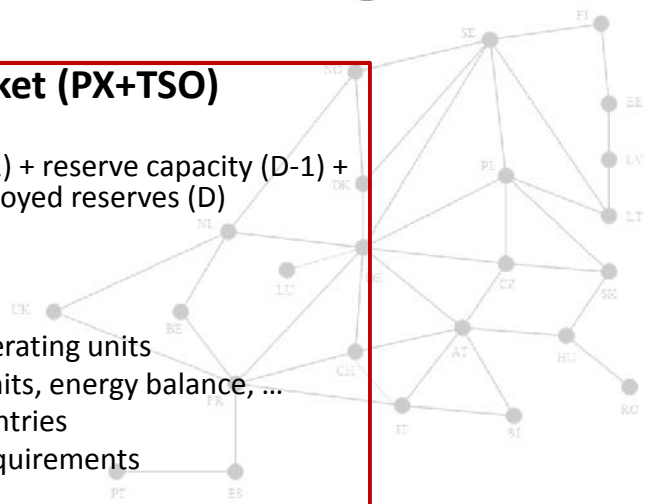
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Market Design

Energy and reserve market (PX+TSO)

- **Minimize** cost of: dispatched energy (D-1) + reserve capacity (D-1) + expected deployed reserves (D)
- Power balance (D-1)
- Power balance on deviations (D)
- Capacity and ramping constraints of generating units
- Storage constraints: charge/discharge limits, energy balance, ...
- Limits on the power flow among the countries
- Minimum upward/downward reserve requirements
- Scheduled and deployed reserve limits





Annual operating cost

Case	Annual operating cost (M€)
Proposed capacity in 2050	420.8
Proposed capacity in 2050 (without storages)	587.7
Installed capacity in 2016	1863.3

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Day-ahead market prices

€/MWh	Minimum	Mean	Maximum
AT	6.0	24.2	33.6
BE	28.2	32.1	32.3
CH	4.3	24.0	42.6
CZ	10.0	24.9	32.4
DE	6.1	23.3	32.3
DK	6.0	20.5	32.3
EE	24.2	29.4	32.3
ES	2.7	15.0	32.4
FI	25.3	42.3	97.2
FR	2.7	14.4	32.4
HU	9.4	27.9	33.4
IT	2.7	17.5	32.3
LT	21.5	28.0	35.0
LU	6.1	23.3	32.3
LV	23.0	28.6	33.8
NL	17.9	28.2	32.5
NR	30.6	30.9	32.4
PL	10.0	22.8	32.3
PT	2.7	14.8	32.4
RO	8.9	27.0	33.3
SE	26.3	30.5	32.5
SI	4.6	21.3	32.5
SK	10.2	26.3	33.1
UK	8.0	17.2	32.9

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Expected cost recovery per country and technology

(M€)	Nucl	Coal	CCGT	HRes	HRoR	Wons	Woff	SoPV	SoTH	Biom
AT	0.0	3.3	3.5	25.4	586.7	131.6	0.0	174.3	0.0	171.5
BE	0.0	0.0	22.5	0.0	2.3	244.6	41.3	177.5	0.0	253.8
CH	286.3	0.0	0.0	57.7	13.5	104.5	0.0	145.2	0.0	39.8
CZ	415.0	259.8	0.8	7.4	32.3	12.2	0.0	111.5	0.0	130.0
DE	0.0	1670.1	-15.3	2.5	548.0	1398.7	200.1	2296.4	0.0	1195.0
DK	0.0	2.0	-1.1	0.0	0.0	190.0	41.2	14.9	0.0	388.2
EE	0.0	46.0	-0.1	0.0	1.6	60.2	0.0	0.3	0.0	82.6
ES	0.0	3.5	-7.1	19.8	65.0	496.0	0.0	889.7	576.5	225.7
FI	121.3	47.4	170.0	0.0	569.4	278.5	32.7	8.5	0.0	888.4
FR	0.0	83.4	-16.7	13.8	458.1	2105.5	-1.5	1895.8	0.0	331.1
HU	296.1	0.4	0.3	1.6	11.3	23.7	0.0	-0.4	0.0	90.7
IT	0.0	89.6	-17.4	23.3	1080.4	422.8	0.0	1240.5	135.0	772.1
LT	174.2	0.0	0.1	0.5	10.6	62.9	0.0	2.4	0.0	35.7
LU	0.0	0.0	1.4	0.0	0.3	7.9	0.0	3.9	0.0	6.8
LV	0.0	2.0	-0.1	0.0	48.6	33.7	0.0	0.5	0.0	29.5
NL	0.0	354.5	9.2	0.0	-0.1	520.3	43.2	185.8	0.0	606.4
NR	0.0	0.0	-0.5	39.1	-2.6	47.2	27.8	0.0	0.0	0.0
PL	1045.2	654.1	-0.1	1.8	62.9	448.6	0.0	-0.2	0.0	535.9
PT	0.0	0.0	-0.3	4.3	189.1	103.7	0.0	60.3	91.9	60.0
RO	228.9	89.0	-1.4	16.9	215.4	161.3	0.0	166.9	0.0	68.1
SE	354.1	0.8	0.8	46.7	0.0	1001.2	0.0	27.8	0.0	794.1
SI	48.8	15.5	-0.1	0.0	96.4	-0.3	0.0	18.9	0.0	27.5
SK	31.9	43.8	-0.1	4.8	105.9	3.8	0.0	44.7	0.0	101.2
UK	277.2	9.1	16.7	0.6	-3.2	397.7	-39.8	104.3	0.0	1122.1
EU	3279.0	3374.1	165.0	266.0	4091.8	8256.2	345.1	7569.5	803.5	7956.1

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Revenue adequacy per country

	(M€)
AT	-12.3
BE	970.3
CH	822.4
CZ	234.2
DE	2167.0
DK	-200.4
EE	-40.1
ES	1409.7
FI	1019.5
FR	535.6
HU	554.2
IT	1266.3
LT	-29.1
LU	90.2
LV	96.1
NL	848.2
NR	870.9
PL	157.3
PT	137.4
RO	-64.5
SE	-3.7
SI	64.0
SK	374.1
UK	796.2
EU	12063.5

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Day-ahead generation in the EU

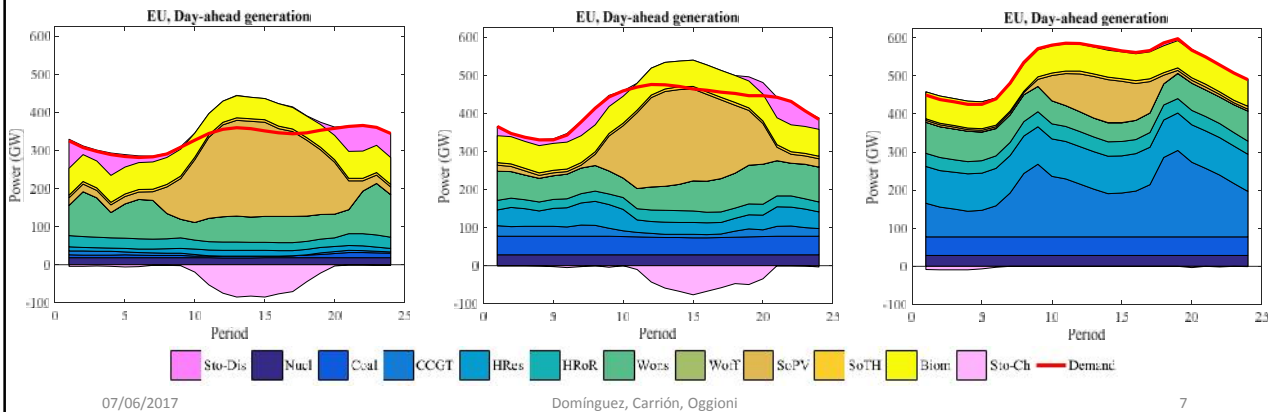


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August 7th 2050

September 2nd 2050

January 20th 2050



Reserve capacity scheduling in the EU

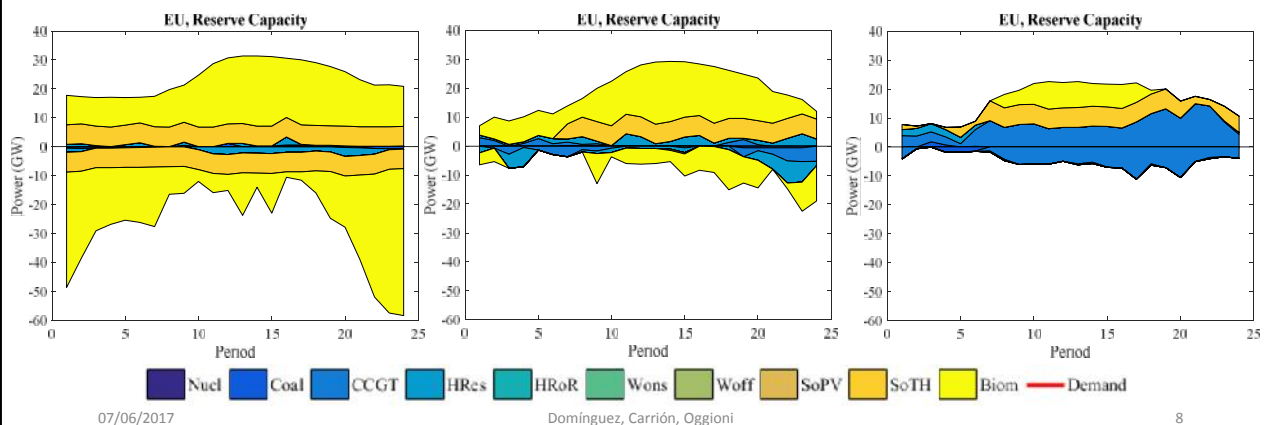


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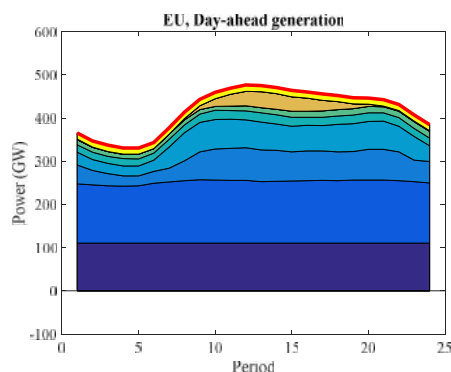
January 20th 2050



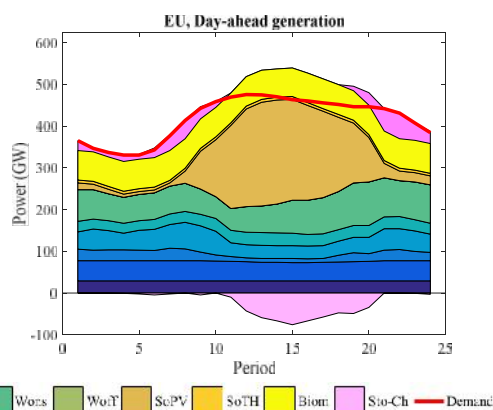
Day-ahead generation in the EU



September 2nd 2050
(Installed capacity in 2016)



September 2nd 2050
(Installed capacity in 2050)



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Conclusions



- Jointly scheduling energy and reserve capacity in all European countries allows a more **efficient integration** of the renewable power production, which is a key point in the renewable-dominated European power system expected for 2050.
- **Electricity prices** in the day-ahead and balancing markets in 2050 will be comparatively lower to the current ones.
- Generating units attain **cost recovery** in expectation in every country, except for the CCGT units that may need uplifts to compensate their expenses. The electricity system in most of the countries is **revenue adequate**.
- The availability of **energy storage** capacity allows to decrease the operating costs.

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Thanks for your attention!



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