

Supplementary file of the manuscript: Evaluation and Prioritization of Power-Generating Systems Using a Life Cycle Assessment and a Multicriteria Decision-Making Approach

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Table S1: impact categories of the energy systems

Impact category	Unit	Geothermal power plant, 100MW	Hard coal power plant, 100MW	Gas power plant, 100MW	Nuclear power plant, 100MW	Oil power plant, 100MW	Thermal storage system, solar thermal parabolic trough, 100 MW	Wind power plant, 100MW
Global warming	kg CO ₂ eq	6,99E+09	37754853	6219209	7,21E+07	3,20E+07	70824160	40488545
Stratospheric ozone depletion	kg CFC11 eq	2,31E+03	1,162,388	2,564,939	2,77E+01	1,10E+01	252,939	258,806
Ionizing radiation	kBq Co-60 eq	8,40E+08	1497205	268138,1	4,93E+06	1,09E+06	1371305	1970741
Ozone formation, Human health	kg NO _x eq	1,66E+07	125136,7	29515,12	2,14E+05	1,37E+05	206489,8	95094,85
Fine particulate matter formation	kg PM _{2.5} eq	1,30E+07	69499,21	14675,68	1,63E+05	6,67E+04	154442,4	87549,95
Ozone formation, Terrestrial ecosystems	kg NO _x eq	1,69E+07	129615,6	30174,11	2,17E+05	1,41E+05	210524	97855
Terrestrial acidification	kg SO ₂ eq	2,26E+07	131003	32919,9	2,70E+05	1,34E+05	249889,2	142371,5
Freshwater eutrophication	kg P eq	3,01E+06	18983,74	4,677,372	3,22E+04	1,55E+04	18312,34	13143,34
Marine eutrophication	kg N eq	2,46E+05	1,593,349	2,383,919	2,37E+03	1,14E+03	1429,14	5656,58
Terrestrial ecotoxicity	kg 1,4-DCB	7,37E+09	1,42E+08	30872871	4,15E+08	1,24E+08	1,75E+08	4,38E+08
Freshwater ecotoxicity	kg 1,4-DCB	2,58E+08	7692497	2875959	8,06E+06	6,92E+06	4226064	13944435
Marine ecotoxicity	kg 1,4-DCB	3,49E+08	9920477	3601791	1,04E+07	8,84E+06	5441618	17220655
Human carcinogenic toxicity	kg 1,4-DCB	2,19E+09	43246773	2405892	3,71E+07	2,72E+07	18133928	36768005
Human non-	kg 1,4-DCB	6,82E+09	96800271	36850108	1,22E+08	9,08E+07	50784352	71082150

carcinogenic toxicity								
Land use	m2a crop eq	3,87E+08	3445135	1376414	6,72E+06	2,97E+06	26058452	2463657
Mineral resource scarcity	kg Cu eq	4,09E+07	1062719	175255,7	1,56E+06	7,86E+05	12172944	1569013
Fossil resource scarcity	kg oil eq	1,67E+09	8217430	1592464	1,73E+07	7,19E+06	16923978	10750605
Water consumption	m3	5,88E+07	364686,6	52945,41	6,05E+05	2,47E+05	353528	666768

Table S2: Decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
A1	7.0E+09	2.3E+03	8.4E+08	1.7E+07	1.3E+07	1.7E+07	2.3E+07	3.0E+06	2.5E+05	7.4E+09	2.6E+08	3.5E+08	2.2E+09	6.8E+09	3.9E+08	4.1E+07	1.7E+09	5.9E+07
A2	3.8E+07	1.2E+01	1.5E+06	1.3E+05	6.9E+04	1.3E+05	1.3E+05	1.9E+04	1.6E+03	1.4E+08	7.7E+06	9.9E+06	4.3E+07	9.7E+07	3.4E+06	1.1E+06	8.2E+06	3.6E+05
A3	6.2E+06	2.6E+00	2.7E+05	3.0E+04	1.5E+04	3.0E+04	3.3E+04	4.7E+03	2.4E+02	3.1E+07	2.9E+06	3.6E+06	2.4E+06	3.7E+07	1.4E+06	1.8E+05	1.6E+06	5.3E+04
A4	7.2E+07	2.8E+01	4.9E+06	2.1E+05	1.6E+05	2.2E+05	2.7E+05	3.2E+04	2.4E+03	4.2E+08	8.1E+06	1.0E+07	3.7E+07	1.2E+08	6.7E+06	1.6E+06	1.7E+07	6.1E+05
A5	3.2E+07	1.1E+01	1.1E+06	1.4E+05	6.7E+04	1.4E+05	1.3E+05	1.6E+04	1.1E+03	1.2E+08	6.9E+06	8.8E+06	2.7E+07	9.1E+07	3.0E+06	7.9E+05	7.2E+06	2.5E+05
A6	7.1E+07	2.5E+01	1.4E+06	2.1E+05	1.5E+05	2.1E+05	2.5E+05	1.8E+04	1.4E+03	1.8E+08	4.2E+06	5.4E+06	1.8E+07	5.1E+07	2.6E+07	1.2E+07	1.7E+07	3.5E+05
A7	4.0E+07	2.6E+01	2.0E+06	9.5E+04	8.8E+04	9.8E+04	1.4E+05	1.3E+04	5.7E+03	4.4E+08	1.4E+07	1.7E+07	3.7E+07	7.1E+07	2.5E+06	1.6E+06	1.1E+07	6.7E+05
Wj	5.0E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02	5.6E-02

*geothermal power plant (A1), Hard coal power plant (A2), Gas power plant (A3), Nuclear power plant (A4), Oil power plant(A5), solar thermal (A6), Wind power plant (A7),

**Global warming (C1),Stratospheric ozone depletion (C2), Ionizing radiation (C3), Ozone formation Human health (C4), Fine particulate matter formation (C5), Ozone formation Terrestrial ecosystems (C6), Terrestrial acidification (C7), Freshwater eutrophication (C8), Marine eutrophication (C9), Terrestrial ecotoxicity (C10), Freshwater ecotoxicity (C11), Marine ecotoxicity (C12), Human carcinogenic toxicity (C13), Human non-carcinogenic toxicity (C14), Land use (C15), Mineral resource scarcity (C16), Fossil resource scarcity (C17), Water consumption (C18)

Wj-Weight from the entropy method

Table S3: Normalized decision matrix for COPRAS

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
A1	0.9642	0.9569	0.9869	0.9536	0.9590	0.9534	0.9592	0.9670	0.9519	0.8476	0.8551	0.8630	0.9300	0.9357	0.8999	0.7024	0.9642	0.9625
A2	0.0052	0.0048	0.0018	0.0072	0.0051	0.0073	0.0056	0.0061	0.0062	0.0163	0.0255	0.0245	0.0184	0.0133	0.0080	0.0183	0.0047	0.0060
A3	0.0009	0.0011	0.0003	0.0017	0.0011	0.0017	0.0014	0.0015	0.0009	0.0036	0.0095	0.0089	0.0010	0.0051	0.0032	0.0030	0.0009	0.0009
A4	0.0099	0.0115	0.0058	0.0123	0.0120	0.0122	0.0115	0.0103	0.0092	0.0477	0.0267	0.0257	0.0158	0.0167	0.0156	0.0268	0.0100	0.0099
A5	0.0044	0.0046	0.0013	0.0079	0.0049	0.0080	0.0057	0.0050	0.0044	0.0143	0.0229	0.0219	0.0116	0.0125	0.0069	0.0135	0.0042	0.0040
A6	0.0098	0.0105	0.0016	0.0119	0.0114	0.0119	0.0106	0.0059	0.0055	0.0201	0.0140	0.0135	0.0077	0.0070	0.0606	0.2091	0.0098	0.0058
A7	0.0056	0.0107	0.0023	0.0055	0.0065	0.0055	0.0060	0.0042	0.0219	0.0504	0.0462	0.0426	0.0156	0.0098	0.0057	0.0269	0.0062	0.0109

Table S4: Weighted Normalized Decision Matrix (COPRAS)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
A1	0.0480	0.0535	0.0552	0.0533	0.0536	0.0533	0.0536	0.0540	0.0532	0.0474	0.0478	0.0482	0.0520	0.0523	0.0503	0.0393	0.0539	0.0538
A2	0.0003	0.0003	0.0001	0.0004	0.0003	0.0004	0.0003	0.0003	0.0003	0.0009	0.0014	0.0014	0.0010	0.0007	0.0004	0.0010	0.0003	0.0003
A3	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0005	0.0005	0.0001	0.0003	0.0002	0.0002	0.0001	0.0000
A4	0.0005	0.0006	0.0003	0.0007	0.0007	0.0007	0.0006	0.0006	0.0005	0.0027	0.0015	0.0014	0.0009	0.0009	0.0009	0.0015	0.0006	0.0006
A5	0.0002	0.0003	0.0001	0.0004	0.0003	0.0004	0.0003	0.0003	0.0002	0.0008	0.0013	0.0012	0.0006	0.0007	0.0004	0.0008	0.0002	0.0002
A6	0.0005	0.0006	0.0001	0.0007	0.0006	0.0007	0.0006	0.0003	0.0003	0.0011	0.0008	0.0008	0.0004	0.0004	0.0034	0.0117	0.0005	0.0003
A7	0.0003	0.0006	0.0001	0.0003	0.0004	0.0003	0.0003	0.0002	0.0012	0.0028	0.0026	0.0024	0.0009	0.0005	0.0003	0.0015	0.0003	0.0006

Table S5: Result of COPRAS method

SI-		S-MIN		S-MIN/S-I		Qi	Ui	Rank	Alternatives
0.922675452		0.002599528		0.002817		0.001418	0.281738	7	geothermal power plant,
0.010264853				0.253246		0.127437	25.32456	3	Hard coal power plant
0.002599528				1		0.503216	100	1	Gas power plant
0.016132578				0.161135		0.081086	16.11353	5	Nuclear power plant
0.008789804				0.295744		0.148823	29.57436	2	Oil power plant
0.023778668				0.109322		0.055013	10.93219	6	solar thermal
0.015759118				0.164954		0.083007	16.49539	4	Wind power plant,

Table S6: Normalized decision matrix for ARAS

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
OV	0.3721	0.3639	0.3557	0.3285	0.3591	0.3290	0.3352	0.3025	0.3746	0.3582	0.2473	0.2501	0.4153	0.2305	0.2715	0.3801	0.3636	0.3735
A1	0.0003	0.0004	0.0001	0.0006	0.0004	0.0006	0.0005	0.0005	0.0004	0.0015	0.0028	0.0026	0.0005	0.0012	0.0010	0.0016	0.0003	0.0003
A2	0.0613	0.0803	0.0637	0.0775	0.0758	0.0766	0.0842	0.0745	0.0561	0.0779	0.0924	0.0908	0.0231	0.0878	0.1085	0.0627	0.0705	0.0542
A3	0.3721	0.3639	0.3557	0.3285	0.3591	0.3290	0.3352	0.3025	0.3746	0.3582	0.2473	0.2501	0.4153	0.2305	0.2715	0.3801	0.3636	0.3735
A4	0.0321	0.0337	0.0193	0.0453	0.0323	0.0458	0.0409	0.0439	0.0377	0.0266	0.0882	0.0866	0.0269	0.0696	0.0556	0.0427	0.0335	0.0327
A5	0.0723	0.0849	0.0875	0.0708	0.0790	0.0704	0.0823	0.0913	0.0783	0.0892	0.1028	0.1019	0.0367	0.0936	0.1258	0.0848	0.0805	0.0801
A6	0.0327	0.0369	0.0696	0.0470	0.0341	0.0472	0.0442	0.0773	0.0625	0.0632	0.1683	0.1655	0.0551	0.1673	0.0143	0.0055	0.0342	0.0559
A7	0.0572	0.0361	0.0484	0.1020	0.0602	0.1015	0.0775	0.1076	0.0158	0.0252	0.0510	0.0523	0.0272	0.1195	0.1517	0.0425	0.0539	0.0297

OV-Optimal Value

Table S7: Weighted Normalized Decision Matrix (ARAS)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
OV	0.0185	0.0203	0.0199	0.0184	0.0201	0.0184	0.0187	0.0169	0.0209	0.0200	0.0138	0.0140	0.0232	0.0129	0.0152	0.0212	0.0203	0.0209
A1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000
A2	0.0031	0.0045	0.0036	0.0043	0.0042	0.0043	0.0047	0.0042	0.0031	0.0044	0.0052	0.0051	0.0013	0.0049	0.0061	0.0035	0.0039	0.0030
A3	0.0185	0.0203	0.0199	0.0184	0.0201	0.0184	0.0187	0.0169	0.0209	0.0200	0.0138	0.0140	0.0232	0.0129	0.0152	0.0212	0.0203	0.0209
A4	0.0016	0.0019	0.0011	0.0025	0.0018	0.0026	0.0023	0.0025	0.0021	0.0015	0.0049	0.0048	0.0015	0.0039	0.0031	0.0024	0.0019	0.0018
A5	0.0036	0.0047	0.0049	0.0040	0.0044	0.0039	0.0046	0.0051	0.0044	0.0050	0.0057	0.0057	0.0021	0.0052	0.0070	0.0047	0.0045	0.0045
A6	0.0016	0.0021	0.0039	0.0026	0.0019	0.0026	0.0025	0.0043	0.0035	0.0035	0.0094	0.0093	0.0031	0.0093	0.0008	0.0003	0.0019	0.0031
A7	0.0028	0.0020	0.0027	0.0057	0.0034	0.0057	0.0043	0.0060	0.0009	0.0014	0.0029	0.0029	0.0015	0.0067	0.0085	0.0024	0.0030	0.0017

OV-Optimal value

Table S8: Result of ARAS method

	Si		ki	Energy Alternative	Rank
OV	0.333692		1		
A1	0.000868		0.002601	geothermal power plant,	7
A2	0.073286		0.219621	Hard coal power plant	3
A3	0.333692		1	Gas power plant	1
A4	0.044159		0.132334	Nuclear power plant	6
A5	0.084079		0.251966	Oil power plant	2
A6	0.06579		0.197158	solar thermal	4
A7	0.064436		0.1931	Wind power plant,	5
So	0.333692				

Table S9: Dataset used for analysis.

Input	Wind power plant	Hard coal power plant	Nuclear power plant	Geothermal power plant	Oil power plant	Wind power plant	Solar power plant
Aluminium, cast alloy		3.20e+4 kg	6.40e+4 kg		9.60e+4 kg		
Aluminium scrap, new	8.45e+2 kg					8.45e+2 kg	50 kg
Aluminium, wrought alloy	8.45e+2 kg	6.80e+4 kg	1.36e+5 kg		2.04e+5 kg	8.45e+2 kg	
Cast iron	2.64e+4 kg				4.50e+5 kg	2.64e+4 kg	2.99e+4 kg
Concrete, normal		1.68e+4 m3	2.00e+5 m3		5.08e+4 m3		1.73e+3 m3
Control cabinet, heat and power co-generation unit, 160kW electrical							3 units
Copper, cathode	1.59e+3 kg	1.50e+5 kg	1.47e+6 kg		7.50e+5 kg	1.59e+3 kg	9.83e+3 kg
Deep well, drilled, for geothermal power				3.20e+4 m			
Diesel, burned in building machine		2.16e+7 MJ	1.90e+8 MJ		2.70e+8 MJ		
Diesel, burned in diesel-electric generating set, 18.5kW							1.13e+7 MJ
Drawing of pipe, steel							2.22e+5 kg
Electricity, medium voltage	6.75e+4 kWh	1.35e+6 kWh	5.31e+8 kWh		5.62e+6 kWh	6.75e+4 kWh	
Excavation, hydraulic digger			1.26e+5 m3				4.07e+3 m3
Expanded perlite							5.59e+5 kg
Extrusion, plastic pipes							18 kg
Foam glass							1.22e+5 kg
Fibre cement facing tile			5.30e+6 kg				
Glass fibre							9kg
Glass fibre reinforced plastic, polyamide, injection moulded	4.10e+4 kg					4.10e+4 kg	
Heat, district or industrial, other than natural gas		2.16e+7 MJ	1.65e+8 MJ		2.56e+8 MJ		

Heat and power co-generation unit, 1MWel, 6.4MWth				5.05 unit			
Inert waste, for final disposal			3.79e+8 kg	2.23e+5 kg			
Injection moulding							8 kg
Iron-nickel-chromium alloy							4.18e+4 kg
Lead	0.5 kg					0.5 kg	
Lubricating oil	1.15e+3 kg		2.00e+5 kg		6.00e+4 kg	1.15e+3 kg	
Nitrate salts, for solar power application							2.96e+7 kg
Occupation, construction site		5.00e+4 m2*year	3.61e+6 m2*year				
Occupation, industrial area		4.40e+5 m2*year	7.60e+6 m2*year	2.40e+5 m2*year	3.75e+6 m2*year		
Occupation, traffic area, road network		2.07e+5 m2*year					
Paper, woodfree, coated			4.25e+6 kg				
Particleboard, cement bonded							1 m3
Plywood			8.00e+3 m3				
Polyethylene, high density, granulate	27 kg	1.50e+5 kg			3.00e+5 kg	27kg	18 kg
Polyvinylchloride, bulk polymerised	6 kg					6kg	
Polystyrene, high impact							8kg
Refractory, basic, packed							4.09e+5 kg
Reinforcing steel		1.10e+7 kg	4.00e+7 kg		3.30e+7 kg		2.56e+6 kg
Sand							9.40e+4 kg
Scrap copper	1.59e+3 kg					1.59e+3 kg	
Scrap steel	9.39e+4 kg					9.39e+4 kg	
Section bar rolling, steel	4.23e+4 kg					4.23e+4 kg	
Sheet rolling, aluminium	8.45e+2 kg					8.45e+2 kg	50 kg

Sheet rolling, chromium steel	5.16e+4 kg					5.16e+4 kg	51 kg
Sheet rolling, steel							2.87e+2 kg
Silicone product							7.18e+3 kg
Steel, chromium steel 18/8, hot rolled	5.16e+4 kg	1.00e+5 kg	2.06e+7 kg		7.50e+5 kg	5.16e+4 kg	5.73e+4 kg
Steel, low-alloyed, hot rolled	1.59e+4 kg	9.00e+5 kg	5.57e+6 kg	2.23e+5 kg	2.25e+6 kg	1.59e+4 kg	2.83e+4 kg
Stimulation, deep well				4.00e+4 m3			
Stone wool		1.00e+5 kg			3.00e+5 kg		1.40e+5 kg
Synthetic rubber	100 kg					100kg	3 kg
Tap water							1.05e+5 kg
Tin	0.5 kg						
Tin plated chromium steel sheet, 2 mm							100 m2
Transformation, from industrial area			1.90e+5 m2				
Transformation, from pasture, man made			3.04e+4 m2				
Transformation, from unspecified		2.50e+4 m2	1.60e+5 m2		1.25e+5 m2		
Transformation, from unspecified, natural (non-use)				8.00e+3 m2			
Transformation, to industrial area		1.70e+4 m2	1.90e+5 m2	8.00e+3 m2	1.25e+5 m2		
Transformation, to unspecified			1.90e+5 m2				
Transformation, to traffic area, road network		8.00e+3 m2					
Transformer, high voltage use							1.74e+4 kg
Waste cement in concrete and mortar					1.12e+8 kg		
Waste glass	2.66e+4 kg					2.66e+4 kg	
Waste mineral oil	1.15e+3 kg				6.00e+4 kg	1.15e+3 kg	

Waste mineral wool		1.00e+5 kg			3.00e+5 kg		
Waste plastic, mixture	1.44e+4 kg					1.44e+4 kg	
Waste polyethylene/polypropylene product	27 kg	1.50e+5 kg			3.00e+5 kg	27 kg	
Waste polyvinylchloride	6 kg					6 kg	
Waste reinforced concrete		4.20e+7 kg					
Welding, arc, steel							
Wire drawing, copper	1.59e+3 kg					1.59e+3 kg	9.83e+3 kg
Scrap copper	1.59e+3 kg					1.59e+3 kg	