

Supplementary Information

The Environmental Life Cycle Impact Assessment of Electricity Production from Distributed Solar Photovoltaic Systems

Atif Ali¹, Theodore W. Koch¹, Timothy A. Volk¹, Robert W. Malsheimer¹, Mark H.
Eisenbies¹, Danielle Kloster¹, Tristan R. Brown¹, Nehan Naim¹, Obste Therasme^{1*}

¹ Department of Sustainable Resources Management, State University of New York College of
Environmental Science and Forestry, Syracuse, NY, USA - 13210

Corresponding Author: *otherasm@esf.edu

Panel and site characteristics data are listed below:

Table S1: Panel characteristics data of installed panels in NYS

OBJECT ID	Power Capacity (kW)	Initial Annual Electricity output (kWh)	Electricity per Panel (kWh/p)	Port to Site Distance (km)	Insolation (kWh/m ² /d)	Panel Efficiency (%)	Panel Weight (kg)	Ground Mount	Roof Mount	Mon	Pol	Area/p (m ²)
6	858	394664	346.20	394.00	4.92	19.30	26.5	Yes		Yes		1.94
7	261	257326	210.23	111.13	4.93	19.30	26.5	Yes		Yes		1.94
9	589	586375	318.51	264.30	4.84	16.97	23.1	Yes			Yes	2.06
10	2985	3231875	362.72	305.23	4.74	17.40	21.99	Yes				2.01
13	2635	2573960	327.23	524.19	4.58	16.97	23.1		Yes		Yes	2.06
14	2438	3001363	381.56	124.35	4.84	19.30	26.5	Yes		Yes		1.94
15	2985	3133628	351.70	296.12	4.81	16.97	23.1	Yes			Yes	2.06
16	2985	2925268	328.31	310.09	4.90	16.50	24	Yes			Yes	2.00
17	2985	2948277	330.90	272.21	4.81	17.30	24	Yes			Yes	2.00
18	347	378746	370.96	28.09	4.75	16.97	22.5	Yes			Yes	1.95
19	439	411640	318.61	89.88	5.01	18.40	22.9	Yes		Yes		1.96
20	332	549137	562.64	89.88	5.01	15.70	27.7	Yes			Yes	1.94
21	1221	868597	227.62	202.60	4.77	17.30	24	Yes		Yes		2.00
24	2631	2245515	268.28	481.95	4.65	17.30	24	Yes			Yes	2.00
25	533	521227	298.53	40.50	4.91	17.30	24	Yes			Yes	2.00
26	249	290957	381.83	57.98	4.98	15.48	22.5	Yes		Yes		1.94
27	1901	1731734	291.54	167.13	4.94	15.48	22.5	Yes		Yes		1.94
28	2461	2461166	310.01	437.29	4.55	16.97	22.4	Yes			Yes	1.95
29	2985	3079666	345.64	292.40	4.76	18.10	22.9		Yes	Yes		1.96
30	500	573311	390.01	28.11	4.75	16.80	22.5	Yes		Yes		2.00
32	2461	2843739	358.20	585.54	4.42	17.12	22	Yes		Yes		1.96
33	2985	3150492	353.59	296.23	4.81	17.20	22	Yes			Yes	2.01
34	1025	1048522	353.04	64.30	4.97	16.49	25.5	Yes			Yes	1.94
38	2795	3414270	400.17	114.42	4.94	16.49	22.5		Yes		Yes	1.94
40	2828	3021188	347.18	557.76	4.46	17.74	26		Yes	Yes		1.95
41	2792	2450006	272.04	310.39	4.37	17.38	22		Yes	Yes		1.96
42	2843	3005656	343.58	384.90	4.44	16.00	27.57	Yes			Yes	1.94
43	2902	3185959	356.77	122.09	4.46	16.97	22.4	Yes			Yes	1.95
44	2486	1849553	227.44	310.57	4.37	16.97	22.4	Yes			Yes	1.95
45	2828	2522413	289.87	556.17	4.47	16.80	24	Yes			Yes	2.00
46	2902	3261356	376.43	559.43	4.45	18.10	22.9	Yes		Yes		1.96
49	1981	1938283	313.03	557.22	4.79	17.30	26	Yes		Yes		1.94
50	2693	2825446	419.70	388.49	4.75	18.10	22.9	Yes		Yes		1.96
52	2902	3033046	339.65	139.91	4.81	18.10	22.9	Yes		Yes		1.96
54	2906	2870874	330.90	472.05	4.65	16.80	24	Yes			Yes	2.00

55	556	568150	347.71	474.88	4.43	18.85	22	Yes		Yes	2.26
57	415	482204	406.92	14.40	4.95	22.20	18.6		Yes	Yes	1.63
59	848	848031	406.73	23.06	4.86	17.40	23.17		Yes	Yes	1.96
65	749	818447	382.45	14.45	4.98	21.40	18.6		Yes	Yes	1.63
66	1068	1147172	374.89	11.50	4.94	16.80	21.81	Yes		Yes	1.98
70	3000	3041762	319.41	461.08	4.40	17.78	23	Yes		Yes	1.94
71	2726	3396617	398.94	266.71	4.89	17.30	24	Yes		Yes	2.00
72	2762	3358428	443.77	264.54	4.87	17.90	23.5	Yes		Yes	2.02
73	2696	3023742	358.94	540.65	4.65	17.20	22	Yes		Yes	2.01
74	1342	1394485	368.91	537.40	4.51	19.30	21.7	Yes		Yes	2.07
77	1251	1375694	368.42	44.53	4.46	17.40	22	Yes		Yes	2.01
78	230	213509	296.54	430.66	4.93	17.50	26	Yes		Yes	1.94
82	2757	2505216	301.04	386.43	4.40	17.20	22	Yes		Yes	2.01
83	2723	3153885	376.40	459.14	4.42	18.56	23.8	Yes		Yes	2.16
85	3012	2659322	291.34	563.36	4.62	16.49	25.5	Yes		Yes	1.94
86	3000	3143607	344.69	563.44	4.53	20.30	23.49	Yes		Yes	2.02
87	3010	2897188	317.67	483.64	4.53	17.30	24	Yes		Yes	2.00
88	3029	3130479	351.34	311.53	4.62	17.01	22.5	Yes		Yes	1.94
89	981	1035755	364.19	61.35	4.40	16.49	23	Yes		Yes	1.94
90	1085	1175494	362.81	297.65	5.00	17.10	23.99	Yes		Yes	2.00
93	2812	3267975	366.04	510.33	4.80	16.73	22	Yes		Yes	1.94
94	1259	624944	171.31	19.77	4.43	17.00	23.1		Yes	Yes	2.06
95	307	370937	435.37	370.65	4.94	19.30	26.49		Yes	Yes	1.94
96	1401	1415389	404.17	541.51	4.37	16.80	25.8		Yes	Yes	1.98
98	944	831593	303.94	381.76	4.62	19.60	23.5		Yes	Yes	2.02
99	808	1003231	422.24	569.63	4.67	16.49	26.5		Yes	Yes	1.94
100	1310	1515999	389.92	179.36	4.47	17.40	23.17		Yes	Yes	1.96
101	2434	3005498	425.95	247.61	4.86	22.20	18.6		Yes	Yes	1.63
102	2184	2898248	490.90	120.64	4.87	17.01	27	Yes		Yes	1.94
103	2710	3571386	454.72	138.57	4.88	18.81	26.5		Yes	Yes	1.94
105	3011	3622673	406.90	173.06	4.98	22.20	18.6		Yes	Yes	1.63
106	3013	3563020	384.36	135.65	4.95	17.30	24	Yes		Yes	2.00
107	3002	3651942	419.67	285.01	4.96	18.85	22	Yes		Yes	1.94
108	474	592545	399.83	123.19	4.71	17.30	24	Yes		Yes	2.00
109	2605	3444815	476.07	118.41	4.94	18.81	26.5	Yes		Yes	1.94
110	383	484550	448.66	453.23	4.90	16.42	22	Yes		Yes	1.92
112	3062	3529909	380.38	394.05	4.37	16.54	23.5	Yes		Yes	1.93
113	2745	3193918	401.45	149.45	4.37	18.04	21.9		Yes	Yes	1.94
114	2299	2913988	437.27	488.85	4.90	20.10	19.9	Yes		Yes	1.79
115	2759	2873118	380.04	493.88	4.55	16.20	26.5	Yes		Yes	1.94
116	2841	2843271	365.27	539.20	4.44	17.20	22	Yes		Yes	2.01
117	2575	2824204	400.26	495.21	4.54	16.51	26		Yes	Yes	1.94
118	1983	2159831	397.61	269.40	4.42	16.97	22.5	Yes		Yes	1.95

120	1534	1337498	300.83	458.43	4.90	16.97	22.5	Yes		Yes	1.95
121	2774	1353079	160.97	278.98	4.35	16.97	22.5	Yes		Yes	1.95
122	3062	3696619	398.34	137.55	4.90	17.30	24	Yes		Yes	2.00
123	3065	3408885	367.02	389.45	5.03	17.00	22		Yes	Yes	1.94
124	2757	3278353	410.20	279.40	4.42	17.50	22.19	Yes		Yes	1.94
125	3062	3539854	381.45	36.15	4.89	16.72	22.4	Yes		Yes	1.95
126	1102	1353079	417.62	87.21	4.89	18.85	22	Yes		Yes	1.94
128	3003	3751456	468.46	176.27	4.92	17.31	27.5		Yes	Yes	1.96
130	380	456660	432.44	19.60	4.95	17.60	23	Yes		Yes	2.00
131	2772	2825554	356.76	119.98	4.97	17.01	22.5	Yes		Yes	1.94
132	2772	3219718	406.53	119.93	4.97	17.23	22.4	Yes		Yes	1.95
133	3540	3975395	387.47	367.47	4.27	19.10	26.49	Yes		Yes	1.94
135	1689	2087555	426.38	210.89	4.69	16.51	26	Yes		Yes	1.94
136	2732	3001018	378.92	305.16	4.46	18.85	22	Yes		Yes	1.94
137	2705	2061172	266.71	203.45	4.74	17.52	23	Yes		Yes	1.94
138	2751	3389948	425.13	191.75	4.80	17.30	24	Yes		Yes	2.00
139	2772	3130640	395.28	540.47	4.55	16.00	27.57	Yes		Yes	1.94
140	2782	3221154	399.45	179.54	4.86	17.23	22.4	Yes		Yes	1.95
141	631	708648	410.10	35.88	4.90	15.70	27.66	Yes		Yes	1.94
142	1310	1227544	304.45	159.18	4.88	19.10	26.49	Yes		Yes	1.94
143	1777	1973743	388.84	461.71	4.44	16.97	22.4	Yes		Yes	1.99
144	2444	3160891	510.81	168.90	4.98	17.30	24	Yes		Yes	2.00
145	2706	3069758	442.39	533.95	4.64	17.30	24	Yes		Yes	2.00
146	3017	3154516	392.06	177.05	4.90	18.90	22.7	Yes		Yes	1.98
148	820	928273	373.70	28.33	4.60	18.52	22	Yes		Yes	1.95
149	2794	2913869	359.74	534.09	4.68	16.36	22.9	Yes		Yes	1.96
150	3001	3153911	388.80	199.22	4.79	17.14	22.49	Yes		Yes	1.99
151	3003	3141759	392.33	146.29	4.91	17.00	22.19	Yes		Yes	1.94
152	3024	3647727	452.35	169.80	4.94	19.30	25		Yes	Yes	2.10
153	471	569973	411.24	173.70	5.03	17.01	22.5	Yes		Yes	1.94
157	2794	3021286	373.00	245.61	4.44	17.90	23.5	Yes		Yes	2.02
160	731	592820	263.48	318.04	4.56	17.78	22		Yes	Yes	1.94
161	2772	2511657	331.18	517.55	4.37	17.10	24	Yes		Yes	2.00
162	1739	1854495	367.96	367.47	4.40	19.40	18.68	Yes		Yes	2.01
163	919	751767	294.58	20.10	4.94	17.30	24	Yes		Yes	2.00
164	2794	2872425	385.46	227.64	4.85	19.07	21.9	Yes		Yes	1.94
76	5500	2535551	300.35	419.21	4.96	19.40	18.68	Yes		Yes	2.01
129	5400	6707644	481.46	267.12	4.74	17.30	24	Yes		Yes	2.00
147	4500	4919173	379.33	375.54	4.32	16.16	22		Yes	Yes	1.92
154	5600	7105061	497.45	168.07	4.96	17.09	22	Yes		Yes	1.94
155	5600	5925000	414.05	168.27	4.92	19.10	23.5	Yes		Yes	2.02
156	6300	7073756	404.86	338.88	4.39	19.10	26.49	Yes		Yes	1.94

The list of inventories used for modeling of the environmental impacts of distributed solar PV system is listed in Table S2.

Table S2: List of inventories used for the modeling

For End-of-Life Modeling	For Panel & BOS Manufacturing, Installation, Operation, and Transportation Modeling
Transport, lorry 3.5-7.5t, EURO5/US- US-EI U	Heat, natural gas, at industrial furnace >100kW/US- US-EI U
Transport, lorry 7.5-16t, EURO5/US- US-EI U	Electricity, at eGrid, NYUP, 2010/kWh/RNA
Transport, lorry 16-32t, EURO5/US- US-EI U	Diesel, combusted in industrial equipment/US
Electricity, at eGrid, NYUP, 2010/kWh/RNA	Steel, low-alloyed, at plant/US- US-EI U
Heat, natural gas, at industrial furnace >100kW/US- US-EI U	Aluminium, production mix, cast alloy, at plant/US- US-EI U
Aluminum, primary, ingot, at plant/RNA	Copper, at regional storage/US- US-EI U
Solar glass, low-iron, at regional storage/US- US-EI U	Extrusion, plastic film/US- US-EI U
Copper, primary, at refinery/GLO US-EI U	Concrete, normal, at plant (2380 kg/m3)/US* US-EI U
Silver, at regional storage/US- US-EI U	Vegetable oil, refined {GLO} market for APOS, S
MG-silicon, at plant/NO US-EI U	Plywood, outdoor use, at plant/(625 kg/m3)US- US-EI U
Diesel, burned in building machine/GLO US-EI U	Water, completely softened, at plant/US- US-EI U
Water, completely softened, at plant/US- US-EI U	Aluminum, secondary, extruded/RNA
Nitric acid, 50% in H2O, at plant/US- US-EI U	Single unit truck, long-haul, diesel powered, Northeast region/tkm/RNA (of project USLCI)
Lime, hydrated, loose, at plant/US* US-EI U	Inverter, 500kW, at plant/US-/I US-EI U
Nitrogen oxides	Ocean freighter, diesel powered/US (of project USLCI)
Disposal of fly ash in landfill	Multi-Si wafer {GLO} market for APOS, S
Landfilling of contaminated glass	Single-Si wafer {GLO} market for APOS, S
Landfilling of inert sludge	
Landfilling of sludge with metal residues	
Treatment of recycling of cables	
Incineration of EVA	
Incineration of PVF	
Incineration of plastics from cables	

The regression results for all impact categories except global warming are provided below:

Table S3: Analysis of variance for the optimal regression model for estimating the ozone depletion of solar panels

Variable	Parameter Estimate	Standard Error	F Value	$P_r > t $
Intercept	2.88	9.1×10^{-10}	9.98	0.002
Monocrystalline	3.90	9.94×10^{-11}	15.45	0.0002
Area Power Ratio	1.38	1.16×10^{-10}	139	<0.0001
Average Capacity Factor	-3.77	3.98×10^{-11}	89.68	<0.0001

Table S4: Analysis of variance for the optimal regression model for estimating the smog potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	$P_r > t $
Intercept	0.0011	3.97×10^{-4}	7.13	0.0087
Monocrystalline	5.56×10^{-4}	4.33×10^{-5}	164.86	<0.0001
Area Power Ratio	6.23×10^{-4}	5.08×10^{-5}	150.06	<0.0001
Average Capacity Factor	-1.67×10^{-4}	1.78×10^{-5}	92.35	<0.0001

Table S5: Analysis of variance for the optimal regression model for estimating the acidification potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	$P_r > t $
Intercept	8.15×10^{-5}	3.05×10^{-5}	7.13	0.0089
Monocrystalline	4.34×10^{-5}	3.34×10^{-6}	169	<0.0001
Area Power Ratio	4.80×10^{-5}	3.92×10^{-6}	150.31	<0.0001
Average Capacity Factor	-1.28×10^{-5}	1.34×10^{-6}	92.35	<0.0001

Table S6: Analysis of variance for the optimal regression model for estimating the eutrophication potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	P _r > t
Intercept	1.11×10^{-4}	3.86×10^{-5}	8.41	0.0046
Monocrystalline	3.73×10^{-5}	4.21×10^{-6}	78.67	<0.0001
Area Power Ratio	5.96×10^{-5}	4.94×10^{-6}	145.68	<0.0001
Average Capacity Factor	-1.61×10^{-5}	1.69×10^{-5}	91.58	<0.0001

Table S7: Analysis of variance for the optimal regression model for estimating the carcinogenics potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	P _r > t
Intercept	3.25×10^{-9}	1.02×10^{-9}	10.11	0.0019
Monocrystalline	3.99×10^{-10}	1.12×10^{-10}	12.74	0.005
Area Power Ratio	1.54×10^{-9}	1.31×10^{-10}	138.53	<0.0001
Average Capacity Factor	-4.23×10^{-10}	4.47×10^{-11}	89.68	<0.0001

Table S8: Analysis of variance for the optimal regression model for estimating the non-carcinogenics potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	P _r > t
Intercept	1.88×10^{-8}	5.73×10^{-9}	10.75	0.0014
Monocrystalline	1.02×10^{-9}	6.26×10^{-10}	2.65	0.1058
Area Power Ratio	8.56×10^{-9}	7.35×10^{-10}	135.72	<0.0001
Average Capacity Factor	-2.36×10^{-9}	2.51×10^{-10}	88.73	<0.0001

Table S9: Analysis of variance for the optimal regression model for estimating the respiratory effects potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	P _r > t
Intercept	2.08×10^{-5}	8.49×10^{-6}	6.05	0.0156
Monocrystalline	1.53×10^{-5}	9.26×10^{-7}	272.91	<0.0001
Area Power Ratio	1.35×10^{-5}	1.09×10^{-6}	153.26	<0.0001
Average Capacity Factor	-3.57×10^{-6}	3.71×10^{-7}	92.54	<0.0001

Table S10: Analysis of variance for the optimal regression model for estimating the fossil fuel depletion potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	P _r > t
Intercept	1.85×10^{-2}	6.52×10^{-3}	8.01	0.0031
Monocrystalline	7.16×10^{-3}	7.12×10^{-4}	101	<0.0001
Area Power Ratio	1.01×10^{-2}	8.35×10^{-4}	147.13	<0.0001
Average Capacity Factor	-2.73×10^{-3}	2.85×10^{-4}	91.77	<0.0001

Table S11: Analysis of variance for the optimal regression model for estimating the ecotoxicity potential of solar panels

Variable	Parameter Estimate	Standard Error	F Value	P _r > t
Intercept	0.87	0.26	10.95	0.0013
Monocrystalline	0.029	0.03	1.04	0.3079
Area Power Ratio	0.39	0.04	134.79	<0.0001
Average Capacity Factor	-0.10	0.01	88.36	<0.0001