Microsoft Research Faculty Summit 2014

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Data centers & energy: Did we get it backwards?

Adam Wierman,
Caltech

Microsoft

2 stories about data centers and energy

#1

Data centers are energy hogs

=

#2

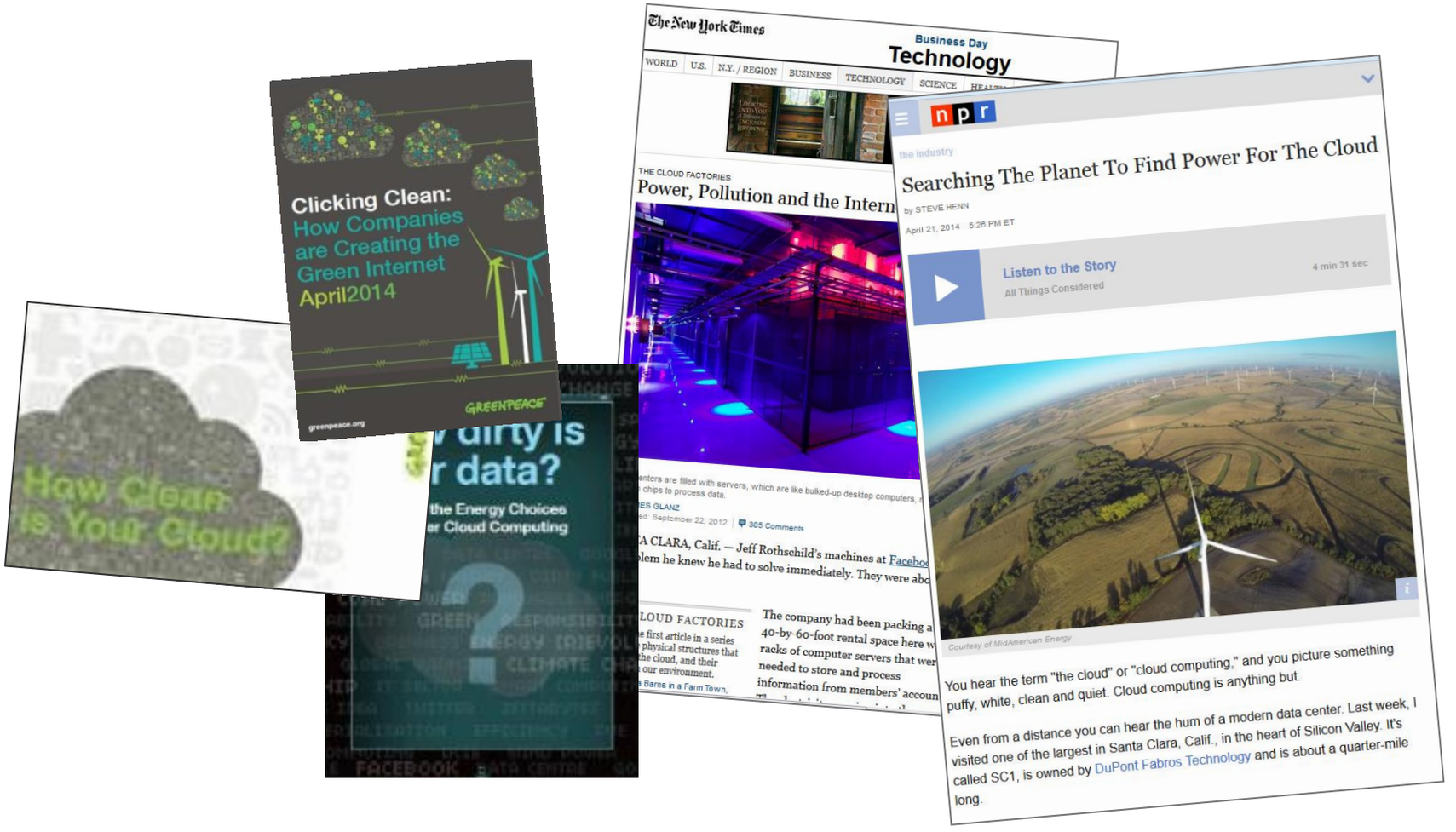
Data centers are valuable resources for making the grid sustainable

=

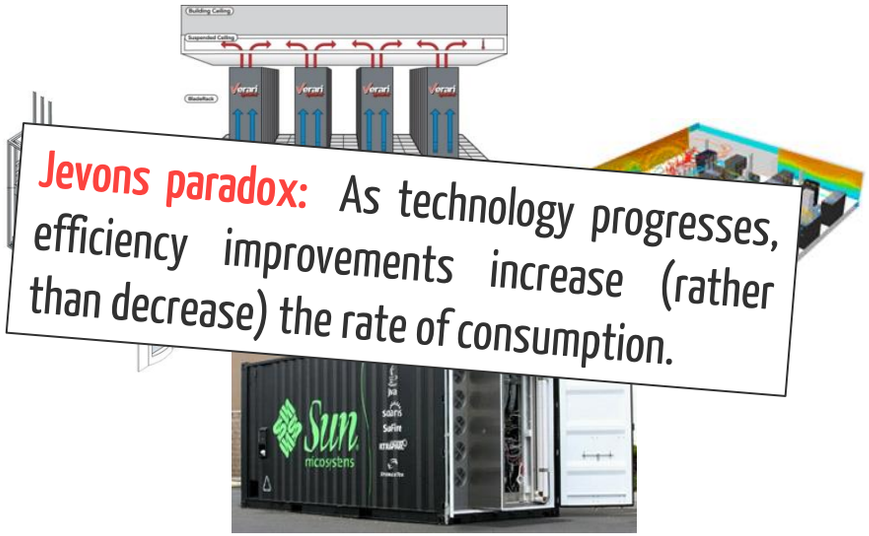
Geo-distributed data centers are key to both

The typical story about energy & data centers: Data centers are energy hogs

The electricity use of data centers is ≈2-3% of the US total,
and it is growing ≈12% a year! Total US use grows ~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)

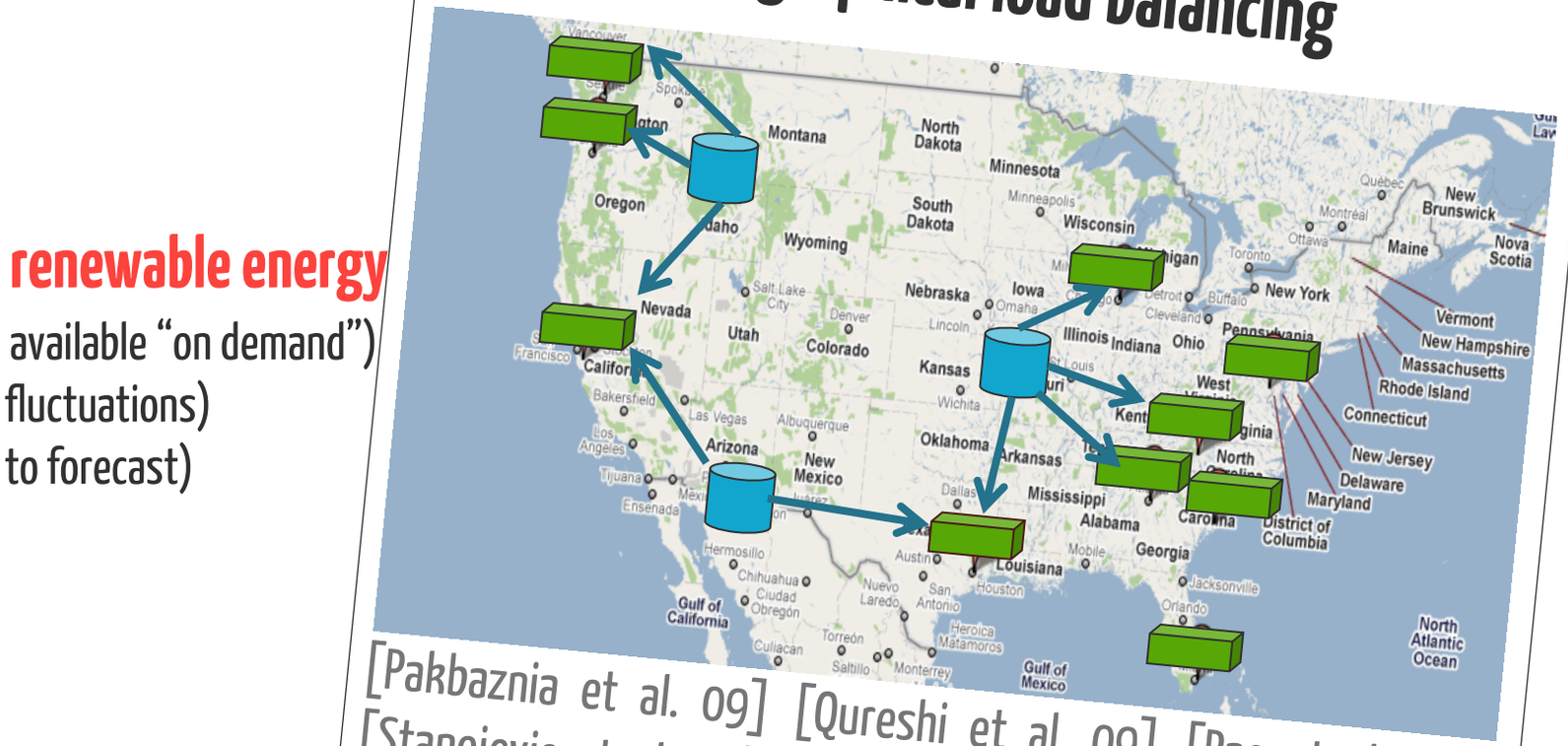
Sustainable data centers

Building management: cooling, lighting, …
Workload management: demand shaping, quality degradation…

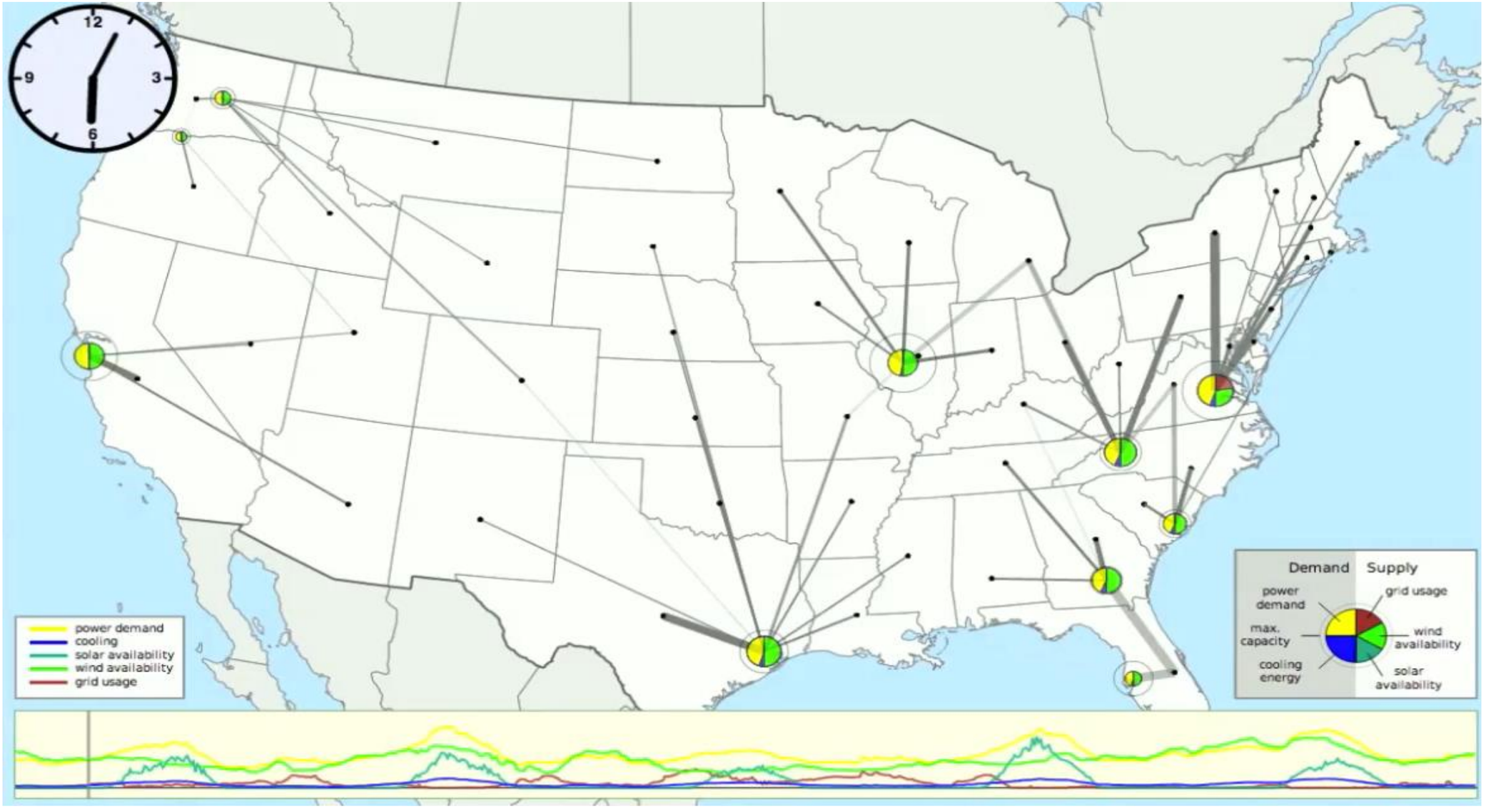
...but incorporating renewable energy

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

Geographical load balancing

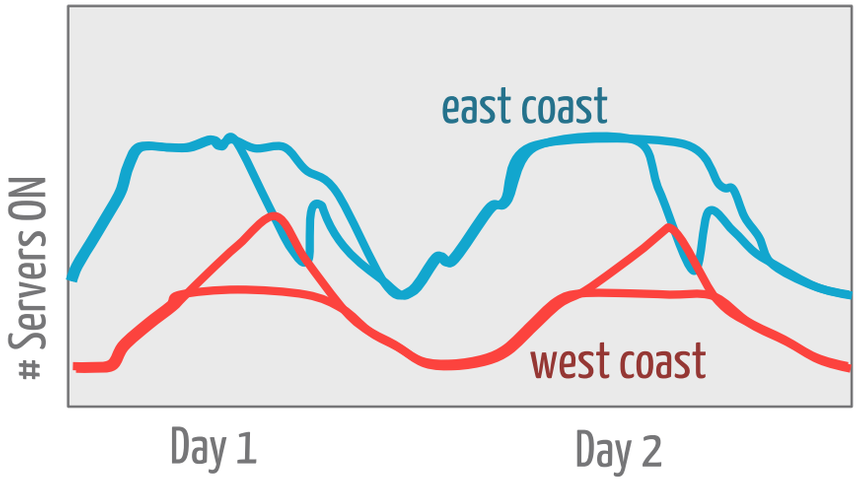


[Pakbaznia et al. 09] [Qureshi et al. 09] [Rao et al. 10] [Stanojevic et al. 10] [Wendell et al 10] [Le et al 2010] [Adnan 12] [Chiu 12 et al], [Liu et al 2011, 2012, 2013] [Lin et al 2011, 2012, 2013], ... survey: [Rahman et al 2014]


12
3
6
9
power demand
cooling
solar availability
wind availability
grid usage
Demand
Supply
power demand
grid usage
max. capacity
wind availability
cooling energy
solar availability

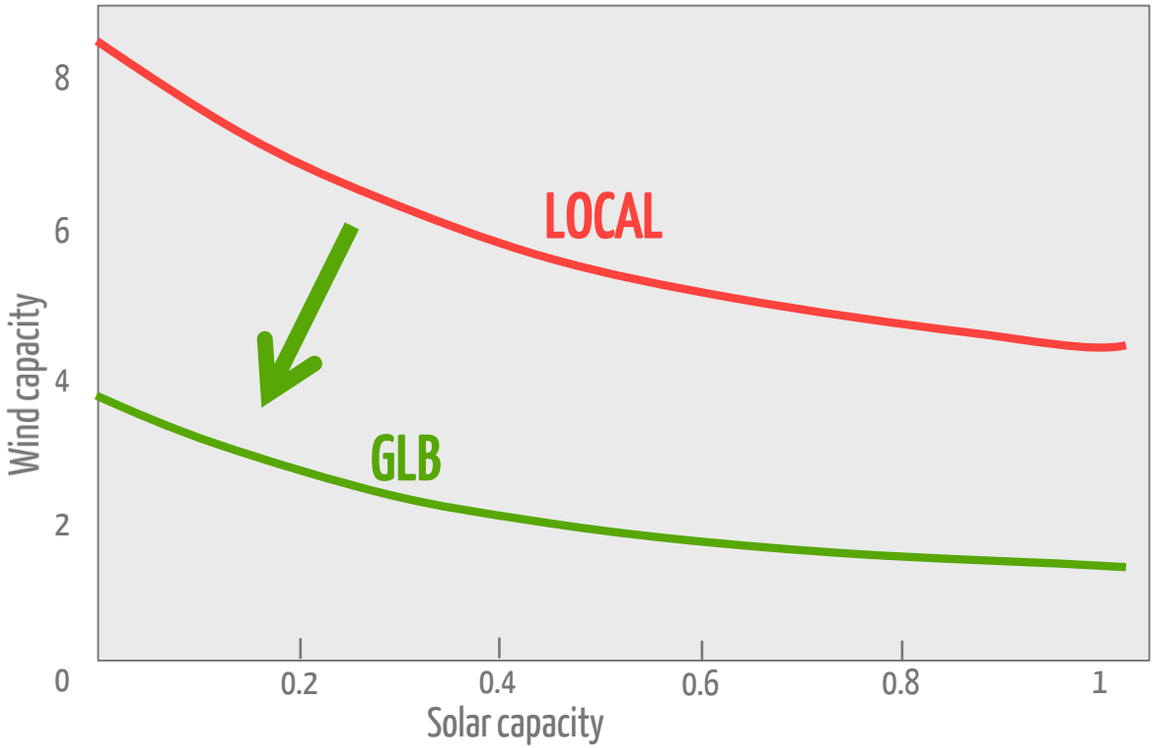
The good

Follow the renewables routing emerges.



The good

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

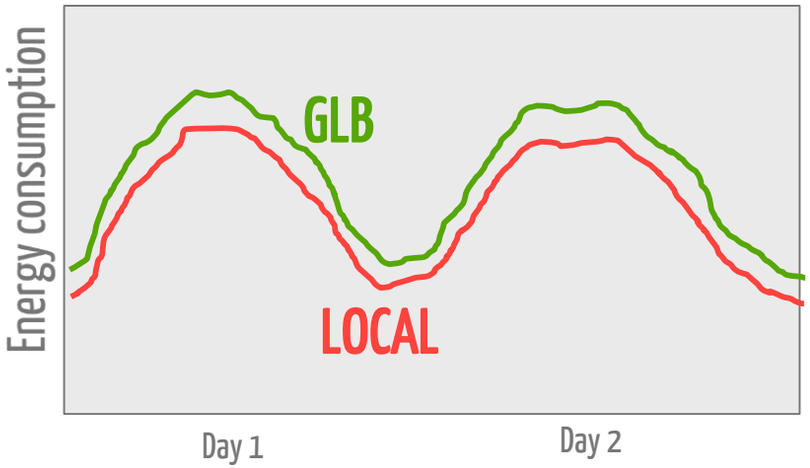


The good

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

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Data centers are valuable resources for making the grid sustainable

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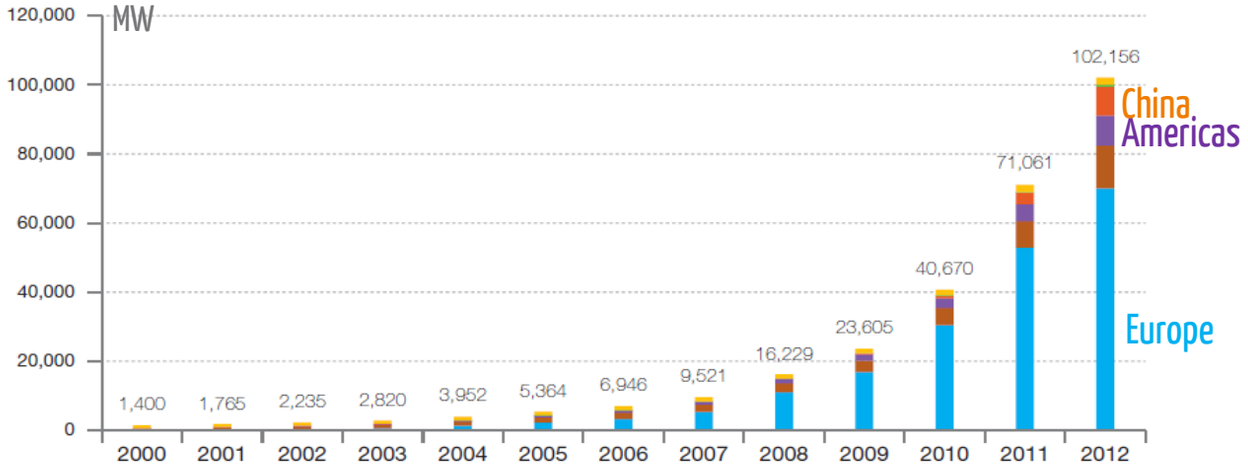
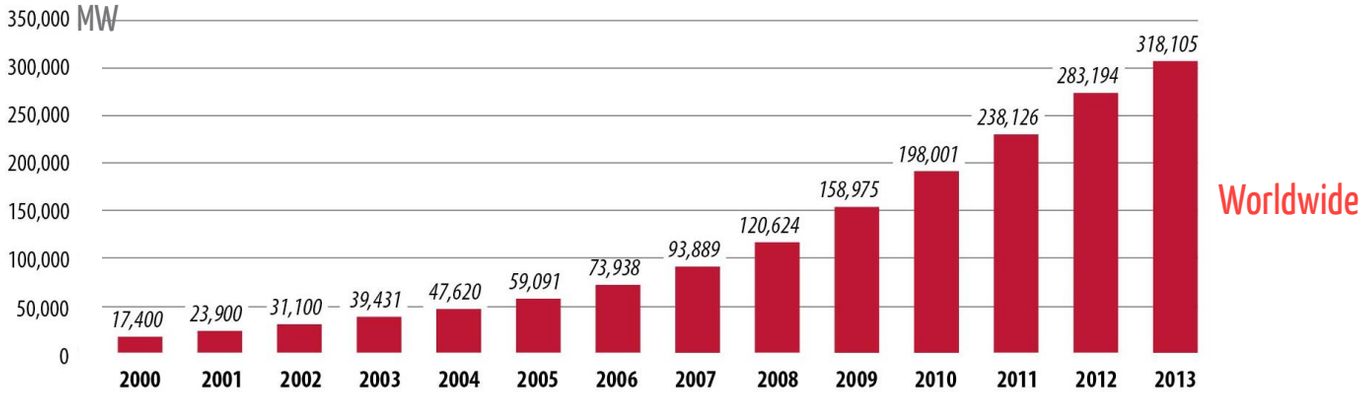
Geo-distributed data centers are key to both

Renewable energy is ~~coming!~~ here!

Solar PV:



Wind:

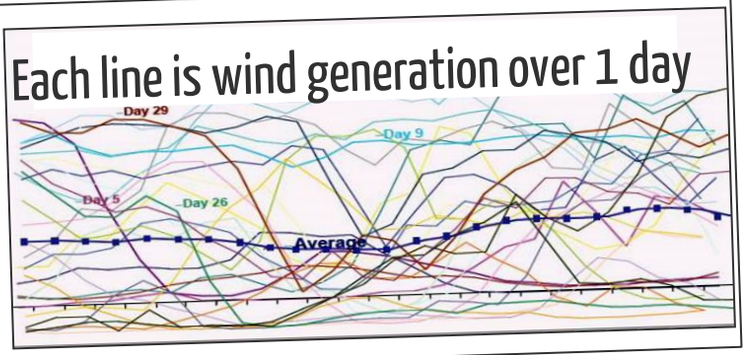


Renewable energy is ~~coming!~~ here!

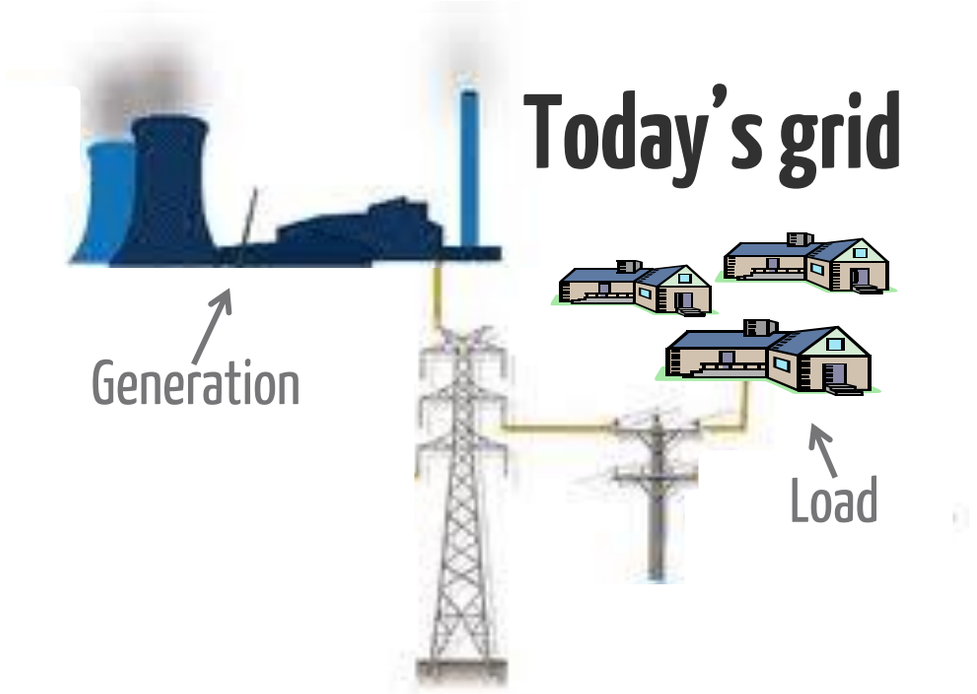
...but incorporation into the grid isn't easy

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

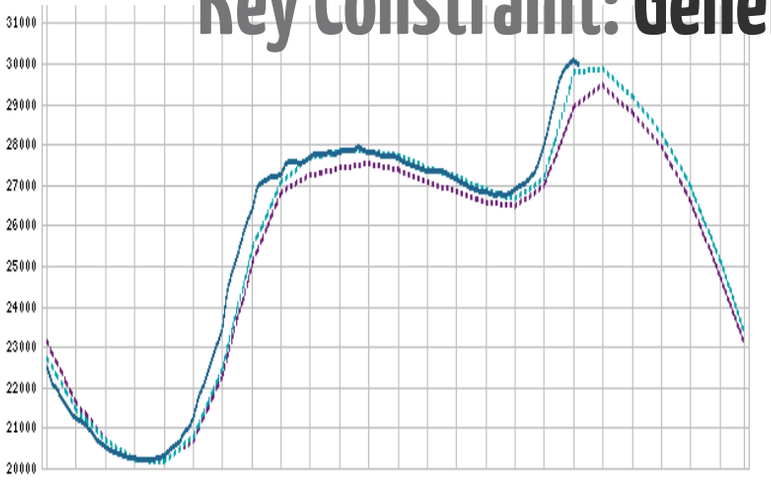
Each line is wind generation over 1 day



Today's grid

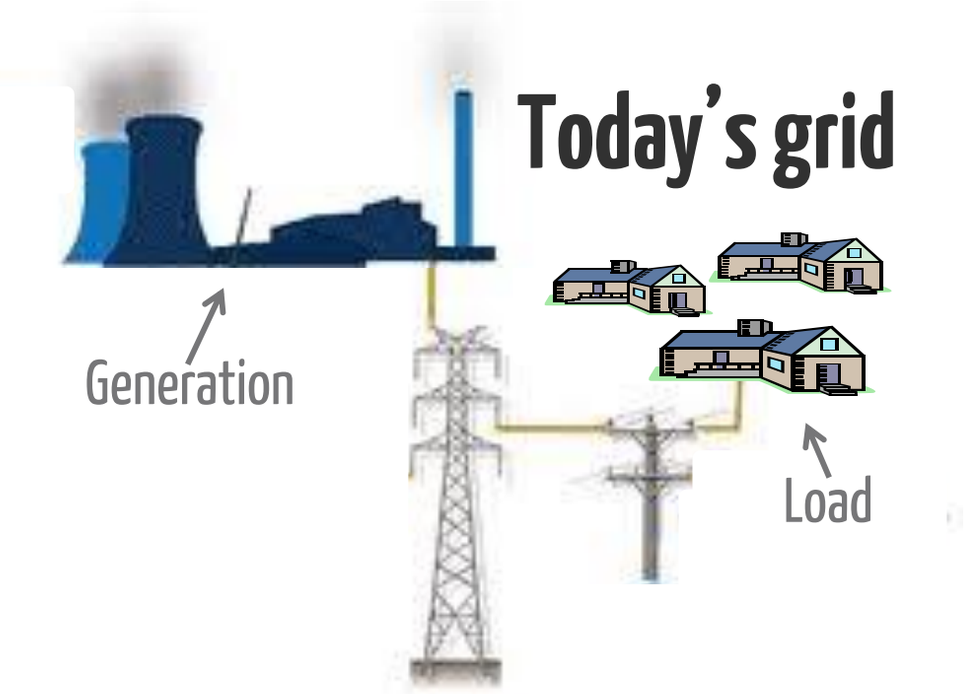


Key Constraint: Generation = Load
(at all times)



low uncertainty

Today's grid



Key Constraint: Generation = Load

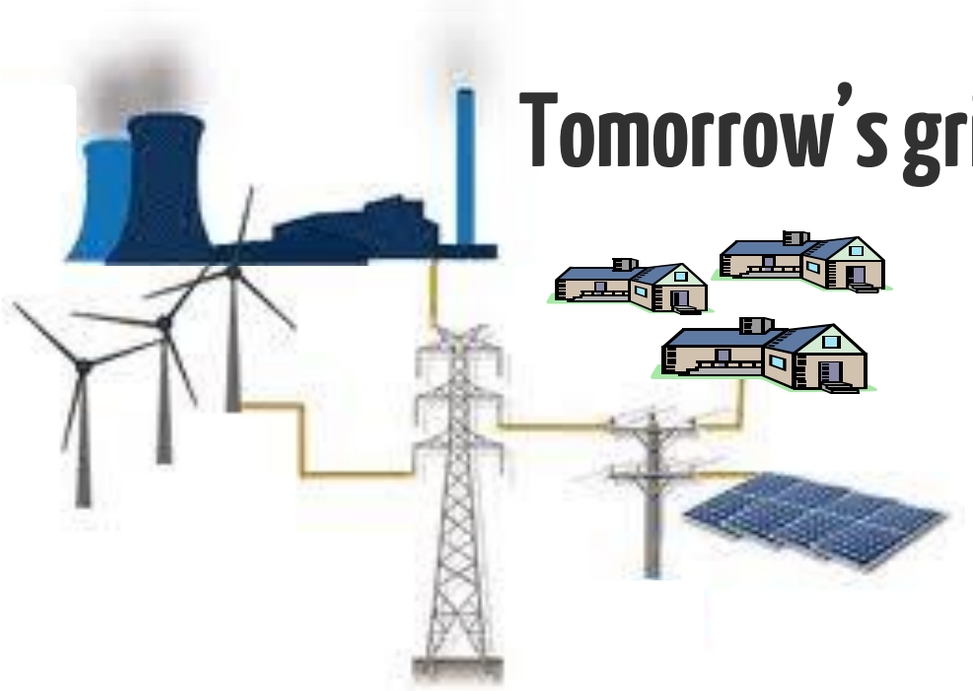
(at all times)

⇒ Generation follows Demand

controllable (via markets)

low uncertainty

Tomorrow's grid



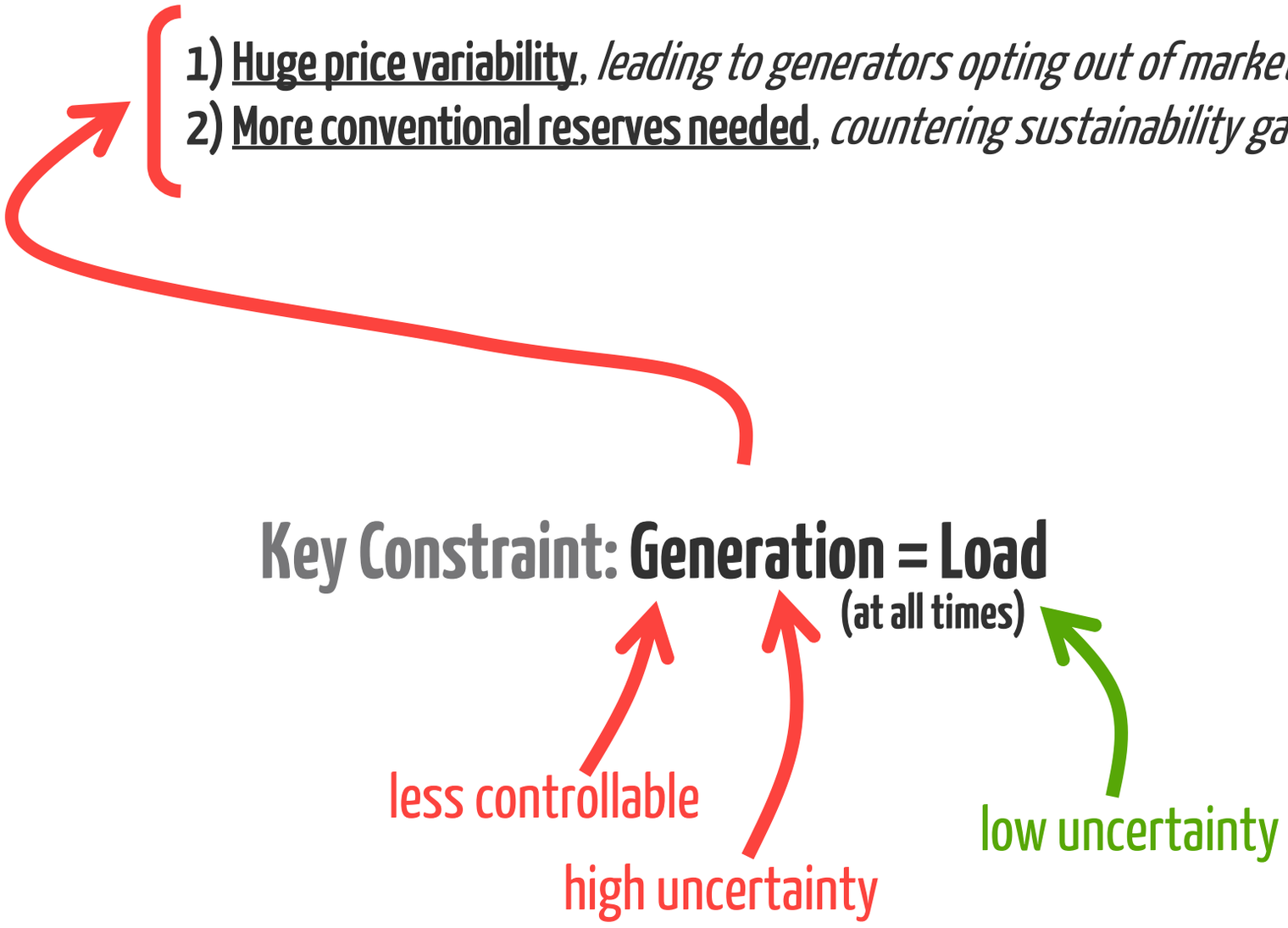
Key Constraint: Generation = Load (at all times)

less controllable

high uncertainty

low uncertainty

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."

The Economist | World politics | Business & finance | Economics | Science & technology | Cultur

European utilities

How to lose half a trillion euros

Like 7.3k Tweet 784

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 51GW; so prices went negative to encourage cutbacks and protect the

"*Energiewende* has so far increased, not decreased, emissions of greenhouse gases."

Germany's energy transition

Sunny, windy, costly and dirty

Germany's new "super minister" for energy and the economy has his work cut out

Jan 18th 2014 | BERLIN | From the print edition

SIGMAR GABRIEL has been on a roll. The boss of Germany's centre-left Social ... herded his party into a ...lor Angela Merkel and ...r. He is jovial, ...ith the *Zeitgeist*. ...'s vision of work-life balance, he plans to take Wednesday afternoons off to pick up his two-year-old daughter from her crèche.

Gabriel in search of an energy miracle

But Mr Gabriel, who is mulling a run for chancellor in 2017, will by then be judged on a more daring project. As part of his coalition deal with Mrs Merkel, he is now a "super minister" combining two portfolios, energy and the economy. He is thus in charge of rescuing Germany's most ambitious and risky domestic reform: the simultaneous exits from nuclear and fossil-fuel energy, collectively known as the *Energiewende*, a term that means energy "turn" or "revolution".

More a marketing slogan than a coherent policy, the *Energiewende* is mainly a set of timetables for different goals. Germany's last nuclear plant is to be switched off in 2022. The share of renewable energy from sun, wind and biomass is meant to rise to 80% of electricity production, and 60% of overall energy use, by 2050. And emissions of greenhouse gases are supposed to fall, relative to those in 1990, by 70% in 2040 and 80-95% by 2050.

German consumers and voters like these targets. But they increasingly dislike their side-effects. First, there is the rising cost of electricity. This is a consequence of a renewable

1) **Huge price variability**, *leading to generators opting out of markets!*
2) **More conventional reserves needed**, *countering sustainability gains!*

Key Constraint: Generation = Load (at all times)

⇒ Demand must follow Generation (to some extent)

less

high uncertainty

low uncertainty

Grid needs huge growth in demand response

⇒ Demand must follow Generation
(to some extent)

Grid needs huge growth in demand response

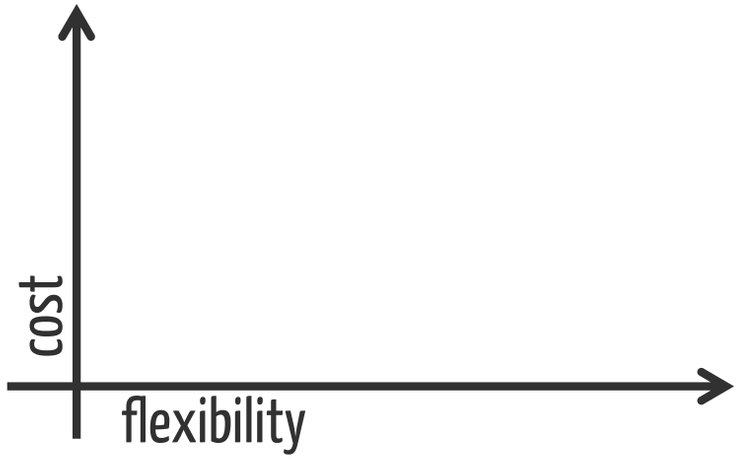
Data centers are a promising option

...they are large loads → 500 kW-100 MW each

...usage is growing quickly → 10-15% growth/year

...highly automated

...they have significant flexibility



Data centers are a promising option

...they are large loads

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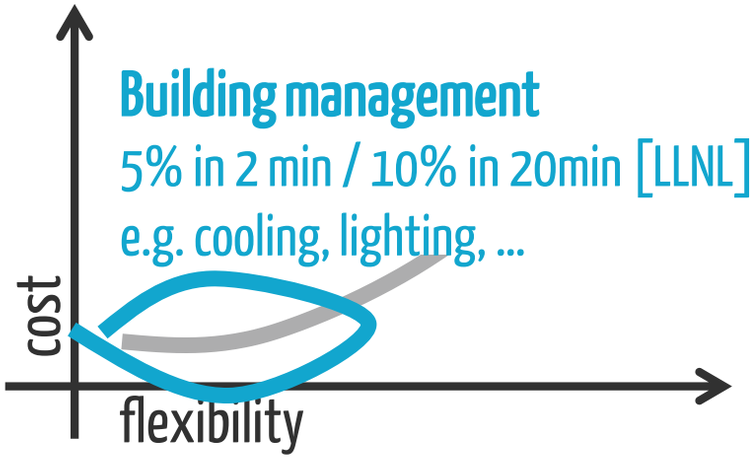
...highly automated

...they have significant flexibility

10+ years of research into energy-efficient data centers



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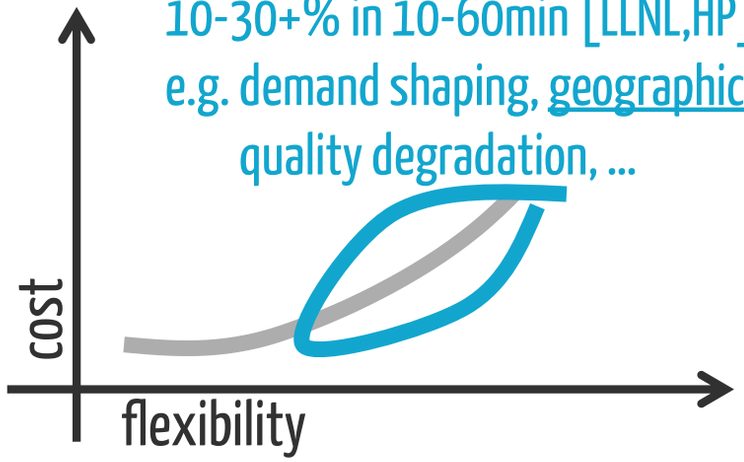
10+ years of research into
energy-efficient data centers

Workload management

10-30+% in 10-60min [LLNL,HP]

e.g. demand shaping, geographical load balancing, quality degradation, …



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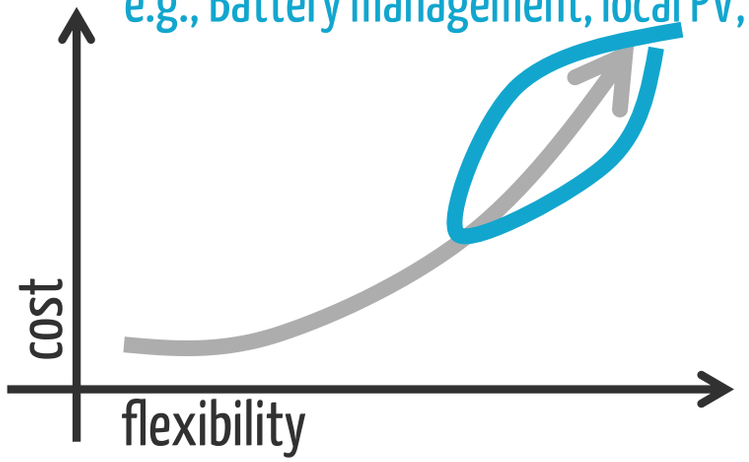
Microgrid management

10-100% in 5-30min

e.g., Battery management, local PV, Backup generation



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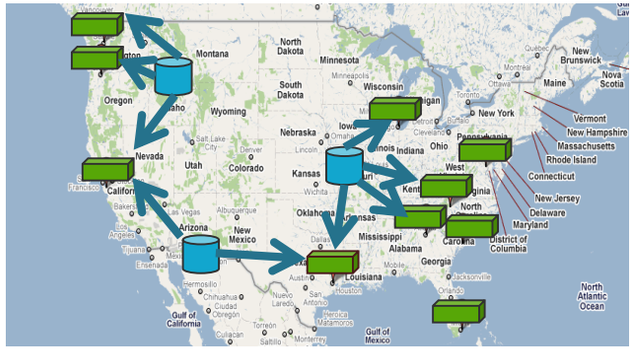
A new story about energy & data centers:

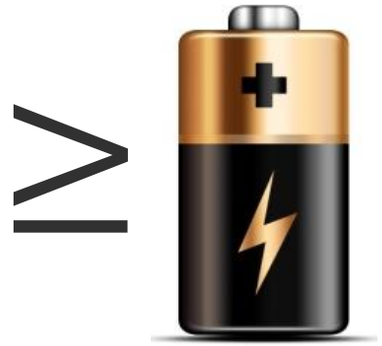
Data centers are valuable resources for making the grid sustainable

=

A new story about energy & data centers:

Data centers are valuable resources for making the grid sustainable



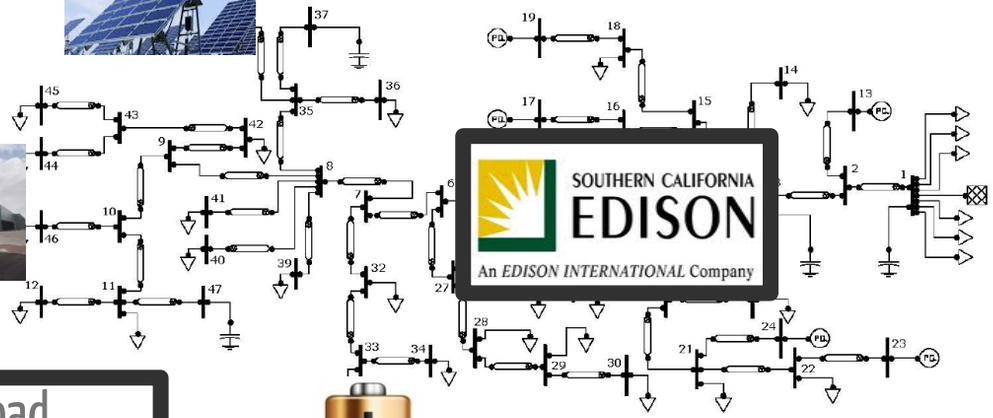


What is the potential of data center demand response?

A case study:

PV

data center



Optimally placed, fast charging rate storage

interactive workload

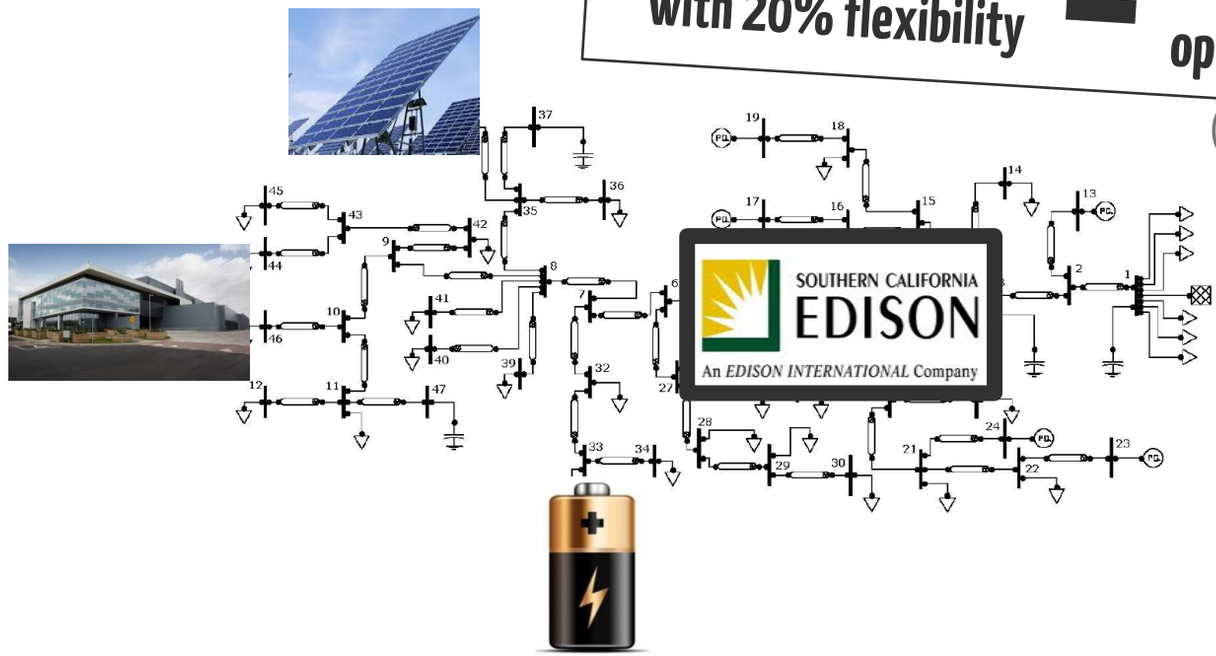
batch workload

PUE

A case study:

20 MW Data Center with 20% flexibility = **???? kWh fast charging, optimally placed storage**

(w.r.t. voltage violations rates)

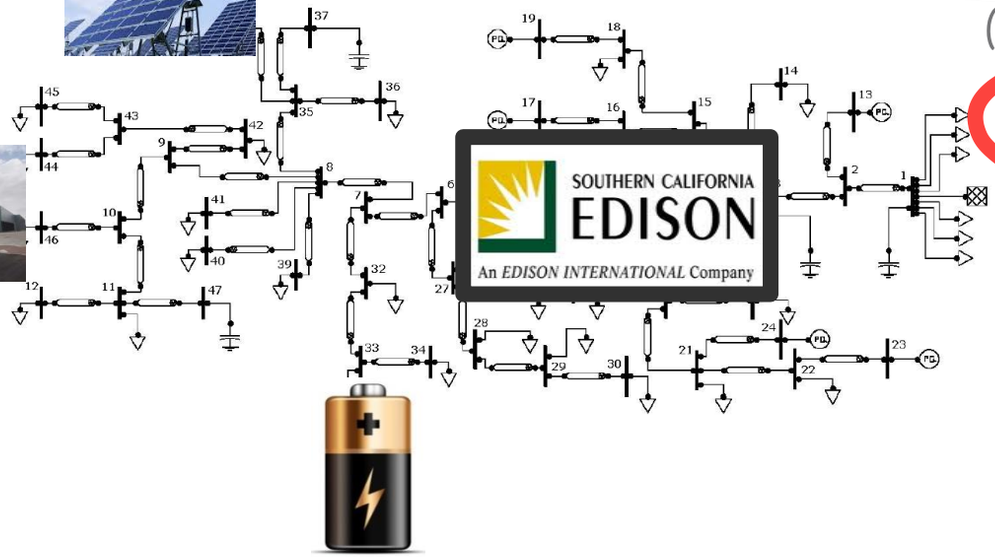


A case study:

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

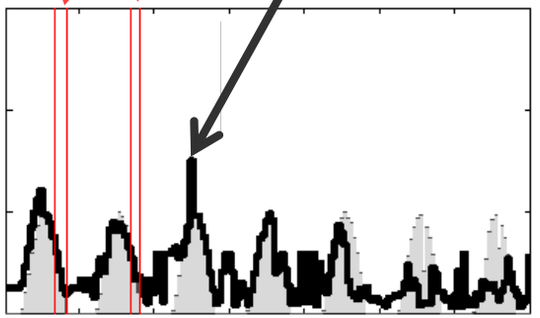
Coincident peak pricing

Wholesale markets

Ancillary service markets

coincident peak warnings

peak



- 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

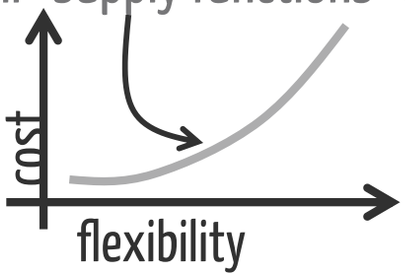
\+ [Camacho et al 2014], [Chen et al 2013, 2014], [Ghamkhari et al 2012, 2014], [Aikema et al 2012, 2013], [Irwin et al 2011], [Urgaonkar et al 2013, 2014], [Li et al 2012, 2013], [Liu et al 2013, 2014]

Economics: New market designs

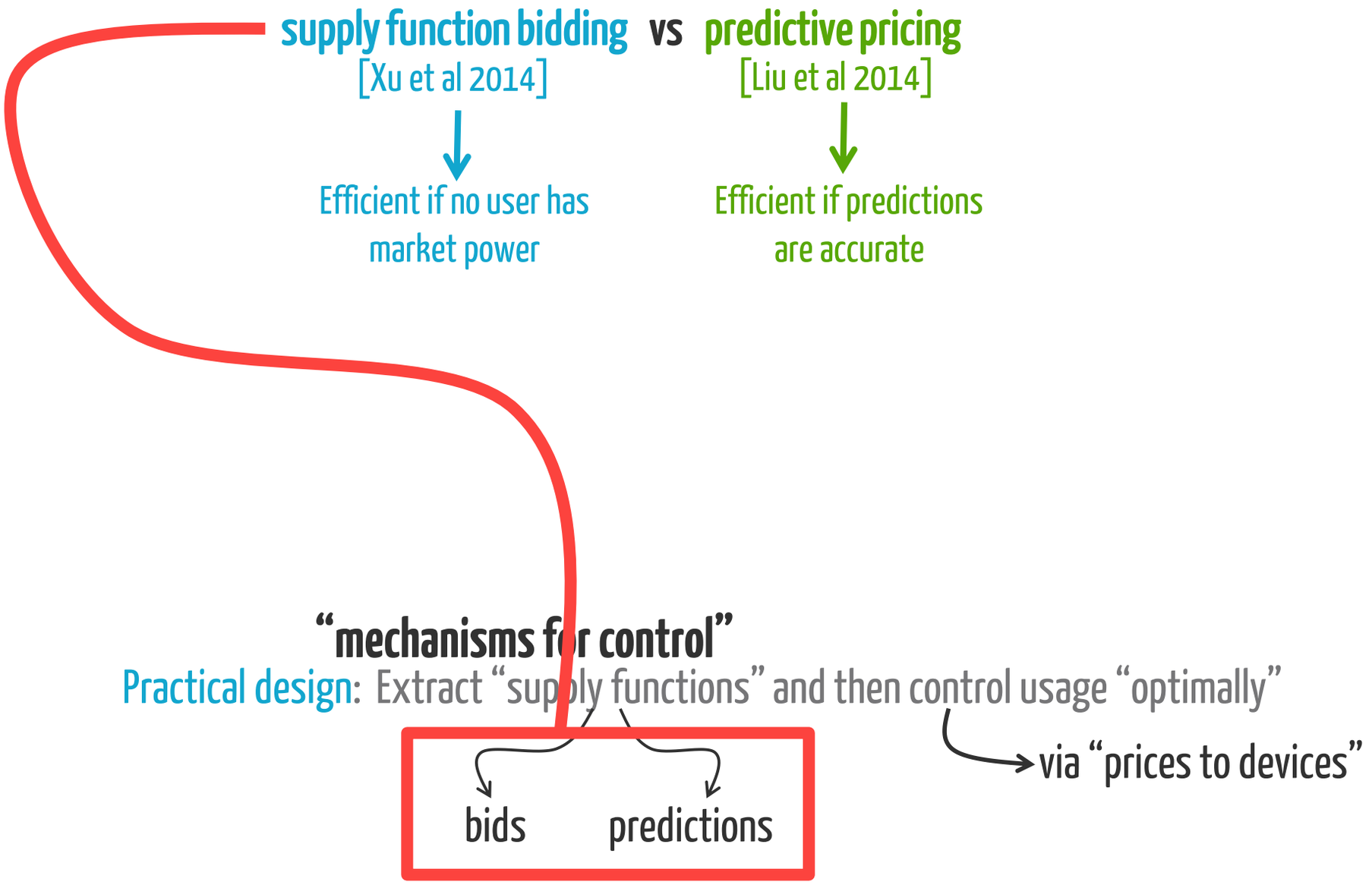
"mechanisms for control"

“mechanisms for control”

Utility ideal: Know all “supply functions” and then control usage “optimally”



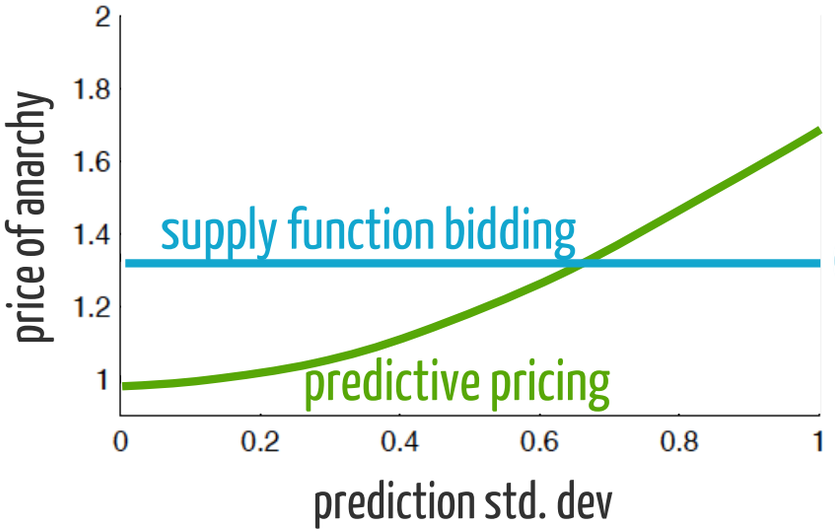
via direct control


supply function bidding
[Xu et al 2014]
vs
predictive pricing
[Liu et al 2014]
Efficient if no user has market power
Efficient if predictions are accurate
"mechanisms for control"
Practical design: Extract "supply functions" and then control usage "optimally"
via "prices to devices"
bids
predictions

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

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Data centers are energy hogs

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#2

Data centers are valuable resources for making the grid sustainable

=

...but we need new market designs to make this happen.

Geo-distributed data centers are key to both

Data centers & energy: *Did we get it backwards?*

Adam Wierman, Caltech
Blog: Rigor + Relevance

- Minghong Lin, Adam Wierman, Lachlan Andrew, and Eno Thereska. Dynamic right-sizing for power proportional data centers. Infocom, 2011. Best Paper award winner.
- Zhenhua Liu, Minghong Lin, Adam Wierman, Steven Low, and Lachlan Andrew. Greening geographical load balancing. Sigmetrics 2011. IEEE Sustainable Computing Register "Pick of the month"
- Zhenhua Liu, Minghong Lin, Adam Wierman, Steven Low, and Lachlan Andrew. Geographical load balancing with renewables. Greenmetrics, 2011. Best Student Paper award winner.
- Zhenhua Liu, Yuan Chen, Cullen Bash, Adam Wierman, et al. Renewable and cooling aware workload management for sustainable data centers. Sigmetrics 2012. Part of the HP NetZero Data Center Architecture, which was named a 2013 Computerworld Laureate.
- Minghong Lin, Lachlan Andrew, and Adam Wierman. Online Algorithms for Geographical Load Balancing. Green Computing Conference, 2012. Best Paper award winner.
- Zhenhua Liu, Adam Wierman, Yuan Chen, Benjamin Razon, and Niangjun Chen. Data Center Demand Response: Avoiding the coincident peak via workload shifting and local generation. Performance Evaluation, 2013. Among top 10 most downloaded in 2013.
- **Zhenhua Liu, Iris Liu, Steven Low, Adam Wierman. Pricing data center demand response. Sigmetrics, 2014**.
- **Adam Wierman, Zhenhua Liu, Iris Liu, and Hamed Mohsenian-Rad. Opportunities and Challenges for Data Center Demand Response. IGCC 2014.**

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California's First-in-Nation Energy Storage Mandate

By Bill Sweet
Posted 25 Oct 2013 | 17:30 GMT

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

Photo: PG&E

West Coast Wattage: A 2-megawatt, 14 megawatt-hour battery facility in Vacaville, Calif. could help California meet a new storage mandate.

California has adopted the United States' first energy storage mandate, requiring the state's three major power companies to have electricity storage

Save the planet and return
your name badge before you
leave (on Tuesday)