

Supplementary Material for:

Energy security analysis for a 100% renewable energy transition in Jordan by 2050

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Table S1: Population projection.

	Unit	2015	2020	2025	2030	2035	2040	2045	2050	Source
Population	[mil]	7.6	8.2	8.5	9.1	9.8	10.5	11.1	11.7	[1]

Table S2: Projection of the power, heat, transportation and desalination demand.

Energy service demand	Unit	2015	2020	2025	2030	2035	2040	2045	2050	
Power demand	[TWh]	14.5	16.3	18.3	20.7	23.3	26.4	30.1	34.4	
Industrial heat demand	[TWh]	9.4	11.2	12.8	14.3	17.4	20.6	23.3	26.6	
Space heating heat demand	[TWh]	13.7	14.4	16.3	20.5	24.8	29.1	32.5	35.1	
Domestic water heating heat demand	[TWh]	4.1	4.5	4.9	5.4	6.0	6.6	7.2	7.9	
Biomass cooking heat demand	[TWh]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Road LDV passenger transport demand	[mil km]	4260	5623	7121	9180	12003	15971	22069	30656	
Road 2W/3W passenger transport demand	[mil km]	247	319	396	500	642	835	1113	1497	
Road Bus passenger transport demand	[mil km]	409	497	584	698	849	1024	1176	1354	

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Road MDV freight transport demand	[mil km]	1741	2274	2845	3614	4662	6073	8043	10793
Road HDV freight transport demand	[mil km]	517	675	844	1072	1383	1802	2386	3202
Rail passenger transport demand	[mil p-km]	187	234	283	347	432	540	683	867
Rail freight transport demand	[mil t-km]	429	540	660	824	1055	1381	1861	2583
Marine passenger transport demand	[mil p-km]	133	134	135	137	138	139	141	143
Marine freight transport demand	[mil t-km]	71911	82767	92925	107531	128165	155394	191842	240848
Aviation passenger transport demand	[mil p-km]	2032	2701	3480	4651	6058	8545	11777	15752
Aviation freight transport demand	[mil t-km]	163	213	271	355	477	658	904	1224
Water desalination demand	[m³/a]	8.1E+06	3.3E+07	1.2E+08	4.1E+08	9.1E+08	1.3E+09	1.5E+09	1.5E+09

Table S3: Projected specific energy demand by transport mode and vehicle type.

Mode and vehicle type	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Road LDV ICE	[kWh _{th} /km]	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5
Road LDV BEV	[kWh _{el} /km]	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Road LDV FCEV	[kWh _{th} /km]	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2
Road LDV PHEV (primary)	[kWh _{el} /km]	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Road LDV PHEV (secondary)	[kWh _{th} /km]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Road 2W/3W ICE	[kWh _{th} /km]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Road 2W/3W BEV	[kWh _{el} /km]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Road Bus ICE	[kWh _{th} /km]	4.1	4.1	4.0	4.0	3.9	3.8	3.8	3.7
Road Bus BEV	[kWh _{el} /km]	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5
Road Bus FCEV	[kWh _{th} /km]	3.1	3.1	2.9	2.9	2.7	2.6	2.5	2.4
Road Bus PHEV (primary)	[kWh _{el} /km]	2.0	2.0	1.9	1.9	1.9	1.9	1.9	1.8

Road Bus PHEV (secondary)	[kWh _{th} /km]	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
Road MDV ICE	[kWh _{th} /km]	2.4	2.3	2.2	2.2	2.1	1.9	1.8	1.7
Road MDV BEV	[kWh _{el} /km]	0.9	0.8	0.8	0.7	0.6	0.6	0.6	0.5
Road MDV FCEV	[kWh _{th} /km]	0.0	1.4	1.3	1.3	1.2	1.1	1.1	1.0
Road MDV PHEV (primary)	[kWh _{el} /km]	1.4	1.4	1.3	1.3	1.2	1.1	1.1	1.0
Road MDV PHEV (secondary)	[kWh _{th} /km]	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Road HDV ICE	[kWh _{th} /km]	3.5	3.4	3.1	3.0	2.8	2.6	2.5	2.3
Road HDV BEV	[kWh _{el} /km]	0.0	1.7	1.5	1.4	1.3	1.2	1.1	1.0
Road HDV FCEV	[kWh _{th} /km]	0.0	2.0	1.8	1.7	1.6	1.5	1.4	1.3
Road HDV PHEV (primary)	[kWh _{el} /km]	0.0	2.3	2.1	2.1	1.9	1.7	1.6	1.5
Road HDV PHEV (secondary)	[kWh _{th} /km]	0.0	0.5	0.5	0.4	0.4	0.4	0.3	0.3
Rail pass fuel	[kWh _{th} /(p-km)]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rail pass electricity	[kWh _{el} /(p-km)]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rail freight fuel	[kWh _{th} /(t-km)]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Rail freight electricity	[kWh _{el} /(t-km)]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine pass fuel	[kWh _{th} /(p-km)]	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
Marine pass electricity	[kWh _{el} /(p-km)]	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Marine pass LH2	[kWh _{th} /(p-km)]	0.0	0.0	0.0	0.6	0.5	0.5	0.5	0.5
Marine pass LNG	[kWh _{th} /(p-km)]	0.0	0.7	0.6	0.6	0.6	0.6	0.6	0.6
Marine freight fuel	[kWh _{th} /(t-km)]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine freight electricity	[kWh _{el} /(t-km)]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine freight LH2	[kWh _{th} /(t-km)]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine freight LNG	[kWh _{th} /(t-km)]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation pass fuel	[kWh _{th} /(p-km)]	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
Aviation pass electricity	[kWh _{el} /(p-km)]	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.1
Aviation pass LH2	[kWh _{th} /(p-km)]	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3
Aviation freight fuel	[kWh _{th} /(t-km)]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Aviation freight electricity	[kWh _{el} /(t-km)]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation freight LH2	[kWh _{th} /(t-km)]	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1

Table S4: Final transport energy demand by mode, segment, and vehicle type.

Road 2W/3W BEV elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Road Bus ICE fuel	TWh _{th}	1.5	1.6	1.1	0.5	0.2	0.2	0.2	0.1
Road Bus BEV elec	TWh _{el}	0.1	0.2	0.5	1.0	1.3	1.5	1.7	1.8
Road Bus FCEV H2	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road Bus PHEV fuel	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Road Bus PHEV elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road MDV ICE fuel	TWh _{th}	4.1	4.7	4.9	3.7	1.5	0.6	0.6	0.5
Road MDV BEV elec	TWh _{el}	0.0	0.2	0.4	1.2	2.3	2.9	3.7	4.5
Road MDV FCEV H2	TWh _{th}	0.0	0.0	0.0	0.1	0.3	0.7	0.9	1.1
Road MDV PHEV fuel	TWh _{th}	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4
Road MDV PHEV elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Road HDV ICE fuel	TWh _{th}	1.8	2.2	2.3	2.5	1.8	0.6	0.2	0.2
Road HDV BEV elec	TWh _{el}	0.0	0.0	0.1	0.2	0.5	1.1	1.3	1.7
Road HDV FCEV H2	TWh _{th}	0.0	0.0	0.0	0.1	0.4	0.8	1.0	1.2
Road HDV PHEV fuel	TWh _{th}	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6
Road HDV PHEV elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Rail pass fuel	TWh _{th}	10.8	12.7	12.5	10.1	5.4	2.8	2.7	2.7
Rail pass elec	TWh _{el}	0.1	0.4	1.2	3.0	5.2	7.0	8.7	10.8
Rail freight fuel	TWh _{th}	0.0	0.0	0.1	0.2	0.8	1.6	2.2	2.8
Rail freight elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine pass fuel	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine pass elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine pass LH2	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Marine pass LNG	TWh _{th}	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Marine freight fuel	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine freight elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine freight LH2	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine freight LNG	TWh _{th}	3.0	3.4	3.8	4.2	4.6	4.8	4.3	2.4
Aviation pass fuel	TWh _{th}	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4
Aviation pass elec	TWh _{el}	0.0	0.0	0.0	0.0	0.1	0.5	1.4	3.2
Aviation pass LH2	TWh _{th}	0.0	0.0	0.0	0.1	0.1	0.3	0.7	1.8
Aviation freight fuel	TWh _{th}	1.1	1.4	1.8	2.3	2.8	3.3	3.6	3.1
Aviation freight elec	TWh _{el}	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4
Aviation freight LH2	TWh _{th}	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.6

Table S5: Projected shares of passenger demand by transport mode and vehicle type.

Passenger mode and vehicle type	2015	2020	2025	2030	2035	2040	2045	2050
Road LDV ICE - liquid fuel	99.6%	94.0%	79.9%	50.0%	20.0%	11.0%	7.0%	4.0%
Road LDV BEV - electricity	0.2%	3.0%	10.0%	39.0%	68.0%	74.0%	73.0%	76.0%
Road LDV FCEV - hydrogen	0.0%	0.0%	0.1%	1.0%	2.0%	5.0%	10.0%	10.0%
Road LDV PHEV - electricity/liquid fuel	0.2%	3.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Road 2W/3W ICE - liquid fuel	70.0%	65.0%	60.0%	40.0%	25.0%	15.0%	10.0%	5.0%
Road 2W/3W BEV - electricity	30.0%	35.0%	40.0%	60.0%	75.0%	85.0%	90.0%	95.0%
Road BUS ICE - liquid fuel	89.4%	78.9%	47.9%	16.9%	5.9%	4.9%	3.9%	2.9%
Road BUS BEV - electricity	10.0%	20.0%	50.0%	80.0%	90.0%	90.0%	90.0%	90.0%
Road BUS FCEV - hydrogen	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Road BUS PHEV - electricity/liquid fuel	0.5%	1.0%	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%
Rail - electricity	56.3%	66.7%	66.7%	66.7%	70.8%	75.0%	87.5%	100.0%
Rail - liquid fuel	43.8%	33.3%	33.3%	33.3%	29.2%	25.0%	12.5%	0.0%
Marine - liquid fuel	100%	99.4%	98.4%	95.9%	91.2%	79.4%	57.2%	26.1%
Marine - electricity	0.0%	0.1%	0.6%	1.1%	2.8%	5.6%	7.8%	8.9%
Marine - hydrogen	0.0%	0.0%	0.0%	1.0%	3.0%	10.0%	25.0%	45.0%
Marine - LNG	0.0%	0.5%	1.0%	2.0%	3.0%	5.0%	10.0%	20.0%
Aviation - liquid fuel	100%	100%	100%	100%	96.5%	86.0%	68.5%	43.9%
Aviation - electricity	0.0%	0.0%	0.0%	0.0%	1.2%	4.7%	10.5%	18.7%
Aviation - hydrogen	0.0%	0.0%	0.0%	0.0%	2.3%	9.3%	21.0%	37.4%

Table S6: Projected shares of freight demand by transport mode and vehicle type.

Freight mode and vehicle type	2015	2020	2025	2030	2035	2040	2045	2050
Road MDV ICE - liquid fuel	99.6%	88.9%	78.0%	47.0%	16.0%	5.0%	4.0%	3.0%
Road MDV BEV - electricity	0.2%	10.0%	19.0%	48.0%	75.0%	80.0%	80.0%	80.0%
Road MDV FCEV - hydrogen	0.0%	0.1%	1.0%	2.0%	5.0%	10.0%	10.0%	10.0%
Road MDV PHEV - electricity/liquid fuel	0.2%	1.0%	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%
Road HDV ICE - liquid fuel	100%	97.5%	88.0%	77.0%	46.0%	12.0%	4.0%	3.0%
Road HDV BEV - electricity	0.0%	1.0%	8.0%	15.0%	30.0%	50.0%	50.0%	50.0%
Road HDV FCEV - hydrogen	0.0%	0.5%	2.0%	5.0%	20.0%	30.0%	30.0%	30.0%
Road HDV PHEV - electricity/liquid fuel	0.0%	1.0%	2.0%	3.0%	4.0%	8.0%	16.0%	17.0%
Rail - electricity	56.3%	66.7%	66.7%	66.7%	70.8%	75.0%	87.5%	100.0%
Rail - liquid fuel	43.8%	33.3%	33.3%	33.3%	29.2%	25.0%	12.5%	0.0%
Marine - liquid fuel	100%	99.4%	98.4%	95.9%	91.2%	79.4%	57.8%	26.7%
Marine - electricity	0.0%	0.1%	0.6%	1.1%	2.8%	5.6%	7.2%	8.3%
Marine - hydrogen	0.0%	0.0%	0.0%	1.0%	3.0%	10.0%	25.0%	45.0%
Marine - LNG	0.0%	0.5%	1.0%	2.0%	3.0%	5.0%	10.0%	20.0%

Aviation - liquid fuel	100%	100%	100%	100%	97.7%	90.7%	79.0%	62.6%
Aviation - electricity	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aviation - hydrogen	0.0%	0.0%	0.0%	0.0%	2.3%	9.3%	21.0%	37.4%

Table S7: Projected final energy demand by sector.

Sector	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Power demand	[TWh]	14.5	16.3	18.3	20.7	23.3	26.4	30.1	34.4
Heat demand	[TWh]	27.2	30.1	34.0	40.2	48.1	56.3	63.1	69.6
Transport demand	[TWh]	15.1	18.2	19.6	20.2	19.4	21.1	25.0	29.5
Desalination demand	[TWh]	0.04	0.17	0.52	1.50	3.18	4.42	4.83	4.96
Total	[TWh]	56.8	64.8	72.4	82.6	94.0	108.2	123.0	138.5

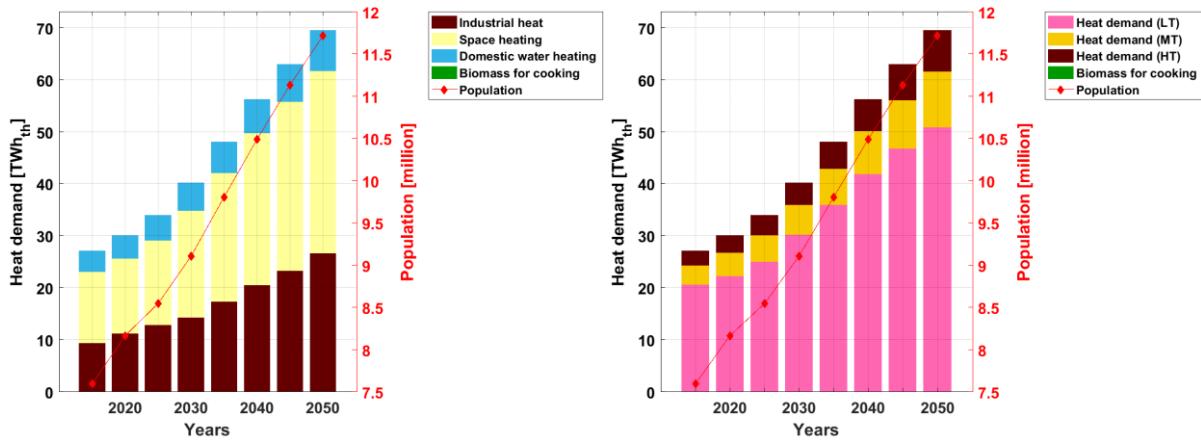


Figure S1: Heat demand by categories (left) and heat demand by application and temperature levels (right).

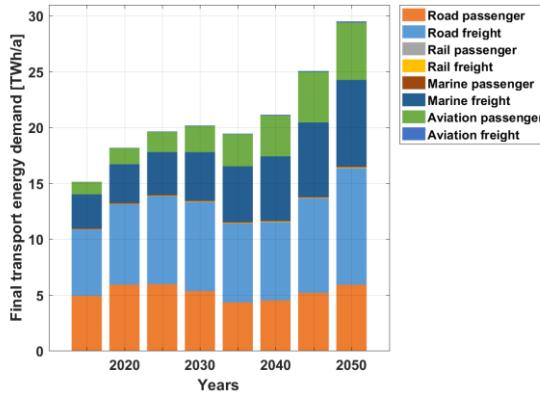


Figure S2: Final transport energy demand classified for passenger and freight of different modes.

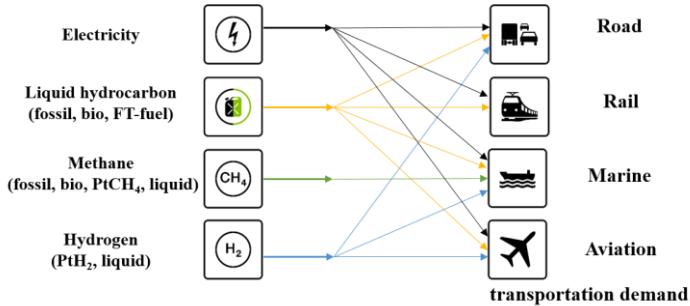


Figure S3: Schematic of the transport modes and corresponding fuels utilised [2,3].

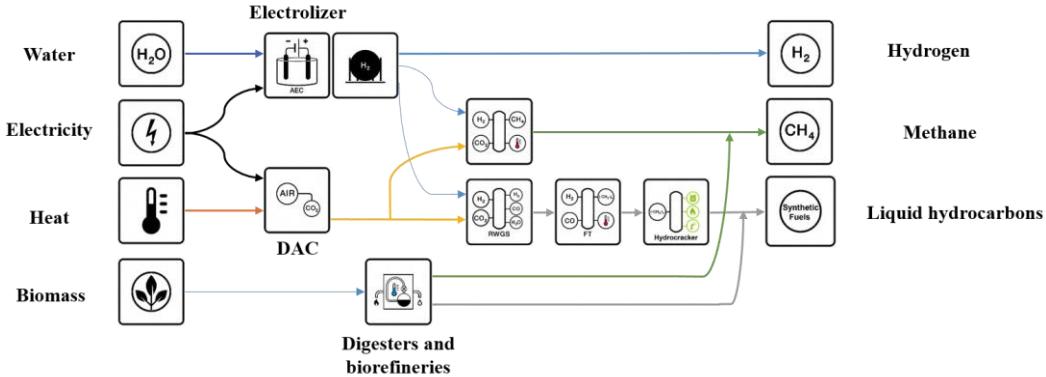


Figure S4: Schematic of the value chain elements in the production of sustainable fuels [2,3].

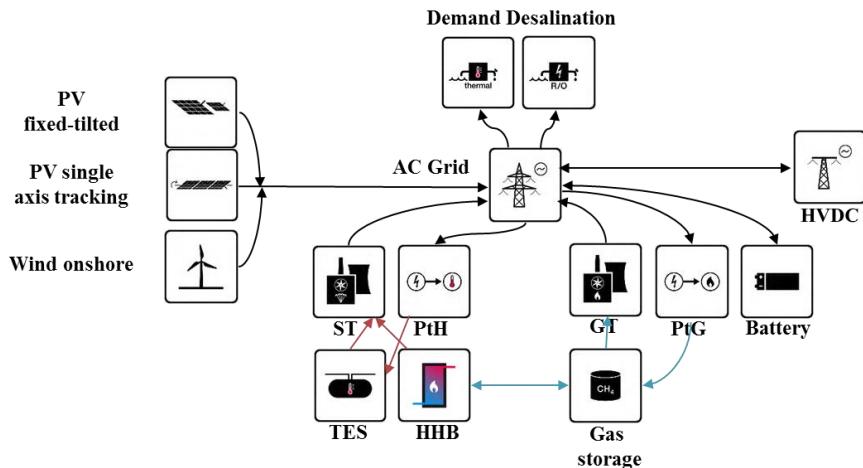


Figure S5: Schematic of the LUT Energy System Transition model for the desalination sector [2,3].

Table S8: Financial and technical assumptions used in the model for different technologies

Technologies		Unit	2015	2020	2025	2030	2035	2040	2045	2050	Sources
PV rooftop – residential	Capex	€/kW _{el}	1360	1169	966	826	725	650	589	537	[4]
	Opex fix	€/(kW _{el} a)	20.4	17.6	15.7	14.2	12.8	11.7	10.7	9.8	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	35	35	35	40	40	40	
PV rooftop - commercial	Capex	€/kW _{el}	1360	907	737	623	542	484	437	397	[4]
	Opex fix	€/(kW _{el} a)	20.4	17.6	15.7	14.2	12.8	11.7	10.7	9.8	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	

	Lifetime	years	30	30	35	35	35	40	40	40	
PV rooftop - industrial	Capex	€/kW _{el}	1360	682	548	459	397	353	318	289	[4]
	Opex fix	€/(kW _{el} a)	20.4	17,6	15,7	14,2	12,8	11,7	10,7	9,8	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	35	35	35	40	40	40	
PV optimally tilted (fixed tilted)	Capex	€/kW _{el}	1000	580	466	390	337	300	270	246	[4]
	Opex fix	€/(kW _{el} a)	15	13.2	11.8	10.6	9.6	8.8	8.0	7.4	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	35	35	35	40	40	40	
PV single-axis tracking	Capex	€/kW _{el}	1150	638	513	429	371	330	297	271	[4,5]
	Opex fix	€/(kW _{el} a)	17.3	15.0	13.0	12.0	11.0	10.0	9.0	8.0	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	35	35	35	40	40	40	
Wind onshore	Capex	€/kW _{el}	1250	1150	1060	1000	965	940	915	900	[6]
	Opex fix	€/(kW _{el} a)	25	23	21	20	19	19	18	18	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	25	25	25	25	25	25	25	25	
Wind offshore	Capex	€/kW _{el}	3220	2880	2700	2580	2460	2380	2320	2280	[7]
	Opex fix	€/(kW _{el} a)	113	92	84	77	71	67	58	52	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	20	25	25	25	25	25	25	25	
Hydro Reservoir/Dam	Capex	€/kW _{el}	1650	1650	1650	1650	1650	1650	1650	1650	[7]
	Opex fix	€/(kW _{el} a)	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5	
	Opex var	€/(kWh _{el})	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
	Lifetime	years	50	50	50	50	50	50	50	50	
Hydro Run-of-River	Capex	€/kW _{el}	2560	2560	2560	2560	2560	2560	2560	2560	[7]
	Opex fix	€/(kW _{el} a)	76.8	76.8	76.8	76.8	76.8	76.8	76.8	76.8	
	Opex var	€/(kWh _{el})	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
	Lifetime	years	50	50	50	50	50	50	50	50	
Geothermal power	Capex	€/kW _{el}	5250	4970	4720	4470	4245	4020	3815	3610	[7,8]
	Opex fix	€/(kW _{el} a)	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	40	40	40	40	40	40	40	40	
Coal PP	Capex	€/(kW _{el})	1500	1500	1500	1500	1500	1500	1500	1500	[9,10]
	Opex fix	€/(kW _{el} a)	20	20	20	20	20	20	20	20	
	Opex var	€/(kWh)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
	Lifetime	years	40	40	40	40	40	40	40	40	
Nuclear PP	Capex	€/(kW _{el})	6210	6003	6003	5658	5658	5244	5244	5175	[9,11,12]

	Opex fix	€/(kW _{el} a)	162	157	157	137	137	116	116	109	
	Opex var	€/(kWh _{el})	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	
	Lifetime	years	40	40	40	40	40	40	40	40	
CCGT	Capex	€/(kW _{el})	775	775	775	775	775	775	775	775	[9]
	Opex fix	€/(kW _{el} a)	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	35	35	35	35	35	35	35	35	
OCGT	Capex	€/(kW _{el})	475	475	475	475	475	475	475	475	[13]
	Opex fix	€/(kW _{el} a)	14.25	14.25	14.25	14.25	14.25	14.25	14.25	14.25	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	35	35	35	35	35	35	35	35	
Steam turbine (CSP)	Capex	€/(kW _{el})	1000	968	946	923	902	880	860	840	[3]
	Opex fix	€/(kW _{el} a)	20	19.4	18.9	18.5	18	17.6	17.2	16.8	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	25	25	25	25	30	30	30	30	
Biomass PP	Capex	€/kW _{el}	2755	2620	2475	2330	2195	2060	1945	1830	[3]
	Opex fix	€/(kW _{el} a)	55.4	47.2	44.6	41.9	39.5	37.1	35	32.9	
	Opex var	€/(kWh _{el})	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	
	Lifetime	years	25	25	25	25	25	25	25	25	
CHP NG Heating	Capex	€/kW _{el}	880	880	880	880	880	880	880	880	[3]
	Opex fix	€/(kW _{el} a)	74.8	74.8	74.8	74.8	74.8	74.8	74.8	74.8	
	Opex var	€/(kWh _{el})	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
	Lifetime	years	30	30	30	30	30	30	30	30	
CHP Oil Heating	Capex	€/kW _{el}	880	880	880	880	880	880	880	880	[3]
	Opex fix	€/(kW _{el} a)	74.8	74.8	74.8	74.8	74.8	74.8	74.8	74.8	
	Opex var	€/(kWh _{el})	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
	Lifetime	years	30	30	30	30	30	30	30	30	
CHP Coal Heating	Capex	€/kW _{el}	2030	2030	2030	2030	2030	2030	2030	2030	[3]
	Opex fix	€/(kW _{el} a)	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	
	Opex var	€/(kWh _{el})	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	
	Lifetime	years	40	40	40	40	40	40	40	40	
CHP Biomass Heating	Capex	€/kW _{el}	3560	3300	3145	2990	2870	2750	2645	2540	[3]
	Opex fix	€/(kW _{el} a)	81.9	75.9	72.3	68.8	66	63.3	60.8	58.4	
	Opex var	€/(kWh _{el})	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	
	Lifetime	years	25	25	25	25	25	25	25	25	
CHP Biogas	Capex	€/kW _{el}	503	429	400	370	340	326	311	296	[3]
	Opex fix	€/(kW _{el} a)	20.1	17.2	16.0	14.8	13.6	13.0	12.4	11.8	
	Opex var	€/(kWh _{el})	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	

	Lifetime	years	30	30	30	30	30	30	30	
Waste incinerator	Capex	€/kW _{el}	5940	5630	5440	5240	5030	4870	4690	4540
	Opex fix	€/(kW _{el} a)	267.3	253.4	244.8	235.8	226.4	219.1	211.0	204.3
	Opex var	€/(kWh _{el})	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	Lifetime	years	30	30	30	30	30	30	30	
Biogas digester	Capex	€/kW _{th}	771	731	706	680	653	632	609	589
	Opex fix	€/(kW _{th} a)	30.8	29.2	28.2	27.2	26.1	25.3	24.3	23.6
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0
	Lifetime	years	20	20	20	20	25	25	25	25
Biogas upgrade	Capex	€/kW _{th}	340	290	270	250	230	220	210	200
	Opex fix	€/(kW _{th} a)	27.2	23.2	21.6	20	18.4	17.6	16.8	16
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0
	Lifetime	years	20	20	20	20	25	25	25	25
CSP (solar field, parabolic trough)	Capex	€/kW _{th}	438.3	344.5	303.6	274.7	251.1	230.2	211.9	196
	Opex fix	€/(kW _{th} a)	10.1	7.9	7	6.3	5.8	5.3	4.9	4.5
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0
	Lifetime	years	25	25	25	25	25	25	25	25
Residential Solar Heat Collectors - Space Heating	Capex	€/kW _{th}	1286	1214	1179	1143	1071	1000	929	857
	Opex fix	€/(kW _{th} a)	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0
	Lifetime	years	20	25	25	30	30	30	30	30
Residential Solar Heat Collectors - hot water	Capex	€/kW _{th}	485	485	485	485	485	485	485	
	Opex fix	€/(kW _{th} a)	4.85	4.85	4.85	4.85	4.85	4.85	4.85	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	
	Lifetime	years	15	15	15	15	15	15	15	
DH Electric Heating	Capex	€/kW _{th}	100	100	100	75	75	75	75	
	Opex fix	€/(kW _{th} a)	1.47	1.47	1.47	1.47	1.47	1.47	1.47	
	Opex var	€/(kWh _{th})	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
	Lifetime	years	35	35	35	35	35	35	35	
DH Heat Pump	Capex	€/kW _{th}	700	660	618	590	568	554	540	530
	Opex fix	€/(kW _{th} a)	2	2	2	2	2	2	2	
	Opex var	€/(kWh _{th})	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
	Lifetime	years	25	25	25	25	25	25	25	
DH Natural gas Heating	Capex	€/kW _{th}	75	75	75	100	100	100	100	
	Opex fix	€/(kW _{th} a)	2.775	2.775	2.775	3.7	3.7	3.7	3.7	
	Opex var	€/(kWh _{th})	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
	Lifetime	years	35	35	35	35	35	35	35	
DH Oil	Capex	€/kW _{th}	75	75	75	100	100	100	100	[3]

Heating	Opex fix	€/(kW _{th} a)	2.775	2.775	2.775	3.7	3.7	3.7	3.7	3.7	
	Opex var	€/(kWh _{th})	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
	Lifetime	years	35	35	35	35	35	35	35	35	
DH Coal Heating	Capex	€/kW _{th}	75	75	75	100	100	100	100	100	[3]
	Opex fix	€/(kW _{th} a)	2.775	2.775	2.775	3.7	3.7	3.7	3.7	3.7	
	Opex var	€/(kWh _{th})	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
	Lifetime	years	35	35	35	35	35	35	35	35	
DH Biomass Heating	Capex	€/kW _{th}	75	75	75	100	100	100	100	100	[3]
	Opex fix	€/(kW _{th} a)	2.8	2.8	2.8	3.7	3.7	3.7	3.7	3.7	
	Opex var	€/(kWh _{th})	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	
	Lifetime	years	35	35	35	35	35	35	35	35	
DH Geothermal Heating	Capex	€/kW _{th}	3936	3642	3384	3200	3180	3160	3150	3146	[3]
	Opex fix	€/(kW _{th} a)	144	133	124	117	116	115	115	115	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	22	22	22	22	22	22	22	22	
Local Electric Heating	Capex	€/kW _{th}	800	800	800	800	800	800	800	800	[3]
	Opex fix	€/(kW _{th} a)	10	10	10	10	10	10	10	10	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	30	30	30	30	30	30	
Local Heat Pump	Capex	€/kW _{th}	800	780	750	730	706	690	666	650	[3]
	Opex fix	€/(kW _{th} a)	16	15.6	15	7.3	7.1	6.9	6.7	6.5	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	20	20	20	20	20	20	20	20	
Local Natural gas Heating	Capex	€/kW _{th}	800	800	800	800	800	800	800	800	[3]
	Opex fix	€/(kW _{th} a)	27	27	27	27	27	27	27	27	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	22	22	22	22	22	22	22	22	
Local Oil Heating	Capex	€/kW _{th}	440	440	440	440	440	440	440	440	[3]
	Opex fix	€/(kW _{th} a)	18	18	18	18	18	18	18	18	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	20	20	20	20	20	20	20	20	
Local Coal Heating	Capex	€/kW _{th}	500	500	500	500	500	500	500	500	[3]
	Opex fix	€/(kW _{th} a)	10	10	10	10	10	10	10	10	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	15	15	15	15	15	15	15	
Local Biomass Heating	Capex	€/kW _{th}	675	675	675	750	750	750	750	675	[3]
	Opex fix	€/(kW _{th} a)	2	2	2	3	3	3	3	3	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	

	Lifetime	years	20	20	20	20	20	20	20	20	
Local Biogas Heating	Capex	€/kW _{th}	800	800	800	800	800	800	800	800	[3]
	Opex fix	€/(kW _{th} a)	27	27	27	27	27	27	27	27	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	22	22	22	22	22	22	22	22	
Water electrolysis	Capex	€/kW _{H2}	800	685	500	363	325	296	267	248	[17,18]
	Opex fix	€/(kW _{H2} a)	32	27	20	12.7	11.4	10.4	9.4	8.7	
	Opex var	€/(kWh _{H2})	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
	Lifetime	years	30	30	30	30	30	30	30	30	
Methanation	Capex	€/kW _{CH4}	547	502	368	278	247	226	204	190	[17,18]
	Opex fix	€/(kW _{CH4} a)	25.16	23.09	16.93	12.79	11.36	10.4	9.38	8.74	
	Opex var	€/(kWh _{CH4})	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	
	Lifetime	years	30	30	30	30	30	30	30	30	
CO ₂ direct air capture	Capex	€/tCO ₂ a	1000	730	493	335	274.4	234	210.6	195	[19]
	Opex fix	€/tCO ₂ a	40	29.2	19.7	13.4	11	9.4	8.4	7.8	
	Opex var	€/tCO ₂	0	0	0	0	0	0	0	0	
	Lifetime	years	20	20	30	30	30	30	30	30	
Fischer-Tropsch Unit	Capex	€/kW _{FTLiq}	947	947	947	947	947	852.3	852.3	852.3	[3]
	Opex fix	€/kW _{FTLiq}	28.41	28.41	28.41	28.41	28.41	25.57	25.57	25.57	
	Opex var	€/kWh _{FTLiq}	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	30	30	30	30	30	30	
Battery storage	Capex	€/(kWh _{el})	400	270	182	134	108	92	78	70	[20]
	Opex fix	€/(kWh _{el} a)	24	9	5	3.75	3	2.5	2.125	1.875	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery interface	Capex	€/(kW _{el})	200	135	91	67	54	46	39	35	[20]
	Opex fix	€/(kW _{el} a)	0	0	0	0	0	0	0	0	
	Opex var	€/(kW _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery PV prosumer - residential storage	Capex	€/(kWh _{el})	603	407	280	209	170	146	124	111	[3]
	Opex fix	€/(kWh _{el} a)	36.2	13.6	7.7	5.8	4.7	4	3.4	3	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery PV prosumer - residential interface	Capex	€/(kW _{el})	302	204	140	104	85	73	62	56	[3]
	Opex fix	€/(kW _{el} a)	0	0	0	0	0	0	0	0	
	Opex var	€/(kW _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery PV	Capex	€/(kW _{el})	513	346	235	174	141	120	102	91	[3]

prosumer - commercial storage	Opex fix	€/(kWh _{el} a)	30.8	11.5	6.5	4.9	3.9	3.3	2.8	2.5	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery PV prosumer - commercial interface	Capex	€/(kWh _{el})	256	173	117	87	70	60	51	46	[3]
	Opex fix	€/(kWh _{el} a)	0	0	0	0	0	0	0	0	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery PV prosumer - industrial storage	Capex	€/(kWh _{el})	435	294	198	146	118	100	85	76	[3]
	Opex fix	€/(kWh _{el} a)	26.1	9.8	5.4	4.1	3.3	2.7	2.3	2	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
Battery PV prosumer - industrial interface	Capex	€/(kWh _{el})	218	147	99	73	59	50	42	38	[3]
	Opex fix	€/(kWh _{el} a)	0	0	0	0	0	0	0	0	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	20	20	20	20	20	20	20	
PHES	Capex	€/(kWh _{el})	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	[7]
	Opex fix	€/(kWh _{el} a)	1.335	1.335	1.335	1.335	1.335	1.335	1.335	1.335	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	50	50	50	50	50	50	50	50	
PHES interface	Capex	€/(kWh _{el})	650	650	650	650	650	650	650	650	[7]
	Opex fix	€/(kWh _{el} a)	0	0	0	0	0	0	0	0	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	50	50	50	50	50	50	50	50	
A-CAES	Capex	€/(kWh _{el})	35	35	32.6	31.1	30.3	29.8	27.7	26.3	[7]
	Opex fix	€/(kWh _{el} a)	0.53	0.53	0.50	0.47	0.46	0.45	0.42	0.40	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	40	55	55	55	55	55	55	55	
A-CAES interface	Capex	€/(kWh _{el})	600	600	558	530	518	510	474	450	[7]
	Opex fix	€/(kWh _{el} a)	0	0	0	0	0	0	0	0	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	40	55	55	55	55	55	55	55	
Gas Storage	Capex	€/(kWh _{el})	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	[21]
	Opex fix	€/(kWh _{el} a)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
	Opex var	€/(kWh _{el})	0	0	0	0	0	0	0	0	
	Lifetime	years	50	50	50	50	50	50	50	50	
Gas Storage interface	Capex	€/(kW _{th})	25.8	25.8	25.8	25.8	25.8	25.8	25.8	25.8	[21]
	Opex fix	€/(kW _{th} a)	31	31	31	31	31	31	31	31	
	Opex var	€/(kW _{th})	36.2	36.2	36.2	36.2	36.2	36.2	36.2	36.2	

	Lifetime	years	41.4	41.4	41.4	41.4	41.4	41.4	41.4	41.4	
Hot Heat Storage	Capex	€/(kWh _{th})	50.8	41.8	32.7	26.8	23.3	21	19.3	17.5	[3]
	Opex fix	€/(kWh _{th} a)	0.76	0.63	0.49	0.4	0.35	0.32	0.29	0.26	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	25	25	25	25	30	30	30	30	
District Heat Storage	Capex	€/(kWh _{th})	50	40	30	30	25	20	20	20	[3]
	Opex fix	€/(kWh _{th} a)	0.8	0.6	0.5	0.5	0.4	0.3	0.3	0.3	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	25	25	25	25	30	30	30	30	
Hydrogen Storage	Capex	€/(kWh _{th})	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	[22]
	Opex fix	€/(kWh _{th} a)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	15	15	15	15	15	15	15	
Hydrogen Storage interface	Capex	€/(kW _{th})	255.9	255.9	255.9	255.9	255.9	255.9	255.9	255.9	[22]
	Opex fix	€/(kW _{th} a)	10.23	10.23	10.23	10.23	10.23	10.23	10.23	10.23	
	Opex var	€/(kWh _{th})	0	0	0	0	0	0	0	0	
	Lifetime	years	15	15	15	15	15	15	15	15	
CO ₂ Storage	Capex	€/ton	142	142	142	142	142	142	142	142	[19]
	Opex fix	€/(ton a)	9.94	9.94	9.94	9.94	9.94	9.94	9.94	9.94	
	Opex var	€/ton	0	0	0	0	0	0	0	0	
	Lifetime	years	30	30	30	30	30	30	30	30	
Reverse Osmosis Seawater Desalination	Capex	€/(m ³ /day)	1150	960	835	725	630	550	480	415	[23]
	Opex fix	€/(m ³ /day a)	46	38.4	33.4	29	25.2	22	19.2	16.6	
	Consumption	kWh _{th} /m ³	0	0	0	0	0	0	0	0	
	Lifetime	years	25	25	30	30	30	30	30	30	
	Consumption	kWh _{el} /m ³	4.1	3.6	3.35	3.15	3	2.85	2.7	2.6	
Multi Stage Flash Standalone	Capex	€/(m ³ /day)	2000	2000	2000	2000	2000	2000	2000	2000	[23]
	Opex fix	€/(m ³ /day a)	100	100	100	100	100	100	100	100	
	Consumption	kWh _{th} /m ³	85	85	85	85	85	85	85	85	
	Lifetime	years	25	25	25	25	25	25	25	25	
	Consumption	kWh _{el} /m ³	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
Multi Stage Flash Cogeneration	Capex	€/(m ³ /day)	3069	3069	3069	3069	3069	3069	3069	3069	[3]
	Opex fix	€/(m ³ /day a)	121.4	121.4	121.4	121.4	121.4	121.4	121.4	121.4	
	Consumption	kWh _{th} /m ³	202.5	202.5	202.5	202.5	202.5	202.5	202.5	202.5	
	Lifetime	years	25	25	25	25	25	25	25	25	
	Consumption	kWh _{el} /m ³	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
Multi Effect Distillation	Capex	€/(m ³ /day)	1438	1200	1044	906.3	787.5	687.5	600	518.8	[23]
	Opex fix	€/(m ³ /day a)	47.44	39.60	34.44	29.91	25.99	22.69	19.80	17.12	

Standalone	Consumption	kWh _{th} /m ³	68	51	44	38	32	28	28	28	[3]
	Lifetime	years	25	25	25	25	25	25	25	25	
	Consumption	kWh _{el} /m ³	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Multi Effect Distillation Cogeneration	Capex	€/(m ³ /day)	2150	2150	2150	2150	2150	2150	2150	2150	[3]
	Opex fix	€/(m ³ /day a)	61.69	61.69	61.69	61.69	61.69	61.69	61.69	68.81	
	Consumption	kWh _{th} /m ³	168	168	168	168	168	168	168	168	
	Lifetime	years	25	25	25	25	25	25	25	25	
	Consumption	kWh _{el} /m ³	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Water Storage	Capex	€/m ³	64.59	64.59	64.59	64.59	64.59	64.59	64.59	64.59	[23]
	Opex fix	€/(m ³ a)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	
	Opex var	€/m ³	0	0	0	0	0	0	0	0	
	Lifetime	years	50	50	50	50	50	50	50	50	

Table S9: Energy to power ratio and self-discharge rates of storage technologies. In the case of Energy/Power ratios, the values are by 2050, as a result of the optimisation.

Technology	Efficiency [%]	Self-Discharge [%/h]	Sources
Battery	90	0	[21]
PHES	85	0	[7]
A-CAES	70	0.1	[7]
TES	90	0.2	[21]
Gas storage	100	0	[21]

Table S10: Financial assumptions for the fossil-nuclear fuel prices and GHG emission cost

Component	Unit	2015	2020	2025	2030	2035	2040	2045	2050	Sources
Coal	€/MWh _{th}	7.7	7.7	8.4	9.2	10.2	11.1	11.1	11.1	[24]
Fuel oil	€/MWh _{th}	52.5	35.2	39.8	44.4	43.9	43.5	43.5	43.5	[13]
Fossil gas	€/MWh _{th}	21.8	22.2	30.0	32.7	36.1	40.2	40.2	40.2	[24]
Uranium	€/MWh _{th}	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	[11]
GHG emissions	€/tCO _{2eq}	9	28	52	61	68	75	100	150	[24]
GHG emissions by fuel type										
Coal			tCO _{2eq} /MWh _{th}				0.34	[25]		
Oil			tCO _{2eq} /MWh _{th}				0.25	[25]		
Fossil gas			tCO _{2eq} /MWh _{th}				0.21	[26]		

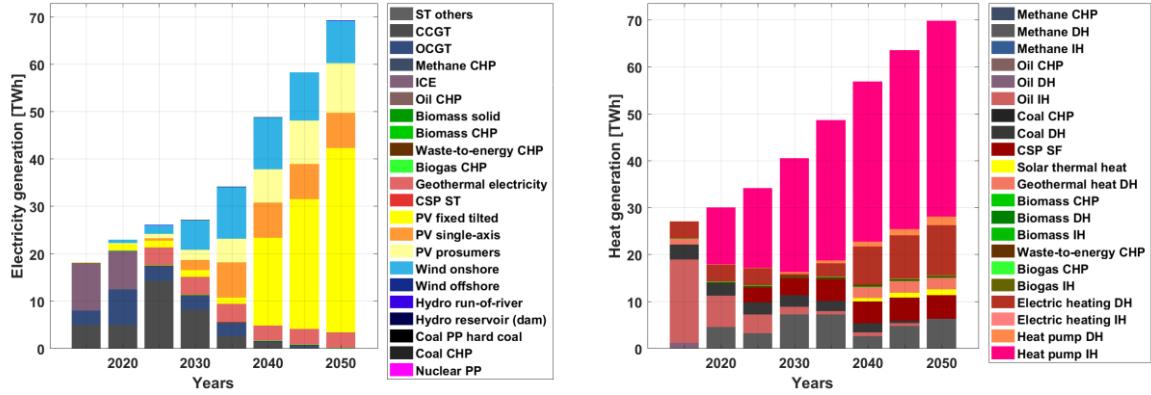


Figure S6: Electricity generation (left) and heat generation (right) for power and heat sectors during the transition for Jordan.

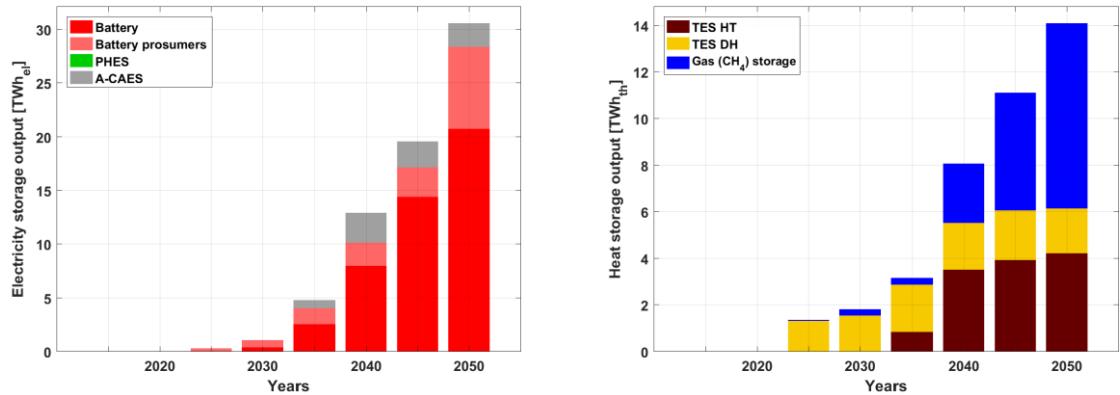


Figure S7: Electricity storage output (left) and heat storage output (right) for power and heat sectors during the transition for Jordan.

Table S11: Installed capacity – power and heat sectors.

Biomass solid	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biogas dig	GW	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.05
Biogas Upgrade	GW	0.00	0.00	0.01	0.03	0.03	0.03	0.03	0.03
Coal PP hard coal	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE	GW	1.36	1.09	0.82	0.82	0.00	0.00	0.00	0.00
Nuclear PP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methane CHP	GW	0.00	0.00	0.04	0.04	0.04	0.04	0.04	0.04
Oil CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste-to-energy CHP	GW	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.02
Biogas CHP	GW	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.05
Electric heating DH	GW	0.70	0.70	0.70	0.68	1.78	2.81	3.02	3.25
Heat pump DH	GW	0.00	0.00	0.02	0.12	0.18	0.27	0.31	0.39
Methane DH	GW	0.00	1.25	1.25	1.25	1.25	1.25	1.25	1.57
Oil DH	GW	0.69	0.59	0.56	0.54	0.47	0.42	0.27	0.00
Coal DH	GW	0.38	0.33	0.31	0.30	0.26	0.24	0.15	0.00
Biomass DH	GW	0.00	0.00	0.01	0.01	0.01	0.02	0.05	1.10
Solar thermal heat	GW	0.00	0.00	0.00	0.00	0.02	0.35	0.53	0.68
Geothermal heat DH	GW	0.15	0.00	0.00	0.00	0.00	0.29	0.29	0.29
Electric heating IH	GW	2.74	2.74	2.19	1.64	1.09	0.55	0.00	0.36
Heat pump IH	GW	0.00	3.09	5.36	9.77	13.99	16.40	19.73	31.43
Methane IH	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Oil IH	GW	12.31	7.45	7.45	7.45	7.55	9.63	9.98	9.98
Biomass IH	GW	0.08	0.06	0.05	0.06	0.10	0.10	0.10	0.26
Biogas IH	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Battery prosumers RES	GWh	0.00	0.00	0.60	1.57	4.02	6.25	8.30	9.44
Battery prosumers COM	GWh	0.00	0.00	0.15	0.40	1.08	1.70	2.29	2.59
Battery prosumers IND	GWh	0.00	0.00	0.18	0.38	0.83	1.19	1.55	1.81
Battery	GWh	0.00	0.00	0.00	0.70	6.98	20.42	35.81	52.73
PHES	GWh	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TES HT	GWh	0.00	0.00	0.00	0.00	7.00	13.97	14.54	15.28
TES DH	GWh	0.00	0.00	4.23	4.74	6.08	6.59	7.07	6.33
A-CAES	GWh	0.00	0.00	0.00	0.00	4.43	15.40	15.40	22.09
Gas (CH4) storage	GWh	0.00	0.00	0.48	2.61	2.66	895.82	1175.05	2892.98

Table S12: Installed capacity – transport sector.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
PV prosumers	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PV fixed tilted	GW	0.00	0.02	0.35	1.75	3.61	7.86	11.21	14.15
PV single-axis	GW	0.00	0.02	0.19	0.19	0.19	2.45	5.17	9.91
CSP ST	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind onshore	GW	0.00	0.01	0.18	0.25	0.30	0.30	0.30	0.12
Wind offshore	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro run-of-river	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro reservoir (dam)	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geothermal electricity	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CCGT	GW	0.02	0.10	0.10	0.10	0.10	0.10	0.10	0.08
OCGT	GW	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
ST others	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass solid	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal PP hard coal	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nuclear PP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methane CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste-to-energy CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biogas CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water electrolysis	GW _{el}	0.00	0.00	0.01	0.06	0.29	3.41	6.39	10.10
Water electrolysis	GW _{H2}	0.00	0.00	0.01	0.05	0.24	2.86	5.37	8.48
CO ₂ DAC	MtCO ₂ /a	0.00	0.00	0.00	0.00	0.00	0.57	0.57	1.50
Methanation	GW _{CH4}	0.00	0.00	0.00	0.00	0.02	0.02	0.09	0.25
Fischer–Tropsch	GW _{liq}	0.00	0.00	0.00	0.00	0.00	0.62	1.04	1.44
Steam reforming	GW _{H2}	0.00	0.00	0.01	0.02	0.05	0.00	0.00	0.00
Battery prosumers	GWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Battery	GWh	0.00	0.00	0.04	1.35	4.66	9.08	13.40	19.07
PHES	GWh	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
A-CAES	GWh	0.00	0.01	2.04	5.40	7.08	7.08	7.08	7.08
TES HT	GWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TES DH	GWh	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Gas (CH ₄) storage	GWh	0.00	0.00	0.00	0.04	0.12	0.12	5.36	27.05

Table S13: Installed capacity – desalination sector.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
PV prosumers	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PV fixed tilted	GW	0.00	0.00	0.00	0.00	1.05	1.80	2.06	3.04
PV single-axis	GW	0.00	0.00	0.03	0.22	0.22	0.22	0.22	0.22
CSP solar field	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind onshore	GW	0.00	0.00	0.00	0.18	0.18	0.18	0.18	0.18
Wind offshore	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro run-of-river	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro reservoir (dam)	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geothermal	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CCGT	GW	0.00	0.02	0.06	0.14	0.14	0.14	0.14	0.14
OCGT	GW	0.00	0.00	0.00	0.19	0.34	0.34	0.34	0.34
Steam turbine	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass solid	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal PP hard coal	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nuclear PP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste-to-energy	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biogas CHP	GW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Battery prosumers	GWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Battery	GWh	0.00	0.00	0.00	0.18	3.57	6.11	7.01	8.37
PHES	GWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A-CAES	GWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TES storage	GWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas (CH4) storage	GWh	0.00	0.00	0.00	0.00	0.06	0.29	0.59	36.06

Table S14: Electricity generation – power and heat sectors.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
PV prosumers RES	GWh	0	120	586	1390	3318	4578	5830	6759
PV prosumers COM	GWh	0	31	149	351	904	1272	1623	1873
PV prosumers IND	GWh	0	35	168	344	776	1244	1667	1915
PV fixed tilted	GWh	57	1384	1384	1384	1383	18436	27436	38892
PV single-axis	GWh	0	0	477	2141	7429	7429	7429	7429
CSP ST	GWh	0	0	0	0	0	0	0	0
Wind onshore	GWh	4	690	1908	6250	10884	10884	10196	8975
Wind offshore	GWh	0	0	0	0	0	0	0	0
Hydro run-of-river	GWh	13	19	19	19	19	19	19	19

Hydro reservoir (dam)	GWh	27	41	41	41	41	41	41	41
Geothermal electricity	GWh	0	0	3847	3847	3847	3244	3244	3244
CCGT	GWh	4978	4978	14330	8205	2686	1539	435	0
OCGT	GWh	3053	7545	2882	2837	2642	244	525	524
ST others	GWh	0	0	0	0	0	0	0	0
Biomass solid	GWh	0	0	0	0	0	0	0	0
Coal PP hard coal	GWh	0	0	0	0	0	0	0	0
ICE	GWh	10089	8098	0	0	0	0	0	0
Nuclear PP	GWh	0	0	0	0	0	0	0	0
Methane CHP	GWh	0	0	217	181	120	64	45	32
Oil CHP	GWh	0	0	0	0	0	0	0	0
Coal CHP	GWh	0	0	0	0	0	0	0	0
Biomass CHP	GWh	0	0	0	0	0	0	0	0
Waste-to-energy CHP	GWh	0	38	76	116	116	116	116	116
Biogas CHP	GWh	53	67	79	33	31	41	63	57

Table S15: Electricity storage output – power and heat sectors.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Battery	TWh	0.00	0.00	0.30	1.08	4.05	10.15	17.13	28.37
PHES	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A-CAES	TWh	0.00	0.00	0.00	0.00	0.75	2.79	2.45	2.20
TES	TWh	0.00	0.00	0.00	0.00	0.85	3.52	3.93	4.22
Gas (CH4) storage	TWh	0.00	0.00	0.05	0.27	0.28	2.55	5.05	7.94

Table S16: Heat generation – heat sector.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Methane CHP	GWh	0	0	152	129	86	46	33	23
Oil CHP	GWh	0	0	0	0	0	0	0	0
Coal CHP	GWh	0	0	0	0	0	0	0	0
CSP SF	GWh	0	0	3243	3668	4567	4588	4949	4976
Biomass CHP	GWh	0	0	0	0	0	0	0	0
Waste-to-energy CHP	GWh	0	38	76	116	116	116	116	116
Biogas CHP	GWh	53	67	79	33	31	41	63	57
Electric heating DH	GWh	0	0	152	129	86	46	33	23
Heat pump DH	GWh	0	0	0	0	0	0	0	0
Methane DH	GWh	0	0	0	0	0	0	0	0
Oil DH	GWh	0	0	0	0	0	0	0	0
Coal DH	GWh	0	104	194	294	288	313	314	311

Biomass DH	GWh	66	84	92	39	35	52	79	71
Solar thermal heat	GWh	0	0	3243	3668	4567	4588	4949	4976
Geothermal heat DH	GWh	1276	0	0	0	0	2445	2445	2445
Electric heating IH	GWh	1	63	27	8	2	1	0	13
Heat pump IH	GWh	0	12157	17025	24253	29887	34142	38165	41663
Methane IH	GWh	0	0	0	0	0	0	0	34
Oil IH	GWh	17755	6641	4027	1596	760	904	626	0
Biomass IH	GWh	42	42	42	43	48	48	48	46
Biogas IH	GWh	0	0	0	0	47	677	1014	1296

Table S17: Heat storage output – heat sector.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
TES HT	TWh	0.00	0.00	0.00	0.00	0.85	3.52	3.93	4.22
TES DH	TWh	0.00	0.00	1.33	1.56	2.04	2.01	2.14	1.94
Gas (CH4) storage	TWh	0.00	0.00	0.05	0.27	0.28	2.55	5.05	7.94

Table S18: Electricity generation – transport sector.

Waste-to-energy CHP	GWh	0	0	0	0	0	0	0	0
Biogas CHP	GWh	0	0	0	0	0	0	0	0

Table S19: Electricity storage output – transport sector.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Battery	TWh	0.00	0.00	0.02	0.55	1.86	3.48	5.29	7.50
PHEs	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A-CAES	TWh	0.00	0.00	0.43	1.33	1.90	1.86	1.75	1.76
TES	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas (CH4) storage	TWh	0.00	0.00	0.00	0.00	0.08	0.04	0.35	1.80

Table S20: Sustainable fuels production (output) – transport sector.

Technology	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Electrolyser	GWh	0	0	19	179	894	9133	16974	26415
Methanation	GWh	0	0	0	1	80	38	349	1803
FT	GWh	0	0	0	0	1	4262	7654	10324
FT Kerosene	GWh	0	0	0	0	1	852	1531	3136
FT diesel	GWh	0	0	0	0	1	2557	4592	5123
FT naphtha	GWh	0	0	0	0	0	852	1531	2065
LNG	GWh	0	16	36	84	147	291	707	1779
LH2	GWh	0	0	0	37	173	728	2167	4868

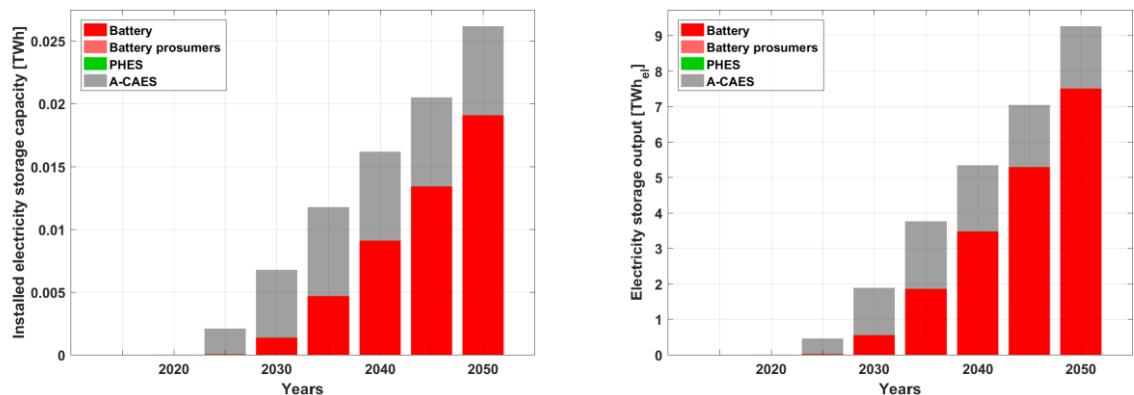


Figure S8: Transport sector - Installed storage generation capacity (left) and storage output (right) for transport sector from 2015 to 2050 for Jordan.

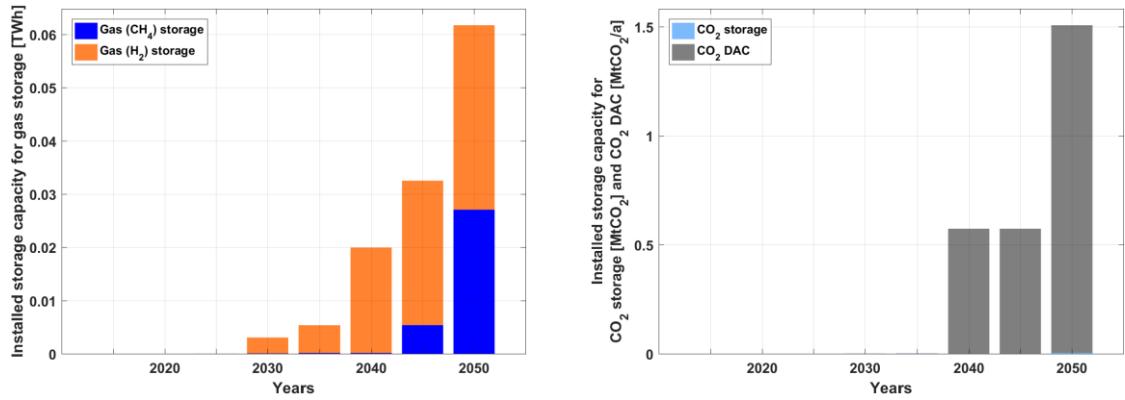


Figure S9: Transport sector - Installed capacity for gas storage (left) and CO₂ direct air capture and CO₂ storage (right). It should be noted that the capacities for the CO₂ direct air capture and CO₂ storage are not summed up, but only presented in one figure due to the connection between these two technologies.

Table S21: Electricity generation – desalination sector.

Table S22: Electricity storage output – desalination sector.

TES storage	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas (CH4) storage	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07

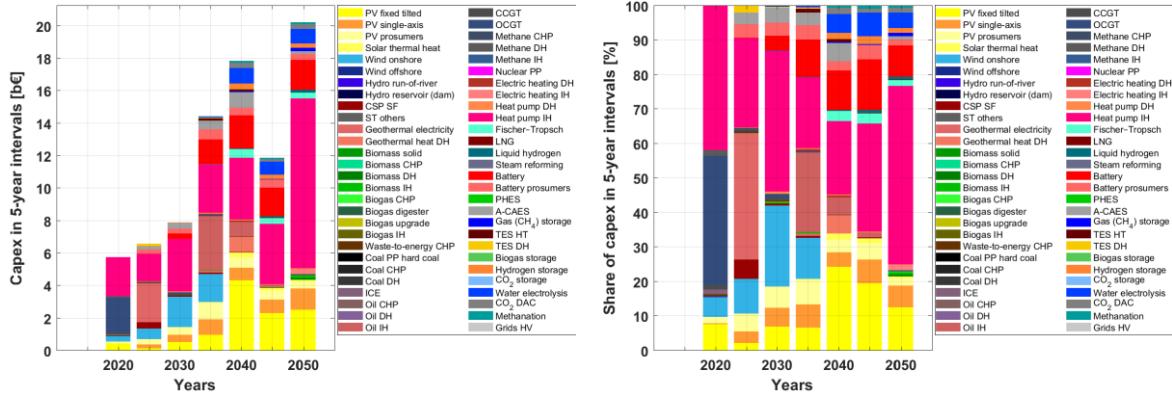


Figure S10: Integrated sector – Capital expenditure for five-year intervals presented in absolute (left) and shares (right).

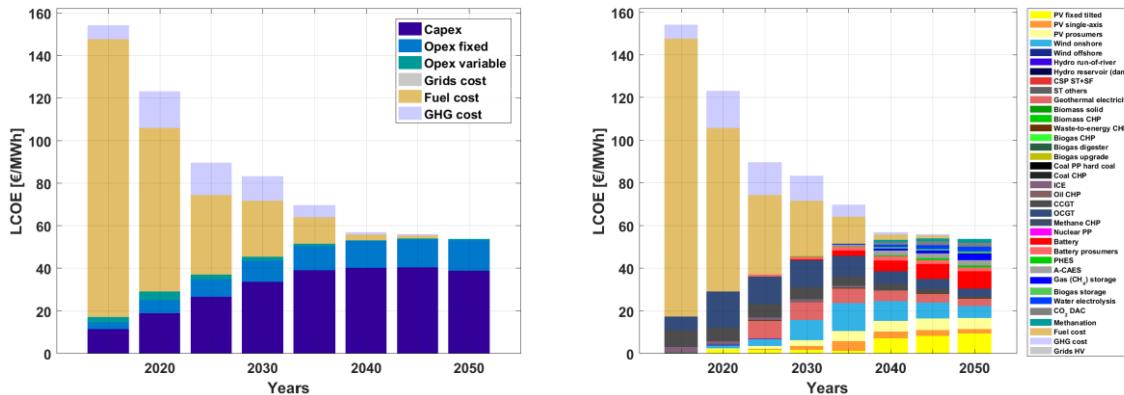


Figure S11: Power sector – Levelised cost of electricity by main cost categories (left) and technologies (right).

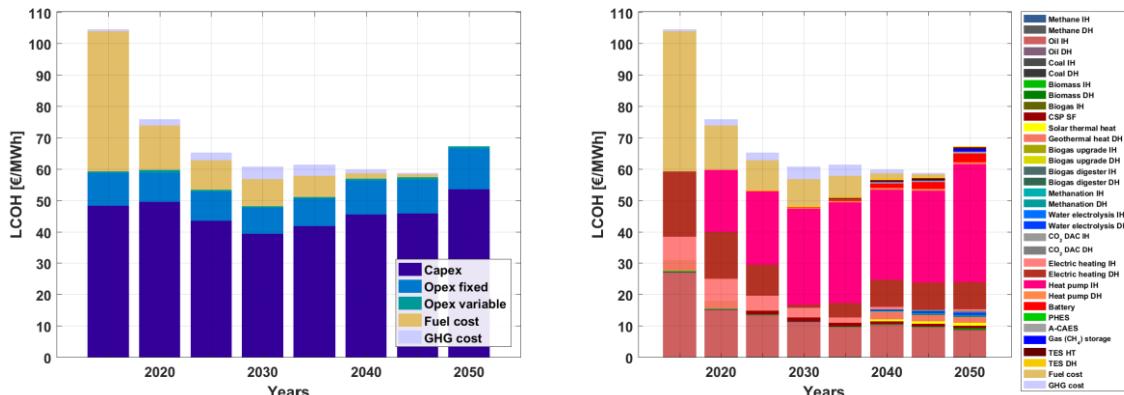


Figure S12: Heat sector – Levelised cost of heat by main cost category (left) and technologies (right).

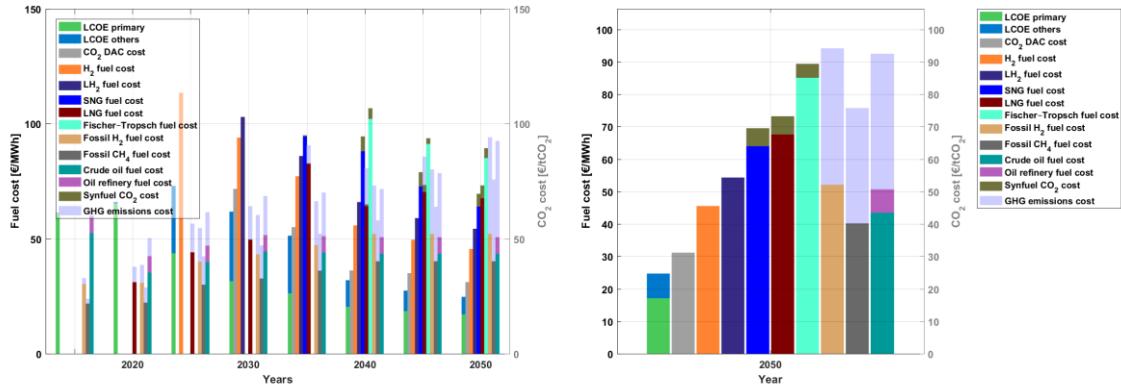


Figure S13: Fuel costs for the transport sector during the transition period (left) and fuel costs in 2050 (right).

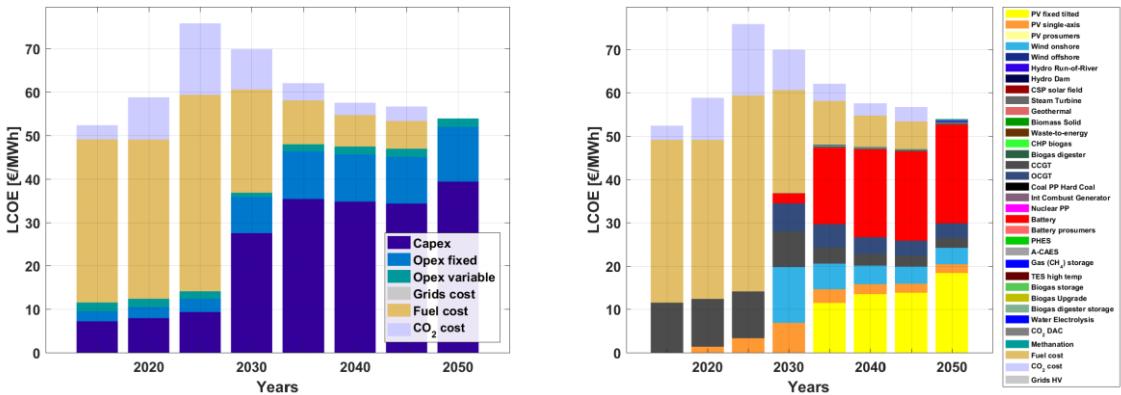


Figure S14: Desalination sector – Levelised cost of electricity by main cost categories (left) and technologies (right).

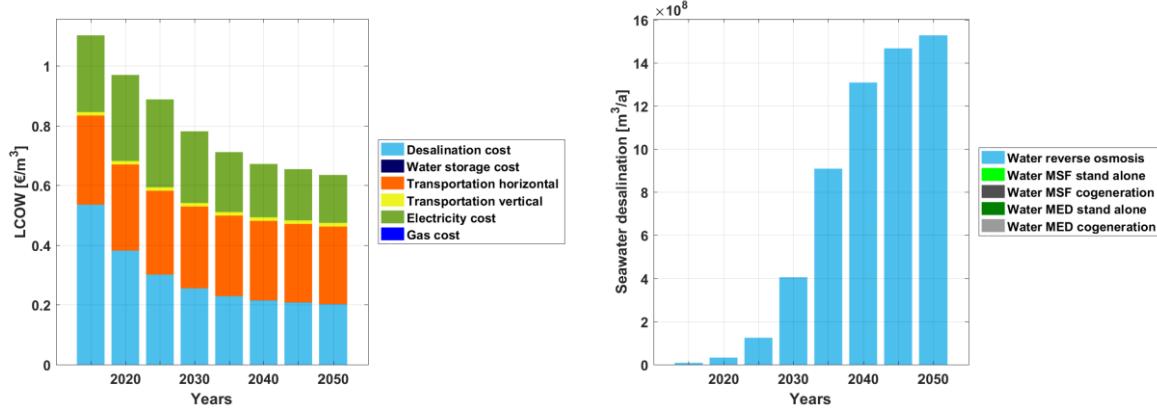


Figure S15: Desalination sector – Levelised cost of water by main cost categories (left) and seawater desalination production by technology (right).

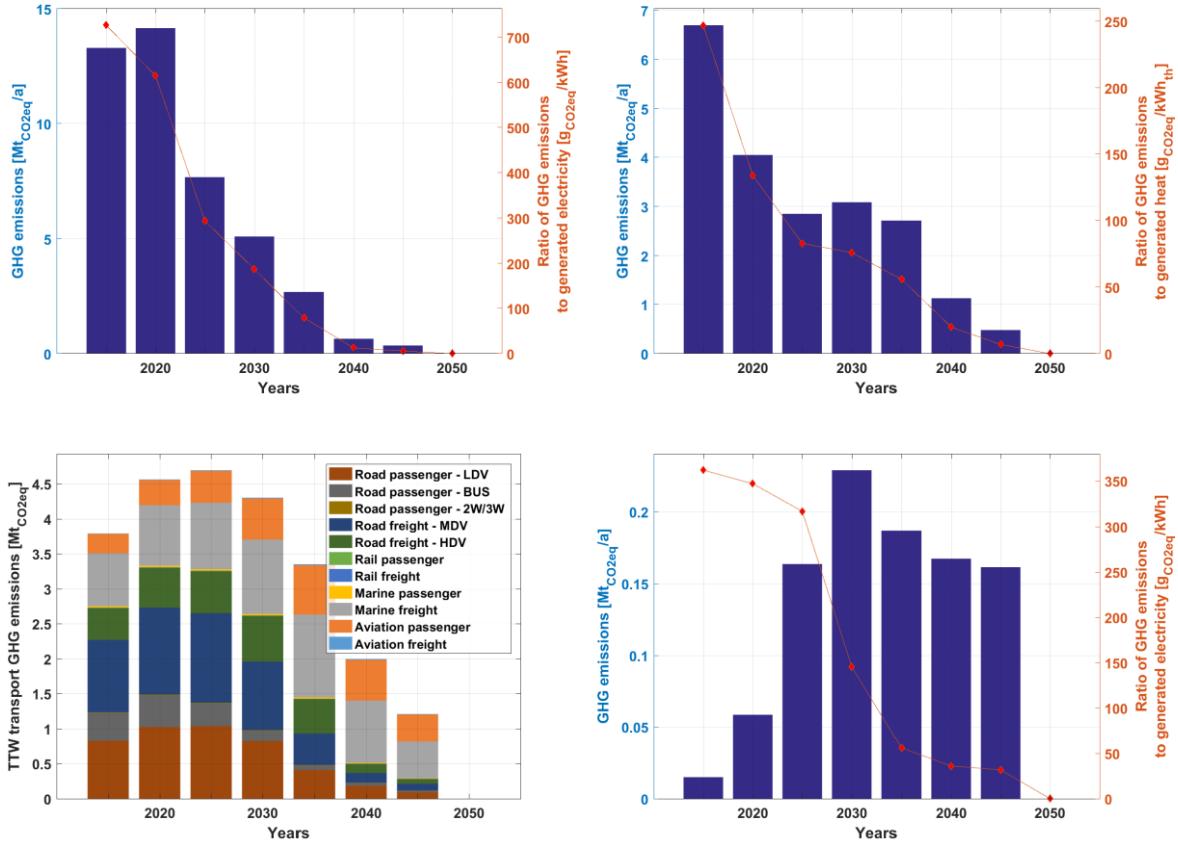


Figure S16: GHG emissions for power (top left), heat (top right), transport (bottom left) and desalination (bottom right) sectors during the transition from 2015 to 2050.

Sectoral employment

Total direct jobs in the power sector increase substantially from over 5000 jobs in 2015 to around 40,000 jobs by 2050. Solar PV emerges as the prime job creator, as the transition from fossil fuels based power system to a completely solar PV dominated system occurs during the transition, as illustrated by Figure S17 (left). Similarly, in the heat sector the transition away from fossil fuels based heat towards electric, heat pumps and bioenergy based heating creates more jobs through the transition up to nearly 50,000 direct jobs in 2050 as shown in Figure S17 (right). Heat pumps emerge as the most prominent job creator in the heat sector.

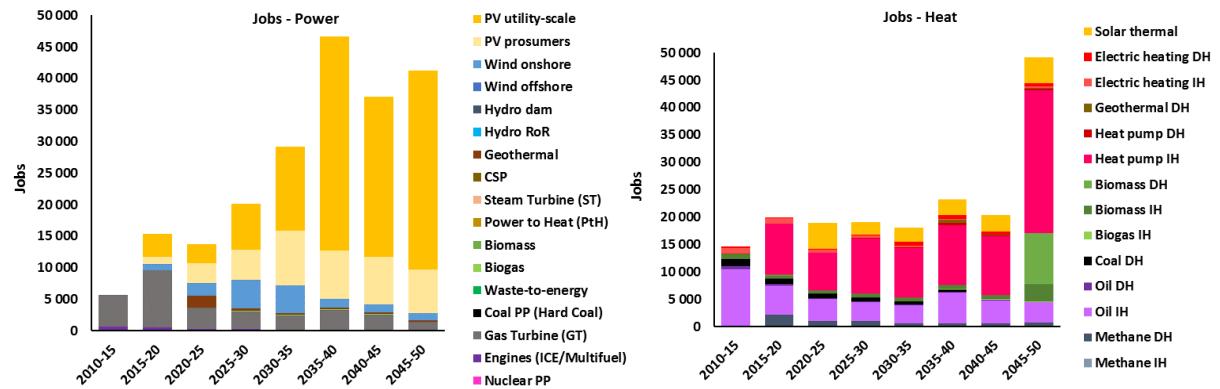


Figure S17: Jobs created by the various power generation technologies (left) and jobs created by the different heat generation technologies (right) during the energy transition from 2015 to 2050 in Jordan.

Storage technologies play a key role in complementing renewable electricity generation and enhance sectoral integration with flexibility options. Storage jobs are created from 2025 onwards through the transition, as highlighted by Figure S18 (left). Battery storage technologies provide the bulk of the jobs, as they emerge as the

most abundant storage option. As synthetic fuels production picks up from 2030 onwards, jobs are created mostly in the later part of the transition as highlighted by Figure S18 (right).

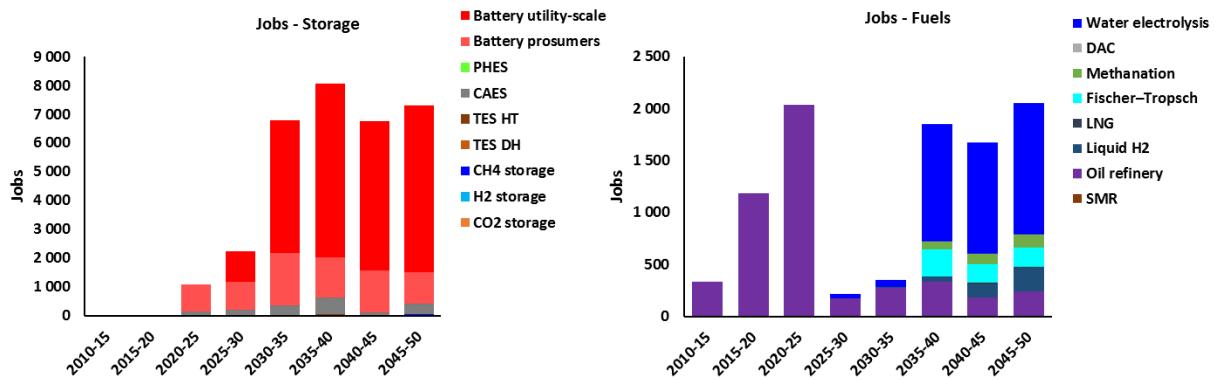


Figure S18: Jobs created by the various storage technologies (left) and jobs created by the different fuel production technologies (right) during the energy transition from 2015 to 2050 in Jordan.

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Abbreviations

A-CAES	Adiabatic compressed air energy storage
CAPEX	Capital expenditures
CCS	Carbon capture and storage
CCGT	Combined cycle gas turbine
CHP	Combined heat and power
CO ₂	Carbon dioxide
CSP	Concentrated solar thermal power
DAC	CO ₂ Direct air capture
DH	District heating
FT	Fischer-Tropsch
GHG	Greenhouse gas
GT	Gas turbine
GW	Gigawatt
HDV	Heavy duty vehicle
HHB	Hot heat burner
HT	High temperature
HVAC	High voltage alternating current

HVDC	High voltage direct current
ICE	Internal combustion engine
IH	Individual heating
LCOC	Levelised Cost of Curtailment
LCOE	Levelised Cost of Energy
LCOH	Levelised Cost of Heat
LCOS	Levelised Cost of Storage
LCOW	Levelised Cost of Water
LDV	Light duty vehicle
LNG	Liquefied natural gas
LT	Low temperature
LUT	Lappeenranta University of Technology
MDV	Medium duty vehicle
MT	Medium temperature
MW	Megawatt
MWh	Megawatt hour
OCGT	Open cycle gas turbine
OECD	Organization for Economic Co-operation and Development
OPEX	Operational expenditures
PHES	Pumped hydro energy storage
PP	Power plant
PtG	Power-to-gas
PtH	Power-to-heat
p-km	passenger kilometre
PV	Photovoltaic
SF	Solar Field
SNG	Synthetic natural gas
ST	Steam turbine
TES	Therma energy storage
TTW	Tank-to-wheel
TWh	Terawatt hour
t-km	tonne kilometre
2W	two wheelers
3W	three wheelers
€	Euro