Supplemental Information for

Regional variability and uncertainty of electric vehicle life cycle CO_2 emissions across the United States

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S.1. Geographical boundaries of NERC and eGRID regions

In this analysis, we use three levels of aggregation as boundaries for analysis: North American Electric Reliability Corporation (NERC) regions, eGRID regions, and finally states. NERC is the electric power reliability organization of North America - including the U.S., Canada, and Baja California, Mexico – with the main mission of ensuring reliability of the bulk power system in the region (NERC 2014). NERC regions are identified based on the power control area (PCA) servicing a region. Meanwhile, the U.S. Environmental Protection Agency (EPA) defined the eGRID subregions based on the NERC regions and PCAs. NERC and eGRID boundaries may not necessarily coincide with geopolitical boundaries such as the state (e.g., TRE is not the same as Texas).

We show representative maps of the NERC and eGRID subregions in Figure S1 and Figure S2.

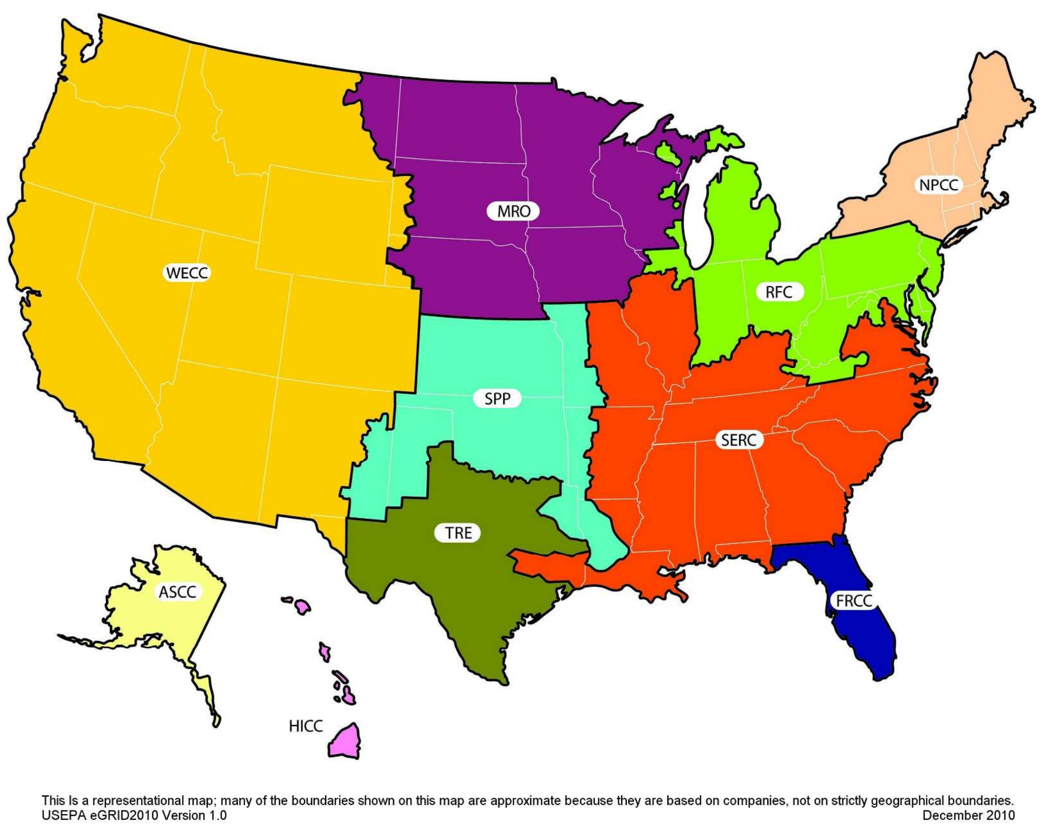


Figure S1. Representational Map of NERC regions. Reprinted from U.S. EPA. 2010. NERC region representational map. accessible online: http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_NERC_regions.jpg. Copyright 2010 U.S. EPA.

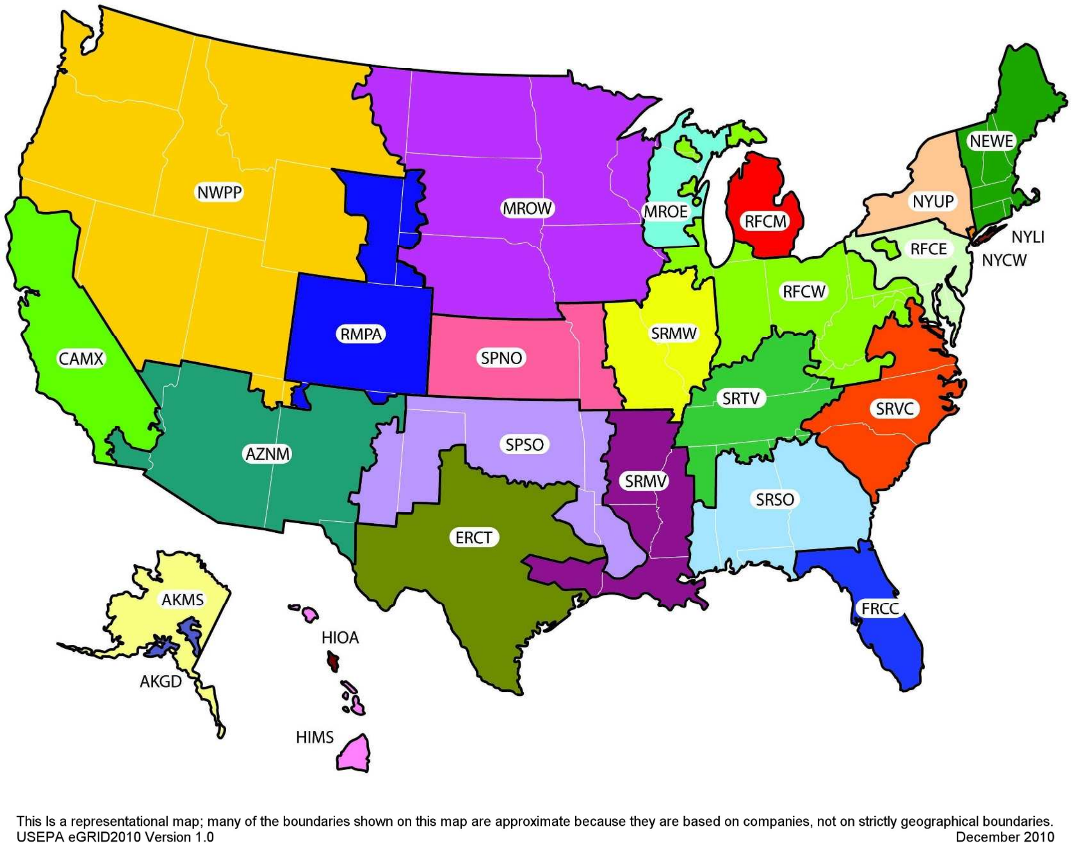


Figure S2. Representational Map of eGRID sugregions. Reprinted from U.S. EPA. 2010. eGRID subregion representational map. accessible online: http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_eGRID_subregions.jpg. Copyright 2010 U.S. EPA.

S.2. Data sources and values

Summary of data sources by life-cycle stage. Table S1 summarizes the data sources for emissions rate used to compute emissions for each life stage. These include vehicle upstream, manufacture, and assembly; battery upstream and manufacturing (Lithium-ion); gasoline upstream and distribution; gasoline combustion; electricity upstream; and electricity production.

Table S1. Summary of data sources by life-cycle stage.

Stage	Method/Source	Value or distribution used
I. Vehicle Upstream, Manufacture and Assembly (Resource extraction and production of materials needed for vehicle assembly; all material and energy needed during vehicle manufacturing and assembly)		
ICEV	Avg.: GREET estimate for Generic 1532 kg	Normal(2169,230) kg CO_2
HEV	GREET estimate for HEV 1683 kg	Normal(2002,17) kg CO_2
PHEV	GREET estimate for PHEV20 1746 kg; GREET estimate for PHEV40 1959 kg	PHEV20=1995 kg CO_2 PHEV40=2165 kg CO_2
BEV	GREET estimate for BEV 2104 kg	2, 244 kg CO_2
II. Battery Upstream and Manufacturing (Lithium-ion) for PHEV and BEV	Battery Capacity, Specific Energy, and EV AER: fueleconomy.gov Battery mnfg. and assembly emission rate: Hart et al. (2013), Zackrisson et al. (2010), Notter et al. (2010), and Majeau-Bettez et al. (2011)	Normal(15,5) kg CO_2/kg
III. Gasoline Upstream and Distribution (extraction, refining, and distribution from refineries to gasoline stations)	Low: Venkatesh et al. (2011) Avg.: Low and High Avg. High: GREET 2013	Normal(2.4,0.01) kg CO_2/gal
IV. Gasoline Combustion	Low: EPA 2014 Avg.: Low and High Avg. High: Venkatesh et al. (2011)	Normal(8.7,0.2) kg CO_2/gal
V. **Electricity Life Cycle** (Upstream: fossil fuel extraction, production, and transportation to power plants; Generation: fossil fuel combustion during generation (includes electricity consumed and onsite, transmission, and distribution).	Detailed in following sections	

Vehicle and Battery Assumptions. We summarize in Table S2 and in Table S3 the vehicle and battery assumptions used in computations as described in the Methods section. All values are from fueleconomy.gov except for sales-weighted average fuel economy, which was obtained from the Eco-driving Index (University of Michigan Transportation Institute 2013). Gasoline fuel economy values correspond to combined driving. All vehicles are model year 2014. Assumed best estimate lifetime vehicle miles traveled is the midpoint (125,000 mi) of the assumed mileage range of ~100,000 mi/vehicle (assuming about 10, 088 mi/vehicle annual mileage and 9.6 average vehicle life [NHTS 2009]) to ~150,000 mi/vehicle (assuming about 13, 476 mi annual mileage [U.S. Department of Transportation 2015] times 11.4 years average vehicle lifetime [IHS Inc. 2014]).

Table S2. Summary of vehicle all electric range (AER) and energy use assumptions.

Vehicle Model	**AER (mi)**	**Combined Electricity Use (kWh/mi)** [fueleconomy.gov]	**Combined Fuel Economy (mpg)**
2014 Chevrolet Volt (PHEV) [fueleconomy.gov]	38	0.35	37
2014 Nissan Leaf (BEV) [fueleconomy.gov]	84	0.29	
2014 Toyota Prius HEV [fueleconomy.gov]			50
Sales Weighted Ave. CV [UMTI 2013]			24.6

Table S3. Lithium-ion battery assumptions.

Vehicle Model	Battery Energy Capacity (kWh)	Battery Specific Energy (kWh/kg)	Charging Rate (kW)	Charge Time (hrs)
Chevrolet Volt [fueleconomy.gov]	16	0.080	3.3	4
Nissan Leaf [fueleconomy.gov]	24	0.0873	3.3	8

Marginal and average emission factors. While eGRID sub-regions do not always correspond precisely to NERC region boundaries, we group eGRID sub-regions by the NERC region with which they are most closely associated. We use eGRID 2012 annual average emissions factors for year 2009, shown in

Table S4, either at the eGRID sub-region level or at the NERC region level. Table S5 and Table S6 show marginal emissions factors estimates used in the analysis. Table S5 provides the hourly generation-based marginal emission factors, in kg CO_2 per MWh from Siler-Evans et al. (2012). Table S6 shows the hourly consumption-based marginal emission factors, in kg of CO_2 per MWh from Graff Zivin *et al.* 2014.

Table S4. Regional average generation-based emission factors in kg CO_2/MWh (Source: eGRID 2012)

NERC region	NERC region name	NERC Region annual CO_2 emission rate (kg/MWh)	eGRID subregion acronym	eGRID subregion name	eGRID subregion annual CO_2 emission rate (kg/MWh)
FRCC	Florida Reliability Coordinating Council	534	FRCC	FRCC All	534
MRO	Midwest Reliability Organization	736	MROE	MRO East	722
			MROW	MRO West	739
NPCC	Northeast Power Coordinating Council	297	NYLI	NPCC Long Island	611
			NEWE	NPCC New England	330
			NYCW	NPCC NYC/Westchester	277
			NYUP	NPCC Upstate NY	226
RFC	Reliability First Corporation	621	RFCE	RFC East	430
			RFCM	RFC Michigan	753
			RFCW	RFC West	690
SERC	SERC Reliability Corporation	566	SRMW	SERC Midwest	794
			SRMV	SERC Mississippi Valley	455
			SRSO	SERC South	601
			SRTV	SERC Tennessee Valley	616
			SRVC	SERC Virginia/Carolina	470
SPP	Southwest Power Pool	756	SPNO	SPP North	824
			SPSO	SPP South	725
TRE	Texas Regional Entity	536	ERCT	ERCOT All	536
WECC	Western Electricity Coordinating Council	432	CAMX	WECC California	299
			NWPP	WECC Northwest	372
			RMPA	WECC Rockies	828
			AZNM	WECC Southwest	540

Table S5. Hourly generation-based marginal emission factors, kg CO_2/ MWh (adapted from Siler-Evans et al., 2011).

Hour	FRCC	MRO	NPCC	RFC	SERC	SPP	TRE	WECC
1AM	503	908	459	695	625	474	478	473
2AM	490	949	474	770	711	665	545	491
3AM	496	959	508	803	778	765	577	543
4AM	554	940	522	798	816	796	653	560
5AM	565	918	522	794	816	791	657	574
6AM	567	891	499	782	794	638	583	574
7AM	572	861	473	725	707	726	561	561
8AM	541	820	486	704	768	668	628	486
9AM	603	758	503	690	661	613	522	489
10AM	554	700	500	657	589	489	481	458
11AM	527	714	493	648	574	483	474	469
12PM	452	699	482	642	596	510	467	478
1PM	453	695	486	621	609	519	447	472
2PM	462	691	476	633	620	511	451	501
3PM	484	702	461	635	658	525	444	505
4PM	472	740	478	671	622	512	455	522
5PM	459	745	481	697	618	512	459	529
6PM	394	708	496	650	599	544	480	523
7PM	371	683	494	648	622	549	499	502
8PM	468	700	494	636	660	555	484	485
9PM	520	688	514	668	649	543	488	509
10PM	513	613	497	637	562	484	473	486
11PM	503	665	502	581	463	450	418	453
12AM	545	834	450	633	512	428	398	449

Table S6. Hourly consumption-based marginal emission factors, in kg CO_2/MWh (adapted from Graff Zivin et al., 2014).

Hour	FRCC	MRO	NPCC	RFC	SERC	SPP	TRE	WECC
1AM	608	1175	481	685	558	340	463	381
2AM	603	866	331	785	581	612	490	376
3AM	553	1284	599	635	653	417	503	381
4AM	540	1279	640	621	658	503	513	381
5AM	549	1275	662	626	649	562	508	363
6AM	572	1275	612	667	590	653	485	349
7AM	653	1211	535	717	476	794	454	322
8AM	671	1270	617	640	395	789	431	299
9AM	689	1066	562	662	345	789	426	308
10AM	794	975	549	662	358	640	426	349
11AM	821	1075	644	567	449	526	417	386
12PM	748	1129	680	490	544	440	417	399
1PM	603	1102	689	449	599	413	413	399
2PM	508	1080	658	449	599	390	417	390
3PM	440	1034	640	458	576	395	417	376
4PM	404	984	658	458	549	431	417	372
5PM	404	989	635	467	535	417	417	363
6PM	422	903	603	494	526	404	413	358
7PM	472	807	594	517	503	435	408	358
8PM	522	767	526	553	485	417	408	363
9PM	558	744	503	576	472	408	404	367
10PM	581	821	581	549	485	395	404	363
11PM	612	921	476	612	476	349	413	367
12AM	662	1030	481	649	508	327	431	372

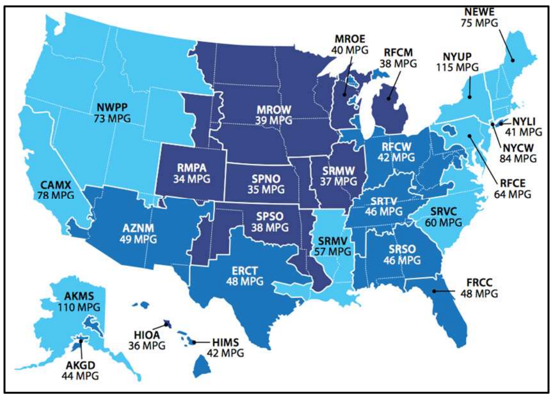
Table S7. 2009 State average emission factors in kg CO_2/MWh (adapted from eGRID 2012)

State	Average State EF (kg/MWh)	State	Average State EF (kg/MWh)
AL	472	MT	653
AK	511	NE	725
AZ	492	NV	481
AR	505	NH	272
CA	252	NJ	249
CO	788	NM	826
CT	262	NY	264
DE	814	NC	525
DC	1127	ND	933
FL	541	OH	808
GA	583	OK	678
HI	693	OR	165
ID	54	PA	517
IL	484	RI	406
IN	922	SC	374
IA	737	SD	414
KS	759	TN	486
KY	928	TX	564
LA	512	UT	841
ME	227	VT	1
MD	559	VA	451
MA	505	WA	130
MI	691	WV	912
MN	634	WI	687
MS	500	WY	960
MO	820		2.1.1.1.1.1

S.3. Comparison of Results in Prior Studies

Figure S3, shows a set of maps that highlights differences in two studies, (a) Anair & Mahmassani (2012) and (b) Yawitz *et al.* (2013). These studies vary in life cycle scope, vehicle assumptions, regional boundaries, and grid emissions factors. In particular, variation in grid emissions factors and regional boundaries are key drivers of regional differences in EV benefits.

(a) adapted from Anair & Mahmassani (2012)



(b) adapted from Yawitz et al. (2013)

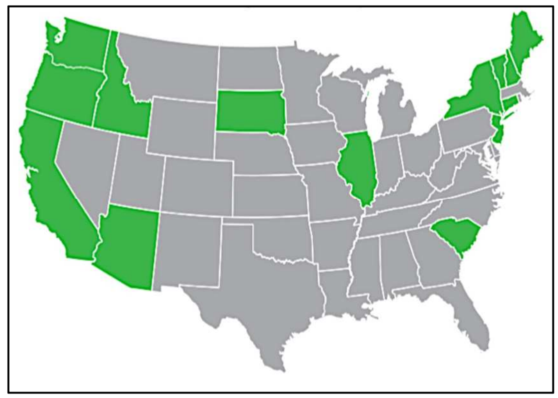


Figure S3.Regional comparisons of CO_2 emissions from EVs vs. gasoline vehicles from two studies (a) Anair & Mahmassani (2012): EV Ratings comparing the Nissan Leaf to gasoline vehicles using 2009 eGRID subregion avg. emission factors [Violet = EV is comparable to a 31-40 mpg gasoline vehicle); Blue = EV is comparable to a 41-50 mpg gasoline vehicle; and Light Blue = EV is comparable to a >51 mpg gasoline vehicle)]. Reprinted from Anair, D. & Mahmassani, A. State of Charge: Electric Vehicles' Global Warming Emissions and Fuel-Cost Savings Across the United States. Copyright 2012 Union of Concerned Scientists; (b) Yawitz et al. (2013): Leaf *vs* Toyota Prius HEV using 2010 state average emissions factors, where the green states are those where the Leaf is the lower emitting vehicle. Reprinted from Yawitz, D., Kenward, A., & Larson, E.. A Roadmap to Climate-friendly Cars: 2013. Climate Central, Princeton, New Jersey. Copyright 2013 Climate Central.

S.4. Comparison of Emission Factors

Figure S4 summarizes hourly emissions factors in each region. In most cases, MEFs are lower than AEFs during peak load times, where natural gas is often the fuel used at the margin (Siler-Evans *et al.*, 2012). Also, hourly estimates for the consumption-based MEFs (Graff-Zivin *et al.*, 2014) vary more by hour and have wider uncertainty ranges, especially for the regions within the eastern interconnect, than the generation-based MEFs (Siler-Evans *et al.,* 2012). This is presumably due to flow between regions but could also be biased by operation of renewable plants.

Discrepancies between generation- and consumption-based MEF values are small in the WECC and TRE regions where trading with other regions is limited. In MRO consumption-based values are much higher than generation-based values (by up to 66%) even though MRO is a net importer from regions that are less carbon-intensive. A potential explanation is that the majority of the energy that MRO imports is supplied by coal power plants in neighboring regions (Graff-Zivin *et al.*, 2014).

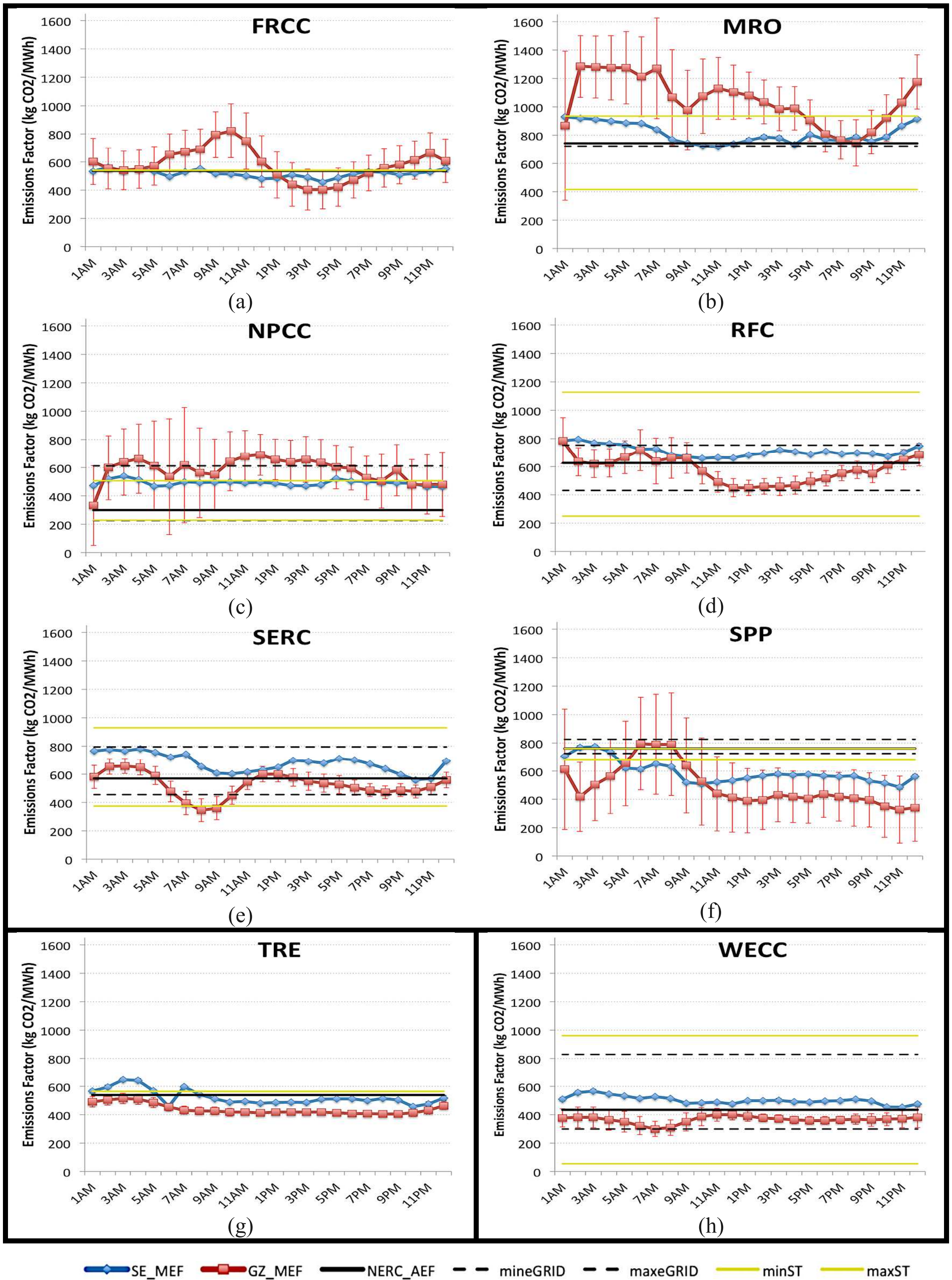


Figure S4. Hourly consumption-based (GZ_MEF) [Graff-Zivin et al. (2014)] and generation-based (SE_MEF) [Siler-Evans et al. (2011)] marginal emission factors by NERC region. Lines show minimum and maximum eGRID subregion and state average emission factors (mineGRID, minST, maxeGRID, and maxST) [eGRID 2012] in each NERC region as indicated by chart headings (e.g., Western Electricity Coordinating Council (WECC)). Error bars show 95% confidence intervals of hourly MEFs.

S.5. Emissions estimates by life cycle stage

To estimate upstream marginal electricity emissions, first, we estimate the marginal grid mix. Next, we determine the estimated emissions factor for each fuel type in the mix. Siler-Evans et al (2011) provide a supplementary data set containing grid mix at 20 load levels. We use linear interpolation to estimate marginal grid mix (percent of marginal generation from coal, natural gas, and oil) at intermediate load values.

To compute upstream electricity emissions by hour, $\widehat{\phi}_{tjr}^{Upstream\_Elec}$ (*j*=generation-based from Siler-Evans et al 2011), we used the following formula, where we assumed distributions/values shown in Table S8.

$$\widehat{\phi}_{tjr}^{Upstream\_Elec} = \sum_{i} M_{itr} * \widehat{\phi}_{i}^{Upstream\_Fuel}$$

Table S8. Upstream fossil fuel emissions estimates (g CO_2/kWh)

Fossil Fuel	Upstream Fuel Emissions ($\widehat{\phi}_{i}^{Upstream\_Fuel}$)
Coal	Normal(mean = 32, std. error = 13)
Gas	Normal(mean = 115, std. error = 44)
Oil	43

Graff Zivin et al. (2014) do not provide a grid mix or load data that can be used to estimate hourly marginal grid. As an approximation of hourly consumption-based upstream electricity emission, $\widehat{\phi}_{tjr}^{Upstream\_Elec}$ $(j = consumption - based)$, we used the following formula:

$$\widehat{\phi}_{itjr,j=consumption-based}^{Upstream\_Elec} = \left(\frac{\widehat{\phi}_{tjr,j=generation-based}^{Upstream\_Elec}}{\widehat{\Upsilon}_{ijrv,j=generation-based}}\right)\widehat{\Upsilon}_{ijrv,j=consumption-based}$$

where $\widehat{\Upsilon}_{ijrv}^{Elec}$ is the vehicle operation electricity emissions estimate for vehicle sample i, vehicle type v, using emissions factors set *j* in region r in g CO_2. This approach may introduce some error, since upstream emissions represent a larger share of natural gas life cycle emissions than for coal; however, we lack information on marginal mix needed to identify marginal upstream emissions using the Graff Zivin estimates.

Descriptive statistics of simulated electricity upstream and production emissions in g CO_2/mi for the Nissan Leaf are summarized in Table S9. Simulated battery and vehicle upstream and manufacturing emissions are illustrated in Figure S5 and Figure S6, respectively. Figure S7 illustrates the relative contribution of each life stage to vehicle life cycle emissions.

Table S9. Nissan Leaf electricity upstream and production emissions estimates (g CO_2/mi) by region.

Region	Emission Factor Type	Charging	Marginal Electricity Upstream Emissions (g CO_2/mi)			Marginal Electricity Production Emissions (g CO_2/mi)		
			5th	Mean	95^{th}	5th	Mean	95th
FRCC	Marginal Consumption	Convenience	13	17	22	120	162	204
		Delayed	12	16	20	132	177	222
	Marginal Generation	Convenience	16	16	17	151	154	158
		Delayed	11	14	18	158	163	167
	Average Generation	Subregion	43	43	43	161	161	162
		State	43	43	43	160	161	161
MRO	Marginal Consumption	Convenience	7	9	11	226	280	334
		Delayed	5	7	9	262	348	434
	Marginal Generation	Convenience	8	8	8	237	241	244
		Delayed	5	5	6	270	273	276
	Average Generation	Subregion	11	13	13	217	222	222
		State	7	13	14	124	222	280
NPCC	Marginal Consumption	Convenience	13	147	26	108	164	220
		Delayed	9	147	28	76	155	234
	Marginal Generation	Convenience	17	167	18	144	147	149
		Delayed	17	149	18	144	147	149
	Average Generation	Subregion	0.1	90	58	68	90	183
		State	28	90	41	0.3	90	152
RFC	Marginal Consumption	Convenience	6	7	7	149	171	192
		Delayed	5	6	7	171	205	240
	Marginal Generation	Convenience	8	8	8	209	211	214
		Delayed	7	7	7	227	229	231
	Average Generation	Subregion	15	15	18	129	188	226
		State	15	15	43	75	188	338
SERC	Marginal Consumption	Convenience	7	8	9	140	156	173
		Delayed	6	6	7	157	176	195
	Marginal Generation	Convenience	10	10	10	195	197	200
		Delayed	8	8	8	221	223	225
	Average Generation	Subregion	35	20	13	136	171	238
		State	12	20	16	112	171	278
SPP	Marginal Consumption	Convenience	5	10	15	59	123	188
		Delayed	3	8	13	64	153	242
	Marginal Generation	Convenience	14	14	14	168	170	173
		Delayed	11	11	11	197	201	204
	Average Generation	Subregion	17	27	32	218	228	247
		State	38	27	15	203	228	228
TRE	Marginal Consumption	Convenience	14	15	16	121	127	134
		Delayed	12	13	14	135	145	155
	Marginal Generation	Convenience	17	18	18	149	152	155
		Delayed	15	15	16	166	170	174
	Average Generation	Subregion	38	38	38	161	161	161
		State	38	38	38	161	161	169
WECC	Marginal Consumption	Convenience	12	13	15	97	110	123
		Delayed	10	12	14	90	111	132
	Marginal Generation	Convenience	18	18	18	145	147	149
		Delayed	16	17	17	152	155	159
	Average Generation	Subregion	38	26	27	90	130	248
		State	9	26	38	16	130	288

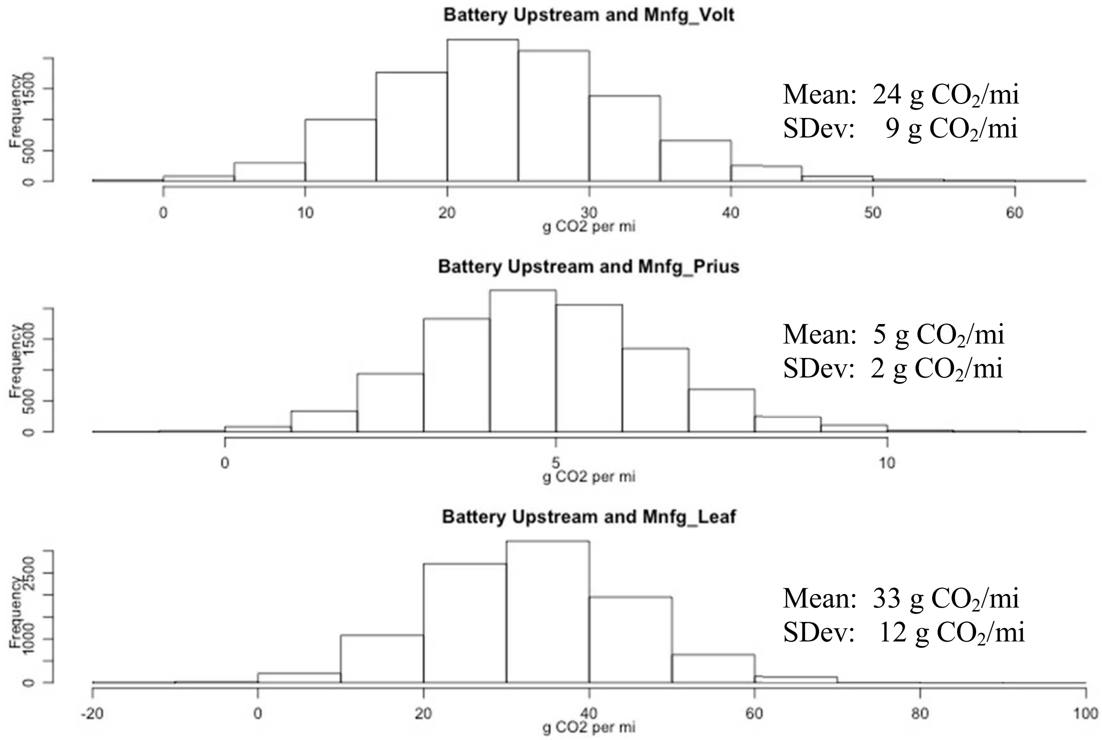


Figure S5. Lithium-ion battery upstream and manufacturing emissions estimate for Chevrolet Volt, Toyota Prius PHEV, and Nissan Leaf

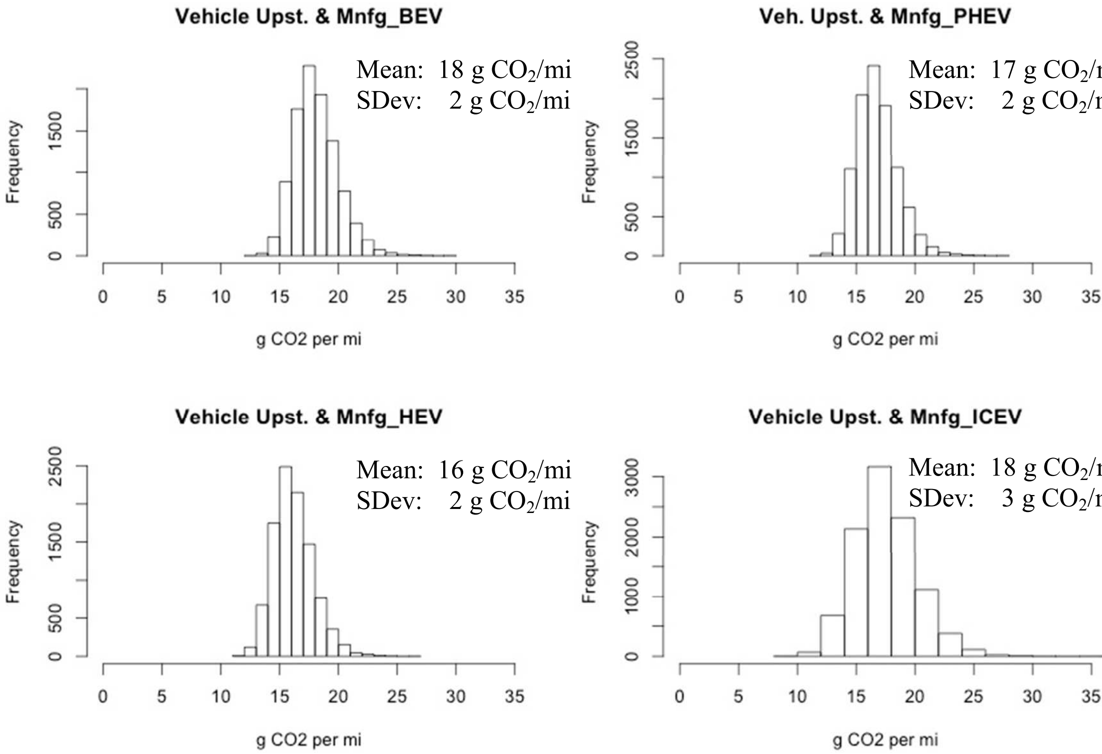


Figure S6. Vehicle upstream and manufacturing emissions estimates by vehicle type - Battery electric vehicle (BEV), Plug-in hybrid electric vehicle (PHEV), Hybrid electric vehicle (HEV), and Internal combustion engine vehicle (ICEV).

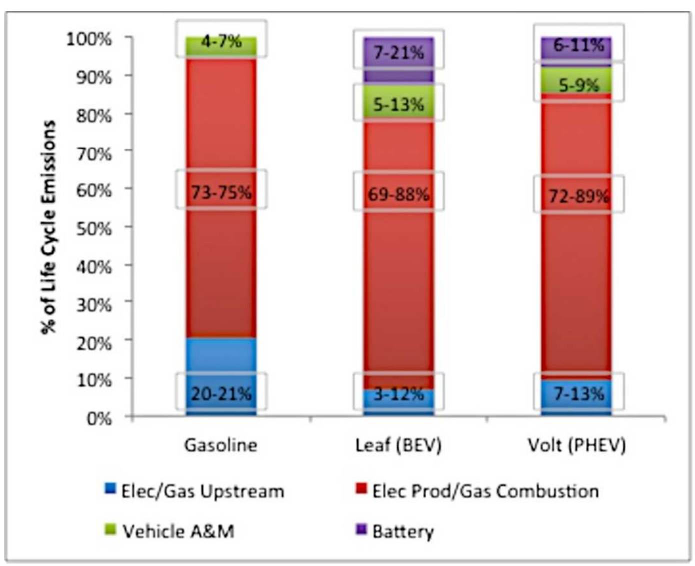


Figure S7. Life cycle emissions by vehicle type using marginal emission factors for EVs. Values show the uncertainty bounds of each life stage emissions estimate.

Table S10 summarizes the probability that the Nissan Leaf is lower emitting than the Toyota Prius Hybrid and Sales-weighted Average ICEV by NERC region and marginal emissions estimation method.

Table S10. Probability that the Nissan Leaf is lower emitting than the Toyota Prius Hybrid and sales-weighted average ICEV (%)

NERC Region	Pr(Nissan Leaf < Prius Hyrbid)				Pr(Nissan Leaf < Avg. ICEV)			
	Cons_ Conv	Cons_ Del	Gen_ Conv	Gen_ Del	Cons_ Conv	Cons_ Del	Gen_ Conv	Gen_ Del
FRCC	75	47	100	100	100	100	100	100
MRO	0	1	0	0	100	96	100	100
NPCC	45	89	100	100	100	100	100	100
RFC	86	1	0	0	100	100	100	100
SERC	91	62	5	0	100	100	100	100
SPP	95	86	94	29	100	100	100	100
TRE	100	100	100	91	100	100	100	100
WECC	100	100	100	91	100	100	100	100

S.6. Statistical Tests

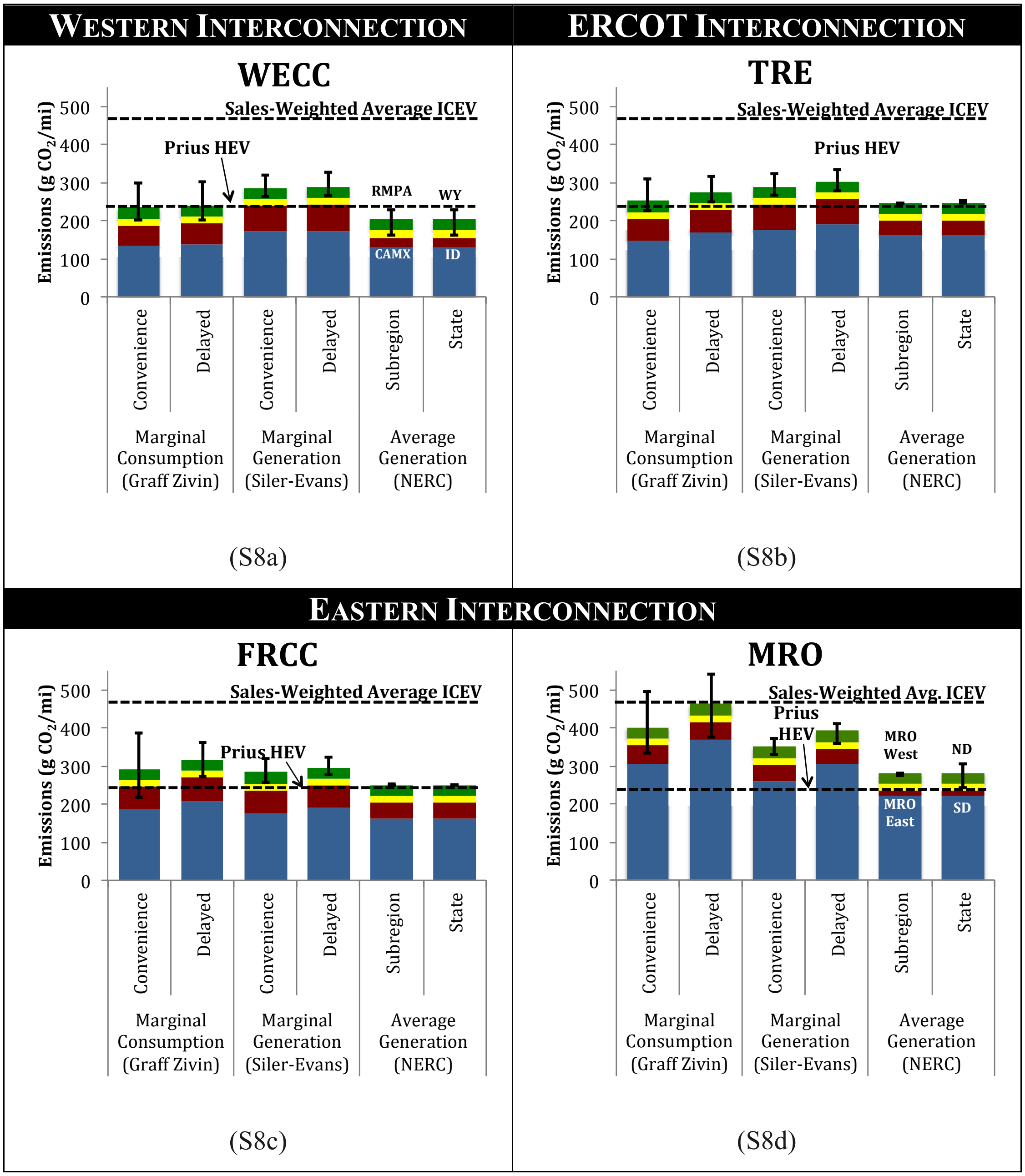
We performed statistical comparisons of the vehicle emissions estimates to verify sufficient Monte Carlo draws to test whether the results are significantly different at 5% significance levels. We summarize the hypotheses and the corresponding tests in Table S11.

Table S11. Statistical comparison of vehicle emissions estimates

	Null Hypothesis	Test
1a	E[Convenience – Delayed] = 0 (Consumption-based marginal emissions estimates)	Paired one-tailed t-test
1b	E[Convenience – Delayed] = 0 (Generation-based marginal emissions estimates)	Paired one-tailed t-test
2a	E[Consumption-based – Generation –based] = 0 (Convenience charging)	Paired two-tailed t-test
2b	E[Consumption-based – Generation –based] = 0 (Delayed charging)	Paired two-tailed t-test
3a-d	E[NERC Average Emissions Estimates - Marginal Emissions Estimates = 0] (Generation- and consumption-based for both delayed and convenience charging)	One-sample two-tailed t-test
4a-d	E[eGRID Average Emissions Estimates - Marginal Emissions Estimates = 0] (Generation- and consumption-based for both delayed and convenience charging)	One-sample two-tailed t-test
5a-d	E[State Average Emissions Estimates - Marginal Emissions Estimates = 0] (Generation- and consumption-based for both delayed and convenience charging)	One-sample two-tailed t-test

S.7. Comparisons with the Chevrolet Volt

Chevrolet Volt life cycle emissions estimates summary graphs



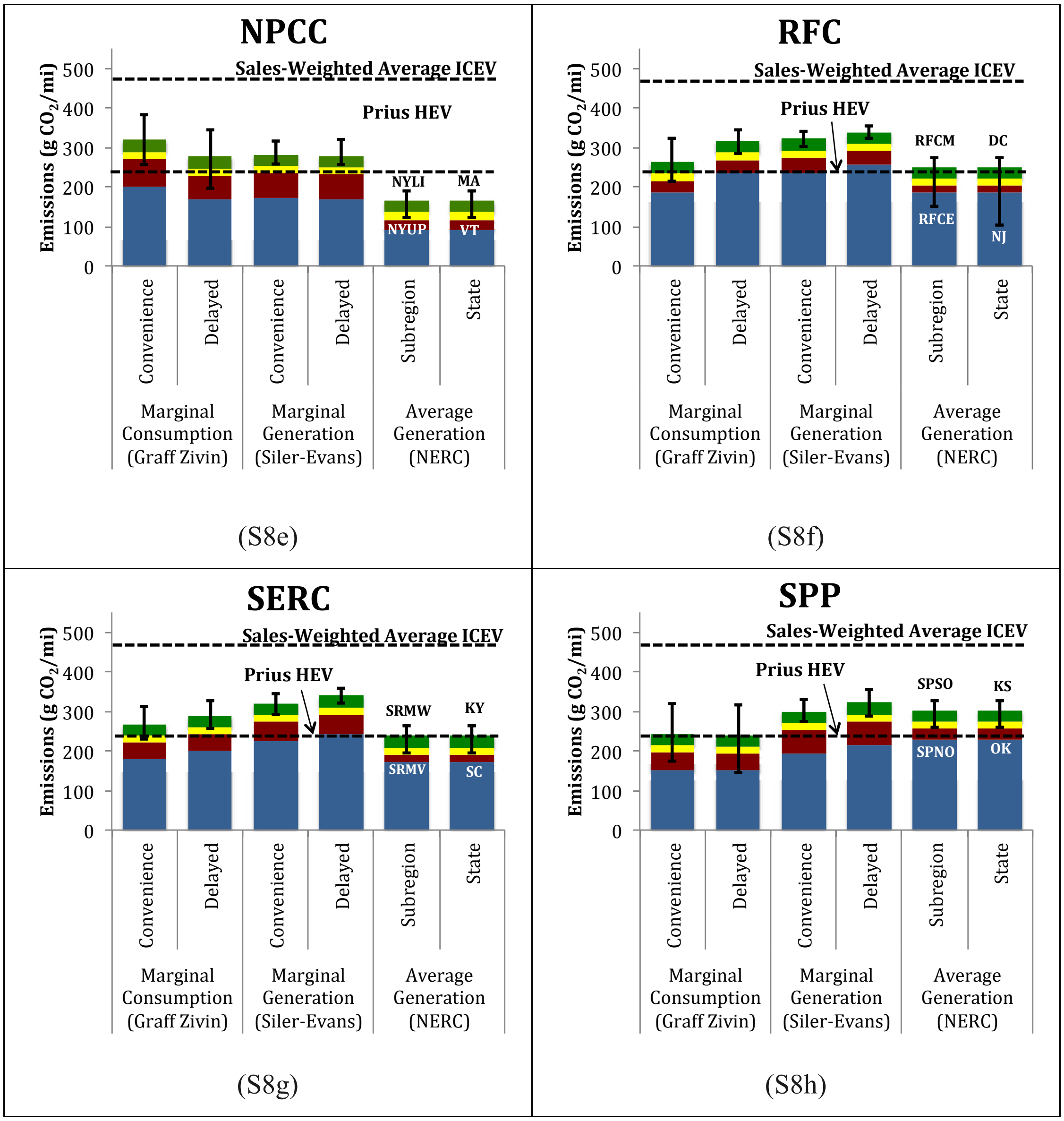


Figure S8. Chevrolet Volt life cycle emissions (g CO_2/mile) using alternative grid emission factors by region. The life cycle stages included are: electricity production (blue); electricity upstream (red); vehicle assembly & manufacturing (yellow); and battery upstream & production (green). The marginal emission cases show expected marginal emissions estimates with error bars for the 5th and 95th percentile values. Average generation estimates show NERC region average emissions estimates with error bars that represent the lowest and highest eGRID subregion or state emissions estimates within each NERC region, respectively. Horizontal lines show expected Toyota Prius Hybrid and sales-weighted average vehicle emissions estimates. Combined driving pattern (45% city and 55% highway) energy use from fueleconomy.gov (2013) was used for all vehicles. FRCC = Florida Reliability Coordinating Council; MRO = Midwest Reliability Organization; NPCC = Northeast Power Coordinating Council; RFC = Reliability First Corporation; SERC = SERC Reliability Corporation; SPP = Southwest Power Pool, RE; TRE = Texas Reliability Entity; WECC = Western Electricity Coordinating Council; ERCOT = Electric Reliability Council of Texas.

The bar graphs in Figure S8 summarize the emissions estimates for Chevrolet Volt for each life stage under different electricity emission factor assumptions. For comparison, lines showing mean estimated Toyota Prius HEV and sales-weighted ICEV are also shown. Marginal error bars show the 5^{th} and 95^{th} percentile values from the simulation to show uncertainty in both marginal emissions factor estimates and other life cycle stage emissions – vehicle assembly and manufacturing emissions and battery upstream and manufacturing. Average emissions estimate illustrate the variability of average emission factors; bar heights show mean simulated emissions using NERC regional emissions factors while error bars show simulated emission using highest and lowest eGRID subregion and state emissions within each NERC region.

The bar graphs show the differences in mean Chevy Volt emission estimates under different emissions factor assumptions. In most cases, mean marginal emissions estimates are higher than mean average emissions estimates. This suggests that benefits from PHEVs similar to the Chevy Volt specifications may have been overestimated in previous studies. The general trend indicates that the Chevy Volt is higher emitting than the Toyota Prius HEV, and in worse conditions (e.g., MRO), could be higher emitting than the sales-weighted average ICEV.

Percentage Differences of Vehicle Life Cycle Emissions

Table S12 summarizes the percentage difference in the simulated marginal emissions of the Chevrolet Volt and two gasoline vehicles - Toyota Prius HEV and sales-weighted average ICEV. As shown, mean estimates show that in all cases, the Chevrolet Volt is lower emitting than the average ICEV. However, when compared to the most efficient gasoline vehicle on the road at present, the Toyota Prius HEV, results indicate that the Chevrolet Volt is higher emitting, on average.

Table S12. Summary of median CO2 emissions difference by region and estimation method computed as vehicle emissions difference divided by gasoline vehicle emissions. Green indicates that the Chevrolet Volt is lower emitting than the gasoline vehicle (Toyota Prius Hybrid or sales-weighted ICEV) while red means vice versa.

NERC Region	Chevrolet Volt – Toyota Prius HEV				Chevrolet Volt – Avg. ICEV			
	Cons_ Conv	Cons_ Del	Gen_ Conv	Gen_ Del	Cons_ Conv	Cons_ Del	Gen_ Conv	Gen_ Del
FRCC	23%	33%	19%	24%	-37%	-32%	-40%	-37%
MRO	69%	94%	47%	64%	-14%	-2%	-25%	-16%
NPCC	34%	16%	18%	16%	-32%	-41%	-40%	-41%
RFC	10%	32%	35%	42%	-44%	-33%	-31%	-28%
SERC	12%	21%	35%	43%	-43%	-39%	-32%	-28%
SPP	2%	0%	25%	35%	-48%	-49%	-36%	-31%
TRE	6%	15%	21%	27%	-46%	-42%	-39%	-36%
WECC	-2%	0%	20%	21%	-50%	-49%	-39%	-39%

Note: The headings are as follows: Cons_ = Consumption-based MEF; Gen_ = Generation-based MEF; _Conv = Convenience Charging; _Del = Delayed Charging

Probability that Chevrolet Volt is lower emitting than the Toyota Prius hybrid and U.S. sales-weighted average ICEV

Table S13 summarizes the probability that the Chevrolet Volt is lower emitting than the Toyota Prius Hybrid and the U.S. sales-weighted average ICEV under the four marginal emission factor scenarios considered. It can be seen that the highest probability of the Volt being lower emitting than the Prius Hybrid is in the western U.S. (WECC region) – about 60%–70% under consumption-based MEFs. This is followed by the south central U.S. (SPP region) – 46% - 48% under consumption-based. Probabilities are low in the rest of the country. These numbers are illustrated in Figure S9.

Table S13. Probability that the Chevrolet Volt is lower emitting than the Toyota Prius Hybrid and sales-weighted average ICEV

NERC Region	Pr(Chevrolet Volt < Prius Hyrbid)				Pr(Chevrolet Volt < Avg. ICEV)			
	Cons_ Conv	Cons_ Del	Gen_ Conv	Gen_ Del	Cons_ Conv	Cons_ Del	Gen_ Conv	Gen_ Del
FRCC	14	1	0	0	100	100	100	100
MRO	0	0	0	0	88	55	100	100
NPCC	2	22	0	0	100	100	100	100
RFC	29	0	0	0	100	100	100	100
SERC	12	1	0	0	100	100	100	100
SPP	48	46	0	0	100	100	100	100
TRE	33	1	0	0	100	100	100	100
WECC	70	59	0	0	100	100	100	100

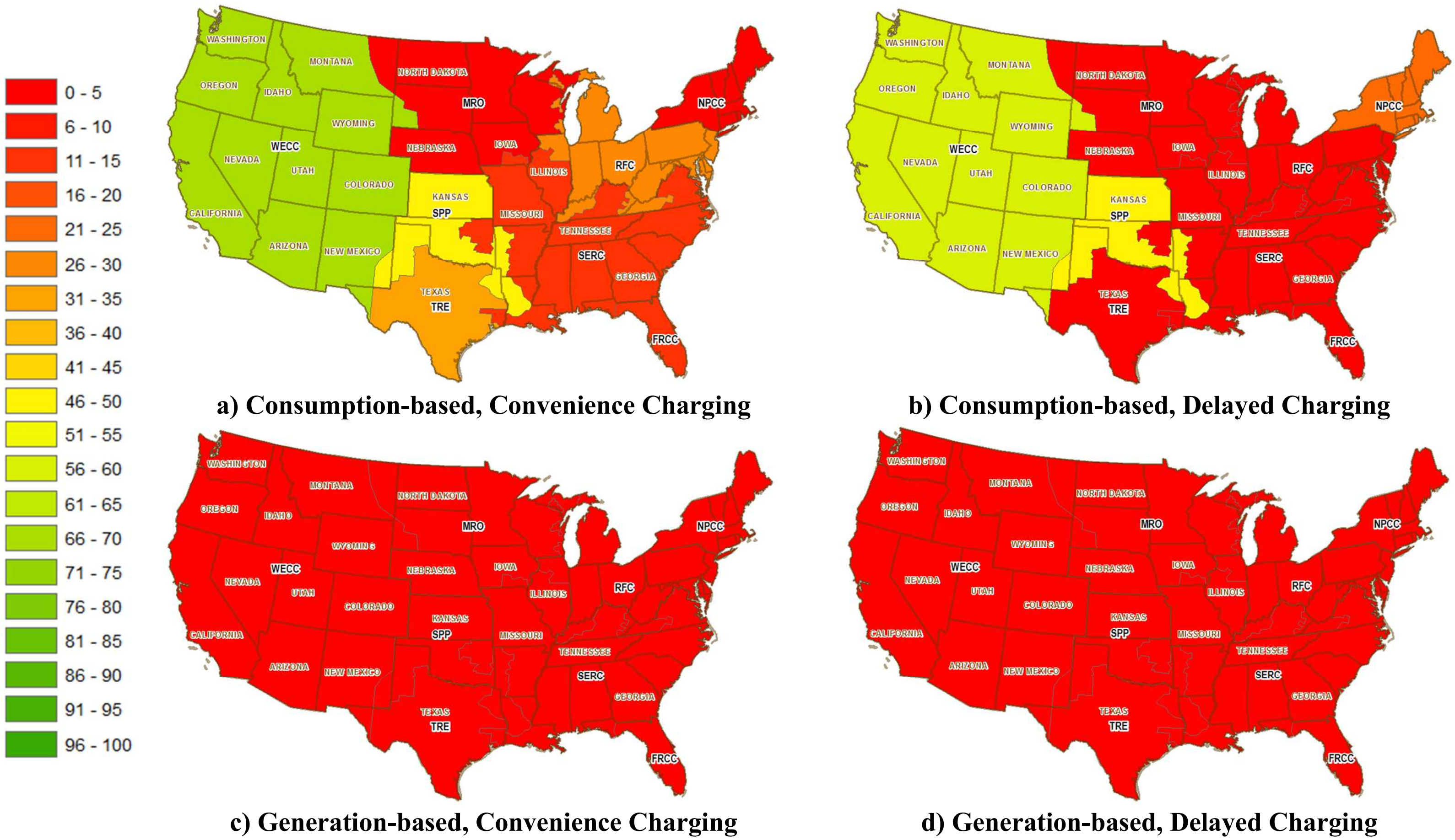


Figure S9. Probability that the Chevrolet Volt is lower CO_2-emitting than the Toyota Prius Hybrid by region and charging scheme.