New Generation - Annex

Building a clean European electricity system by 2035

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About

This document constitutes the annex to the main report entitled "New Generation: Building a clean European electricity system by 2035". It contains data tables which provide additional data and information to complement the content of the main report.

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Table 1.1: Overview of main outcomes of sensitivity scenarios, compared to the Technology Driven pathway

SENSITIVITY SCENARIO Storyline and main outcomes	**2035** Clean Power / Wind and Solar (%)	**2020-2050** Difference in primary gas for power / power system costs (%)
RESISTANCE TO RES Social acceptance issues limit the deployment of onshore wind and utility-scale solar. These limitations push a more geographically dispersed deployment of utility solar across Europe, including in regions with lower resource potentials. The difference in offshore wind deployment in 2035 is minimal due to high technology costs. Additional gas CCS (+106%) compensates for the lower renewable output, increasing gas demand for the power sector by 60% in 2035.	94% 61%	+13% (+5106 TWh) +0.8% (+55bn)
DELAYED INTERCONNECTIONS A combination of lack of preparedness, excessive bureaucracy, or social resistance delay and limit interconnection projects. While this has a negligible impact on wind and solar capacity in 2035, additional gas capacities, both abated and unabated, are deployed to compensate for a less flexible system. Consequently, gas demand for power is 13% higher in 2035.	94% 66%	+6% (+2587 TWh) +0.3% (+24bn)
NO GAS+CCS Given uncertainties around CCS, it may be the case that this technology does not reach commercial maturity before 2050. In the absence of gas CCS, additional wind and solar is required along with an increase in associated flexibilities, such as interconnections and electrolysers. The deficit in firm capacity is compensated by investment in unabated baseload gas. However, given its limited utilisation in a climate compatible pathway, natural gas consumption for power is 13% lower in 2035.	92% 70%	-12% (-4794 TWh) +0.4% (+26bn)

SENSITIVITY SCENARIO Storyline and main outcomes	2035 Clean Power / Wind and Solar (%)	2020-2050 Difference in primary gas for power / power system costs (%)
NUCLEAR PLUS Nuclear plant lifetimes are widely extended to 60 years (unless already stated to close by a specific date), and all planned new nuclear goes ahead (both conventional and Small Modular Reactor units). This alleviates the need for additional baseload generation, primarily reducing the deployment of gas CCS by almost 60% in 2035 and gas consumption for power by 15%. Higher nuclear capacity does not minimise the required wind and solar deployment for clean power by 2035.	94% 65%	-9% (-3832 TWh) -0.2% (-12bn)
LOWER DEMAND FLEXIBILITY Governments and regulators fail to incentivise and enable the uptake of consumer technologies and behaviours required to deliver the assumed demand-side flexibility. Lower demand-side flexibility is compensated by increasing that on the supply-side to manage supply-demand imbalances. This drives investment in thermal assets, primarily unabated gas peaking capacity which increases by 50% by 2035.	94% 67%	+3% (+1285 TWh) +1.2% (+85bn)
ALTERNATIVE HYDROGEN SUPPLY The power system is only required to supply half as much hydrogen, with the shortfall supplied by alternative sources (dedicated off-grid electrolysis or imports from outside of Europe). Overall system power demand is reduced, easing the solar and wind deployment challenge in the medium-term (but not that for grid expansion). However, such a supply strategy may have implications for Europe's energy sovereignty.	93% 65%	-1% (-444 TWh) +0.3% (+18bn)
HIGH FOSSIL FUEL PRICES Fossil fuel prices are higher than those in Technology Driven between 2025 to 2050. Less favourable market conditions for gas generation in 2025 spurs a switch to coal (mostly lignite), and additional deployment of solar. The gas-to-coal switch uses more carbon budget at an earlier stage, bringing forward investment in clean firm generation in the form of gas CCS in 2030, by which point the gas price has mostly returned to the originally assumed level.	95% 68%	-4% (-1492 TWh) +2% (+145bn)

SENSITIVITY SCENARIO Storyline and main outcomes	2035 Clean Power / Wind and Solar (%)	2020-2050 Difference in primary gas for power / power system costs (%)
LIMITED NEW GAS No new unabated gas capacity (either baseload or peaking) is deployed after 2025. The shortfall in dispatchable capacity is primarily compensated by earlier investment in clean dispatchable technologies (hydrogen turbines and gas CCS) and utility-scale batteries. In 2035, the difference in gas for power is minimal as additional gas CCS plants compensate for the required thermal generation.	96% 67%	-1% (-408 TWh) -0.1% (-10bn)
TECHNOLOGY DRIVEN - B Additional utility-scale battery capacity is added to the system throughout the pathways - linked to installed solar capacity - to address the bias against battery projects resulting from the wholesale market-only modelling approach. This reduces the size of the gas fleet (abated and unabated) in 2035; however, it is not a direct trade-off between battery storage and thermal capacities given their different functionalities. The additional battery storage also slightly tips the balance of renewable deployment in the favour of solar. In view of this evidence, it is likely the main pathways represent a mild overestimate of thermal capacity requirements.	94% 69%	-3% (-1318 TWh) +0.7% (+48bn)

Table 1.2: 2035 capacities of key technologies in the sensitivity scenarios, compared to the Technology Driven pathway

	Technology Driven	Resistance to RES	Delayed Interconnections	No Gas+CCS	Nuclear Plus	Lower Demand Flexibility	Alternative Hydrogen Supply	Higher Fossil Fuel Prices	Limited New Gas	Technology Driven - B
Wind (GW)	784	633 (-19%)	769 (-2%)	794 (+1%)	748 (-5%)	783 (0%)	741 (-6%)	785 (0%)	783 (0%)	778 (-1%)
Solar (GW)	802	914 (+14%)	803 (0%)	845 (+5%)	768 (-4%)	790 (-2%)	660 (-18%)	805 (0%)	776 (-3%)	855 (+7%)
Fossil capacities (GW)	266	275 (+4%)	277 (+4%)	293 (+10%)	268 (+1%)	311 (+17%)	266 (0%)	260 (-2%)	186 (-30%)	249 (-7%)
Clean dispatchable (GW)	400	437 (+9%)	415 (+4%)	366 (-9%)	413 (+3%)	407 (+2%)	406 (+1%)	406 (+2%)	465 (+16%)	393 (-2%)
Electrolyser (GW)	192	183 (-4%)	189 (-1%)	196 (+3%)	185 (-3%)	192 (0%)	94 (-51%)	191 (0%)	191 (0%)	192 (0%)
Battery Storage (GWh)	246	246 (0%)	248 (+1%)	256 (+4%)	247 (0%)	148 (-40%)	247 (0%)	246 (0%)	289 (+17%)	445 (+81%)
Interconnection (2020=1)	1.96	1.72 (-12%)	1.56 (-21%)	2.04 (+4%)	1.91 (-3%)	1.98 (+1%)	1.97 (0%)	1.97 (0%)	2.02 (+3%)	1.93 (-2%)

Annex 2: 2035 Country-level data

Table 2.1: Country-level data for the Technology Driven pathway in 2035

	Power generation (%)		Installed capacity (GW)					(GWh)	Imp/ Exp capacity (GW)
	Clean Power	Wind & Solar	Wind	Solar	Fossil capacities	Clean dispatchable	Electrolyser	Battery storage	Interconnection
AL	92%	45%	0.9	1.6	0.3	1.5	0.3	0.0	7.4
AT	91%	55%	11.1	27.5	4.2	20.8	2.4	7.0	13.7
BA	99%	87%	10.2	0.9	0.3	2.3	0.9	0.8	6.1
BE	76%	73%	11.2	12.4	9.3	1.9	2.8	4.9	12.5
BG	97%	60%	5.6	12.7	1.8	7.6	1.4	1.6	7.6
CH	100%	13%	0.4	7.0	0.0	19.3	1.0	4.2	17.0
CY	73%	57%	0.4	1.8	1.2	0.2	0.2	0.2	0.1
CZ	90%	25%	7.2	5.1	8.3	10.9	1.5	3.0	5.6
DE	90%	79%	150.8	203.9	67.5	30.2	23.7	41.6	42.5
DK	100%	96%	30.9	4.0	0.0	3.3	9.9	4.0	17.1
EE	96%	92%	3.1	0.5	1.2	0.9	0.3	0.4	2.5
ES	99%	91%	100.4	131.7	12.3	29.4	52.3	16.7	14.1
FI	99%	35%	15.5	1.2	2.2	11.7	2.3	2.5	5.6
FR	99%	58%	114.2	78.5	12.4	70.3	21.2	33.7	46.7
GR	96%	89%	20.2	19.9	3.1	4.8	4.6	2.5	9.2
HR	94%	66%	5.1	4.9	1.1	3.3	0.5	1.2	9.2
HU	85%	50%	5.0	12.7	5.6	3.6	1.4	2.2	12.1
IE	98%	96%	22.1	0.9	2.5	1.0	6.8	4.1	3.7
IT	92%	61%	34.1	131.4	25.7	45.3	14.4	27.3	12.9
LT	96%	83%	2.8	0.9	1.6	1.8	0.4	1.0	2.2
LU	98%	33%	0.6	1.0	0.3	2.2	0.3	2.1	3.0
LV	92%	78%	3.6	0.7	1.5	1.8	0.5	0.5	2.0
ME	100%	85%	2.5	0.4	0.2	1.3	0.1	0.2	6.8
MK	93%	46%	0.3	1.1	0.1	0.8	0.2	0.5	6.4
MT	59%	43%	0.0	0.6	0.5	0.1	0.0	0.0	0.2
NL	87%	84%	34.6	25.0	17.8	2.4	6.1	8.6	11.9

	Power generation (%)		Installed capacity (GW)					(GWh)	Imp/ Exp capacity (GW)
	Clean Power	Wind & Solar	Wind	Solar	Fossil capacities	Clean dispatchable	Electrolyser	Battery storage	Interconnection
NO	100%	32%	21.9	0.9	0.3	32.0	4.8	3.5	14.7
PL	87%	59%	28.0	28.4	30.5	13.0	5.5	8.1	16.0
PT	99%	81%	12.6	28.1	1.2	12.3	9.2	4.9	3.5
RO	85%	45%	7.3	16.0	5.4	8.6	2.7	3.5	5.6
RS	95%	37%	3.2	1.1	0.4	4.2	0.8	1.7	16.3
SE	100%	42%	23.5	5.7	0.1	25.1	2.6	6.8	17.3
SI	97%	29%	0.3	3.5	0.4	2.9	0.5	1.2	7.9
SK	93%	38%	2.8	8.3	1.4	6.6	0.8	1.2	7.5
UK	89%	75%	92.0	22.0	45.3	17.3	9.4	44.9	24.2

Table 2.2: Country-level data for the System Change pathway in 2035

	Power generation (%)		Installed capacity (GW)					(GWh)	Imp/ Exp capacity (GW)
	Clean Power	Wind & Solar	Wind	Solar	Fossil capacities	Clean dispatchable	Electrolyser	Battery storage	Interconnection
AL	100%	59%	1.9	1.6	0	1.5	0.3	0	7.5
AT	100%	64%	11.05	37.2	0.3	23.8	4.9	23.9	16.5
BA	100%	88%	10.24	0.9	0	2.3	2.4	2.8	6.1
BE	87%	79%	11.21	13.8	4.3	10.9	5.7	16.9	15.8
BG	99%	88%	5.62	24.7	0.2	6.2	6.4	5.6	7.5
CH	100%	20%	1.67	8.9	0	18.9	1	14.3	16.3
CY	86%	85%	0.36	3.4	0.6	0	0.8	1.8	0.2
CZ	79%	47%	7.21	21.6	8.6	8.4	4.4	10.4	8.1
DE	91%	83%	150.82	277.4	46.9	39	48.8	142.5	48.1
DK	100%	96%	33.49	4.9	0	2	8.3	12	20.9
EE	92%	89%	3.11	0.5	1.4	0.5	0.5	1.3	5.3
ES	100%	93%	100.43	194.8	3.2	34.9	92.8	57.2	15.6
FI	97%	51%	19.77	1.2	5.1	7.9	3	8.5	7
FR	100%	82%	114.2	253.5	3.9	51.6	57.7	115.5	46.7
GR	99%	94%	20.2	46.1	0.6	4.8	17.9	8.7	9.9
HR	99%	74%	5.12	9.7	0.2	3.2	1.4	4.2	10.8
HU	94%	83%	4.97	49.3	3.1	6.9	13.3	7.6	15.8
IE	100%	96%	22.22	7.5	0.7	3.1	6.8	12.4	3.8
IT	96%	75%	34.09	191.8	11.2	50.8	53.2	121.8	13.7
LT	99%	93%	8.58	1.2	1	1.6	0.8	3.3	4.5
LU	65%	53%	0.62	1.5	0.9	1.4	0.4	6.2	3
LV	98%	89%	5.98	0.7	0.9	1.6	2.2	1.7	4.1
ME	100%	86%	2.53	0.4	0	1.3	0.1	0.5	7
MK	99%	51%	0.36	1.1	0	0.8	0.3	1.5	6.6
MT	65%	62%	0	0.6	0.3	0	0.1	0.3	0.2
NL	98%	91%	34.63	25	2.9	11.9	9.7	25.9	17.7
NO	100%	43%	34.15	0.9	0.3	32	10.1	8.7	20.5
PL	86%	77%	28.01	89	14.6	30.3	16.4	27.8	18.4

	Power generation (%)		Installed capacity (GW)					(GWh)	Imp/ Exp capacity (GW)
	Clean Power	Wind & Solar	Wind	Solar	Fossil capacities	Clean dispatchable	Electrolyser	Battery storage	Interconnection
PT	100%	82%	12.65	28.1	0.1	12.5	11.2	16.3	5
RO	97%	63%	13.15	35.6	1.7	12.4	9.8	12.1	8.2
RS	98%	74%	16.85	0.6	0.6	4.2	1.2	5.8	17.2
SE	100%	48%	28.89	5.7	0	23.2	2.4	20.5	17.3
SI	99%	55%	0.28	5.5	0.8	2.2	1.1	4.1	9.1
SK	98%	53%	2.75	19.9	0.4	8.3	3.2	4.1	8.8
UK	95%	81%	97.71	59.3	25.9	23.3	16.3	135.6	25

Annex 3: Investment Requirements

Table 3.1: Total system costs per pathway (2020-2050)

Cost in €2020 billion

	Stated Policy	Technology Driven	System Change
Wind	1417	1738	1726
Photovoltaic	619	635	858
Other renewables	1239	1259	1202
Nuclear	1187	993	734
Unabated gas	1449	1323	1230
Coal and other non-renewables	708	536	525
New low carbon technologies	227	240	165
Batteries	27	1	12
Interconnections	230	247	270
Electrolysers	99	106	196
Off-grid hydrogen	0	0	0
SMR + CCS	94	96	0
Loss of load and curtailment	10	8	5
Total power system costs	**7306**	**7182**	**6923**
Difference to Stated Policy (%)		***-1.7%***	***-5.2%***
Other energy supply	3870	3367	2786
Total pathway costs	**11175**	**10549**	**9711**
Difference to Stated Policy (%)		***-5.6%***	***-13.1%***

Table 3.2: Power system overnight investment costs - Stated Policy

Cost per 5-year timestep, not annualised (€2020 billion)

	2025	2030	2035	2040	2045	2050
Wind	105	273	231	390	306	182
Solar	45	130	41	153	94	108
Other renewables	56	17	0	0	0	0
Nuclear	5	53	114	0	0	0
Unabated gas	40	31	43	3	0	1
Coal	56	4	2	0	0	0
New low carbon technologies	0	0	0	119	14	87
Utility-scale batteries	1	5	10	0	1	11
Interconnection	24	17	2	34	33	18
Electrolysers	3	16	6	37	22	18
Total	***335***	***547***	***450***	***736***	***470***	***425***

**includes both baseload and peaking unabated gas*
***includes gas+CCS and/or hydrogen turbines*

Table 3.3: Power system overnight investment costs - Technology Driven

Cost per 5-year timestep, not annualised (€2020 billion)

	2025	2030	2035	2040	2045	2050
Wind	150	407	416	294	240	263
Solar	57	180	71	53	57	66
Other renewables	56	17	6	0	0	0
Nuclear	0	0	0	0	0	0
*Unabated gas**	66	12	12	10	3	0
Coal	0	0	0	0	0	0
*New low carbon technologies***	0	4	43	40	10	118
Utility-scale batteries	0	0	0	0	0	1
Interconnection	24	20	30	26	17	19
Electrolysers	3	16	36	7	19	13
Total	***355***	***657***	***612***	***430***	***347***	***480***

**includes both baseload and peaking unabated gas*
***includes gas+CCS and/or hydrogen turbines*

Table 3.4: Power system overnight investment costs - System Change

Cost per 5-year timestep, not annualised (€2020 billion)

	2025	2030	2035	2040	2045	2050
Wind	163	447	451	309	26	92
Solar	89	282	158	14	24	69
Other renewables	56	17	0	0	0	0
Nuclear	0	0	0	0	0	0
*Unabated gas**	77	0	2	0	0	1
Coal	0	0	0	0	0	0
*New low carbon technologies***	0	22	78	63	0	2
Utility-scale batteries	0	5	2	2	0	0
Interconnection	24	27	53	34	0	3
Electrolysers	12	48	63	1	0	1
Total	***421***	***847***	***806***	***423***	***50***	***168***

**includes both baseload and peaking unabated gas*
***includes gas+CCS and/or hydrogen turbines*

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