Marginal electricity for near-term plug-in and fuel cell vehicle demands in California: Impacts on vehicle greenhouse gas emissions



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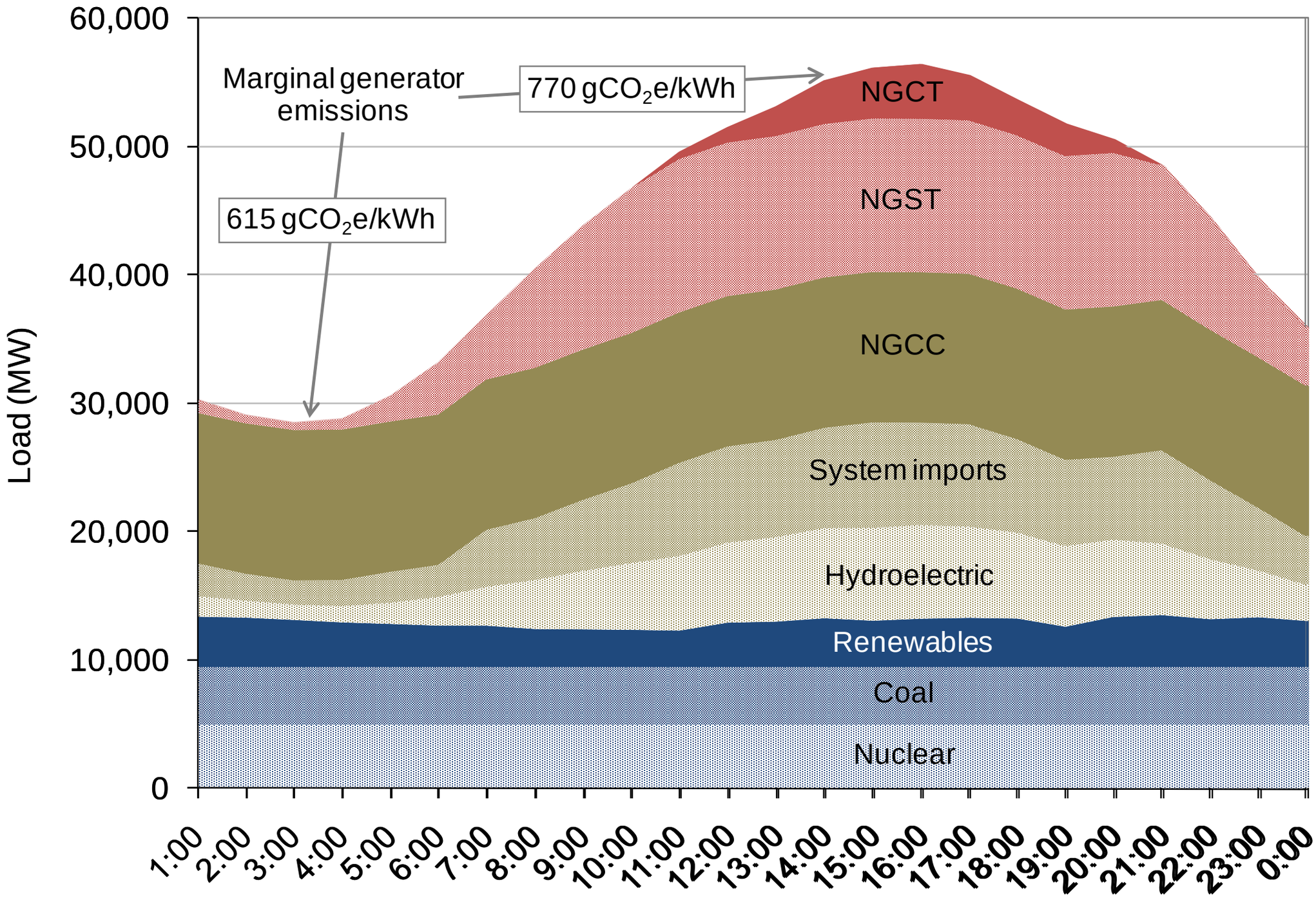
Summary

- Fuel and electricity supply could “converge”
- Vehicle demand impacts on current grid in CA
- 3-region model of CA power supply (EDGE-CA)
- Electricity GHG emissions sensitive to:
  - Demand quantity, timing, and location
  - Power plant availability (especially hydro)
- In CA, marginal emissions > average emissions
- Well-to-wheels vehicle GHG emissions

Findings (for California in 2010)

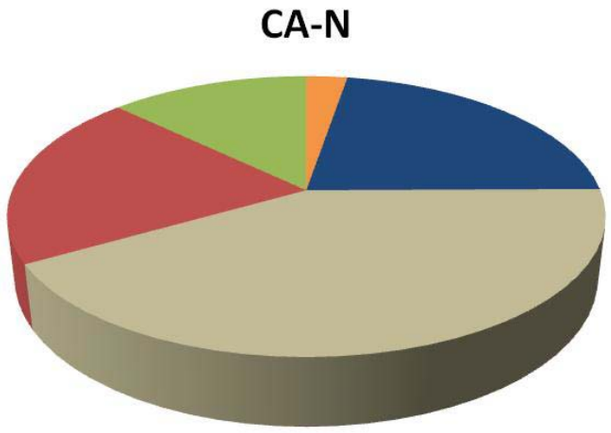
- CA marginal emissions: ~ 625 gCO_2e/kWh
  CA average emissions: ~ 440 gCO_2e/kWh
  LCFS marginal emissions: ~ 377 gCO_2e/kWh
  Gasoline equivalent: ~ 346 gCO_2e/kWh
- Plug-in vehicles emissions lower than HEVs
  - Improved vehicle efficiency, not lower carbon fuel
- Worst time to plug-in: 5pm-8pm
  Best time to plug-in: 2am-4am

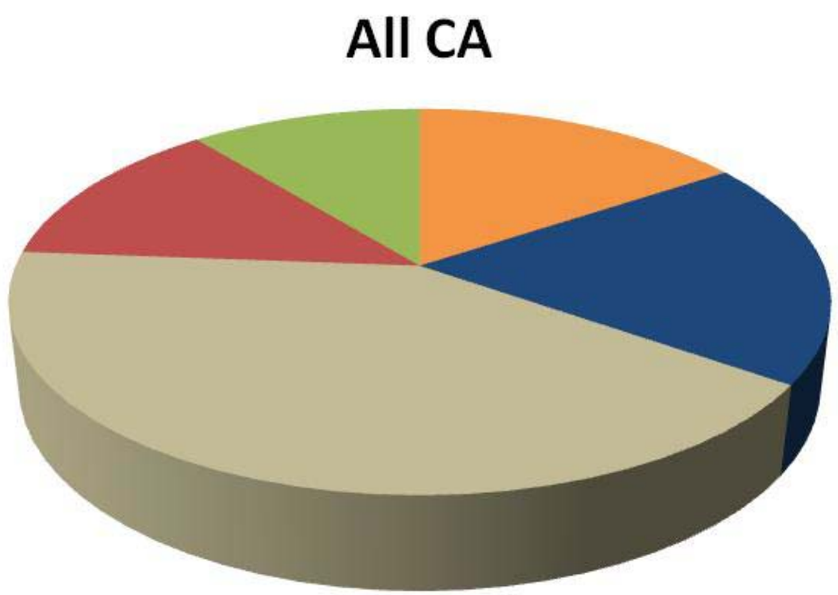
Background: Electricity supply

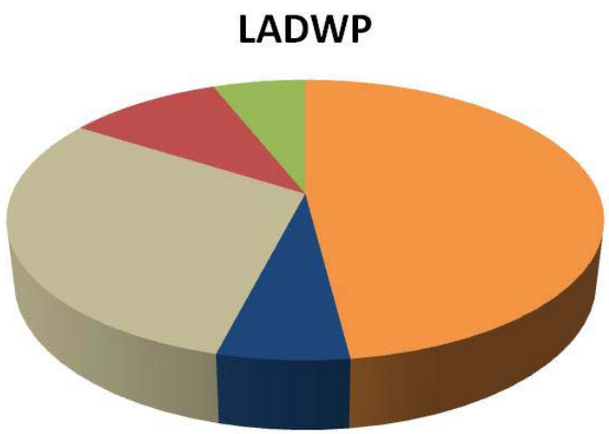


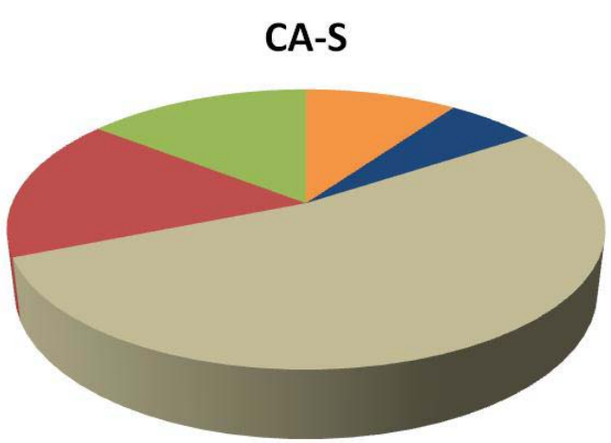
Methods

Regional electricity supply



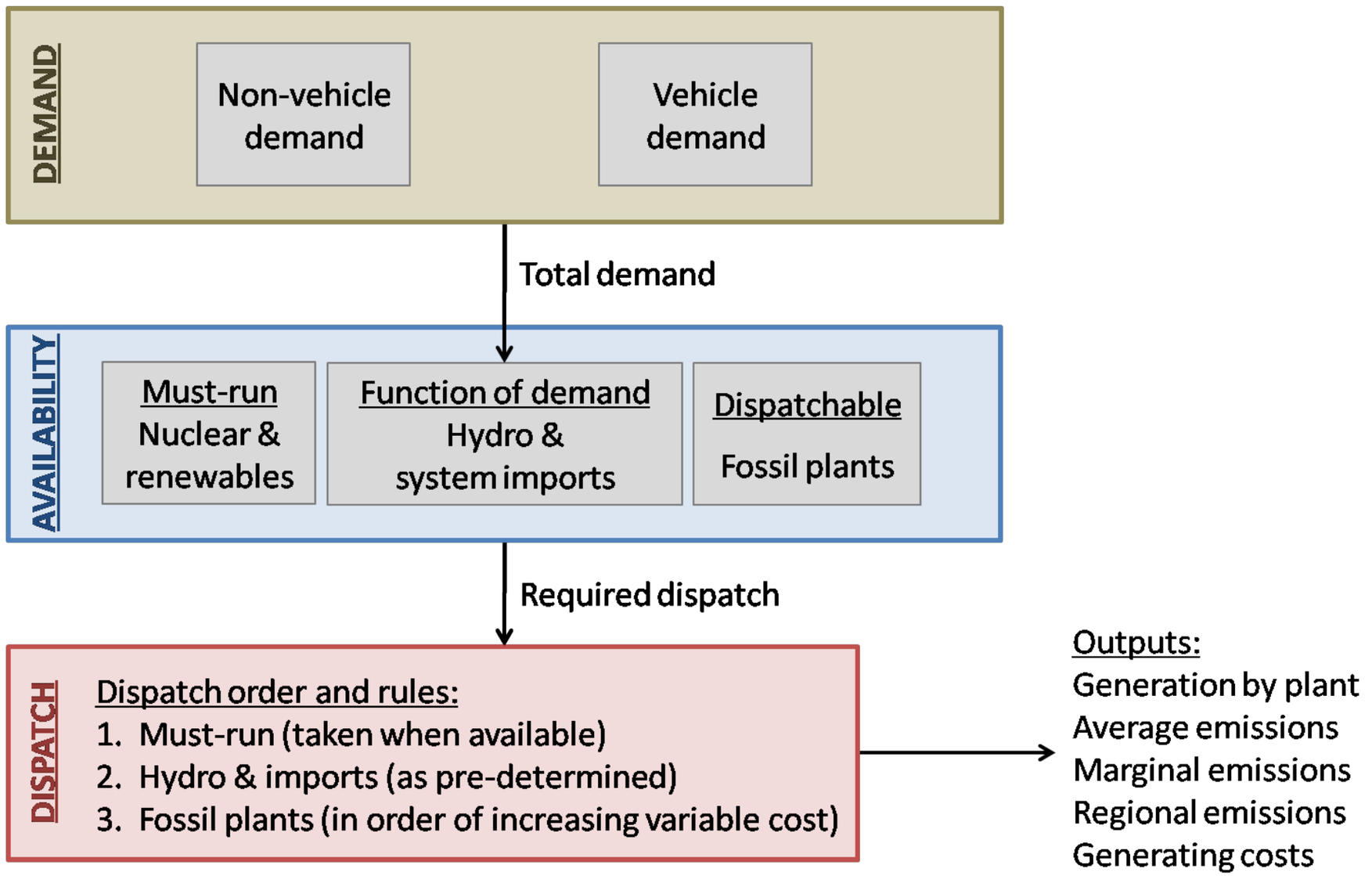






Source: California Energy Commission

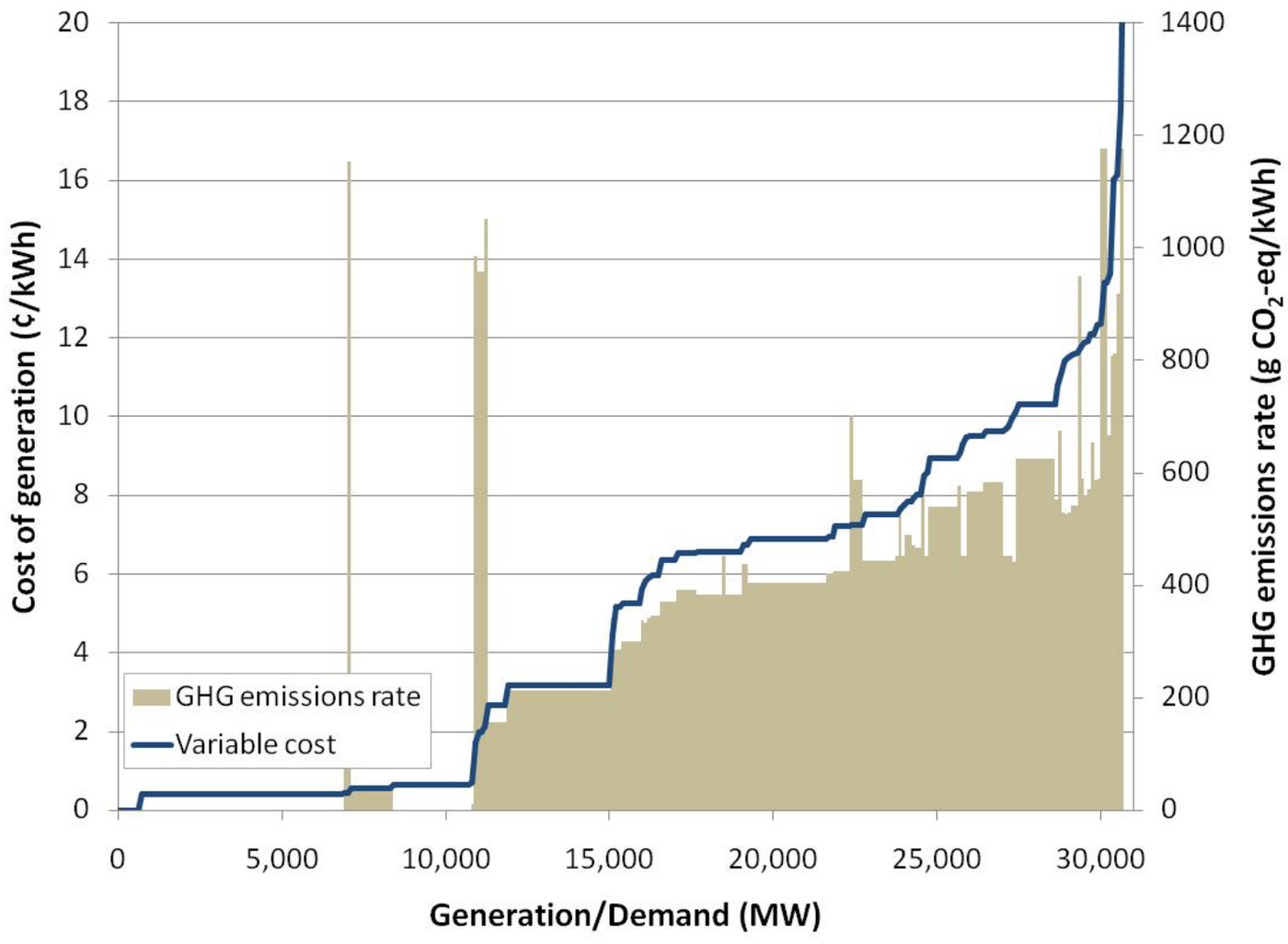
EDGE-CA framework



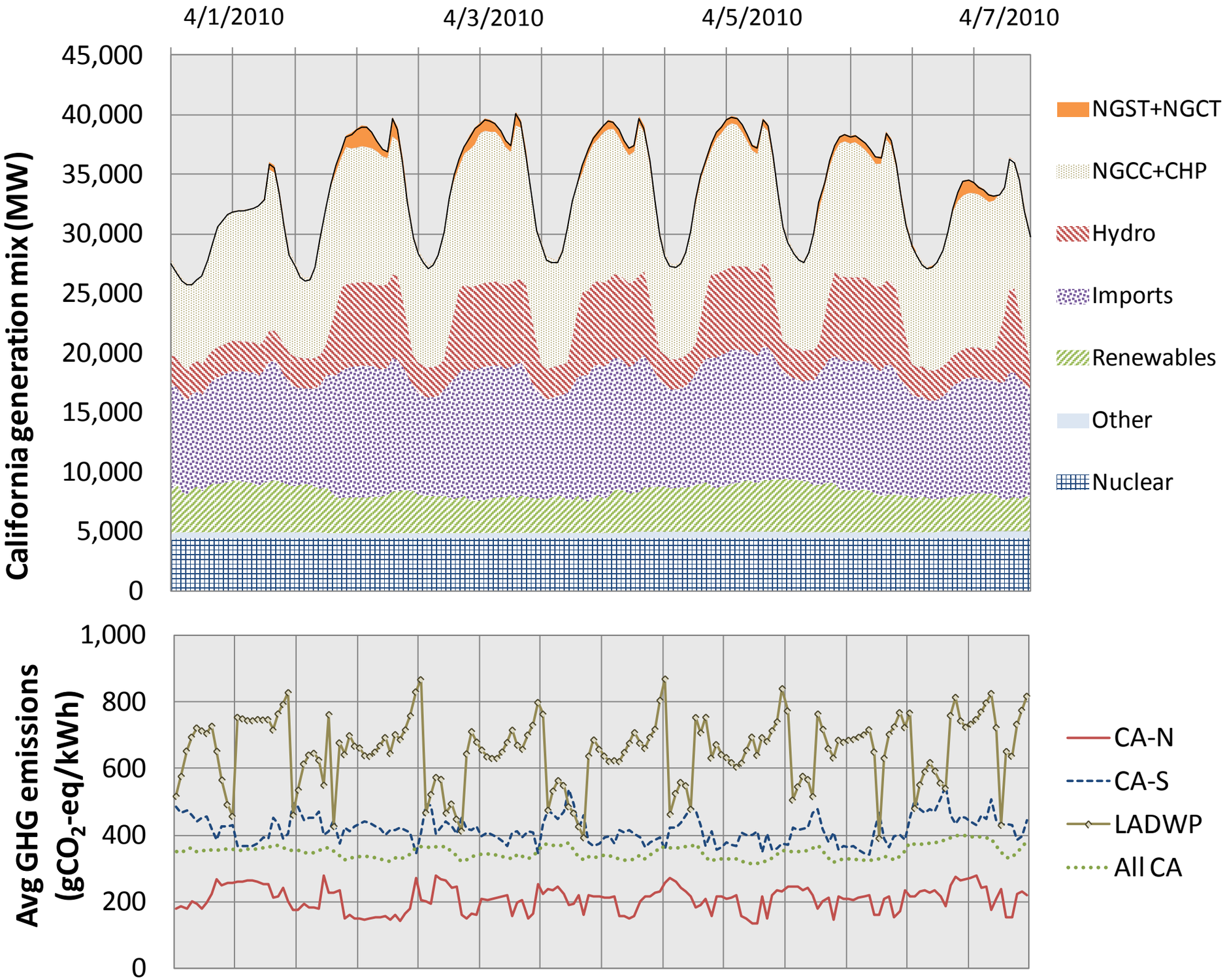
Regional supply curves

- EDGE-CA constructs hourly supply curves for 3 CA regions and transfers power among them

Northern California:



Sample outputs



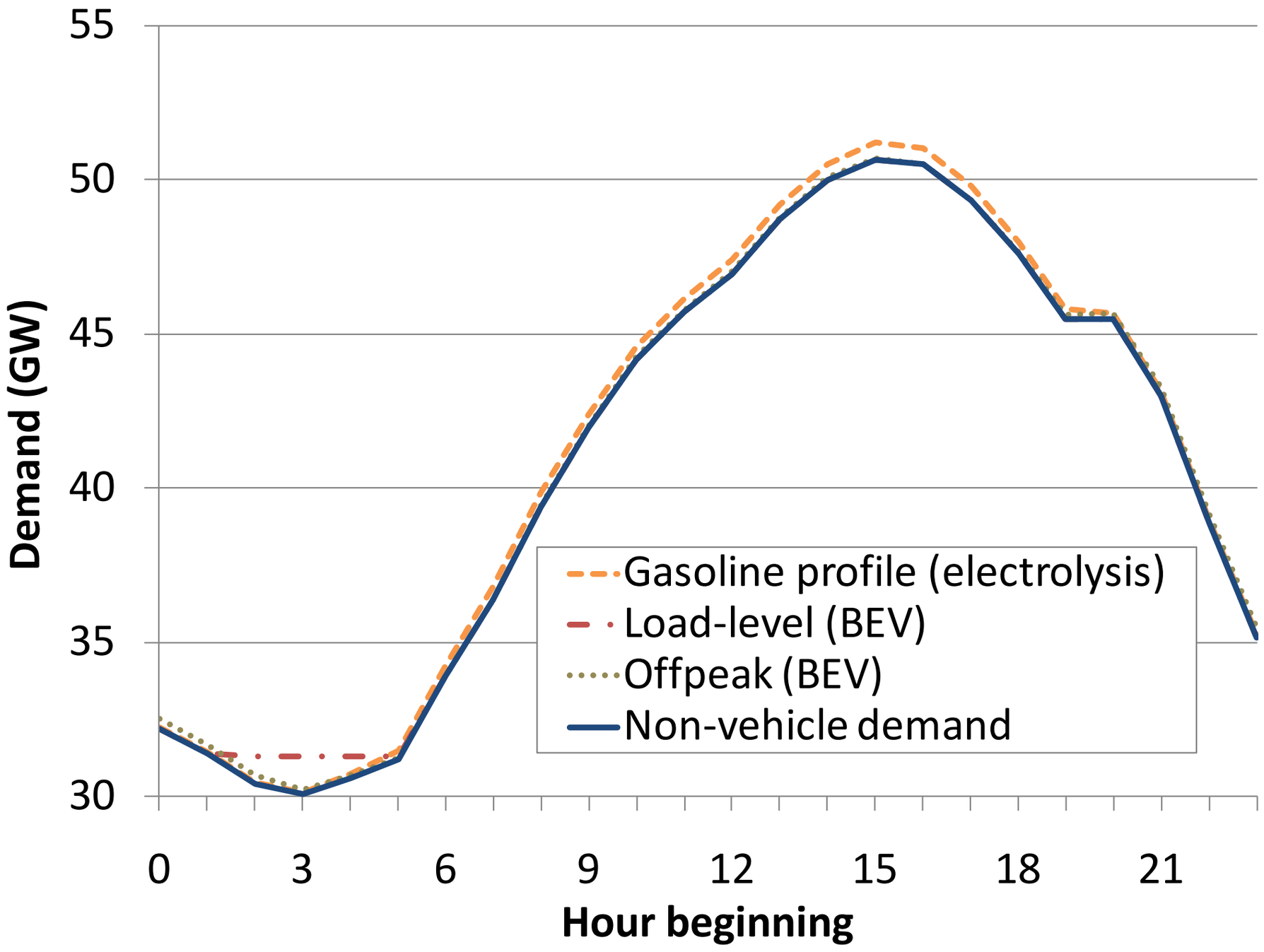
Vehicle assumptions

- Well-to-wells comparison of GHG emissions
- Assumes a vehicle type accounts for 1% of VMT in California in 2010 (~220,000 vehicles)

	Vehicle efficiency parameters			Vehicle energy intensity (MJ/mi)		
	Relative fuel economy [1]	Fuel economy (mpgge)	All- electric fraction [2]	Gasoline	Electricity	Hydrogen
ICE	1.00	30.0	---	3.85	---	---
HEV	1.53	45.9	---	2.52	---	---
PHEV (ICE mode)	1.54	46.2	---	2.50	---	---
PHEV (electric mode)	3.00	90.0	100%	---	1.28	---
PHEV20	1.91	57.4	40%	1.50	0.51	---
PHEV40	2.18	65.3	60%	1.00	0.77	---
BEV	3.50	105.0	---	---	1.10	---
FCV	2.32	69.6	---	---	---	1.66

[1] Based on values from ANL's GREET model; [2] From EPRI (2007)

Vehicle demand timing profiles



Results

Average electricity GHG emissions rates (California in 2010)

- Incl. upstream emissions
- Emissions low in spring
  - Hydro and NW imports availability high
- Emissions high in early fall mornings
  - Hydro and NW imports availability low
  - Coal comprises its highest fraction of generation

All California											
357					411					464	
J	F	M	A	M	J	J	A	S	O	N	D
447	434	432	411	382	362	394	431	443	463	463	453
449	436	430	408	383	370	392	428	444	463	462	457
452	438	429	409	383	369	390	427	445	463	461	459
453	437	427	411	382	368	390	427	445	463	464	459
448	434	433	413	385	372	393	430	447	464	464	457
439	426	441	415	375	365	398	435	453	458	462	451
430	414	433	404	368	363	402	436	459	444	444	445
425	411	420	394	365	365	400	437	445	438	435	440
422	409	395	379	376	370	399	429	447	434	427	436
423	408	386	382	382	380	405	431	449	431	423	433
422	406	390	385	386	387	411	433	438	429	421	432
423	406	392	386	388	389	415	438	443	428	421	434
423	407	392	388	389	395	418	445	450	427	423	435
424	405	392	388	393	395	422	449	449	426	423	436
426	407	392	388	393	398	423	453	443	427	426	436
426	408	392	385	392	398	423	453	444	427	426	436
425	408	391	382	389	397	421	450	441	429	418	429
420	406	398	379	381	394	415	441	447	431	412	422
419	405	394	381	375	385	404	434	433	425	411	421
420	406	389	385	380	379	399	432	434	425	417	423
423	407	385	381	384	382	400	427	424	427	423	425
428	410	398	382	372	370	393	420	437	434	435	430
434	419	417	391	365	359	391	418	445	443	450	437
441	426	430	403	369	357	394	422	444	456	463	446
405	391	387	372	360	358	386	410	416	413	410	412

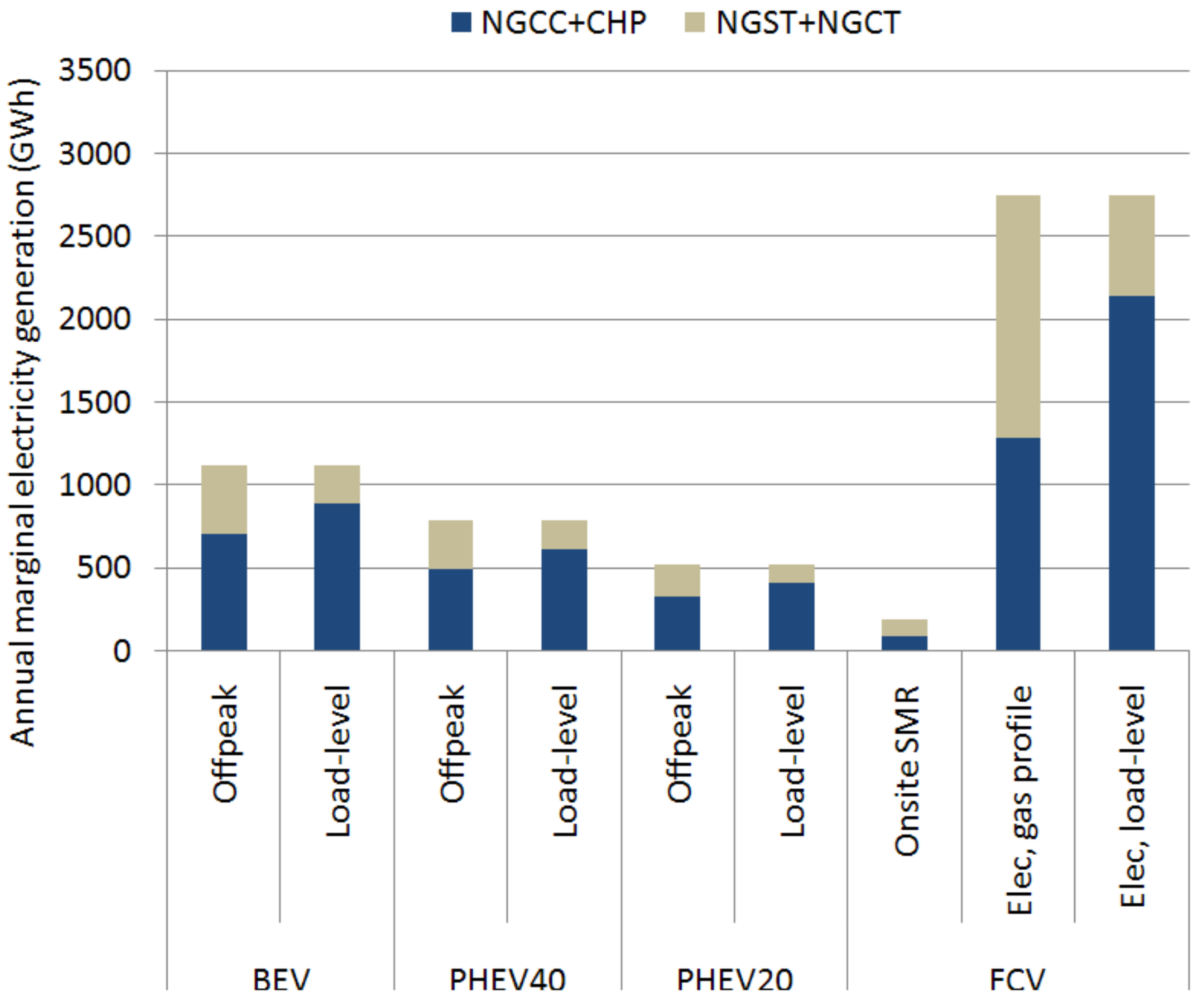
Marginal electricity GHG emissions rates (California in 2010)

Hour	Avg. recharging demand (MW)	Average hourly marginal generation GHG emissions rate (gCO_2-eq/kWh)												
		494					634					774		
		J	F	M	A	M	J	J	A	S	O	N	D	Year
0	307	630	548	612	531	494	564	638	646	608	634	586	641	595
1	307	634	544	589	517	502	548	570	633	583	623	547	630	577
2	276	619	535	586	507	515	530	546	614	571	595	549	630	567
3	184	623	539	588	512	509	543	541	618	576	589	552	629	569
4	123	639	562	609	535	510	546	569	618	596	622	573	639	585
5	61	646	615	632	592	509	543	610	644	630	636	625	653	611
6	31	654	633	640	600	566	600	614	652	639	638	612	640	624
7	15	657	638	644	639	615	616	650	673	654	656	640	641	644
8	15	665	642	661	644	631	651	667	684	672	654	654	652	657
9	46	665	648	653	650	657	667	682	679	679	655	659	660	663
10	77	654	648	661	661	677	681	684	692	673	674	666	662	670
11	77	658	649	665	670	676	681	707	715	694	667	659	664	676
12	77	658	651	658	667	678	687	714	721	710	658	659	663	677
13	77	658	654	658	667	675	685	721	743	699	672	656	652	679
14	77	655	643	660	661	685	688	745	742	691	675	656	658	680
15	31	648	645	669	658	676	690	750	721	712	681	659	654	680
16	15	657	646	653	652	678	683	732	736	699	671	663	658	678
17	15	687	680	656	658	673	679	710	774	704	669	669	671	686
18	61	687	680	666	660	665	668	696	725	699	680	669	685	682
19	123	678	667	670	671	686	679	693	704	705	675	664	672	681
20	184	673	662	660	662	681	687	675	695	683	670	656	666	673
21	276	660	660	662	659	670	681	687	693	680	656	647	664	668
22	307	654	629	636	627	600	695	660	666	663	654	634	661	648
23	307	647	576	625	555	510	590	658	659	645	632	632	648	615
Demand-weighted avg.		647	601	629	590	580	617	639	665	640	640	613	650	626

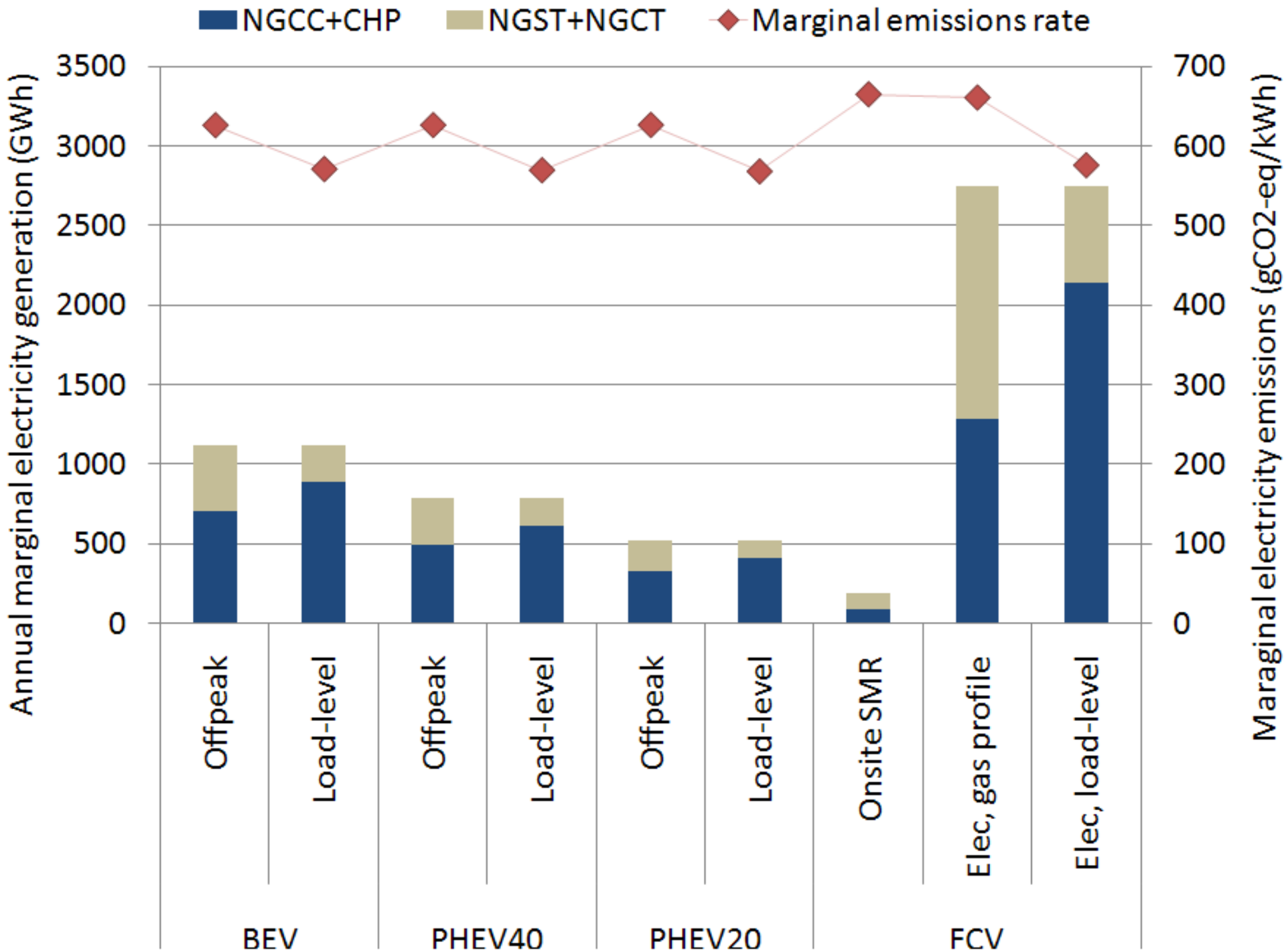
- BEV pathway
- *Offpeak* recharging

- Marginal emissions mostly follow total demand

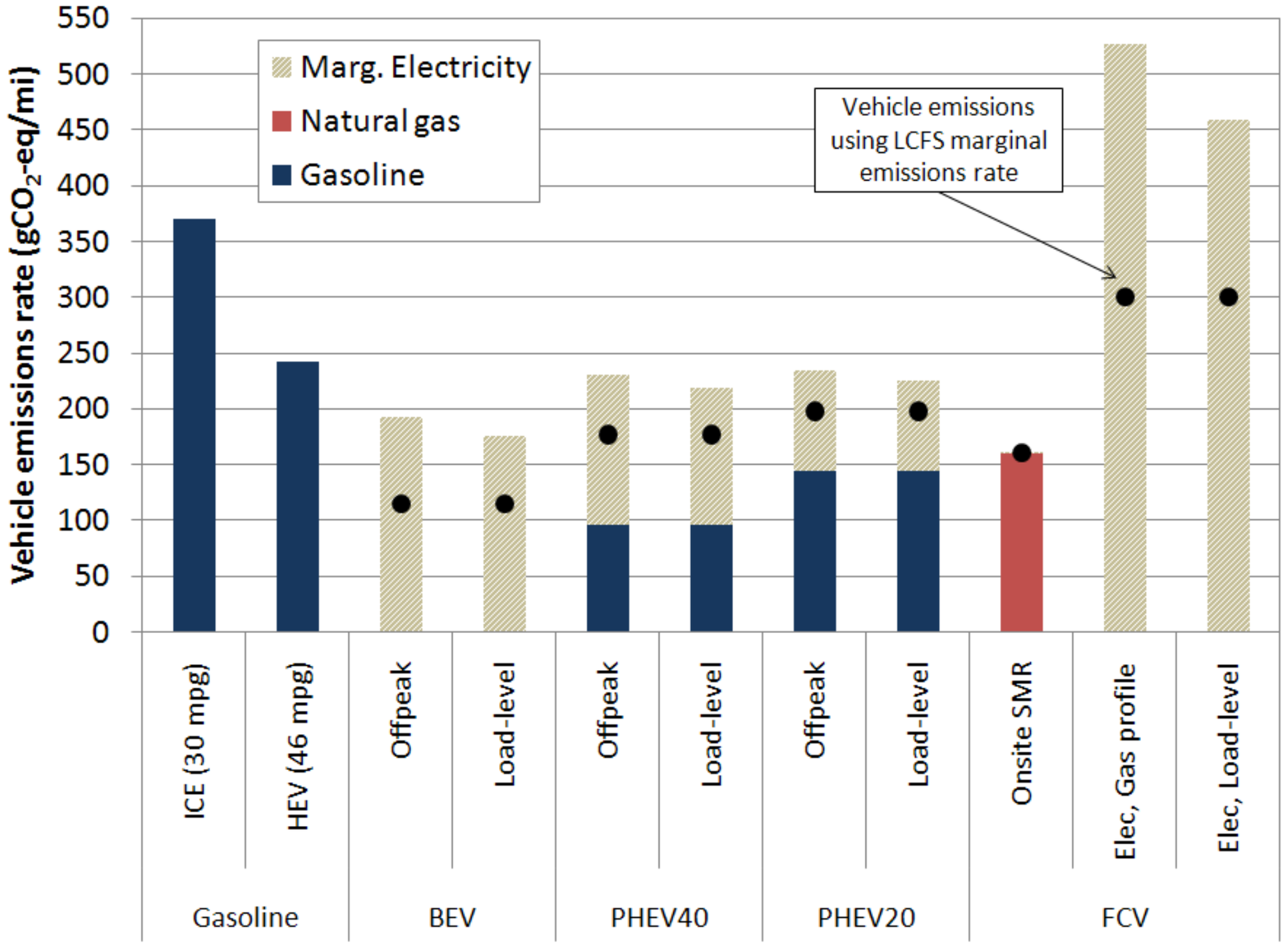
Marginal electricity generation and GHG emissions by vehicle pathway



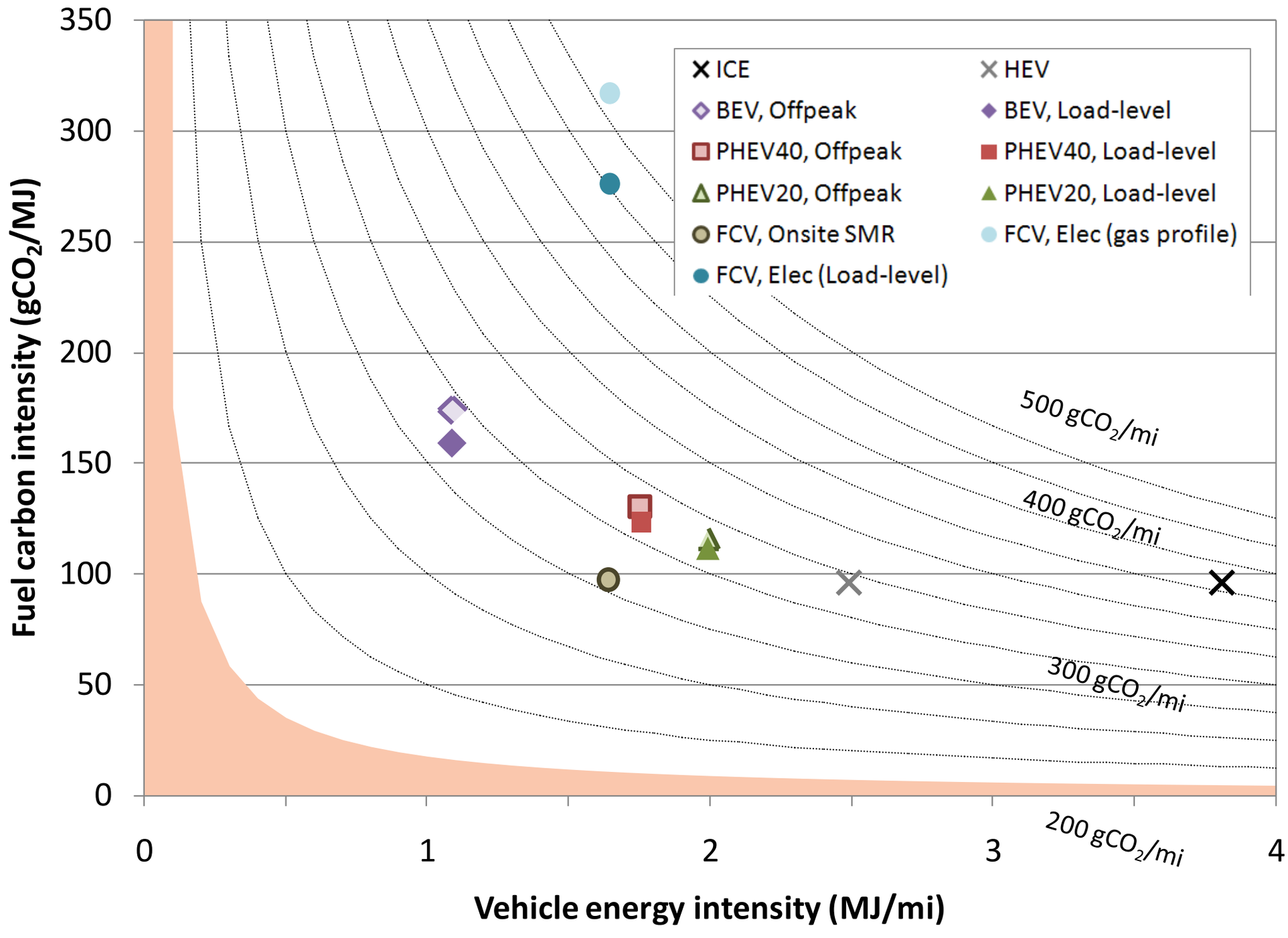
Marginal electricity generation and GHG emissions by vehicle pathway



Well-to-wheels vehicle GHG emissions (California in 2010)



Vehicle efficiency vs. fuel GHG intensity



Vehicle electricity demand impacts in the future (2020-2050)

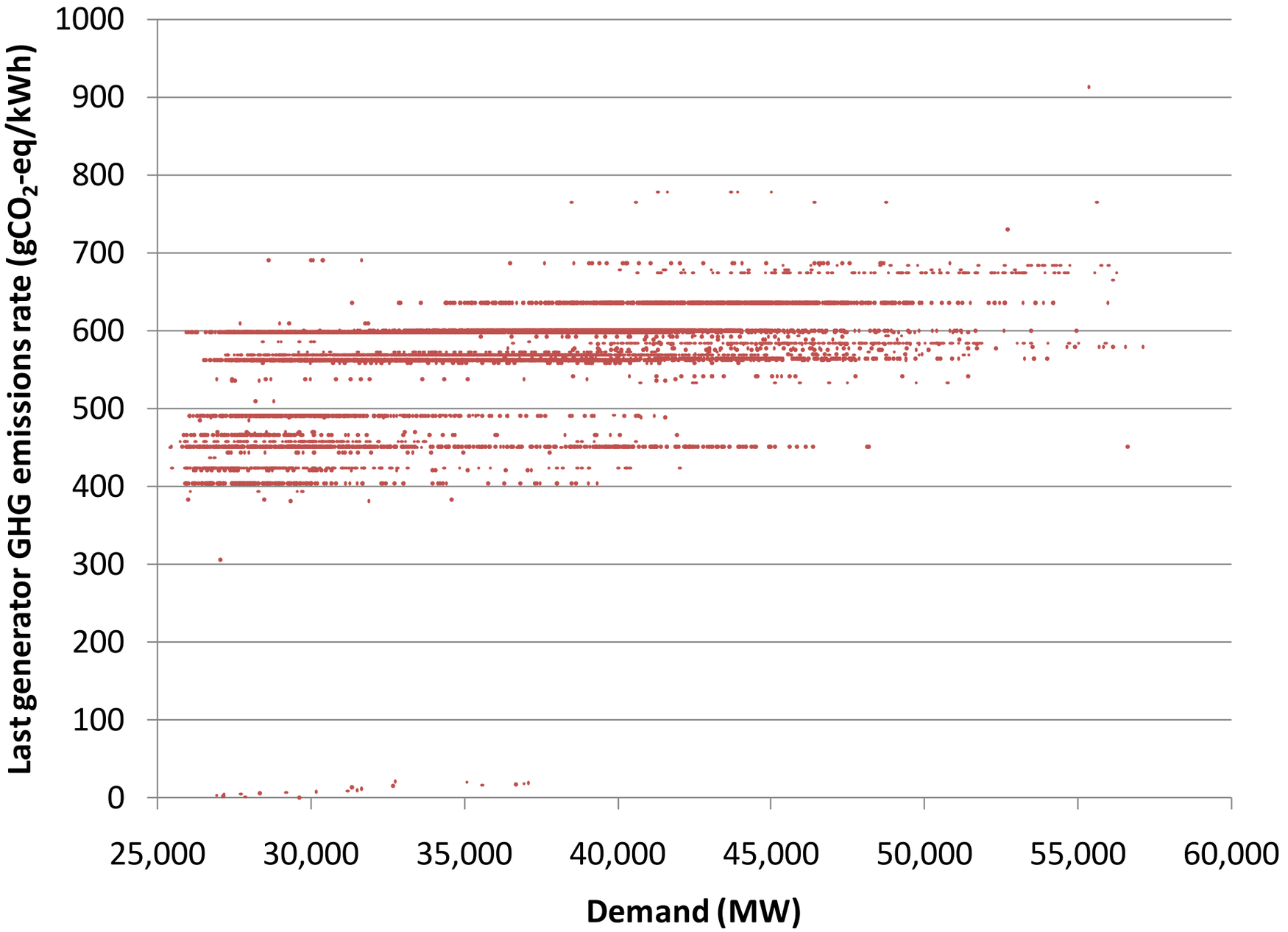
- Vehicle recharging shifts fossil capacity and generation to more highly-utilized plants
- Renewable generation has opposite effect
  - Demand timing affects integration costs
  - Wind vs. solar:
    - Average emissions (solar slightly better)
    - Costs for backup generation (solar slightly better)
    - Marginal emissions (wind quite better)
- Achieving 80% GHG reductions by 2050 difficult

Thank you

- Acknowledgements
  - Sustainable Transportation Energy Pathways (STEPS) Program at the Institute of Transportation Studies at UC Davis
  - Dr. Christopher Yang , Prof. Joan Ogden, Prof. Daniel Sperling
- Funding
  - STEPS and H_2Pathways sponsors
  - CH2M Hill
  - California Energy Commission

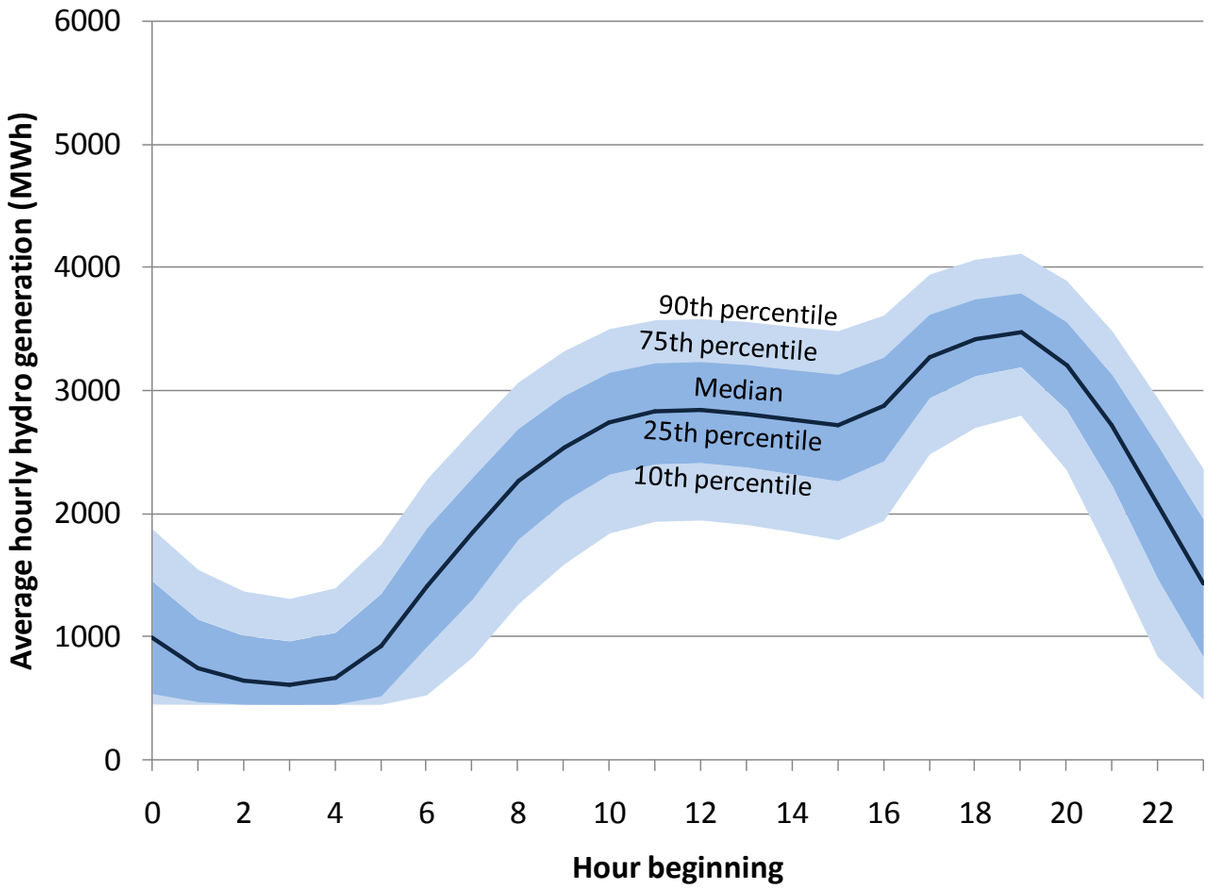
Extra slides

Marginal emissions vs. demand

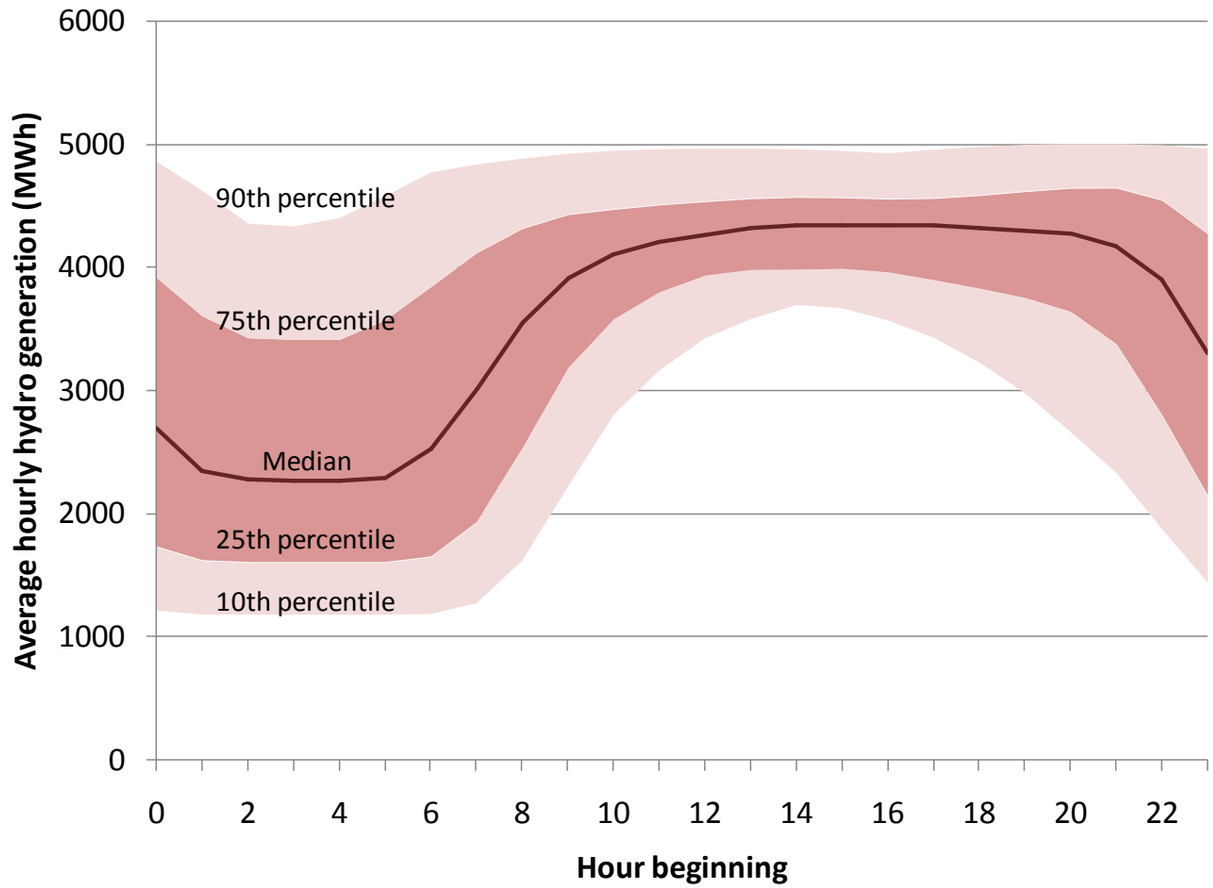


Hydro dispatch (median values)

Fall/Winter



Spring/Summer



Wind availability maps

Hr.	Tehachapi											
	J	F	M	A	M	J	J	A	S	O	N	D
0	12%	8%	49%	98%	59%	96%	100%	76%	12%	8%	49%	49%
1	10%	7%	46%	96%	70%	98%	100%	61%	10%	2%	51%	51%
2	8%	6%	42%	95%	59%	100%	98%	46%	8%	2%	49%	49%
3	6%	8%	36%	92%	67%	100%	91%	41%	6%	2%	55%	55%
4	2%	7%	48%	89%	94%	96%	81%	36%	2%	2%	48%	48%
5	2%	9%	53%	86%	88%	85%	78%	30%	2%	2%	55%	55%
6	2%	9%	39%	85%	99%	80%	68%	24%	2%	7%	41%	41%
7	2%	8%	36%	76%	96%	67%	53%	19%	2%	7%	37%	37%
8	2%	8%	27%	70%	89%	57%	42%	9%	2%	2%	37%	37%
9	8%	7%	34%	68%	92%	59%	28%	8%	8%	2%	30%	30%
10	9%	7%	33%	63%	91%	55%	15%	8%	10%	6%	33%	33%
11	9%	7%	23%	57%	81%	41%	19%	8%	10%	2%	24%	22%
12	10%	8%	20%	51%	70%	33%	15%	10%	8%	8%	27%	20%
13	8%	8%	22%	51%	57%	41%	14%	12%	8%	7%	26%	23%
14	8%	9%	23%	61%	65%	55%	24%	15%	10%	7%	44%	27%
15	14%	7%	46%	81%	80%	68%	30%	24%	14%	6%	55%	55%
16	21%	8%	68%	96%	74%	67%	51%	31%	26%	7%	80%	72%
17	10%	7%	85%	96%	76%	74%	68%	55%	22%	7%	95%	95%
18	13%	11%	91%	100%	70%	80%	83%	68%	17%	2%	80%	80%
19	11%	8%	97%	94%	59%	92%	96%	85%	13%	2%	98%	98%
20	12%	10%	99%	100%	59%	100%	100%	99%	13%	7%	98%	98%
21	11%	10%	94%	100%	30%	100%	100%	99%	12%	7%	91%	91%
22	10%	8%	67%	100%	23%	100%	100%	100%	11%	2%	65%	53%
23	10%	7%	59%	98%	24%	99%	100%	92%	10%	6%	57%	57%

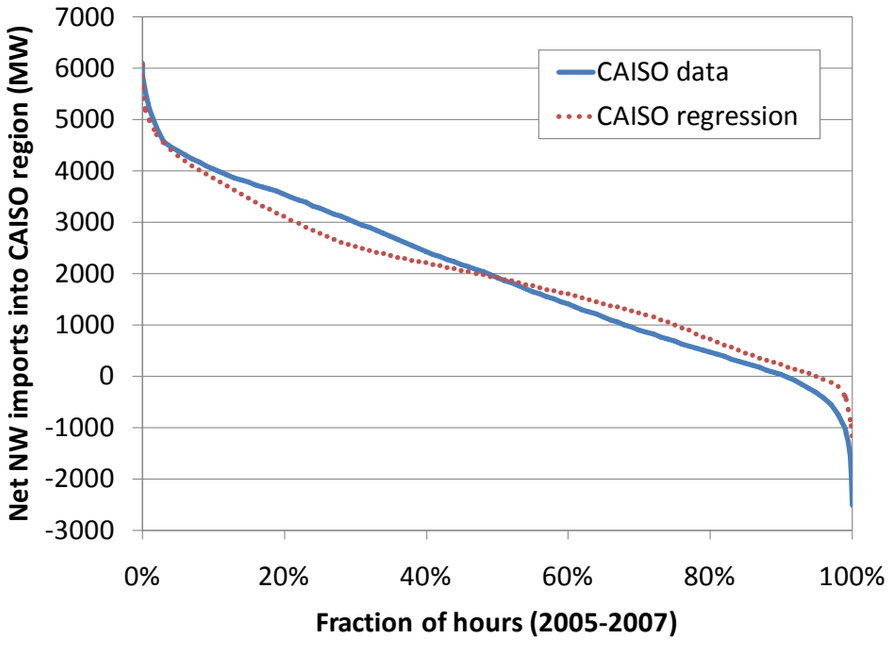
Hr.	San Gorgonio											
	J	F	M	A	M	J	J	A	S	O	N	D
0	14%	20%	67%	95%	100%	100%	100%	74%	70%	78%	12%	2%
1	16%	16%	78%	98%	100%	100%	100%	76%	72%	72%	12%	6%
2	17%	15%	85%	98%	100%	100%	100%	63%	70%	80%	11%	2%
3	14%	23%	83%	95%	100%	100%	100%	57%	61%	59%	9%	2%
4	11%	24%	63%	92%	100%	100%	100%	49%	61%	72%	11%	2%
5	12%	18%	46%	85%	100%	100%	98%	53%	63%	67%	8%	2%
6	10%	21%	46%	88%	100%	100%	94%	51%	63%	59%	8%	2%
7	9%	22%	42%	81%	100%	96%	78%	37%	51%	67%	2%	0%
8	6%	15%	37%	74%	96%	94%	74%	18%	41%	48%	2%	0%
9	2%	13%	23%	57%	83%	88%	59%	10%	17%	26%	2%	0%
10	2%	10%	7%	33%	34%	78%	34%	2%	7%	9%	0%	0%
11	2%	9%	9%	21%	11%	80%	11%	2%	2%	2%	2%	2%
12	2%	9%	9%	10%	8%	86%	31%	2%	2%	7%	2%	0%
13	2%	10%	10%	10%	10%	76%	37%	7%	6%	6%	6%	2%
14	2%	10%	11%	11%	14%	96%	24%	9%	8%	6%	8%	2%
15	2%	14%	9%	22%	23%	100%	39%	10%	10%	6%	2%	2%
16	2%	11%	14%	41%	65%	100%	59%	11%	20%	8%	2%	0%
17	0%	8%	49%	67%	85%	100%	94%	15%	59%	7%	2%	2%
18	0%	9%	46%	88%	94%	100%	100%	36%	49%	2%	0%	2%
19	0%	15%	78%	80%	95%	100%	100%	67%	42%	14%	2%	2%
20	2%	8%	72%	88%	97%	100%	100%	68%	44%	21%	2%	7%
21	6%	12%	63%	99%	100%	100%	100%	91%	53%	34%	2%	2%
22	6%	11%	80%	91%	100%	100%	100%	94%	53%	63%	7%	7%
23	8%	18%	80%	99%	100%	100%	100%	70%	67%	61%	8%	6%

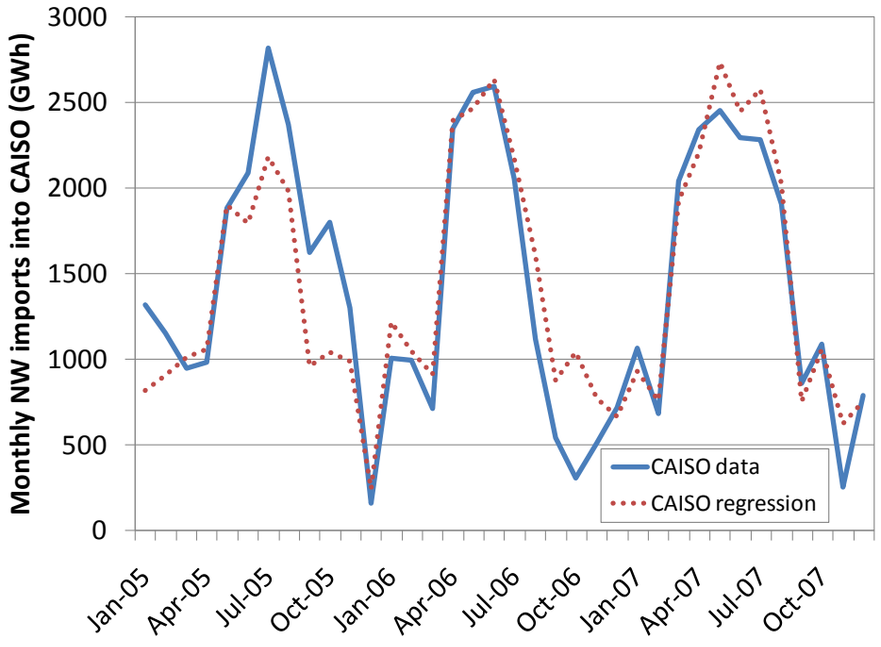
Hr.	Altamont											
	J	F	M	A	M	J	J	A	S	O	N	D
0	0%	2%	13%	67%	61%	100%	92%	100%	78%	7%	2%	0%
1	0%	6%	18%	53%	76%	89%	80%	74%	61%	2%	2%	0%
2	0%	2%	7%	59%	33%	81%	59%	92%	49%	6%	2%	0%
3	0%	2%	8%	37%	19%	61%	57%	39%	27%	2%	2%	0%
4	0%	8%	7%	49%	13%	44%	42%	23%	8%	2%	0%	0%
5	2%	8%	2%	37%	11%	34%	21%	15%	2%	0%	0%	0%
6	0%	7%	2%	30%	2%	26%	19%	2%	2%	2%	2%	0%
7	0%	2%	2%	24%	2%	17%	10%	2%	2%	2%	2%	0%
8	0%	6%	0%	18%	2%	11%	10%	0%	0%	2%	2%	0%
9	2%	6%	0%	15%	2%	21%	11%	2%	0%	0%	0%	0%
10	2%	7%	0%	20%	9%	20%	8%	2%	0%	2%	2%	0%
11	0%	6%	2%	17%	10%	21%	9%	2%	2%	0%	2%	0%
12	0%	2%	2%	18%	9%	18%	8%	6%	2%	2%	2%	0%
13	0%	6%	2%	19%	12%	20%	9%	9%	6%	2%	2%	0%
14	0%	6%	2%	16%	15%	21%	21%	13%	7%	2%	2%	0%
15	0%	6%	6%	20%	21%	21%	27%	24%	8%	2%	6%	0%
16	0%	2%	2%	28%	34%	42%	37%	21%	8%	2%	2%	0%
17	0%	0%	2%	37%	34%	55%	63%	23%	8%	2%	0%	0%
18	0%	2%	7%	49%	57%	78%	85%	34%	10%	2%	0%	0%
19	0%	6%	10%	76%	94%	94%	100%	89%	27%	8%	0%	0%
20	0%	7%	9%	74%	95%	99%	100%	100%	31%	9%	2%	0%
21	0%	8%	12%	96%	94%	100%	100%	100%	72%	9%	2%	0%
22	0%	9%	14%	88%	94%	100%	100%	100%	53%	7%	2%	0%
23	0%	8%	14%	78%	89%	100%	100%	100%	63%	8%	2%	0%

Hr.	Solano											
	J	F	M	A	M	J	J	A	S	O	N	D
0	24%	16%	31%	41%	31%	30%	57%	39%	41%	20%	19%	8%
1	26%	17%	28%	49%	22%	41%	53%	41%	39%	21%	14%	10%
2	24%	19%	27%	44%	28%	33%	55%	42%	42%	17%	12%	10%
3	22%	18%	30%	39%	24%	37%	55%	42%	41%	16%	11%	9%
4	20%	21%	30%	42%	19%	31%	57%	37%	31%	16%	10%	9%
5	21%	18%	31%	37%	20%	30%	46%	42%	33%	12%	13%	11%
6	20%	22%	26%	34%	18%	22%	49%	34%	26%	14%	12%	11%
7	21%	26%	26%	37%	12%	21%	51%	37%	31%	12%	16%	8%
8	18%	24%	21%	37%	8%	21%	55%	34%	31%	12%	14%	7%
9	18%	17%	22%	36%	14%	27%	61%	31%	24%	13%	10%	2%
10	19%	17%	23%	37%	16%	24%	55%	37%	30%	11%	14%	6%
11	20%	26%	23%	37%	15%	22%	46%	37%	21%	14%	17%	8%
12	20%	20%	16%	33%	17%	21%	41%	34%	20%	11%	16%	12%
13	21%	18%	21%	33%	17%	21%	34%	27%	17%	10%	19%	9%
14	24%	19%	17%	30%	22%	24%	44%	31%	19%	13%	11%	8%
15	26%	19%	16%	37%	24%	27%	51%	36%	23%	10%	9%	8%
16	23%	30%	13%	46%	41%	30%	61%	49%	23%	10%	6%	7%
17	23%	24%	17%	48%	46%	46%	67%	53%	27%	14%	2%	2%
18	22%	23%	21%	46%	53%	46%	63%	59%	27%	14%	6%	8%
19	24%	21%	22%	49%	48%	41%	53%	49%	27%	15%	8%	8%
20	23%	23%	24%	37%	39%	27%	53%	41%	28%	12%	14%	8%
21	27%	20%	26%	41%	31%	26%	42%	42%	34%	14%	10%	9%
22	23%	18%	21%	44%	31%	24%	46%	51%	39%	18%	16%	10%
23	23%	21%	23%	39%	24%	42%	53%	46%	33%	17%	21%	9%

NW imports regression (adj R^2=0.72)

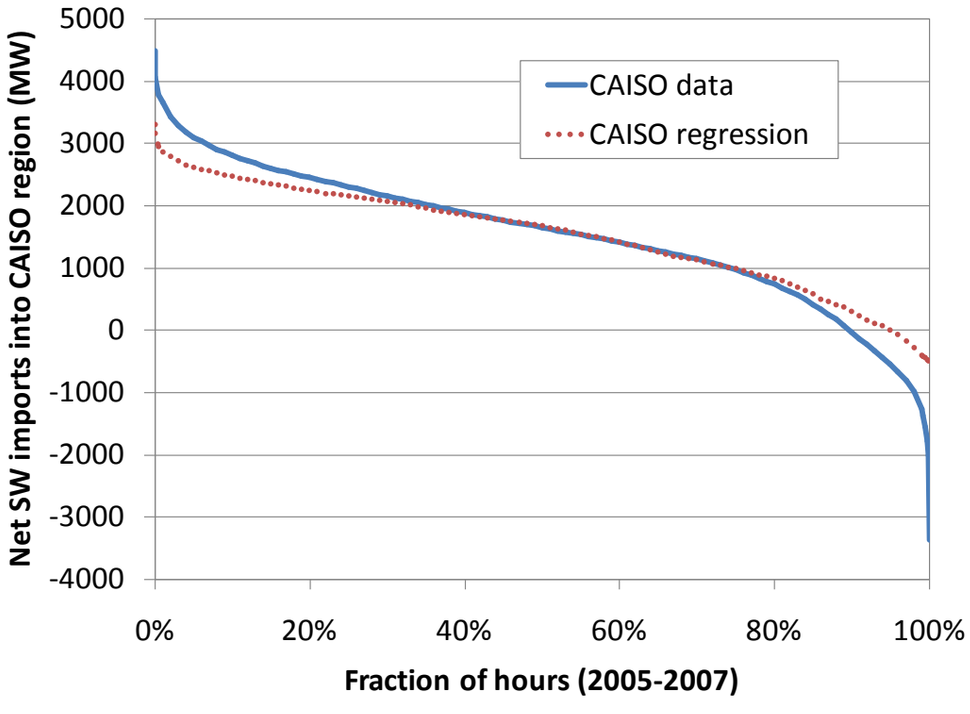
Variable	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	-5344.568	90.574		-59.008	.000
nloadmon	7827.370	43.610	.633	179.485	.000
peakdema	.040	.001	.153	27.513	.000
cahydnuk	-.347	.007	-.254	-47.731	.000
wahdd	-3.267	.034	-.605	-95.104	.000
wahydro	.535	.004	.514	121.554	.000

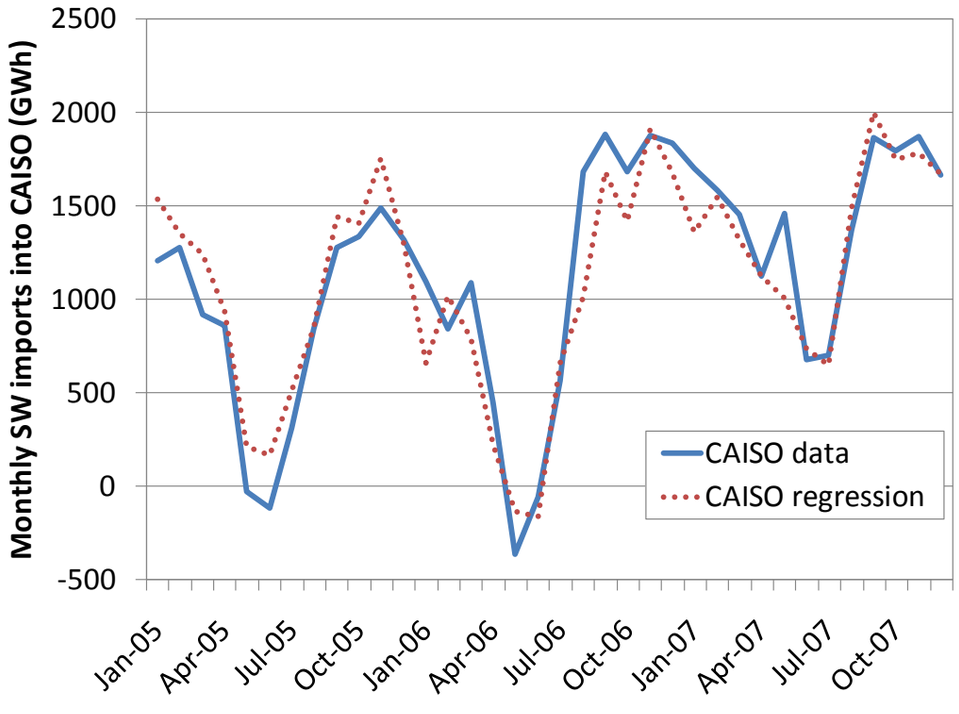




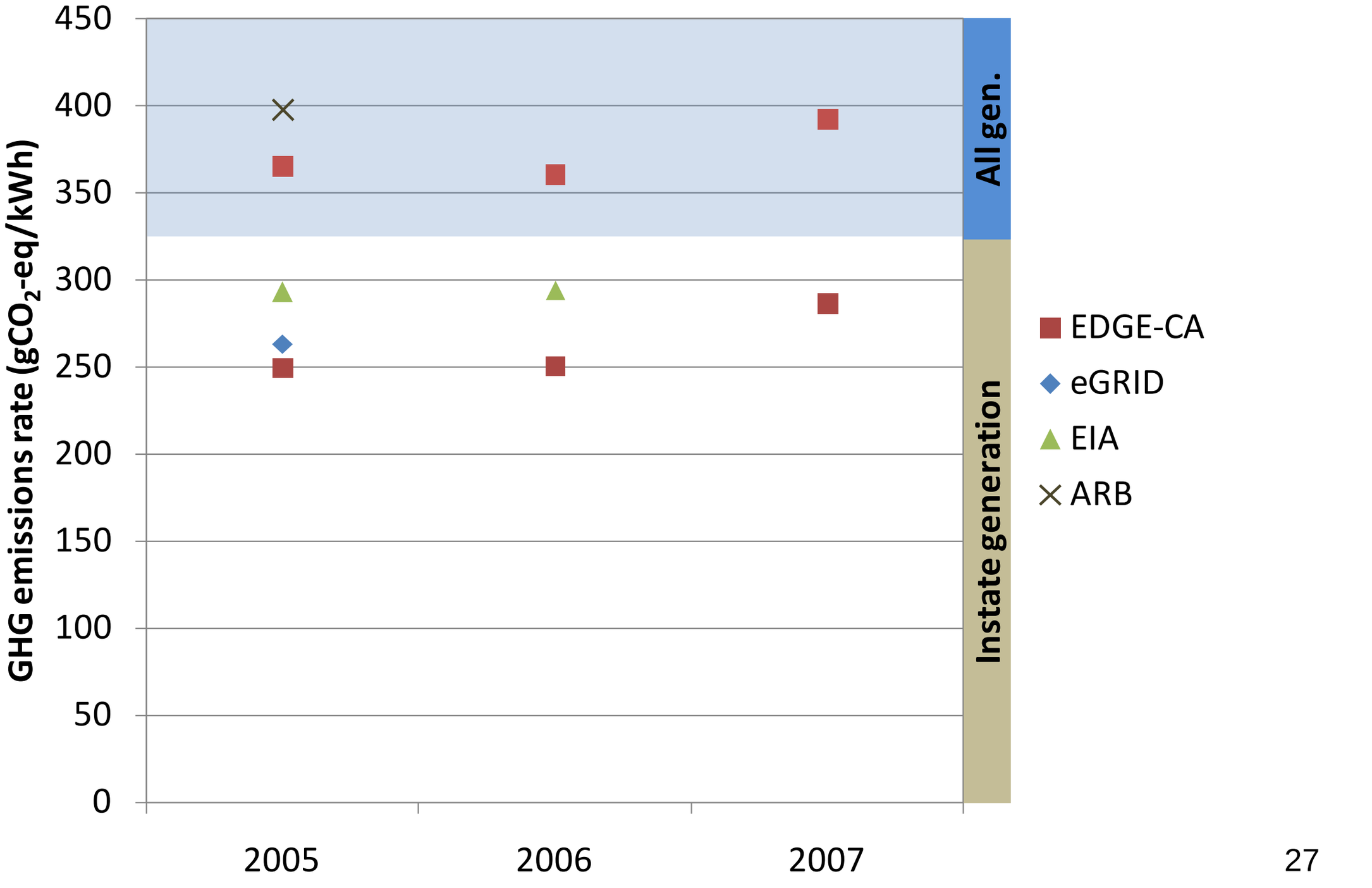
SW imports regression (adj R^2=0.56)

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-1997.655	89.791		-22.248	.000
nloadmon	4152.895	63.637	.482	65.259	.000
peakdema	.111	.002	.604	69.057	.000
cahydnuk	-.468	.005	-.491	-87.906	.000
nwregres	-1.941	.049	-.317	-39.742	.000
azdd	.335	.010	.162	33.467	.000
aznuke	-.345	.006	-.418	-53.236	.000

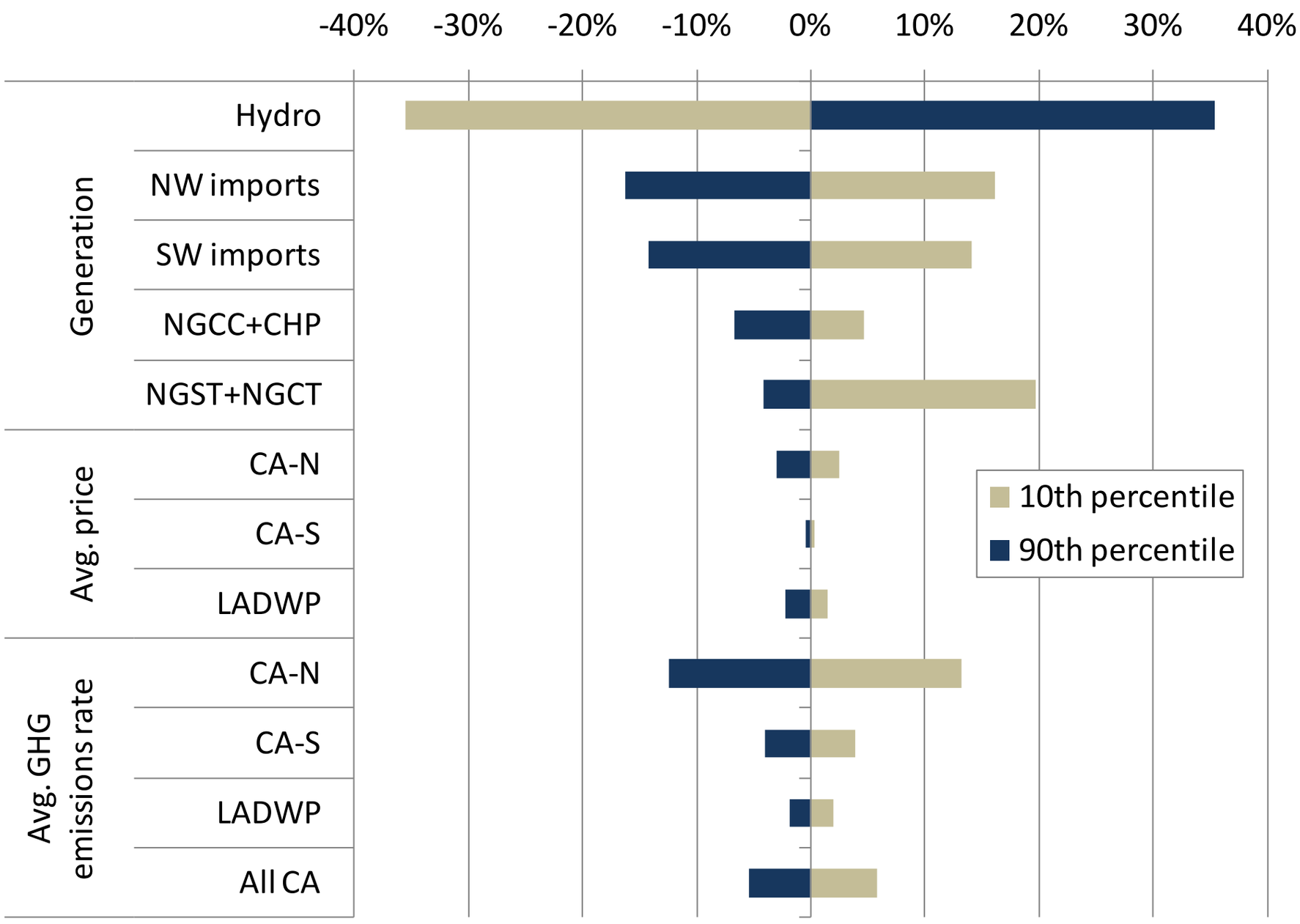




EDGE-CA validation



Sensitivity to annual hydro energy



Sensitivity of marginal emissions