Electronic Supplementary Information

Assessing the undesired impacts on water sustainability from climate change mitigation technologies in fossil-based power generation

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1 Terminology

Table ESI 1: Terminology used in this work

Term	Descriptions as used in this work
Water withdrawal	Water consumption represents a “direct measurable impact” and is the **net** “amount of water that is evaporated, transpired, incorporated into products or crops or otherwise removed from the immediate water environment” (1). It is the volume of water that is made unavailable to other users as a result of the process (2).
Water consumption	Water withdrawal represents a “regional water impact” as water may be returned to the water body for reuse(2) (called discharge). It is the **gross** “amount of water removed from the ground or diverted from a water source” (1). The reporting of consumption is often favoured over withdrawal(3).
Process water discharge	In this work, process water discharge is the difference between withdrawal and consumption.
Water usage	In this work “water usage” refers to both water consumption and withdrawal.
Water scarcity/Water stress	Water scarcity, sometimes referred to as water stress, is often defined as the ratio of demand of water to what is available. Pfister et al. (4) define this in their work as WTA, which is the ratio of total withdrawals from different users for each watershed to annual freshwater availability. The Water Stress Index (WSI), developed by Pfister et al. (4) is calculated as a function of a modified water stress (WTA*) $$WSI = \frac{1}{1 + e^{-6.4WTA^*}\left(\frac{1}{0.01} - 1\right)} \qquad (1)$$ where WTA* is the product of the variation factor (VF) and the ratio of total annual freshwater withdrawals and hydrological availability. The VF distinguishes watersheds that have strongly regulated flows (SRF) and non-SRF:

Term	Descriptions as used in this work
	$$WTA^* = \begin{cases} \sqrt{VF} \times WTA, & \text{for SRF} \\ VF \times WTA, & \text{for non - SRF} \end{cases} \quad (2)$$ and $$WTA_i = \frac{\sum_i WU_{ij}}{WA_i} \quad (3)$$ where WA_i is annual freshwater availability and WU_{ij} is withdrawals for different users j, for each watershed i. WTA data values(5) are rated between 0 and 5, 0 being low water stress and 5 being high water stress (Luck, Landis and Gassert (5).

2 Final Green Case Data Set

The final green case data set includes the detailed water usage results described in the method as well as data from Adams *et al.* (6)

Notes:

a. CO_2 equivalent emissions avoided is calculated using a base case. This column notes which base case was used in the calculation.
b. CO_2 equivalent emissions avoided is calculated as the difference between the "*Total Cradle-To-Plant Exit Greenhouse Gas Emissions*" of the base case and the green case
c. Estimated from base case fuel cycle water usage data and green case heat rate
d. Estimated from technology reference case operations water usage data and green case heat rate.

Table ESI 2: Final green case data set

Tag	Technology/Process	Net Plant output	As-Reported Electrical Efficiency (%HHV)	Heat Rate (MJ/MWh)	Percentage of CO_2 Removed	Direct Greenhouse Gas Emissions	Total Cradle-To-Plant Exit Greenhouse Gas Emissions	CO_2 Equivalent Emissions Avoided (GHG emissions avoided)		Fuel Cycle		Operations Cooling		Operations Process		Fuel + Operations	Fuel + Operations	Process water discharge
										Water Withdrawal	Water consumption	Water Withdrawal	Water consumption	Water Withdrawal	Water consumption	Total withdrawal	Total consumption	
Data from Adams *et al.* (6)								Note a	Note b	Note c	Note c	Note d	Note d	Note d	Note d			
		MWe	%HHV	MJ/MWh	%	(tCO_2e/MWh)	(tCO_2e/MWh)		t CO_2e/MWh avoided	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh
SCPC-2	Solvent Based	525	27.4	13139	90	0.215	0.327	SCPC	0.62	0.32	0.31	3.29	2.41	0.57	0.56	4.18	3.28	0.89
SCPC-3	Solvent Based - Adv.amine	837	36.1	9972	90	0.190	0.275	SCPC	0.68	0.24	0.24	2.50	1.83	0.44	0.43	3.17	2.49	0.68
SCPC-4	Solvent Based - Cansolv	822	33.8	10651	90	0.188	0.279	SCPC	0.67	0.26	0.25	2.67	1.95	0.46	0.46	3.39	2.66	0.73
SCPC-5	Solvent Based - Amine	546	27.2	13235	90	0.210	0.323	SCPC	0.63	0.32	0.31	3.31	2.43	0.58	0.57	4.21	3.31	0.90
SCPC-6	Solvent Based - Adv.Amine	616	36.5	9863	90	0.187	0.271	SCPC	0.68	0.24	0.23	2.47	1.81	0.43	0.42	3.14	2.46	0.67
SCPC-7	Solvent based-Chilled Ammonia	549	28.4	12676	90	0.205	0.314	SCPC	0.64	0.31	0.30	3.17	2.32	0.55	0.54	4.03	3.17	0.86
SCPC-8	Solvent based-Chilled Ammonia	549	31.5	11429	90	0.194	0.292	SCPC	0.66	0.28	0.27	2.86	2.10	0.50	0.49	3.63	2.86	0.78
SCPC-9	Solvent based-Chilled Ammonia	559	27.9	12903	90	0.215	0.325	SCPC	0.63	0.31	0.31	3.23	2.37	0.56	0.55	4.10	3.22	0.88
SCPC-10	Solvent based-Chilled Ammonia	614	36.6	9836	88.4	0.192	0.276	SCPC	0.67	0.24	0.23	2.46	1.80	0.43	0.42	3.13	2.46	0.67
SCPC-11	Solvent Based-Amine	519	25.6	14063	94	0.171	0.291	SCPC	0.66	0.34	0.33	3.52	2.58	0.61	0.60	4.47	3.51	0.96
IGCC-1	Solvent Based-Selexol	543	32.6	11043	90	0.147	0.241	SCPC	0.71	0.27	0.26	1.92	1.48	0.55	0.55	2.74	2.29	0.45
IGCC-2	Solvent Based-Selexol	513	31.0	11613	90	0.152	0.251	SCPC	0.70	0.28	0.27	2.02	1.55	0.58	0.58	2.88	2.40	0.48
IGCC-4	Data not available	500	29.9	12040	86	0.204	0.307	SCPC	0.64	0.29	0.28	2.09	1.61	0.60	0.60	2.99	2.49	0.49
IGCC-5	Solvent Based-Selexol NS	694	32.0	11250	90	0.145	0.241	SCPC	0.71	0.27	0.27	1.96	1.50	0.56	0.56	2.79	2.33	0.46
IGCC-6	Solvent Based - Shift + Selexol	455	35.1	10256	94	0.110	0.197	SCPC	0.75	0.25	0.24	1.78	1.37	0.51	0.51	2.54	2.12	0.42
COXY-1	Oxy-fuel	376.1	34.3	10493	91	0.071	0.160	SCPC	0.79	0.25	0.25	1.59	1.14	0.13	0.13	1.98	1.52	0.46
COXY-2	Oxy-fuel	352.9	32.2	11180	90	0.083	0.178	SCPC	0.77	0.27	0.26	1.70	1.22	0.14	0.14	2.11	1.62	0.49
COXY-3	Oxy-fuel	670.3	34.7	10369	94	0.048	0.136	SCPC	0.81	0.25	0.25	1.58	1.13	0.13	0.13	1.95	1.50	0.45

Tag	Technology/Process	Net Plant output	As-Reported Electrical Efficiency (%HHV)	Heat Rate (MJ/MWh)	Percentage of CO_2 Removed	Direct Greenhouse Gas Emissions	Total Cradle-To-Plant Exit Greenhouse Gas Emissions	CO_2 Equivalent Emissions Avoided (GHG emissions avoided)		Fuel Cycle		Operations Cooling		Operations Process		Fuel + Operations	Fuel + Operations	Process water discharge
										Water Withdrawal	Water consumption	Water Withdrawal	Water consumption	Water Withdrawal	Water consumption	Total withdrawal	Total consumption	
Data from Adams *et al.* (6)								**Note a**	**Note b**	**Note c**	**Note c**	**Note d**	**Note d**	**Note d**	**Note d**			
		MWe	**%HHV**	**MJ/MWh**	**%**	**(tCO_2e/MWh)**	**(tCO_2e/MWh)**		**t CO_2e/MWh avoided**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**	**m^3/MWh**
COXY-4	Oxy fuel with 10% air added	669.3	34.7	10384	94	0.048	0.137	SCPC	0.81	0.25	0.25	1.58	1.13	0.13	0.13	1.96	1.50	0.45
COXY-5	Oxy fuel with 20% air added	666.2	34.5	10432	94	0.048	0.137	SCPC	0.81	0.25	0.25	1.59	1.13	0.13	0.13	1.97	1.51	0.46
COXY-6	Oxy fuel with 30% air added	661.2	34.3	10511	94	0.048	0.138	SCPC	0.81	0.25	0.25	1.60	1.14	0.13	0.13	1.98	1.52	0.46
COXY-7	Oxy fuel with 40% air added	654.1	33.9	10626	94	0.049	0.140	SCPC	0.81	0.26	0.25	1.62	1.15	0.13	0.13	2.00	1.54	0.46
COXY-8	Oxy fuel with 50% air added	645.1	33.4	10775	94	0.050	0.142	SCPC	0.81	0.26	0.26	1.64	1.17	0.13	0.13	2.03	1.56	0.47
COXY-9	Oxy-fuel	238.5	32.3	11149	90	0.136	0.231	SCPC	0.72	0.27	0.26	1.69	1.21	0.14	0.14	2.10	1.61	0.49
COXY-10	Oxy-fuel	533.2	32.7	10996	93	0.053	0.147	SCPC	0.80	0.27	0.26	1.67	1.20	0.14	0.14	2.07	1.59	0.48
COXY-11	Oxy-fuel with compression and dehydration	310.0	33.8	10648	100	0.000	0.091	SCPC	0.86	0.26	0.25	1.62	1.16	0.13	0.13	2.01	1.54	0.47
COXY-12	Oxy-fuel with double flash purification	270.6	29.5	12199	92	0.085	0.189	SCPC	0.76	0.29	0.29	1.85	1.33	0.15	0.15	2.30	1.77	0.53
COXY-13	Oxy-fuel with distillation purification	265.8	29.0	12418	90	0.108	0.214	SCPC	0.74	0.30	0.29	1.89	1.35	0.15	0.15	2.34	1.80	0.54
COXY-14	Oxy-fuel	574	36.6	9836	90	0.119	0.203	SCPC	0.75	0.24	0.23	1.50	1.07	0.12	0.12	1.85	1.42	0.43
COXY-16	Oxy-fuel (Case: S22F)	549.0	30.1	11960	90.9	0.099	0.201	SCPC	0.75	0.29	0.28	1.38	0.87	0.14	0.14	1.81	1.29	0.52
COXY-17	Oxy-fuel (Boiler type & Coal rank: USC-subbit)	509.0	31.5	11429	90	0.105	0.203	SCPC	0.75	0.28	0.27	1.74	1.24	0.14	0.14	2.15	1.65	0.50
COXY-18	Oxy-fuel (Boiler type & Coal rank: SCPC-bit)	501.0	31.0	11613	98	0.021	0.120	SCPC	0.83	0.28	0.27	1.77	1.26	0.14	0.14	2.19	1.68	0.51
COXY-19	Oxy-fuel (Boiler type & Coal rank: SCPC-bit)	510.0	31.5	11429	90	0.105	0.203	SCPC	0.75	0.28	0.27	1.74	1.24	0.14	0.14	2.15	1.65	0.50
COXY-20	Oxy-fuel (Boiler type & Coal rank: USC-subbit)	833.0	34.1	10557	90	0.092	0.182	SCPC	0.77	0.25	0.25	1.60	1.15	0.13	0.13	1.99	1.53	0.46
COXY-21	Oxy-combustion Supercritical PC with CO2 Capture	550.0	29.3	12287	99.5	0.000	0.105	SCPC	0.85	0.30	0.29	1.87	1.34	0.15	0.15	2.32	1.78	0.54
COXY-22	Oxy-combustion Supercritical PC with CO2 Capture	555.1	29.5	12203	99.4	0.000	0.104	SCPC	0.85	0.29	0.29	1.85	1.33	0.15	0.15	2.30	1.77	0.53
COXY-23	Oxy-combustion Supercritical PC with CO2 Capture	549.0	29.3	12287	96.9	0.027	0.132	SCPC	0.82	0.30	0.29	1.87	1.34	0.15	0.15	2.32	1.78	0.54
COXY-24	Oxy-combustion Supercritical PC with CO2 Capture	548.7	29.2	12329	85.5	0.076	0.182	SCPC	0.77	0.30	0.29	1.87	1.34	0.15	0.15	2.32	1.78	0.54
COXY-25	Oxy-combustion Ultra-supercritical PC with CO2 Capture	550.0	33.0	10909	99.4	0.000	0.093	SCPC	0.86	0.26	0.26	1.66	1.19	0.14	0.14	2.06	1.58	0.48
COXY-26	Oxy-combustion Ultra-supercritical PC with CO2 Capture	545.3	32.7	11009	93.2	0.060	0.154	SCPC	0.80	0.27	0.26	1.67	1.20	0.14	0.14	2.08	1.59	0.48
IGFC-1	Uses WGS to minimize CO content in SOFC feed	719.0	42.0	8571	100	0.000	0.073	SCPC	0.88	0.21	0.20	0.64	0.39	0.11	0.10	0.96	0.70	0.26
IGFC-2	IGFC-1 but with seasonal SOFC shutdowns to preserve life during low-demand deasons	719.0	42.0	8571	100	0.000	0.073	SCPC	0.88	0.21	0.20	0.64	0.39	0.11	0.10	0.96	0.70	0.26
IGFC-3	IGFC-1 with integrated energy storage	719.0	41.5	8675	100	0.000	0.074	SCPC	0.88	0.21	0.21	0.64	0.39	0.11	0.10	0.97	0.70	0.26
IGFC-4	IGFC-2 with integrated energy storage	719.0	40.6	8867	100	0.000	0.076	SCPC	0.87	0.21	0.21	0.66	0.40	0.12	0.11	0.99	0.72	0.27
IGFC-5	Uses coal syngas directly in SOFC with no WGS	719.0	38.4	9375	100	0.000	0.080	SCPC	0.87	0.23	0.22	0.70	0.43	0.12	0.11	1.05	0.76	0.29
IGFC-6	IGFC-5 with seasonal SOFC shutdowns	719.0	38.4	9373	100	0.000	0.080	SCPC	0.87	0.23	0.22	0.70	0.43	0.12	0.11	1.05	0.76	0.28
IGFC-7	IGFC-5 with integrated energy storage	719.0	38.0	9474	100	0.000	0.081	SCPC	0.87	0.23	0.22	0.70	0.43	0.12	0.11	1.06	0.77	0.29
IGFC-8	IGFC-5 with integrated energy storage	719.0	37.4	9626	100	0.000	0.082	SCPC	0.87	0.23	0.23	0.72	0.44	0.13	0.12	1.07	0.78	0.29

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										Water Withdrawal	Water consumption	Water Withdrawal	Water consumption	Water Withdrawal	Water consumption	Total withdrawal	Total consumption	
	Data from Adams *et al.* (6)							Note a	Note b	Note c	Note c	Note d	Note d	Note d	Note d			
		MWe	%HHV	MJ/MWh	%	(tCO_2e/MWh)	(tCO_2e/MWh)		t CO_2e/MWh avoided	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh	m^3/MWh
IGFC-9	Atm-Pressure IGFC Plant	253.0	49.4	7287	99	0.001	0.064	SCPC	0.89	0.18	0.17	0.54	0.33	0.10	0.09	0.81	0.59	0.22
IGFC-10	Pressurized IGFC	253.0	56.2	6406	99	0.001	0.056	SCPC	0.89	0.15	0.15	0.48	0.29	0.08	0.08	0.71	0.52	0.19
IGFC-11	Partially methanated Syngas IGFC (TREMP)	846.6	44.4	8115	99	0.003	0.072	SCPC	0.88	0.20	0.19	0.60	0.37	0.11	0.10	0.91	0.66	0.25
IGFC-12	Partially methanated Syngas IGFC (HICOM)	925.0	48.5	7425	99	0.006	0.070	SCPC	0.88	0.18	0.18	0.55	0.34	0.10	0.09	0.83	0.60	0.23
IGFC-13	IGFC-DIRECT	865.0	45.3	7943	99	0.007	0.075	SCPC	0.88	0.19	0.19	0.59	0.36	0.10	0.10	0.89	0.64	0.24
IGFC-14	Liquid-tin anode SOFC	93.9	57.2	6294	100	0.000	0.054	SCPC	0.90	0.15	0.15	0.47	0.29	0.08	0.08	0.70	0.51	0.19
NGCC-2	Solvent Based - MEA	789.0	46	7809	90	0.044	0.115	NGCC	0.29	0.07	0.07	1.61	1.21	0.01	0.01	1.69	1.29	0.41
NGCC-3	Solvent Based - Advanced Amine	804.0	47	7660	90	0.043	0.113	NGCC	0.29	0.07	0.07	1.58	1.18	0.01	0.01	1.66	1.26	0.40
NGCC-4	Solvent Based - Econamine FG+	448.9	43	8451	90	0.046	0.123	NGCC	0.28	0.08	0.08	1.74	1.30	0.01	0.01	1.83	1.40	0.44
NGCC-5	Solvent Based - Amine	485.0	42	8491	90	0.045	0.122	NGCC	0.28	0.08	0.08	1.75	1.31	0.01	0.01	1.84	1.40	0.44
NGCC-6	Solvent Based - Amine	389.0	41	8824	94	0.030	0.110	NGCC	0.30	0.08	0.08	1.82	1.36	0.01	0.01	1.92	1.46	0.46
NGFC-1	SOFC base case ($1000/kW installed)	693.0	74	4865	100	0.000	0.044	NGCC	0.36	0.05	0.04	0.55	0.38	0.04	0.04	0.60	0.42	0.18
NGFC-6	Low pressure autothermal reforming (ATR)-six parallel SOFC sections. **(BASELINE CASE1-1)**	550.0	56	6394	-	0.000	0.059	SCPC	0.35	0.06	0.06	0.72	0.49	0.06	0.06	0.67	0.4485	0.22
NGFC-7	Low pressure ATR-eight parallel SOFC sections. ASU oxidant capacity is 58% smaller than the previous case **(CASE 1-7)**	550.0	62	5825	-	0.000	0.053	SCPC	0.35	0.06	0.05	0.66	0.45	0.05	0.05	0.61	0.41	0.20
NGFC-8	High pressure ATR **(CASE 2-1)**	550.0	65	5556	-	0.004	0.055	SCPC	0.35	0.05	0.05	0.63	0.43	0.05	0.05	0.70	0.55	0.15
NGFC-9	High pressure ATR- ASU oxidant capacity is 58% smaller than the previous case **(CASE 2-3)**	550.0	65	5556	-	0.004	0.055	SCPC	0.35	0.05	0.05	0.63	0.43	0.05	0.05	0.48	0.31	0.16
NGFC-10	No ATR **(CASE 3-1)**	550.0	66	5463	-	0.000	0.050	SCPC	0.36	0.05	0.05	0.62	0.42	0.05	0.05	0.52	0.35	0.17

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Notes and references

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