Intermittency and the Value of Renewable Energy

Gautam Gowrisankaran Stanley Reynolds
Mario Samano

University of Arizona

April 20, 2012

Introduction: Renewable energy

- Electricity generation from fossil fuels is the largest single source of greenhouse gas (GHG) emissions worldwide
- Several U.S. states and foreign countries have mandated future renewable generation: **R**enewable **P**ortfolio **S**tandards (**RPS**)
- Many observers consider solar photovoltaics (PV) a crucial part of future renewable energy production
- A key potential problem with renewables is intermittency:
  - Solar facilities produce electricity intermittently, with highest production on clear, sunny days
  - This intermittency increases the variance of energy supply
  - This in turn adds risk to the electric system

The New York Times
The Opinion Pages

WORLD U.S. N.Y. / REGION BUSINESS TECHNOLOGY SCIENCE HEALTH SPORTS OPINION

OP-ED COLUMNIST

Here Comes the Sun

By PAUL KRUGMAN
Published: November 6, 2011

For decades the story of technology has been dominated, in the popular mind and to a large extent in reality, by computing and the things you can do with it. Moore's Law — in which the price of computing power falls roughly 50 percent every 18 months — has powered an ever-expanding range of applications, from faxes to Facebook.

Fred R. Conrad/The New York Times
Paul Krugman

Go to Columnist Page »
Blog: The Conscience of a Liberal

Our mastery of the material world, on the other hand, has advanced much more slowly. The sources of energy, the way we move stuff around, are much the same as they were a generation ago.

But that may be about to change. We are, or at least we should be, on the cusp of an energy transformation, driven by the rapidly falling cost of solar power. That's right, solar power.

If that surprises you, if you still think of solar power as some kind of hippie fantasy, blame our fossilized political system, in which fossil fuel producers have both powerful political allies and a powerful propaganda machine that denigrates alternatives.

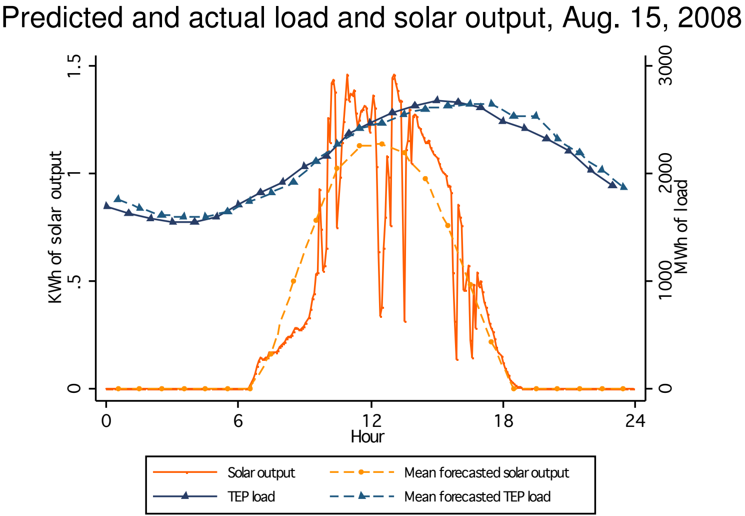
Introduction: Intermittency

- In this project we develop an empirical method to estimate the value of renewables accounting for intermittency
- A simpler approach would use "**levelized costs**" which are the present value of future average costs
- The levelized cost approach misses many specifics:
  - In the short run, operators may need to schedule additional reserve generation to avoid outage
  - In the long run, operators may need to invest in backup fossil fuel plants
  - But, solar plants produce during peak consumption periods, which increases their value

Introduction: What we do

- Our *economic* approach solves for *optimal* changes in backup capacity, generation and operating reserves
- Optimal decisions depend on:
  - Variability of renewable energy source including extent to which it correlates with demand
  - Extent to which output from the source is forecastable
  - Costs of backup generation
- We use the approach to evaluate solar energy in Arizona
- Methods could also be used to estimate the equilibrium value of:
  - technologies such as wind power and storage
  - policies such as real-time pricing

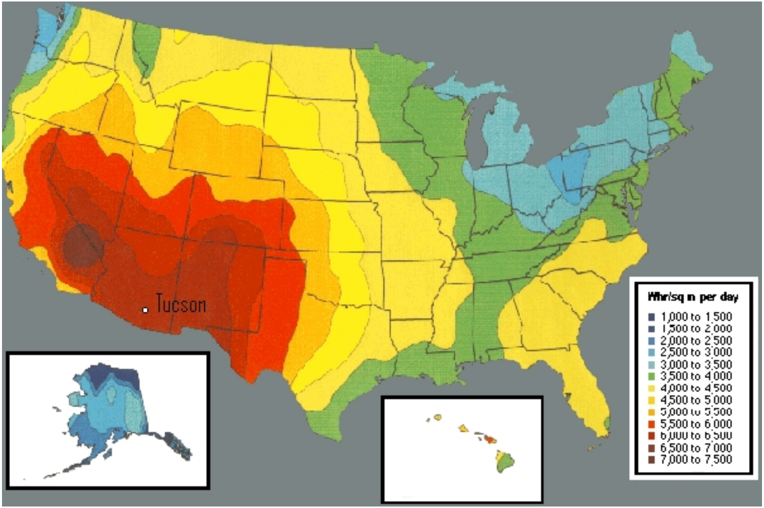
Intermittency: a graphical example



Background: electricity provision in southeastern Arizona

- Tucson one of best U.S. locations for solar generation
  - See Figure for details (in $Wh/m^2/day$)
- Vertically integrated electricity service provider: Tucson Electric Power (TEP)
- Tucson is situated within the Western Interconnection which allows for import or export of power

Background: electricity provision in southeastern Arizona



Outline of model

- System operator is faced with:
  - Solar RPS
  - Retail price of electiricity $\overline{p}$
  - Existing generators
- Initially, she chooses:
  - How many fossil fuel plants to build
  - Price for "curtailment contracts"
    - Curtailment contracts allow flexible customers to be paid not to consume electricity in periods of high demand
- Each morning, operator sees hourly weather forecasts for next day and generator planned outages
  - Computes hourly forecastable solar and load distributions
  - Chooses generators for production and reserves

Outline of model (continued)

- During each production hour – a day after production decisions – generator failure, load and solar output occur
- We can divide outcomes into three possibilities:
  1. Output (including solar) > load
  2. Output < load but output + reserves > load
  3. Output + reserves < load
- Operator balances consumer welfare loss from system outage against reserve and capacity costs

Data

We obtain data from several sources:

- Energy Information Administration (EIA) and EPA data on generator characteristics, and fuel and electricity prices
- ERCOT data from Texas for spinning reserve costs
- TEP/UA solar test site data
  - 1.536 KW fixed installation – no tracking
  - Assume perfect scalability
  - Average hourly output: 0.344 KWh
  - Observed capacity factor 23%
- Load (demand) data from the Federal Energy Regulatory Commission (FERC)
  - Minimum load: 1,403 MWh on Feb. 29, 2AM
  - Maximum load: 3,063 MWh on Aug. 1, 3PM

TEP/UA solar test site

Summary statistics on generator marginal costs

Unit Type	# Units	Mean Size (MW)	Mean MC $/MWh	Mean NOx (lbs./MWh)	Mean SO2 (lbs./MWh)	Mean CO2 (lbs./MWh)
Solar PV	1	0.756 (--)	0 (--)	0 (--)	0 (--)	0 (--)
Coal	10	155 (138)	20.57 (1.24)	3.92 (1.08)	2.35 (1.87)	2,163 (128)
Natural Gas – Combined Cycle	3	62 (20.7)	59.0 (0)	1.26 (0)	0.71 (0)	970 (0)
Natural Gas – Steam Turbine	3	89.0 (13.9)	59.3 (0)	3.90 (0)	6.44 (0)	1,955 (0)
Natural Gas – Gas Turbine	7	30.5 (18.5)	151.9 (109.5)	3.71 (1.48)	1.87 (3.12)	1,921 (47.2)
Potential New Natural Gas - Combined Cycle	By eqm.	60 (0)	38.5 (0)	1.26 (0)	0.71 (0)	970 (0)

Note: Standard deviations in parentheses. MC figures include emissions permits.

Results

- **Simple levelized cost difference value of solar**
  - **Average cost of solar PV: $184/MWh**
  - **Average cost of gas generation: $58 / MWh (EIA, 2011)**
  - **Difference: $126 / MWh**
- Simulation results: effects of 10, 20, 30% RPS
  - AZ has 15% RPS by 2025; CA has 33% RPS by 2020
- Simulation results: costs associated with 20% RPS
- Reoptimizing policies is very important in making renewable energy feasible
- Costs of variability
- Simulation results: RPS policies and CO_2 reductions

Results

- Simple levelized cost difference value of solar
  - Average cost of solar PV: $184/MWh
  - Average cost of gas generation: $58 / MWh (EIA, 2011)
  - Difference: $126 / MWh
- **Simulation results: effects of 10, 20, 30% RPS**
  - **AZ has 15% RPS by 2025; CA has 33% RPS by 2020**
- Simulation results: costs associated with 20% RPS
- Reoptimizing policies is very important in making renewable energy feasible
- Costs of variability
- Simulation results: RPS policies and CO_2 reductions

Results

Table: Outcomes with Different RPS Levels

RPS Policy	0%	10%	20%	30%
Solar PV capacity (MW)	0	846	1,692	2,538
Foregone gas generators (#)	–	3	4	5
Reserves as % of net load	24.2%	28.0%	33.9%	40.2%
Curtail. price p_c ($/MWh)	408	577	717	722
Curtail. quan. (MWh/yr)	33,485	27,033	25,453	30,804
Prob. curtail. Jul. 12PM	13.0%	0.04%	7.2e-7%	8.9e-8%
Prob. curtail. Jul. 6PM	13.0%	25.9%	22.7%	29.3%
Line loss (1000MWh/yr)	1,482	1,386	1,298	1,217
Transmission FC (mil. $/yr)	332.7	326.0	323.0	319.9
Reserve costs (mil. $/yr)	76.4	85.2	97.5	106.9
Loss surplus (mil. $/yr)	–	236.1	496.2	768.0
Loss surplus/solar ($/MWh)	–	138.8	145.9	150.5
CO_2 emissions (mill. tons/yr)	20.9	19.9	18.6	17.4

Results

- Simple levelized cost difference value of solar
  - Average cost of solar PV: $184/MWh
  - Average cost of gas generation: $58 / MWh (EIA, 2011)
  - Difference: $126 / MWh
- Simulation results: effects of 10, 20, 30% RPS
  - AZ has 15% RPS by 2025; CA has 33% RPS by 2020
- **Simulation results: costs associated with 20% RPS**
- **Reoptimizing policies is very important in making renewable energy feasible**
- Costs of variability
- Simulation results: RPS policies and CO_2 reductions

Results

Table: Costs Associated with 20% RPS

RPS policy	Foregone new gas generators	Loss in surplus per MWh solar
Feasible solar	4	\$145.9
Solar cost drop from \$5 to \$2/W	4	\$35.5
No unforecastable variance	7	\$133.4
Fully dispatchable	27	\$89.8
No demand curtailment	0	\$149.4
"Rule of thumb" policy	1	\$677.2

Results

- Simple levelized cost difference value of solar
  - Average cost of solar PV: $184/MWh
  - Average cost of gas generation: $58 / MWh (EIA, 2011)
  - Difference: $126 / MWh
- Simulation results: effects of 10, 20, 30% RPS
  - AZ has 15% RPS by 2025; CA has 33% RPS by 2020
- Simulation results: costs associated with 20% RPS
- Reoptimizing policies is very important in making renewable energy feasible
- Costs of variability
- **Simulation results: RPS policies and CO_2 reductions**

Results

- Current solar costs are \$5 million / MW
- Many analysts believe that costs will soon drop to \$2 million / MW
- U.S. government recently set social cost of carbon values

Table: Welfare Neutral Solar Capital Costs with CO_2 Benefits

RPS Policy Benefit per ton of CO_2 reduction	10%	20%	30%
\$0	1.23	1.04	0.91
\$5	1.30	1.12	1.00
\$21	1.54	1.38	1.26
\$35	1.74	1.61	1.50
\$65	2.18	2.10	2.00

Note: solar capital costs are in millions of dollars per rated megawatt

Conclusions

- We analyze the value of renewable energy with a three-part approach that accounts for intermittency
    1. Process to estimate and calibrate parameters using publicly-available data
    2. Computational approach to compute impact of RPS and other policies
- Biggest limitations: no dynamics and no market power
- Costs of solar per MWh produced increasing in RPS level
- Our methods can be used to understand relative costs of other policies
- Battery storage, electric cars, time-of-day pricing, etc.

Thanks!

msamano@email.arizona.edu