Location, location, location: The variable value of renewable energy and demand-side efficiency resources

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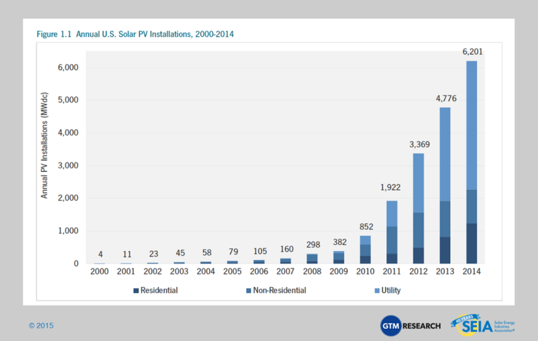
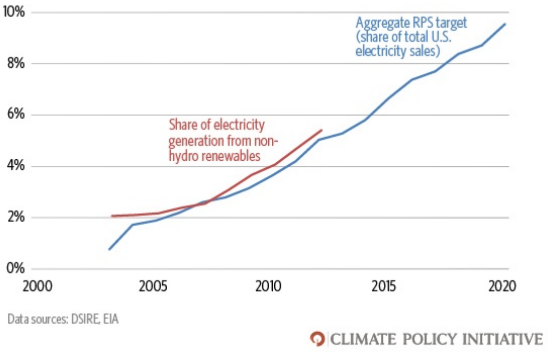
Upward trend in renewable energy and energy efficiency investment



US Grid Connected Solar PV Installations
source: http://www.irecusa.org/2013/07

- Levels of investment in both renewable energy (RE) and energy efficiency (EE) are on the rise.
- RE and EE expected to play a significant role in efforts to reduce greenhouse gas (GHG) emissions from the power sector.

Production-based policy incentives have driven investment in the U.S.



- Many of these investments cannot be rationalized on the basis of private returns alone.
- Production (or capacity) based policy incentives have driven a significant fraction of investment in RE.

Jumping off point

- In principle, incentives should be designed to accurately reflect the external benefits generated by renewable energy and energy efficiency.
- Easier said than done!
- Research that seeks to quantify external benefits generated by RE and EE investments has the potential to constructively inform policy and consumer behavior.
- We focus one dimension of benefits: avoided greenhouse gas (GHG) emissions.

Research objectives

- We estimate the short-run GHG emissions-related benefits generated by incremental investments in energy efficiency (EE) and renewable energy (RE).
- We assess the significance of variation in external marginal benefits across time, space, and technology.
- We consider implications for the design of policy incentives.
- We demonstrate a methodological approach (using public data) that is broadly applicable....

Some current applications..

WattTime

Partners

EMotorWerks Smart [Grid] EV Charging

luxe | urban | life
MODERN HOTELS. MALLS. DEPARTMENT STORES.

strati-fi

Schneider Electric

HERO

ecobee

echoing green

BECI
BERKELEY ENERGY & CLIMATE INSTITUTE
LBNL & UC BERKELEY

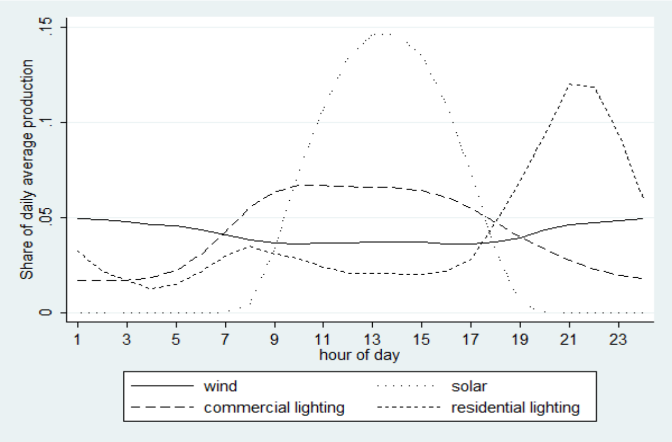
Empirical approach

Analysis is organized around four concepts

1. **Marginal operating emissions rate** (MOER): measures emissions associated with the marginal megawatt produced by dispatchable units in a power system.
2. **Marginal emissions displacement rate** (MEDR): measures the average quantity of emissions displaced per MWh generated (RE) or saved (EE).
3. **Marginal economic value** (MEV): Measures the short-run economic value per MWh generated or saved.
4. **Marginal abatement cost** (MAC): Net cost (levelized investment cost less energy savings) per ton CO_2 avoided.

We focus on four technology types

Resource-specific production profiles



Notes: This figure plots the share of energy generated (or saved) on an average winter day in New York by hour of day. See the data appendix for a discussion of data sources.

Regional unit of analysis: ISO

- A critical building block in this analysis is the change in system-wide emissions associated with an incremental change in production at dispatchable units denoted ϕ_{rt}.
- Regions are defined to be the six major independent system operators (ISOs) that coordinate large-scale pooled electricity markets to economically balance local load with supply on daily, hourly and sub-hourly time scales.
- We estimate the relationship between hourly CO_2 emissions and hourly generation at thermal power plants within an ISO footprint.

Data overview

All data used in the analysis are publicly available:

- Hourly emissions and electricity generation at fossil-fueled power plants (US EPA);
- Simulated hourly production across thousands of wind and solar sites (NREL);
- Simulated hourly savings from a lighting efficiency upgrade in the residential and commercial sector (LBNL);
- Wholesale electricity prices (ISOs);
- Estimates of levelized costs for renewable and energy efficiency (LBNL, DOE)

Except where otherwise noted, the period of analysis is 2010-2012.

Marginal operating emissions rates

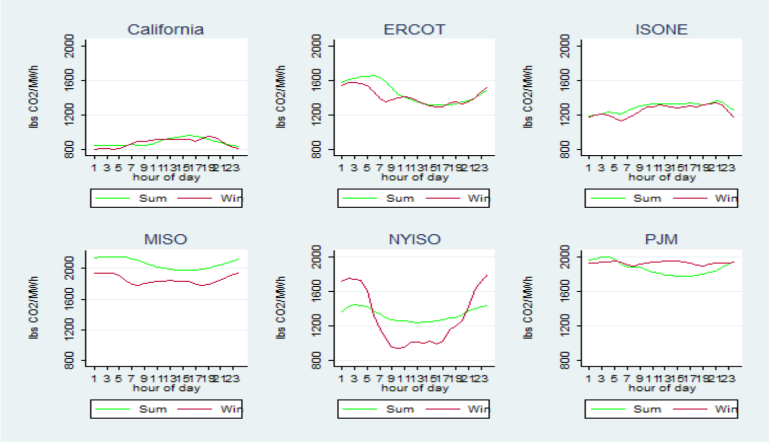
1. Marginal operating emissions rate

Our objective: Isolate the variation in regional electricity generation that most closely mimics the effects of incremental increases in RE or EE in that region.

$$Emissions_{rkt} = \alpha_{rkhs} + \phi_{rkhs} G_{rkt} + \epsilon_{rkt},$$

- We use variation in demeaned electricity generation at thermal power plants in an ISO footprint G_{rkt} to estimate the MOERs.
- ϕ_{rkhs} estimates the marginal operating emissions rate for region r, hour h, cluster k, and season s.

Marginal operating emissions rate profiles (2010-2012)

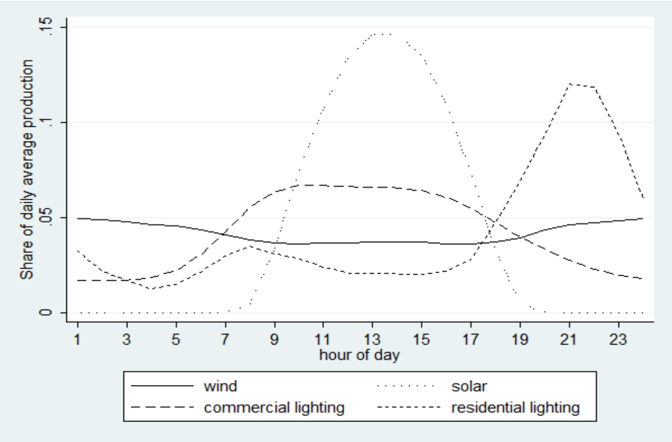


Notes: This figure illustrates point estimates of marginal operating emissions rate by season and region. Average coal-fired emissions rate: 2075 lbs CO2/MWh; Average gas-fired emissions rate: 892 lbs CO2/MWh (CCGT); 1346 lbs CO2/MWh

Marginal operating emissions rate

Recall our four technology types

Resource-specific production profiles



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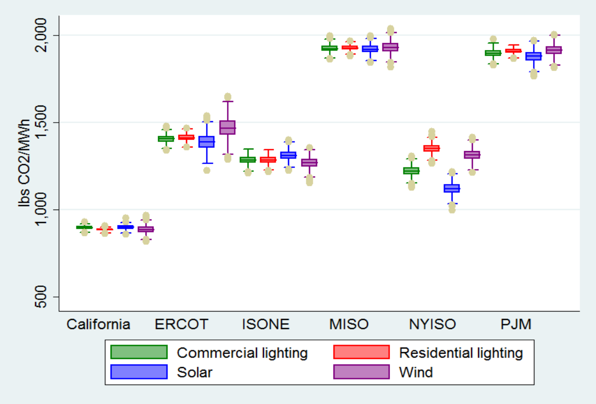
Marginal emissions displacement rates



Notes: This figure summarizes bootstrap repetitions of resource-specific marginal emissions displacement rates estimated by region. Resource profiles for lighting efficiency improvements capture generic seasonal and hourly variation in energy savings. Solar and wind profiles vary within and across days according to simulated meteorological conditions and are site specific. Average coal-fired emissions rate: 2075 lbs CO2/MWh; Average gas-fired emissions rate: 892 lbs CO2/MWh (CCGT); 1346 lbs CO2/MWh

Marginal economic value

Marginal economic value

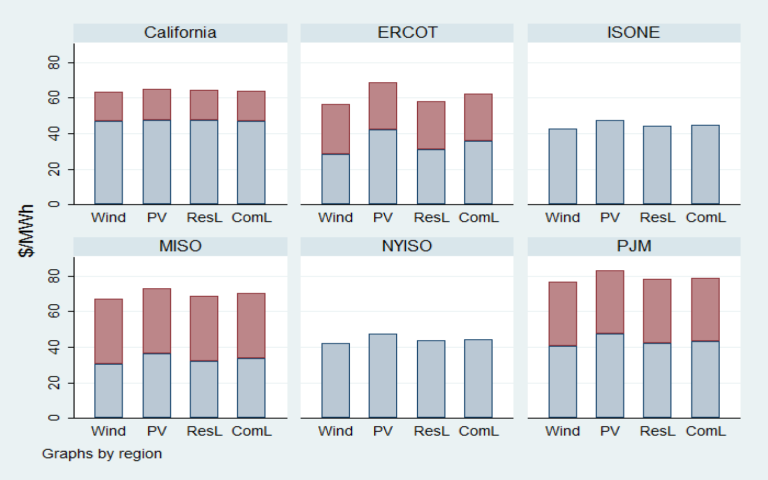
We construct a monetary measure of marginal economic value that includes both the value of avoided emissions (in uncapped regions) and the operating costs (e.g. fuel costs) associated with generation displaced marginal units:

$$EV/MWh = \underbrace{\tau(\overline{\phi_r} + T cov(\phi_r, \omega_{rj}))}_{\text{Emissions displacement value}} + \underbrace{\overline{\lambda_r} + T cov(\lambda_r, \omega_{rj})}_{\text{Avoided operating costs}}$$

$$+ \quad \underbrace{\kappa_r ?}_{\text{capacity value}}$$

We use real-time locational marginal prices to estimate λ_{rj}.

Marginal value (per MWh) by technology type and region (assumes \$38/ton CO_2).



This figure summarizes point estimates of emissions displacement (in red; measured in monetary terms) and operating costs (in blue) displaced per MWh of renewable energy generated or demand-side electricity saved.

4. Net cost per ton of CO_2 reduced

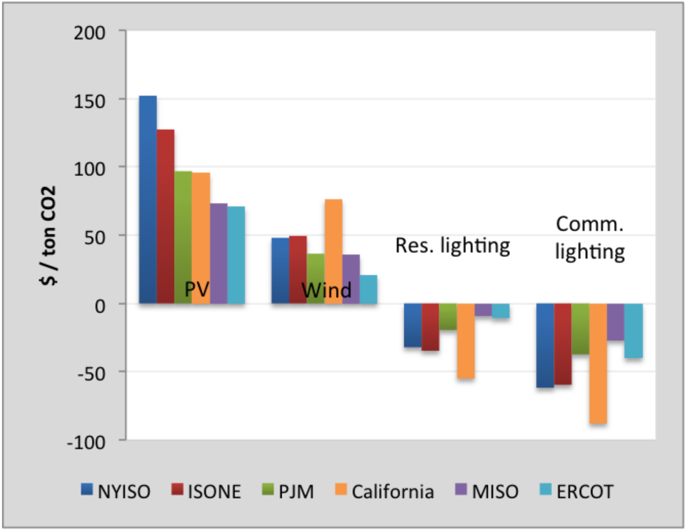
The final step in our analysis incorporates estimates of both benefits and costs of EE and RE investments.

We compute the region- and technology-specific costs per ton of CO_2 displaced as follows:

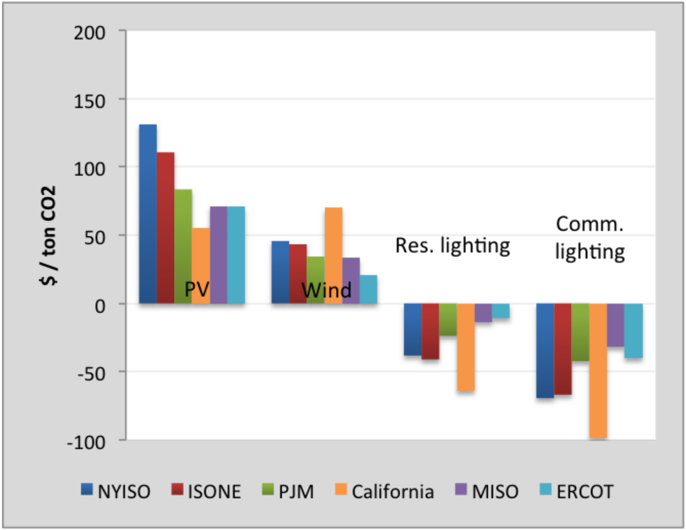
$$\text{MAC}_{rj} = \frac{\text{LCOE}_{rj} - \text{operating cost savings}/\text{MWh}}{\text{emissions displaced}/\text{MWh}},$$

where LCOE_{rj} is the levelized cost of energy (obtained from external sources).

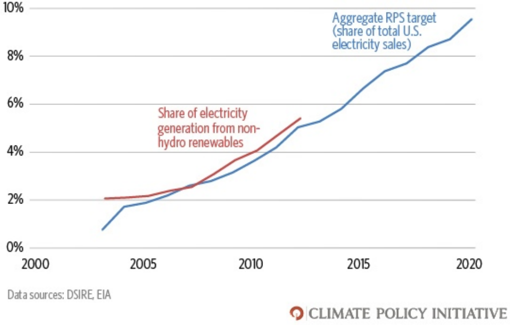
Net cost per ton CO_2 (by region and technology)



Net cost per ton CO_2 (by region and technology): includes capacity value estimates



How do our estimates compare to prevailing policy incentives?



- To what extent can existing policy incentives be rationalized by our less-than-comprehensive measures of external benefits?
- We focus on RPS policies with supporting REC markets, the PTC (wind), and ITC (solar).

How do our estimates compare to prevailing policy incentives?

- In the regions we evaluate, solar subsidies (i.e. RECs and Federal tax credits) ranged from \$40/MWh to \$470/MWh.
- In general, solar PV subsidies exceed estimated GHG emissions benefits by a significant margin (by thousands of dollars per kW).
- Wind subsidies (RPS and Federal tax credits) ranged from \$22/MWh to \$43/MWh over this time period.
- In the case of wind, estimated emissions-related benefits exceed the subsidy value in some states.

Summary of findings

- We estimate the carbon displacement benefits associated with different RE and EE technologies across several regions in the United States over 2010-2012.
- Technology-specific estimates of emissions displacement benefits vary little within regions, even though the timing of energy production does vary substantially across technologies.
- In contrast, we find economically significant variation in emissions-related benefits across regions.
- Prevailing policy incentives do not reflect these patterns of variation in external emissions benefits.

Key caveats

- The analysis conditions on the power system structure, the policy environment, and the technology characteristics we observe in our data.
- Moreover, we have considered the impacts of relatively small increases in renewable energy and efficiency investment.
- Our approach is not well suited to evaluating long run impacts or large, non-incremental investments.
- These caveats notwithstanding, we document economically significant regional variation in marginal emissions externalities.