Toxic Hotspots from Market Design in Regional Climate Policy

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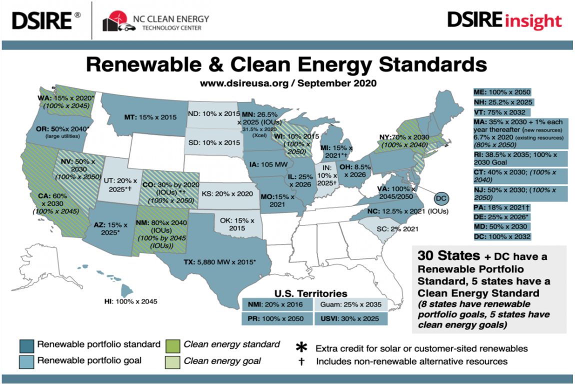
Regional Climate Policies and Electricity Market Design

- Regional climate policies have emerged in the absence of national climate regulation
- For example, renewable and clean energy standards
- Accommodating renewables → changes the grid



Energy Imbalance Market

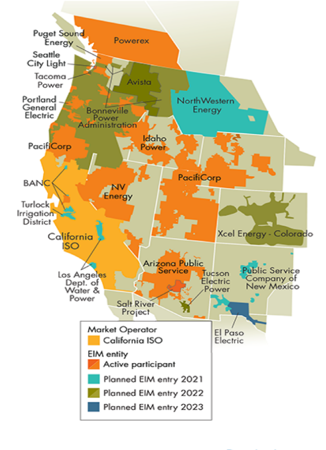
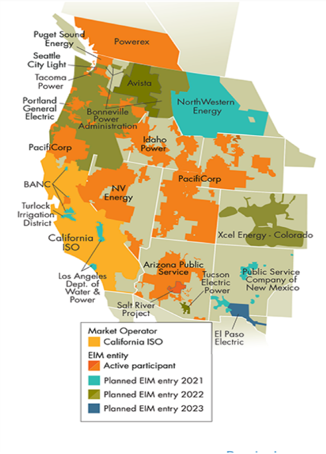


Figure: California ISO's EIM

Energy Imbalance Market



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- California ISO's Western Energy Imbalance Market

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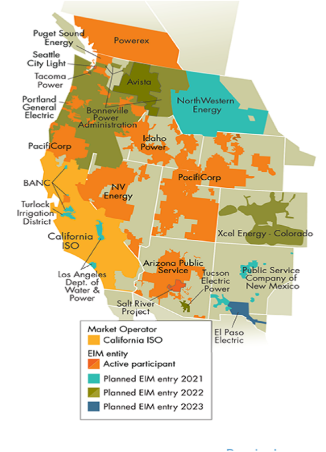

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  - Most efficient market in the West

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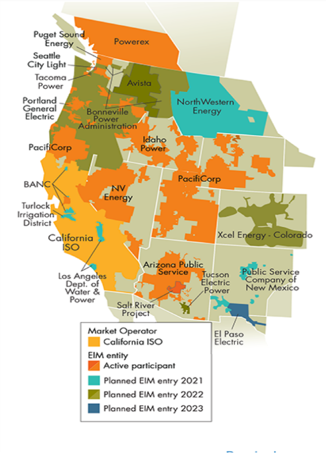

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  - Expanded centralized spot market across rate-regulated region
- Efficient design aims to reduce energy imbalances from intermittent renewables

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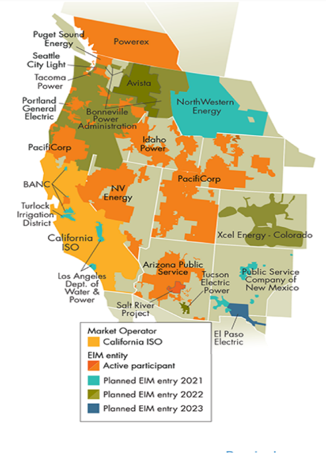

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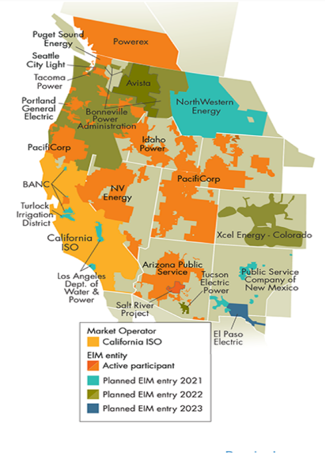

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- Especially important for local pollutants (NOx, SO_2)

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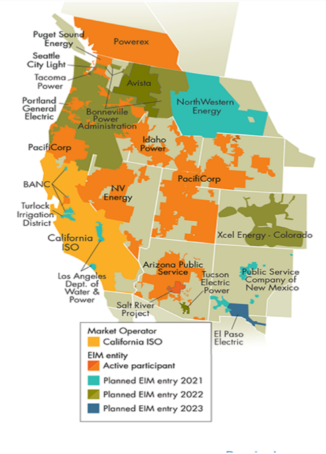

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- Efficient design aims to reduce energy imbalances from intermittent renewables
- Potentially changes dispatch patterns
- Especially important for local pollutants (NOx, SO_2)
  - Localized damages

Policy-Relevant Market Design Changes

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- CAISO's Day-Ahead market expansion
- SPP's Energy Imbalance Market
- PJM's Minimum Offer Price Rule in capacity markets
- European Union's Energy Union

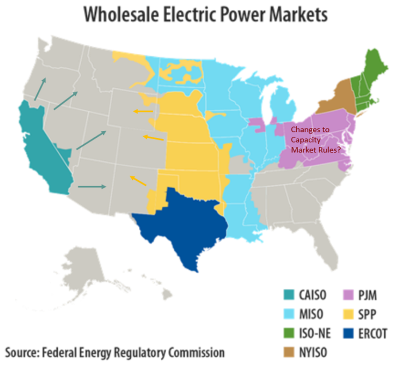

Figure: Wholesale Market Expansion - FERC (Power Markets)

Research Question

- The goal of this research is to determine the temporal and spatial effects of introducing a more centralized and competitive electricity market design on local pollutants:
    - Does the EIM lead to more or less local pollution?
    - When and where are changes (hotspots) occurring?

Expectations

Goals of the EIM

- Enable access to a larger pool of renewable resources
- Manage variability from renewable resources

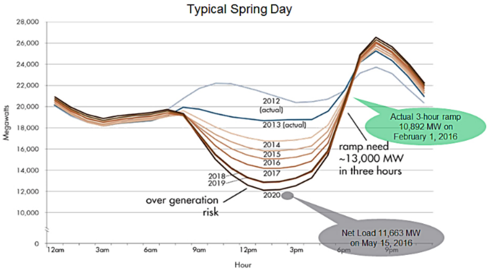

Figure: California Net Demand (Demand less Renewables Production): Actual and Forecasted as of 2016 - CAISO

Expectations

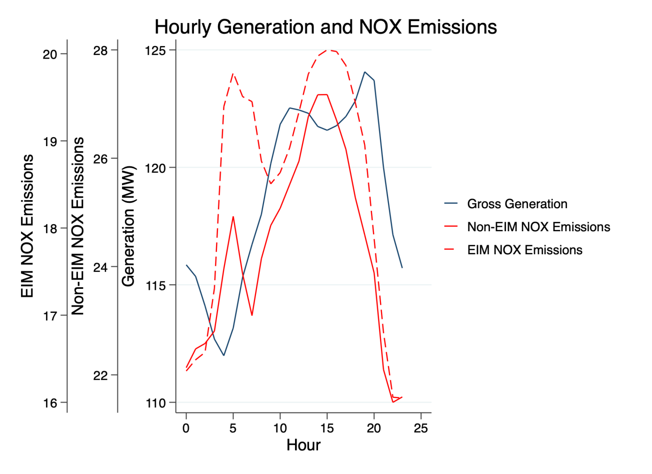

Figure: Hourly Generation and NOx Emissions

Findings

- On average participating in the EIM reduces gas generators' NOx emissions by six pounds per hour
  - Reduction of 26% of NOx emissions from the average gas generator
  - Peak reductions occur when residual load is high
  - Annual reduction of 52,560 pounds of NOx emissions

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- On average participating in the EIM reduces gas generators' NOx emissions by six pounds per hour
  - Reduction of 26% of NOx emissions from the average gas generator
  - Peak reductions occur when residual load is high
  - Annual reduction of 52,560 pounds of NOx emissions
- However, there is significant heterogeneity in the distribution of local pollution outcomes across geographic regions and generators
  - Significant NOx emission reductions from gas generators occur in more remote regions
  - Coal generators in regions close to California experience significant increases in NOx emissions (50%) and SO_2 emissions (31%)
  - Coal generators in more remote regions experience reductions (6 - 15%)

Data

- Hourly NOx and SO_2 emissions (lbs.) from EPA's CEMS program
- Generators mapped into BAs with the DHS HIFLD BA spatial map
- Hourly load from FERC Form 714 Schedule III / CAISO OASIS
- Hourly solar and wind production from CAISO's Daily Renewables Watch
- Matching Variables from FERC/EIA/CEMS

Identification Strategy

- I leverage variation in EIM participation across time and space in a diff-in-diff framework to estimate average effects, use a triple-diff to estimate marginal responses to net load
- To deal with endogenous EIM participation, pre-process the data by matching generators based on characteristics known to influence participation (Tarufelli and Gilbert, 2019)

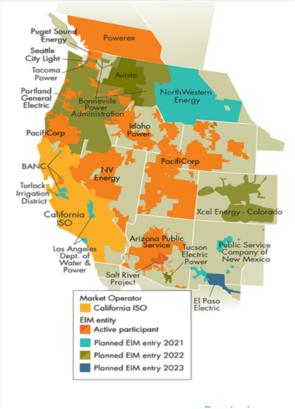


Figure: Energy Imbalance Market 2021 - CAISO

Identification Strategy

$$Y_{ijt} = \alpha + \lambda Post_t + \gamma EverEIM_i * Post_t + \mathbf{X}_{jt}\beta + \mu_i + \epsilon_{ijt} \quad (1)$$

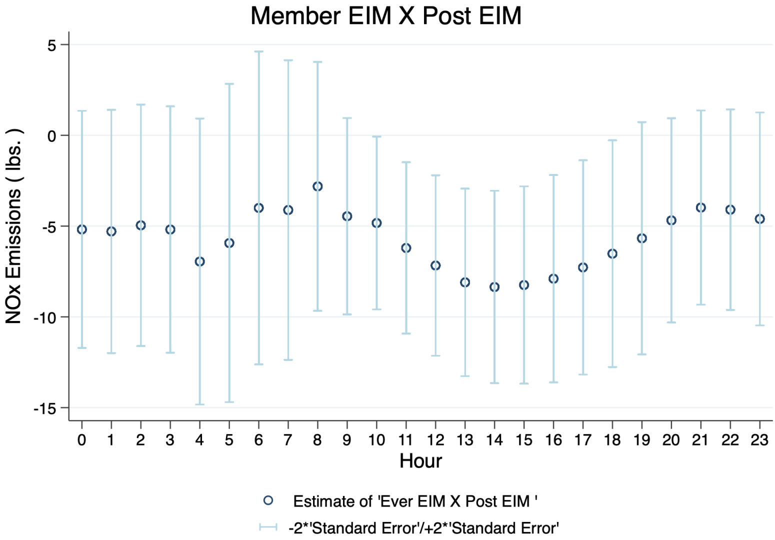
$$\begin{aligned} Y_{ijt} &= \alpha + \lambda_1 Post_t + \gamma_1 EverEIM_i * Post_t \\ &+ \lambda_2 ResidualLoad_t + \lambda_3 ResidualLoad_t * EverEIM_i + \lambda_4 ResidualLoad_t * Post_t \\ &+ \gamma_2 ResidualLoad_t * EverEIM_i * Post_t + \mathbf{X}_{jt}\beta + \mu_i + \epsilon_{ijt}. \quad (2) \end{aligned}$$

- Total NOx or SO_2 emissions (Y_{ijt}) of jth generator in BA (region) i at hour t
- Hourly California ISO residual load ($ResidualLoad_t$)
- Treatment indicator equal to one if the BA (region) is ever an EIM member in the post EIM period
- Vector of controls, $\mathbf{X}_{jt}$, including Hour FE, Day of Week FE, Month X Year FE, heat input, generator age, pollution abatement control technologies; and μ_i, BA (region) FE

Natural Gas NOx Emissions and CA Residual Load

Dep. Var: NOx Emissions (lbs.)	Full	Full	Matched	Matched
Ever EIM X Post EIM	-4.461*	-5.043**	-5.912*	-6.004*
	(2.310)	(2.298)	(3.077)	(3.068)
Post EIM (Centered)	-6.039	-5.088	-6.283	-5.811
	(3.754)	(3.697)	(4.251)	(4.115)
Ever EIM X CA Resid. Load		-0.000234		-8.54e-05
		(0.000158)		(0.000150)
Ever EIM X Post EIM X CA Resid. Load		-5.71e-05		3.14e-05
		(0.000204)		(0.000199)
Post EIM X CA Resid. Load		-2.36e-05		-0.000152
		(0.000148)		(0.000130)
CA Resid. Load		0.000361***		0.000267*
		(0.000106)		(0.000141)
Hourly FERC Load by Planning Area	0.00226***	0.00212***	0.00146***	0.00124***
	(0.000784)	(0.000734)	(0.000416)	(0.000365)
Generator Age	0.937***	0.940***	0.862**	0.864**
	(0.298)	(0.298)	0.310)	(0.311)
Pre-EIM Heat Input	21.03	20.99	28.47	28.46
	(18.67)	(18.63)	(20.56)	(20.58)
Constant	-27.47**	8.021*	-10.23	25.12***
	(11.17)	(3.961)	(12.68)	(4.616)
Observations	5,553,701	5,538,481	3,809,659	3,799,099
R-squared	0.250	0.250	0.383	0.383
Abatement Technology Controls	YES	YES	YES	YES
Hour FE	YES	YES	YES	YES
DOW FE	YES	YES	YES	YES

Hour over Hour Gas NOx Emissions



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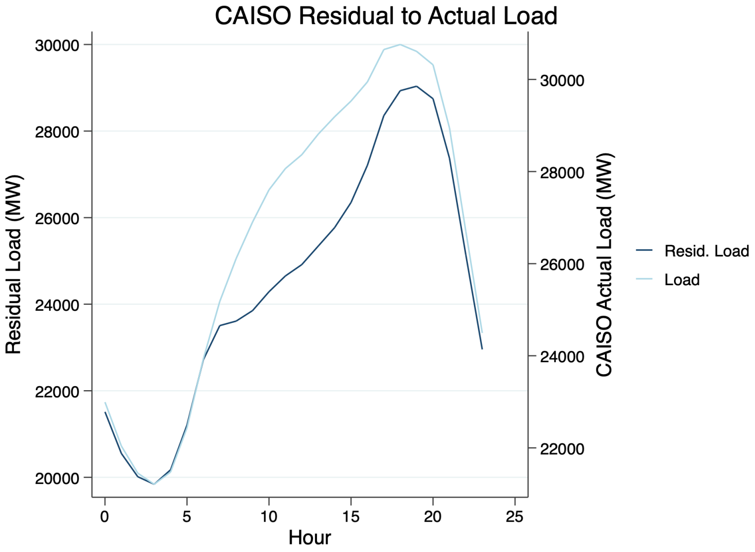


Regional Regressions - Gas Generators

Dep. Var: NOx Emissions (lbs.)	APS	NP	PAC	PSE
Ever EIM X Post EIM	0.746**	0.0501	-24.93***	1.499***
	(0.324)	(0.283)	(0.706)	(0.403)
Post EIM (Centered)	3.403***	1.744**	7.593***	-3.090**
	(1.074)	(0.848)	(2.173)	(1.252)
Ever EIM X CA Resid. Load	0.000716***	4.49e-05**	-8.29e-05***	-7.59e-05*
	(3.06e-05)	(2.27e-05)	(3.19e-05)	(3.90e-05)
Ever EIM X Post EIM X CA Resid. Load	9.54e-05*	-0.000230***	0.000653***	0.000214***
	(5.00e-05)	(3.83e-05)	(5.39e-05)	(5.87e-05)
Post EIM X CA Resid. Load	0.000238***	-0.000112***	-0.000327***	-0.000101**
	(3.51e-05)	(3.16e-05)	(4.26e-05)	(4.22e-05)
CA Resid. Load	-7.98e-05***	0.000323***	0.000388***	4.90e-05
	(2.62e-05)	(2.22e-05)	(2.98e-05)	(3.36e-05)
Hourly FERC Load by Planning Area	0.00111***	0.000185***	-0.00169***	0.00213***
	(7.63e-05)	(5.95e-05)	(0.000102)	(0.000145)
Pre-EIM Heat Input	-19.89***	45.50***	89.83***	34.48***
	(0.956)	(0.901)	(1.747)	(2.160)
Generator Age	0.140***	1.246***	1.328***	-0.0805***
	(0.00759)	(0.0106)	(0.0163)	(0.0206)
Constant	13.83***	7.203***	22.83***	11.69***
	(0.771)	(0.618)	(1.361)	(1.201)
Observations	412,269	1,451,945	902,221	159,416
R-squared	0.126	0.043	0.027	0.035
Abatement Technology Controls	YES	YES	YES	YES
Hour FE	YES	YES	YES	YES
DOW FE	YES	YES	YES	YES
Month X Year FE	YES	YES	YES	YES

Regional Regressions - Coal Generators

Dep. Var: NOx Emissions (lbs.)	APS	NP	PAC
Ever EIM X Post EIM	385.9***	171.9***	-49.21***
	(24.07)	(22.26)	(11.84)
Post EIM (Centered)	-569.4***	-300.2***	-142.1***
	(54.22)	(47.70)	(22.59)
Ever EIM X CA Resid. Load	0.00496***	-0.00114***	-0.00145***
	(0.000478)	(0.000298)	(0.000123)
Ever EIM X Post EIM X CA Resid. Load	0.000837	-0.000937	-0.00285***
	(0.000859)	(0.000580)	(0.000203)
Post EIM X CA Resid. Load	-0.00221***	0.00106***	0.00213***
	(0.000681)	(0.000362)	(0.000161)
CA Resid. Load	0.00398***	0.00457***	0.00716***
	(0.000500)	(0.000293)	(0.000115)
Hourly FERC Load by Planning Area	0.0613***	0.0261***	0.0122***
	(0.00172)	(0.00136)	(0.000387)
cgenerator_efficiency_matched	882.7***	1,198***	-165.2***
	(63.49)	(64.55)	(31.35)
Generator Age	26.10***	9.910***	-8.156***
	(0.732)	(0.317)	(0.355)
Constant	1,075***	810.4***	652.2***
	(38.10)	(26.77)	(13.64)
Observations	464,411	519,070	1,729,465
R-squared	0.128	0.020	0.028
Abatement Technology Controls	YES	YES	YES

Regional Regressions - Coal Generators

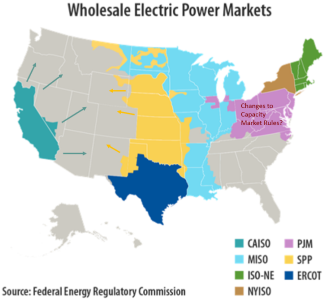
Dep. Var: SO_2 Emissions (lbs.)	APS	NP	PAC
Ever EIM X Post EIM	145.3***	136.2***	-69.43***
	(19.92)	(14.21)	(7.737)
Post EIM (Centered)	-41.21	-275.6***	-204.7***
	(45.46)	(32.87)	(17.23)
Ever EIM X CA Resid. Load	-0.0164***	0.00177***	-0.00270***
	(0.000458)	(0.000279)	(0.000147)
Ever EIM X Post EIM X CA Resid. Load	0.0113***	0.00508***	-0.000386
	(0.000824)	(0.000544)	(0.000244)
Post EIM X CA Resid. Load	-0.00810***	-0.00108***	-4.69e-05
	(0.000654)	(0.000341)	(0.000193)
CA Resid. Load	0.0111***	0.00260***	0.00622***
	(0.000480)	(0.000274)	(0.000138)
Hourly FERC Load by Planning Area	0.0608***	0.0228***	0.000516
	(0.00168)	(0.00128)	(0.000459)
cgenerator_efficiency_matched	3,837***	-1,425***	771.7***
	(73.83)	(64.05)	(21.66)
Generator Age	-76.96***	2.394***	1.587***
	(1.800)	(0.468)	(0.205)
Constant	-2,609***	481.5***	314.1***
	(71.75)	(21.89)	(11.12)
Observations	464,411	519,070	1,729,465
R-squared	0.102	0.040	0.018
Abatement Technology Controls	YES	YES	YES

Summary

- The EIM is leading to average reductions (26%) in NOx emissions for gas generators
- There is significant heterogeneity in the distribution of local pollution outcomes across different geographic regions and generators
- Coal generators NOx emissions are increasing by 50% and SO_2 emissions are increasing by 31% in regions close to CA load centers, whereas more remote regions are decreasing by 6 - 15%
- Increases in NOx and SO_2 emissions led to millions of dollars of damages in these regions

Policy Implications

- My results are informative for continuing changes in wholesale electricity markets
- More generally, when changes in electricity market design affect the pattern of generator dispatch, local pollution hotspots can occur



Next Steps

- Sensitivity of results to staggered adoption design
- Extend dataset to include more recent data