Data centers & energy: Did we get it backwards?

Adam Wierman, Caltech
2 stories about data centers and energy

#1
Data centers are energy hogs

#2
Data centers are valuable resources for making the grid sustainable

Geo-distributed data centers are key to both
The typical story about energy & data centers: Data centers are energy hogs

The electricity use of data centers is \( \approx 2-3\% \) of the US total, and it is growing \( \approx 12\% \) a year! Total US use grows \( \sim 1\% \) a year!
The typical story about energy & data centers: **Data centers are energy hogs**

**Jevons paradox:** As technology progresses, efficiency improvements increase (rather than decrease) the rate of consumption.

Energy-efficiency data centers

Sustainable data centers
...but incorporating renewable energy isn’t easy

- Uncontrollable (not available “on demand”)
- Intermittent (large fluctuations)
- Uncertain (difficult to forecast)

Sustainable data centers

Building management: cooling, lighting, ...
Workload management: demand shaping, quality degradation...
...but incorporating renewable energy

→ Uncontrollable (not available “on demand”)
→ Intermittent (large fluctuations)
→ Uncertain (difficult to forecast)

Building management:
cooling, lighting, …

Workload management:
demand shaping,
quality degradation…

Sustainable data centers

The good

Follow the renewables routing emerges.

# Servers ON

Day 1  Day 2

east coast

west coast
The good

Follow the renewables routing emerges. Huge reductions in grid usage become possible.
The good

Follow the renewables routing emerges. Huge reductions in grid usage become possible.

The bad

GLB uses more energy if data centers don’t have renewables available.
The good

Follow the renewables routing emerges. Huge reductions in grid usage become possible.

The bad

GLB uses more energy if data centers don’t have renewables available.

The ugly

GLB uses dirtier grid electricity too!
2 stories about data centers and energy

#1
Data centers are energy hogs

#2
Data centers are valuable resources for making the grid sustainable

Geo-distributed data centers are key to both
Renewable energy is coming here!

Solar PV:

Wind:

Worldwide
Renewable energy is coming!
...but incorporation into the grid isn’t easy

They are typically
→ Uncontrollable (not available “on demand”)
→ Intermittent (large fluctuations)
→ Uncertain (difficult to forecast)

Each line is wind generation over 1 day
Key Constraint:\[ \text{Generation} = \text{Load} \]
(at all times)

low uncertainty
Key Constraint: \( \text{Generation} = \text{Load} \) (at all times)

\[ \Rightarrow \text{Generation follows Demand} \]

controllable (via markets)

low uncertainty
Key Constraint: $\text{Generation} = \text{Load}$ (at all times)

- less controllable
- high uncertainty
- low uncertainty

Tomorrow's grid
Key Constraint: Generation = Load (at all times)

1) Huge price variability, leading to generators opting out of markets.
2) More conventional reserves needed, countering sustainability gains!
“ON JUNE 16th something very peculiar happened in Germany’s electricity market. The wholesale price of electricity fell to minus €100 per megawatt hour (MWh). That is, generating companies were having to pay the managers of the grid to take their electricity.”

ON JUNE 16th something very peculiar happened in Germany’s electricity market. The wholesale price of electricity fell to minus €100 per megawatt hour (MWh). That is, generating companies were having to pay the managers of the grid to take their electricity. It was a bright, breezy Sunday. Demand was low. Between 2pm and 3pm, solar and wind generators produced 28.9 gigawatts (GW) of power, more than half the total. The grid at that time could not cope with more than 45GW without becoming unstable. At the peak, total generation was over 54GW, so prices went negative to encourage networks and protect the...
“Energiewende has so far increased, not decreased, emissions of greenhouse gases.”
Key Constraint: Generation = Load (at all times)

→ Demand must follow Generation (to some extent)

1) **Huge price variability**, leading to generators opting out of markets!

2) **More conventional reserves needed**, countering sustainability gains!
Grid needs huge growth in demand response

⇒ Demand must follow Generation
(to some extent)
Grid needs huge growth in demand response

Data centers are a promising option
...they are large loads
...usage is growing quickly
...highly automated
...they have significant flexibility

500 kW-100 MW each
10-15% growth/year
Data centers are a promising option
...they are large loads
...usage is growing quickly
...highly automated
...they have significant flexibility

10+ years of research into energy-efficient data centers
Data centers are a promising option
...they are large loads
...usage is growing quickly
...highly automated
...they have significant flexibility

Building management
5% in 2 min / 10% in 20 min [LLNL]
e.g. cooling, lighting, ...

10+ years of research into energy-efficient data centers
Data centers are a promising option
...they are large loads
...usage is growing quickly
...highly automated
...they have significant flexibility

10+ years of research into energy-efficient data centers

Workload management
10-30+% in 10-60min [LLNL,HP]
e.g. demand shaping, geographical load balancing, quality degradation, ...
Data centers are a promising option
...they are large loads
...usage is growing quickly
...highly automated
...they have significant flexibility

Microgrid management
10-100% in 5-30min
e.g., Battery management, local PV, Backup generation

10+ years of research into energy-efficient data centers
A new story about energy & data centers:

Data centers are valuable resources for making the grid sustainable
A new story about energy & data centers:

Data centers are valuable resources for making the grid sustainable
What is the potential of data center demand response?
A case study:

Optimally placed, fast charging rate storage

PV

Data center

Interactive workload

Batch workload

PUE
A case study:

20 MW Data Center with 20% flexibility $\Rightarrow$ ??? kW-hours fast charging, optimally placed storage (w.r.t. voltage violations rates)
A case study:

$20 billion of storage capacity worldwide!

1 MWh if geographical load balancing is used!

20 MW Data Center with 20% flexibility = 700 kWh fast charging, optimally placed storage (w.r.t. voltage violations rates)

$20 billion of storage capacity worldwide!
Where are we today?

- Time of use pricing
- Coincident peak pricing
- Wholesale markets
- Ancillary service markets

Data centers rarely participate
... and if they do it is highly inefficient
Where are we today?

Time of use pricing
Coincident peak pricing
Wholesale markets
Ancillary service markets

- Risky to participate
- Few opportunities for utility to extract response

For more see [Liu et al 2013]
How can we do better?

**Engineering:** Algorithm design for data center participation


**Economics:** New market designs

“mechanisms for control”
Utility ideal: Know all “supply functions” and then control usage “optimally” via direct control
Practical design: Extract "supply functions" and then control usage "optimally" via "prices to devices".

- **Supply function bidding** [Xu et al. 2014]
  - Efficient if no user has market power

- **Predictive pricing** [Liu et al. 2014]
  - Efficient if predictions are accurate

"mechanisms for control"
Supply function bidding vs predictive pricing

[Xu et al 2014]
Efficient if no user has market power

[Liu et al 2014]
Efficient if predictions are accurate

(Data center is ~30% of load)
2 stories about data centers and energy

#1 Data centers are energy hogs = Geo-distributed data centers are key to both

#2 Data centers are valuable resources for making the grid sustainable = ...but we need new market designs to make this happen.
Data centers & energy: Did we get it backwards?

Adam Wierman, Caltech
Blog: Rigor + Relevance

- Adam Wierman, Zhenhua Liu, Iris Liu, and Hamed Mohsenian-Rad. Opportunities and Challenges for Data Center Demand Response. IGCC 2014.
California's First-in-Nation Energy Storage Mandate

By Bill Sweet
Published 25 Oct 2018 | 17:30 GMT

“...power companies required to have electricity storage capacity [of] 1325 MW in place by the end of 2020.”

California has adopted the United States' first energy storage mandate, requiring the state's three major power companies to have electricity storage capacity that meets certain requirements by the end of 2020.
Save the planet and return your name badge before you leave (on Tuesday)