The Cost of Using Wind and Solar Power to Achieve Radical Greenhouse Gas Emission Reductions

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Research Question

How far could California reduce greenhouse gas emissions by switching to wind and solar power?
Renewable Energy Technologies
Intermittency of Wind and Solar Power

SURPLUS ENERGY: Excess renewable power may need to be discarded, raising costs

CAPACITY SHORTFALL: Renewable power may be unavailable during hours of high demand, so other plants must be used instead.
Research Approach

- Use an optimization model to...
  - Decide
    - where to build gas power plants, wind farms, solar facilities and transmission lines
    - when to operate generators
  - In order to
    - provide enough electricity every hour
    - reduce greenhouse gas emissions
  - At the lowest total cost (including a carbon cost)
- Repeat, to see how the system would be redesigned to achieve deeper reductions
INPUTS
Projected Electricity Costs

Levelized Cost of Electricity (US$/kWh)

Year


$0.70
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00

wind farms
natural gas plants
solar thermal troughs
home PV solar systems
natural gas plants + carbon adder
Wind Power Production

hourly data for 2002–04 from numerical weather model run by AWS Truewind

233 sites (23 GW), augmented with an equal number of fictitious lower-wind sites

site locations in this diagram are approximate
Solar Irradiance

Hourly irradiance for 2002–04 measured by California Irrigation Management Information System

117 measurement sites nearby PV systems in the same evapotranspiration zone are assumed to have the same irradiance.
RESULTS
Power System with Emissions 25% below 1990

Average Power Generation

- 5,000 MW
- New Wind
- New Solar Troughs
- New Distributed PV
- Existing Hydro
- Existing Geothermal
- Existing Nuclear
- New CCGT
- Existing Gas Cogen
- Existing Gas
- Existing Coal Cogen
- Existing Coal

Existing Transfer Capability
- 0 MW

New Transfer Capability
- 0 MW
- 36 MW
- 253 MW
Hourly Generator Operation

![Hourly Generator Operation Chart]

- **Power Production or Load (MW)**
  - Hydro
  - Existing Gas
  - New CCGT
  - New Wind
  - New Trough
  - New DistPV
  - Existing Geothermal
  - Existing Nuclear
  - Existing Gas Cogen
  - Existing Coal Cogen
  - Existing Coal
  - System Load
  - Hydro Pumping

**Month and Hour (PST)**

- Jan
- Feb
- Mar
- Apr
- May
- Jun
- Jul
- Aug
- Sept
- Oct
- Nov
- Dec
Effect of Emission Reductions on Power Bills

Average Cost of Electricity in 2022 (US$/kWh)

Emission Reductions Relative to 1990
Effect of Emission Reductions on Power Bills

Average Cost of Electricity in 2022 (US$/kWh)

Emission Reductions Relative to 1990

0%  10%  20%  30%  40%  50%  60%  70%
Improving the Cost–Emissions Tradeoff

Average cost of electricity in 2022 (US$/kWh)

CO₂ emission reductions (electricity + 50% of vehicles), 2022 vs. 1990
Improving the Cost–Emissions Tradeoff

Average cost of electricity in 2022 (US$/kWh)

CO$_2$ emission reductions (electricity + 50% of vehicles), 2022 vs. 1990

identify 2x more wind sites

Power Supply & Load

Feb Apr Jun Aug Oct Dec
Improving the Cost–Emissions Tradeoff

Average cost of electricity in 2022 (US$/kWh)

CO\textsubscript{2} emission reductions (electricity + 50% of vehicles), 2022 vs. 1990

- identify 2x more wind sites
- switch 50% of cars to electricity

Fig: 17
Improving the Cost–Emissions Tradeoff

Average cost of electricity in 2022 (US$/kWh)

$0.05

$0.06

$0.07

$0.08

$0.09

$0.10

0%

20%

40%

60%

80%

100%

CO₂ emission reductions (electricity + 50% of vehicles), 2022 vs. 1990

- Identify 2x more wind sites
- Switch 50% of cars to electricity
- Charge electric cars during best hours

Power Supply & Load

Feb

Apr

Jun

Aug

Oct

Dec
Improving the Cost–Emissions Tradeoff

Average cost of electricity in 2022 (US$/kWh)

- Identify 2x more wind sites
- Switch 50% of cars to electricity
- Charge electric cars during best hours
- Reduce electricity loads by 20%

CO₂ emission reductions (electricity + 50% of vehicles), 2022 vs. 1990
Conclusions

- There is no sharp limit to how much renewable power could be used
  - costs rise smoothly and slowly as the system uses more wind and solar power
- Renewable power should be developed to save fuel and emissions, even if backup plants are needed for peak periods
- Renewable power can become uneconomical when too much is produced at some times
- More renewable power can be used if diverse sites and technologies are developed (e.g., wind and solar)
- Demand-side flexibility may allow more wind and solar power to be used, at a lower cost
  - e.g., well-timed charging of PHEVs, dynamic adjustment of heater or air conditioner thermostats
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