Marginal Damages From Electricity Use By Hour, Season, and Region

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Following the methodology in the paper, we estimate marginal emissions by first modeling a plant's generation response to changes in electricity consumption across the grid using a linear regression model. For plant $i \in N$ at time $t \in T$, we use equation (17) in the paper:

$$y_{it} = x_t b_i + z_{it} d_i + \mu_i(t) + u_{it}, \qquad E(u_{it} \mid X, Z) = 0,$$

where y_{it} denotes net generation, $x_t = [x_t^1, ..., x_t^K]$ denotes electricity consumption (loads) across all regions in plant i's interconnection (nine regions for the East, three regions for the West, and a single region for Texas), z_{it} collects wind speed and solar radiation across plant i's balancing authority, and $\mu_i(t)$ are year-by-week fixed effects. We apply this model separately to each hour of the day (hour 1-hour 24) to capture variation in marginal emissions across time-of-day. We estimate marginal emissions $\Delta = \sum_{i \in N} \omega_i b_i$ with a constrained regression estimator that restricts the estimated coefficients for each load region to be positive and sum to one. The emission factors ω_i are calculated for each plant as the ratio of total emissions over total generation.

Figure 1: Region Map

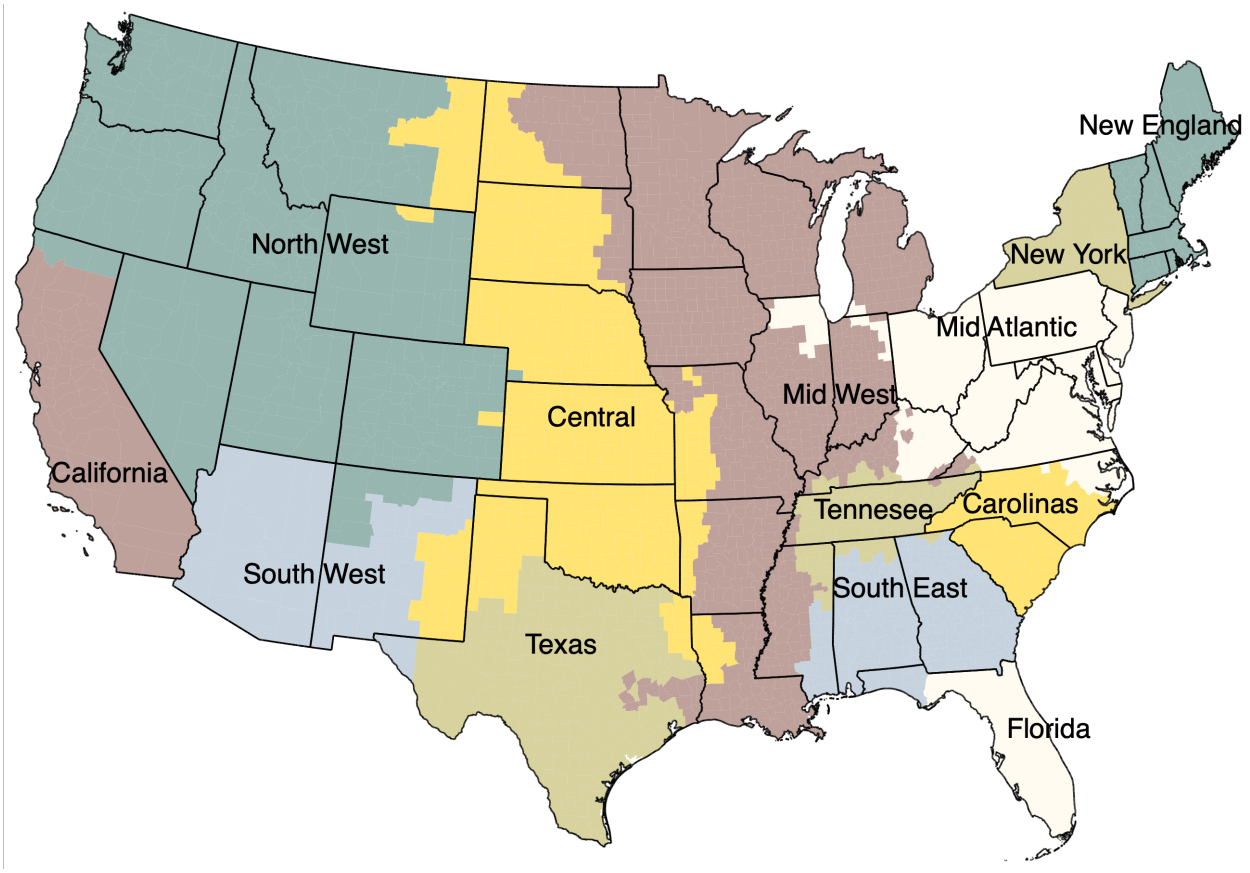


Table 1: Estimated Marginal Emissions (metric tons of CO_2/MWh):

Hour	CAL	CAR	CENT	FLA	MIDA	MIDW	NE	NW	NY	SE	SW	TEN	TEX
						Summer							
1	0.45	0.65	0.56	0.50	0.70	0.62	0.52	0.48	0.55	0.66	0.52	0.64	0.54
2	0.46	0.64	0.46	0.49	0.71	0.65	0.53	0.48	0.53	0.67	0.55	0.67	0.54
3	0.46	0.71	0.37	0.43	0.71	0.67	0.53	0.45	0.51	0.65	0.54	0.69	0.53
4	0.48	0.70	0.35	0.44	0.69	0.69	0.51	0.45	0.46	0.64	0.52	0.69	0.52
5	0.48	0.66	0.25	0.42	0.68	0.69	0.51	0.41	0.49	0.64	0.53	0.66	0.51
6	0.49	0.64	0.22	0.40	0.66	0.70	0.49	0.43	0.51	0.61	0.52	0.64	0.53
7	0.50	0.61	0.21	0.38	0.63	0.68	0.49	0.43	0.50	0.60	0.48	0.63	0.54
8	0.51	0.57	0.25	0.37	0.61	0.67	0.50	0.38	0.49	0.58	0.49	0.60	0.56
9	0.52	0.55	0.31	0.37	0.60	0.64	0.49	0.36	0.51	0.57	0.51	0.62	0.58
10	0.52	0.51	0.38	0.42	0.61	0.62	0.50	0.37	0.52	0.57	0.50	0.61	0.58
11	0.51	0.45	0.52	0.42	0.62	0.62	0.50	0.37	0.50	0.60	0.50	0.56	0.57
12	0.53	0.49	0.56	0.41	0.63	0.63	0.49	0.37	0.57	0.63	0.51	0.50	0.57
13	0.54	0.59	0.58	0.46	0.67	0.63	0.48	0.33	0.57	0.64	0.47	0.56	0.57
14	0.51	0.64	0.64	0.46	0.69	0.63	0.48	0.28	0.56	0.66	0.48	0.63	0.59
15	0.48	0.68	0.70	0.49	0.69	0.64	0.48	0.32	0.50	0.64	0.50	0.62	0.58
16	0.48	0.69	0.72	0.49	0.66	0.65	0.48	0.37	0.50	0.64	0.47	0.60	0.57
17	0.48	0.64	0.75	0.49	0.65	0.65	0.49	0.42	0.50	0.62	0.42	0.57	0.57
18	0.48	0.63	0.73	0.49	0.65	0.65	0.46	0.44	0.52	0.61	0.44	0.54	0.57
19	0.46	0.63	0.71	0.50	0.66	0.64	0.45	0.45	0.53	0.58	0.45	0.53	0.57
20	0.46	0.64	0.69	0.50	0.67	0.64	0.46	0.45	0.53	0.56	0.47	0.52	0.57
21	0.45	0.63	0.67	0.49	0.68	0.63	0.50	0.44	0.51	0.57	0.49	0.55	0.56
22	0.44	0.64	0.65	0.49	0.68	0.64	0.53	0.46	0.50	0.59	0.49	0.55	0.55
23	0.44	0.65	0.66	0.50	0.67	0.64	0.53	0.45	0.52	0.61	0.51	0.55	0.55
24	0.43	0.65	0.58	0.50	0.68	0.64	0.53	0.46	0.53	0.64	0.51	0.59	0.54
						Winter							
1	0.42	0.67	0.62	0.53	0.67	0.63	0.33	0.42	0.40	0.58	0.49	0.51	0.52
2	0.45	0.56	0.67	0.55	0.69	0.64	0.35	0.41	0.48	0.58	0.53	0.54	0.52
3	0.43	0.52	0.69	0.57	0.70	0.67	0.33	0.44	0.55	0.59	0.47	0.52	0.52
4	0.42	0.58	0.73	0.55	0.65	0.70	0.49	0.44	0.55	0.57	0.48	0.54	0.53
5	0.42	0.52	0.76	0.56	0.68	0.69	0.42	0.42	0.59	0.57	0.57	0.52	0.53
6	0.41	0.51	0.75	0.61	0.68	0.68	0.42	0.41	0.65	0.51	0.57	0.52	0.53
7	0.40	0.52	0.74	0.61	0.68	0.67	0.42	0.43	0.60	0.54	0.57	0.56	0.54
8	0.37	0.52	0.77	0.61	0.67	0.66	0.52	0.47	0.49	0.57	0.52	0.50	0.54
9	0.37	0.52	0.77	0.62	0.64	0.67	0.50	0.46	0.53	0.59	0.50	0.47	0.54
10	0.40	0.51	0.76	0.64	0.62	0.68	0.41	0.44	0.39	0.60	0.49	0.44	0.54
11	0.40	0.51	0.76	0.58	0.59	0.65	0.39	0.46	0.32	0.61	0.48	0.39	0.54
12	0.45	0.50	0.73	0.59	0.56	0.62	0.40	0.45	0.20	0.59	0.48	0.38	0.54
13	0.39	0.48	0.71	0.58	0.59	0.60	0.37	0.41	0.25	0.56	0.51	0.37	0.54
14	0.40	0.51	0.71	0.59	0.63	0.61	0.43	0.35	0.35	0.47	0.50	0.39	0.53
15	0.42	0.60	0.74	0.56	0.65	0.60	0.52	0.32	0.39	0.38	0.48	0.63	0.52
16	0.43	0.65	0.76	0.54	0.67	0.63	0.53	0.33	0.41	0.55	0.43	0.59	0.52
17	0.42	0.65	0.73	0.53	0.69	0.64	0.52	0.35	0.43	0.58	0.67	0.62	0.52
18	0.47	0.65	0.70	0.52	0.71	0.66	0.52	0.35	0.43	0.61	0.60	0.62	0.53
19	0.47	0.64	0.64	0.52	0.71	0.67	0.52	0.39	0.42	0.60	0.52	0.64	0.54
20	0.48	0.63	0.60	0.50	0.72	0.67	0.55	0.40	0.45	0.59	0.46	0.63	0.56
21	0.50	0.63	0.59	0.49	0.72	0.68	0.56	0.37	0.44	0.60	0.44	0.63	0.57
22	0.49	0.67	0.61	0.48	0.70	0.69	0.56	0.37	0.42	0.58	0.44	0.61	0.57
23	0.49	0.67	0.63	0.47	0.69	0.68	0.50	0.38	0.42	0.57	0.43	0.58	0.57
24	0.47	0.64	0.62	0.49	0.69	0.65	0.45	0.40	0.42	0.56	0.45	0.54	0.55

Notes: Point estimates. Hours are in Coordinated Universal Time (UTC). Period of observation: 2019-2022. Summer months are May to October. Winter months are November-April.

Table 2: Estimated Marginal Emissions (local damages, U.S. $/MWh):

Hour	CAL	CAR	CENT	FLA	MIDA	MIDW	NE	NW	NY	SE	SW	TEN	TEX
						Summer							
1	3.60	14.76	9.36	5.34	17.75	11.68	6.52	5.48	11.46	7.73	5.10	12.71	5.29
2	3.54	14.90	8.28	5.14	18.14	11.95	6.23	5.45	9.22	7.91	5.46	13.92	5.36
3	3.36	17.63	6.72	3.63	18.43	12.99	6.35	5.14	7.42	7.32	5.12	13.77	5.53
4	3.44	19.67	6.21	6.78	17.95	13.95	7.39	5.10	5.35	6.94	4.91	14.23	5.57
5	3.47	17.88	4.55	3.98	18.10	14.52	6.53	4.82	6.37	6.52	4.90	13.20	5.38
6	3.62	16.99	4.23	3.57	16.75	14.67	5.33	5.08	7.53	6.02	4.97	12.62	5.83
7	3.83	13.81	4.34	3.42	15.13	14.04	5.41	5.35	6.76	5.92	4.48	11.47	5.95
8	4.18	12.40	5.49	3.06	13.82	13.56	5.84	4.90	6.59	5.63	4.68	9.77	6.15
9	4.51	11.49	7.08	2.72	13.76	12.64	5.49	4.50	7.34	6.49	5.19	10.27	6.37
10	4.69	10.71	8.74	5.54	14.47	11.62	5.26	4.70	8.85	6.11	5.28	10.93	6.29
11	4.61	9.54	11.83	5.43	14.67	11.35	5.89	4.52	7.85	6.05	5.50	10.15	6.15
12	4.94	11.04	12.20	3.71	14.95	12.35	4.84	4.29	12.63	6.69	5.13	8.87	6.06
13	5.05	15.06	11.94	5.40	16.47	12.68	4.13	3.65	12.19	6.69	4.35	10.26	6.25
14	5.15	15.83	13.17	5.45	18.74	11.81	4.57	2.91	11.73	7.89	3.94	11.31	6.46
15	4.82	17.54	12.94	5.71	18.89	11.94	4.57	3.42	8.58	7.52	4.29	11.68	6.18
16	4.97	17.72	12.37	5.32	18.01	11.87	4.88	4.25	7.14	7.49	3.84	12.65	6.05
17	4.97	16.72	13.04	5.05	16.57	12.10	4.54	4.80	10.83	7.07	3.78	12.04	5.72
18	4.90	15.84	12.20	4.99	16.87	11.21	4.70	4.85	10.51	6.85	4.07	11.06	5.67
19	4.42	15.58	11.60	5.21	16.64	11.32	4.93	4.94	11.67	6.52	4.39	10.71	5.61
20	4.38	15.37	11.25	5.28	16.53	11.32	5.64	4.81	12.84	6.23	4.34	9.97	5.56
21	4.06	14.79	10.82	5.32	16.40	11.12	6.76	4.85	13.15	6.78	4.44	11.40	5.52
22	3.81	14.54	10.45	5.27	16.42	11.47	7.48	5.04	13.06	7.43	4.56	11.36	5.46
23	3.55	14.67	10.47	5.19	16.30	11.86	7.35	5.22	13.81	7.80	6.37	11.47	5.41
24	3.44	14.88	9.26	5.28	16.80	12.20	7.12	5.47	11.74	8.17	4.79	11.94	5.33
						Winter							
1	3.43	19.68	9.30	8.22	18.05	11.80	4.28	4.62	4.86	6.60	4.31	10.96	4.26
2	3.46	16.84	9.71	9.40	18.54	12.39	4.61	4.09	8.14	6.75	5.19	12.36	4.29
3	2.92	15.90	9.78	11.06	18.72	13.43	4.69	4.47	11.18	7.55	4.47	10.58	4.39
4	2.83	19.86	10.21	10.14	14.26	15.75	10.33	4.69	17.96	8.63	4.36	11.52	4.51
5	2.70	15.26	10.78	11.53	17.35	14.44	15.05	4.40	11.97	7.11	6.02	8.65	4.60
6	2.30	13.02	12.18	12.35	18.25	13.72	7.94	4.55	14.68	7.57	5.85	11.03	4.73
7	2.35	13.58	11.84	12.82	17.56	13.99	9.10	4.97	14.36	7.34	6.59	13.12	5.00
8	2.29	13.44	13.09	12.71	17.93	13.69	11.33	5.67	11.05	7.77	6.07	10.90	5.20
9	2.34	13.48	13.30	13.32	16.82	14.26	10.68	5.72	12.62	8.03	5.55	9.83	5.10
10	2.40	12.88	13.05	15.71	16.58	14.69	7.44	5.57	6.55	7.71	5.29	9.22	5.08
11	2.41	12.36	14.32	13.16	15.00	13.42	5.52	5.68	6.42	8.79	4.85	8.11	5.06
12	3.32	11.70	12.28	12.71	13.71	11.96	5.94	5.54	0.90	8.09	4.37	8.99	5.06
13	2.74	11.00	11.10	11.76	14.73	11.00	4.36	4.88	2.04	7.12	4.49	7.96	4.91
14	3.06	12.63	11.37	11.81	16.14	11.10	6.86	3.92	3.36	5.67	4.17	7.06	4.72
15	3.44	15.83	12.50	11.24	16.77	11.22	9.75	3.36	3.36	4.49	3.89	13.28	4.57
16	3.01	17.97	12.67	10.97	17.05	12.02	9.51	3.50	4.14	7.47	4.31	14.50	4.53
17	2.89	18.06	11.40	8.58	17.89	12.48	8.74	3.93	4.87	7.63	7.26	15.70	4.51
18	3.92	18.23	11.49	7.01	18.87	13.04	7.82	4.21	5.67	7.82	6.43	14.63	4.67
19	4.19	18.50	10.85	6.67	19.28	13.13	7.85	5.02	4.97	7.05	5.12	15.04	5.02
20	4.57	17.74	9.88	5.70	20.01	13.01	8.30	5.20	5.60	7.14	3.99	13.92	5.45
21	4.79	17.60	9.89	5.33	20.38	13.19	8.31	4.82	5.11	6.76	4.12	14.43	5.74
22	4.81	19.33	10.05	5.03	18.42	13.84	9.31	4.64	6.59	6.24	4.16	14.64	5.87
23	4.63	19.10	10.82	5.73	19.38	12.80	7.35	4.82	5.90	5.68	3.61	13.00	5.77
24	4.46	18.73	10.21	6.29	18.74	12.16	6.67	4.87	6.16	5.69	3.75	12.09	5.22

Notes: Point estimates. Hours are in Coordinated Universal Time (UTC). Period of observation: 2019-2022. Summer months are May to October. Winter months are November-April.