S1. Cost assumptions

Table S1: Overnight investment cost assumptions per technology and year. All costs are given in real 2015 money.

Technology	Unit	2020	2025	2030	2035	2040	2045	2050	source
Onshore Wind	€/kW	1118	1077	1035	1006	977	970	963	[1]
Offshore Wind	€/kW	1748	1660	1573	1510	1447	1431	1415	[1]
Solar PV (utility-scale)	€/kW	398	326	254	221	188	169	151	[2]
Solar PV (rooftop)	€/kW	1127	955	784	723	661	600	539	[3]
OCGT	€/kW	453	444	435	429	423	417	411	[1]
CCGT	€/kW	880	855	830	822	815	807	800	[1]
Coal power plant	€/kW_{el}	3845	3845	3845	3845	3845	3845	3845	[4]
Lignite	€/kW_{el}	3845	3845	3845	3845	3845	3845	3845	[4]
Nuclear	€/kW_{el}	7940	7940	7940	7940	7940	7940	7940	[4]
Reservoir hydro	€/kW_{el}	2208	2208	2208	2208	2208	2208	2208	[5]
Run of river	€/kW_{el}	3312	3312	3312	3312	3312	3312	3312	[5]
PHS	€/kW_{el}	2208	2208	2208	2208	2208	2208	2208	[5]
Gas CHP	€/kW	590	575	560	550	540	530	520	[1]
Biomass CHP	€/kW_{el}	3381	3295	3210	3135	3061	2986	2912	[1]
Coal CHP	€/kW	1900	1880	1860	1841	1822	1803	1783	[1]
Biomass central heat plant	€/kW_{th}	875	854	832	812	792	773	753	[1]
Biomass power plant	€/kW_{el}	3381	3295	3210	3135	3061	2986	2912	[1]
HVDC overhead	€/MWkm	400	400	400	400	400	400	400	[6]
HVDC inverter pair	€/MW	150000	150000	150000	150000	150000	150000	150000	[6]
Battery storage	€/kWh	232	187	142	142	142	142	142	[1]
Battery inverter	€/kW	270	215	160	160	160	160	160	[1]
Electrolysis	€/kW_{el}	600	575	550	537	525	512	500	[1]
Fuel cell	€/kW_{el}	1300	1200	1100	1025	950	875	800	[1]
H_2 storage underground	€/kWh	3.0	2.5	2.0	1.8	1.5	1.4	1.2	[1]
H_2 storage tank	€/kWh	57	50	44	35	27	24	21	[1]
DAC (direct-air capture)	€/(tCO_2/a)	772	577	383	317	251	230	210	[7]
Methanation	€/kW_{H_2}	1000	1000	1000	1000	1000	1000	1000	[8]
Central gas boiler	€/kW_{th}	60	55	50	50	50	50	50	[1]
Decentral gas boiler	€/kW_{th}	195	190	185	181	176	172	167	[1]
Central resistive heater	€/kW_{th}	70	65	60	60	60	60	60	[1]
Decentral resistive heater	€/kWh_{th}	100	100	100	100	100	100	100	[8]
Central water tank storage	€/kWh	0.6	0.6	0.5	0.5	0.5	0.5	0.5	[1]
Decentral water tank storage	€/kWh	18	18	18	18	18	18	18	[1, 9]
Decentral air-sourced heat pump	€/kW_{th}	940	895	850	827	805	782	760	[1]
Central ground-sourced heat pump	€/kW_{th}	564	535	507	494	482	469	456	[1]
Decentral ground-sourced heat pump	€/kW_{th}	1500	1450	1400	1350	1300	1250	1200	[1]

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Table S2: Efficiency, lifetime and FOM cost per technology (values shown corresponds to 2020).

Technology	FOM[a] [%/a]	Lifetime [a]	Efficiency	Source
Onshore Wind	1.2	27		[1]
Offshore Wind	2.3	27		[1]
Solar PV (utility-scale)	1.6	30		[2]
Solar PV (rooftop)	1.2	30		[3]
OCGT	1.8	25	0.4	[1]
CCGT	3.3	25	0.56	[1]
Coal power plant	1.6	40	0.33	[4]
Lignite	1.6	40	0.33	[4]
Nuclear	1.4	40	0.33	[4]
Reservoir hydro	1.0	80	0.9	[5]
Run of river	2.0	80	0.9	[5]
PHS	1.0	80	0.75	[5]
Gas CHP	3.3	25		[1]
Biomass CHP	3.6	25		[1]
Coal CHP	1.6	25	0.48	[1]
Biomass central heat plant	5.8	25	1.03	[1]
Biomass power plant	3.6	25	0.3	[1]
HVDC overhead	2.0	40		[6]
HVDC inverter pair	2.0	40		[6]
Battery storage		20		[1]
Battery inverter	0.2	20	0.95	[1]
Electrolysis	5.0	25	0.64	[1]
Fuel cell	5.0	10	0.5	[1]
H_2 storage underground	0.0	100	0.99	[1]
H_2 storage tank	1.0	25		[1]
DAC (direct-air capture)	4.0	30		[7]
Methanation	3.0	25	0.8	[8]
Central gas boiler	3.2	25	1.03	[1]
Decentral gas boiler	10.5	20	0.97	[1]
Central resistive heater	1.5	20	0.99	[1]
Decentral resistive heater	2.0	20	0.9	[8]
Central water tank storage	0.5	20		[1]
Decentral water tank storage	1.0	20		[1, 9]
Water tank charger/discharger			0.84	
Decentral air-sourced heat pump	3.0	18		[1]
Central ground-sourced heat pump	0.4	25		[1]
Decentral ground-sourced heat pump	1.8	20		[1]

[a] Fixed Operation and Maintenance (FOM) costs are given as a percentage of the overnight cost per year.
[b] Hydroelectric facilities are not expanded in this model and are considered to be fully amortized.
[c] Efficiency for Combined Heat and Power (CHP) plants depends on the electricity/heat output and it is modelled as described in the text.
[d] Coefficient of performance (COP) of heat pumps is modelled as a function of temperature, as described in the text.
[e] Investments in methanation and DAC are not allowed independently, only together as 'Methanation+DAC', see text.

Table S3: Costs and emissions coefficient of fuels.

Fuel	Cost [€/MWh$_{th}$]	Source	Emissions [tCO$_2$/MWh$_{th}$]	Source
coal	8.2	[10]	0.34	[11]
lignite	2.9	[5]	0.41	[11]
gas	20.1	[10]	0.2	[11]
oil	50.0	[12]	0.27	[11]
nuclear	2.6	[4]	0	
solid biomass	25.2	[13, 14]	0	

[a] Raw biomass fuel cost is assumed as the middle value of the range provided in the references for different European countries and types of sustainable biomass.

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