Cost-aware load shifting for geographically distributed data centers

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Photo source: http://www.google.com/about/datacenters/gallery/#/tech

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Research Question

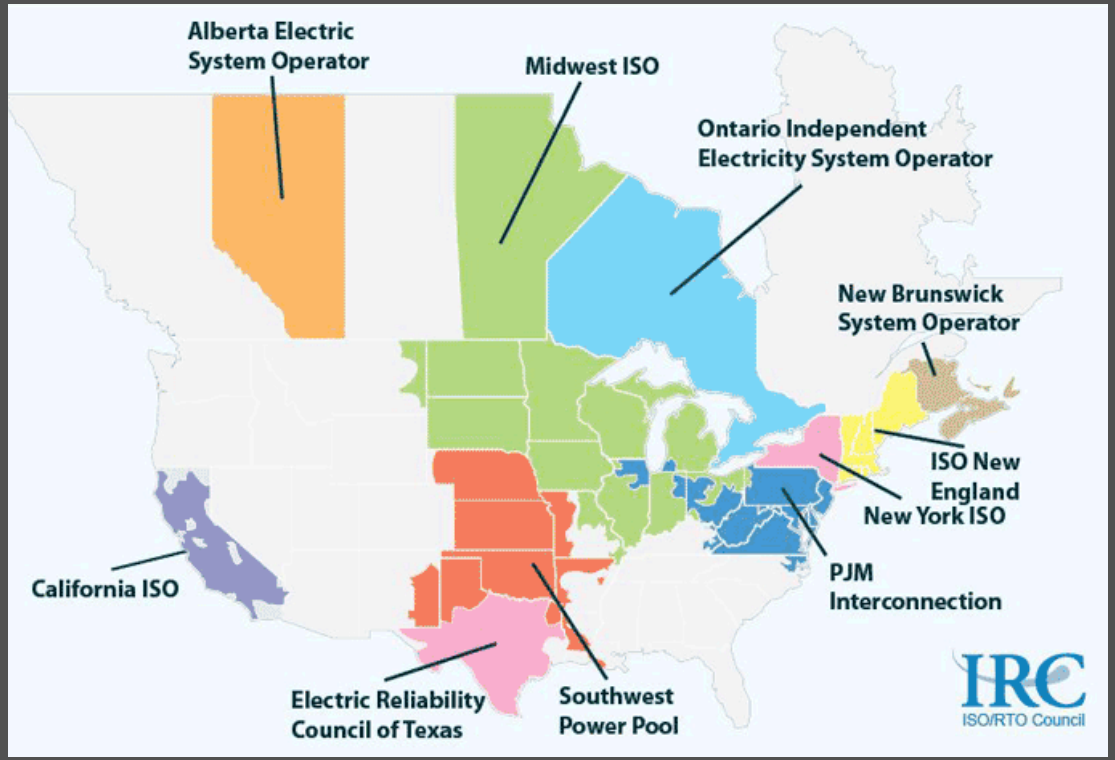
"Physics tells us it's easier to ship photons than electrons; that is, it's cheaper to ship data over fiber optic cables than to ship electricity over high-voltage transmission lines."*

What are the potential savings from shifting computing load among nodes in a network of geographically distributed data centers to minimize the true social cost of electricity used in their operation?

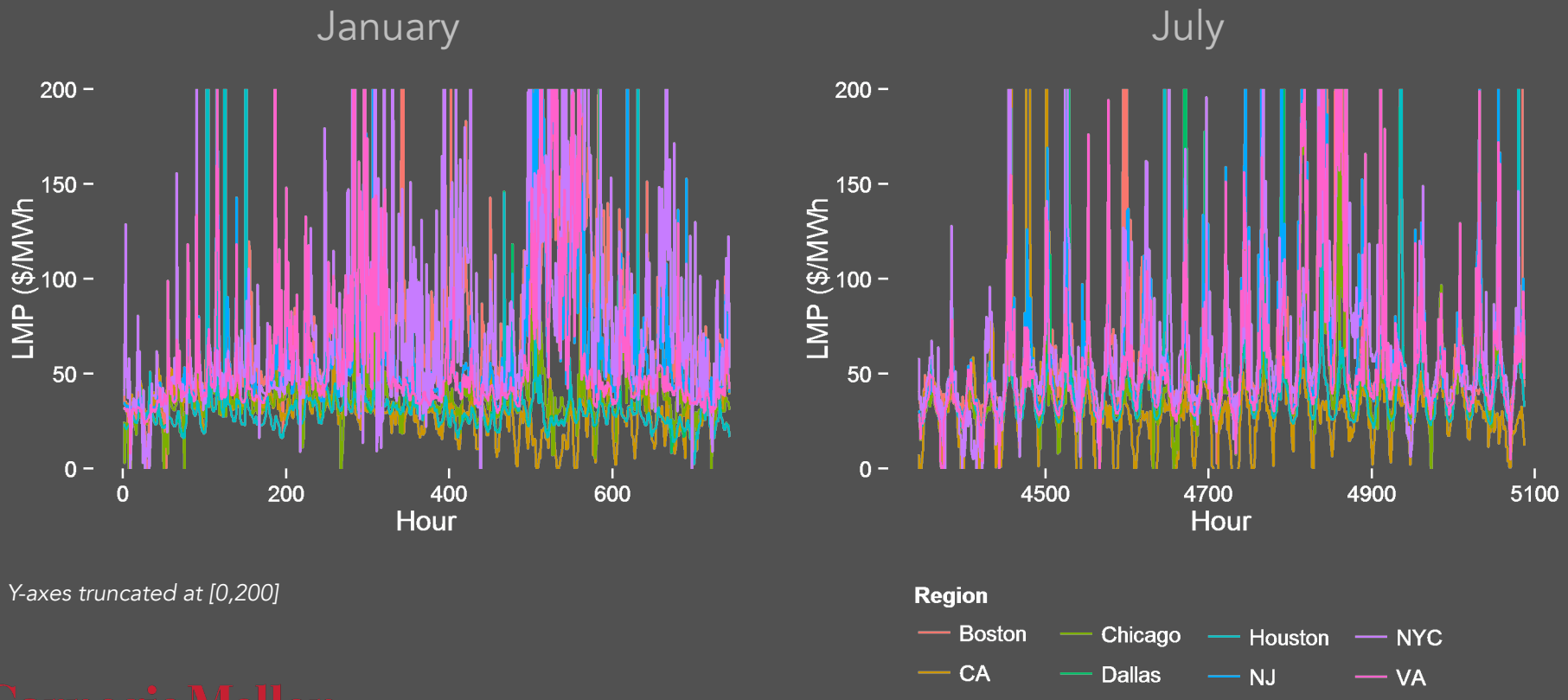
*Armbrust, et al. 2009. Above the clouds: a Berkeley view of cloud computing.

Electricity prices from RTOs/ISOs

- Locational marginal prices (LMPs) for real-time wholesale market
- At relevant aggregate pricing nodes (APNs)
- Aggregated to hour intervals



LMPs vary temporally and spatially



Y-axes truncated at [0,200]

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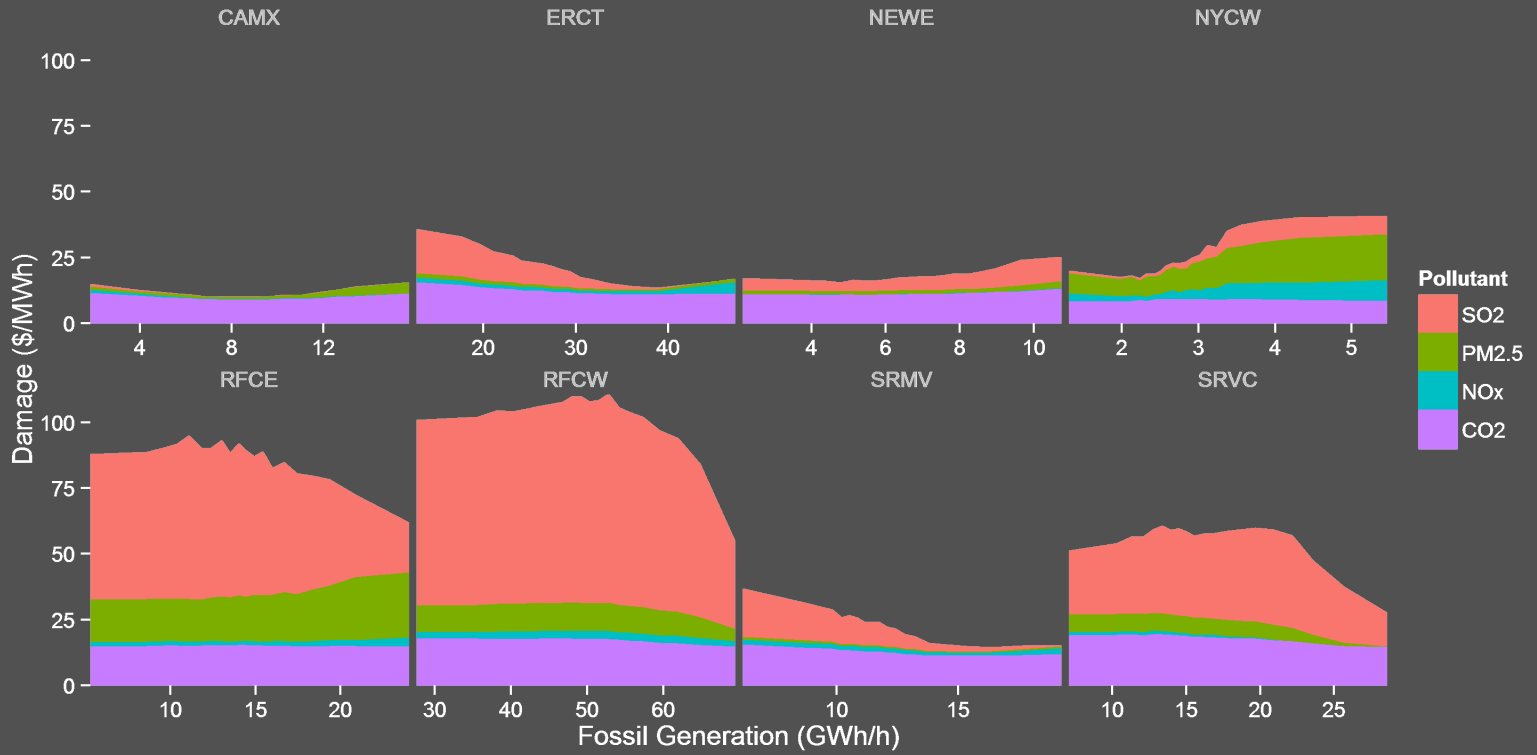
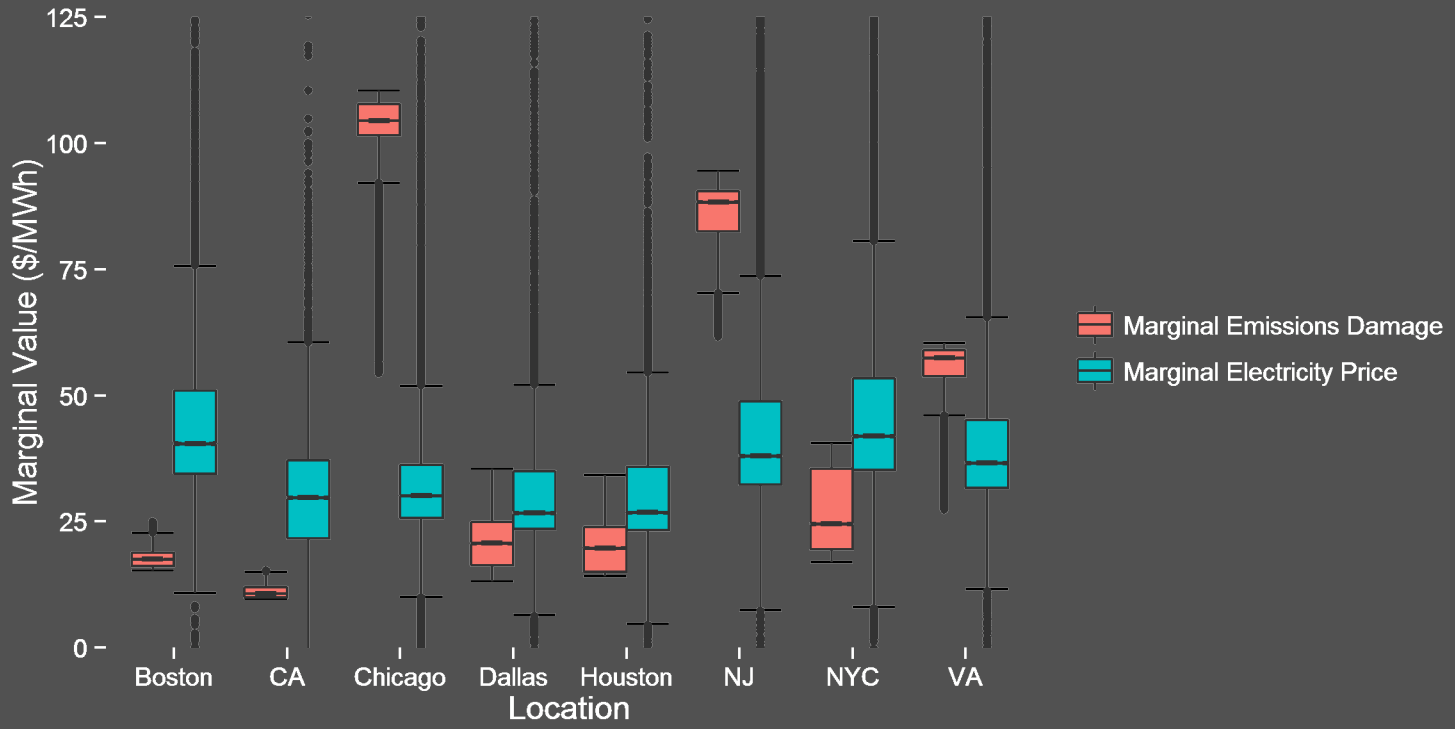
Marginal damages by eGRID subregion from marginal emissons factors respository*



*Siler-Evans, et al. 2013. Regional variations in the health, environmental, and climate benefits of wind and solar generation. *PNAS* 110.29.

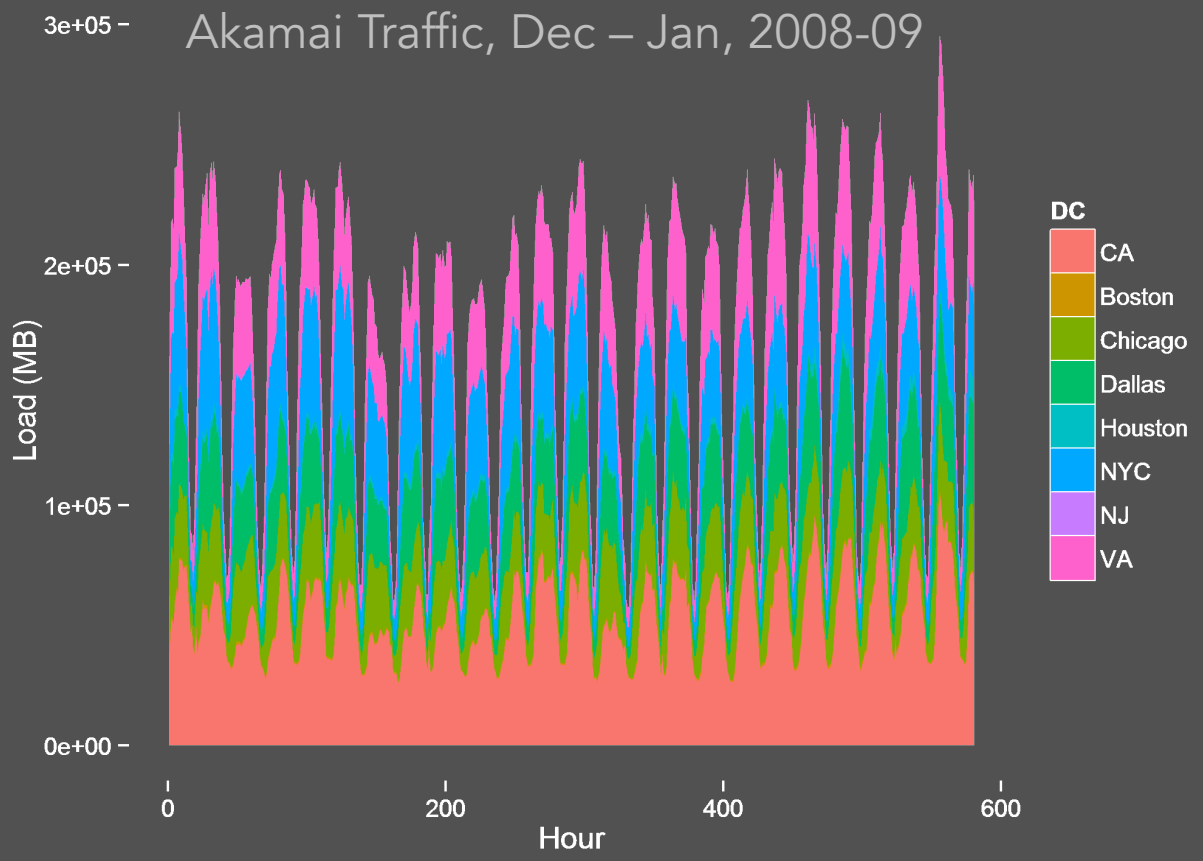
LMPs and marginal damages not uniformly correlated



Network traffic from Akamai CDN

- 25 data centers on a public CDN
- 5-min load data over 24 days
- Reduced and aggregated locations to match LMP data
- Simulate 1 year of traffic
- Convert traffic to energy: 1 kWh/GB*

*Malmodin J, et al (2014). Life Cycle Assessment of ICT: Carbon Footprint and Operational Electricity Use from the Operator, National, and Subscriber Perspective in Sweden. *Journal of Industrial Ecology*, 18(6), pp.829–845.



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Final set: eight data centers

DC Location	ISO/RTO	Zone (APNode)	eGRID Subregion
California	CAISO	PGE	CAMX
Houston	ERCOT	Houston	SRMV*
Dallas	ERCOT	North	ERCT
Chicago	PJM	ComEd	RFCW
Virginia	PJM	Dominion	SRVC
New Jersey	PJM	PSEG	RFCE
New York	NYISO	NYC	NYCW
Boston	ISO-NE	NEMASSBOST	NEWE

Optimize as minimum cost problem

minimize:

$$z = f(\mathbf{X}_{i,t}) = \sum_{i,t}(\mathbf{c}_{i,t} * \mathbf{X}_{i,t}) \quad (1)$$

with respect to $\mathbf{X}_{i,t}$ *and subject to:*

$$\sum_{i}(\mathbf{X}_{i,t}) = d_t \qquad \forall t \quad (2)$$

$$\mathbf{X}_{i,t} \leq s_i \qquad \forall i,t \quad (3)$$

$$\mathbf{X}_{i,t} \geq 0 \qquad \forall i,t \quad (4)$$

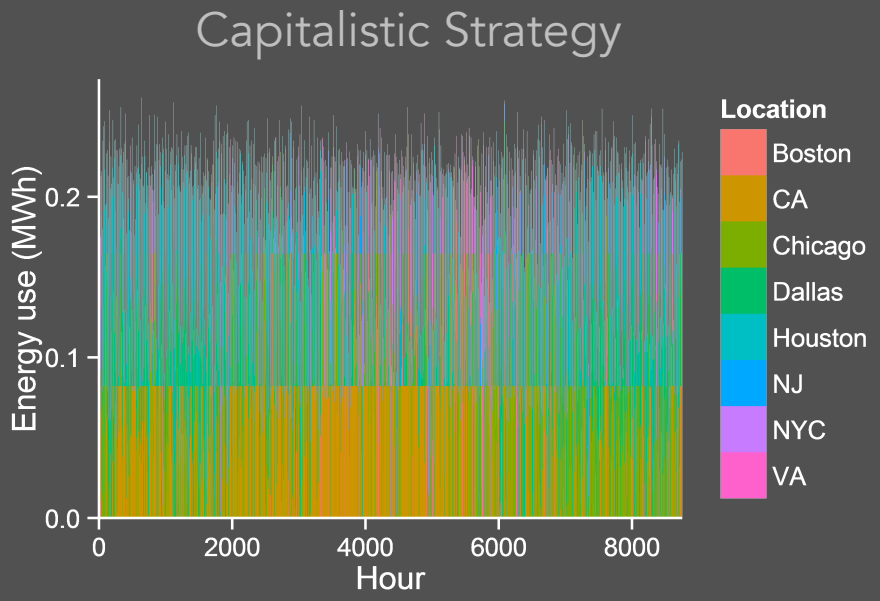
where:

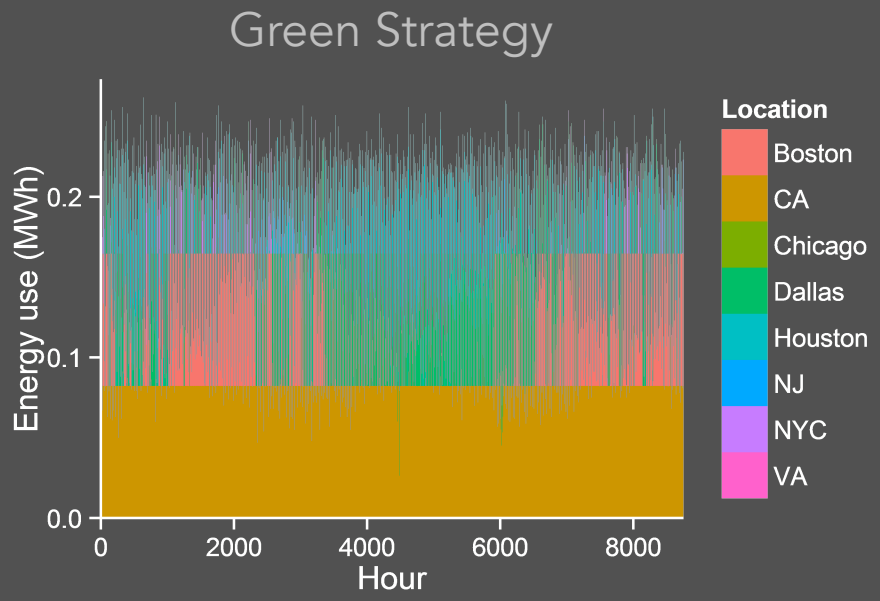
$\mathbf{X}_{i,t}$ is the energy required at location i in hour t
$\mathbf{c}_{i,t}$ is the cost of energy at location i in hour t
d_t is the service demand at time t
s_i is the service capacity at location i

Change objective *z* for different scenarios:

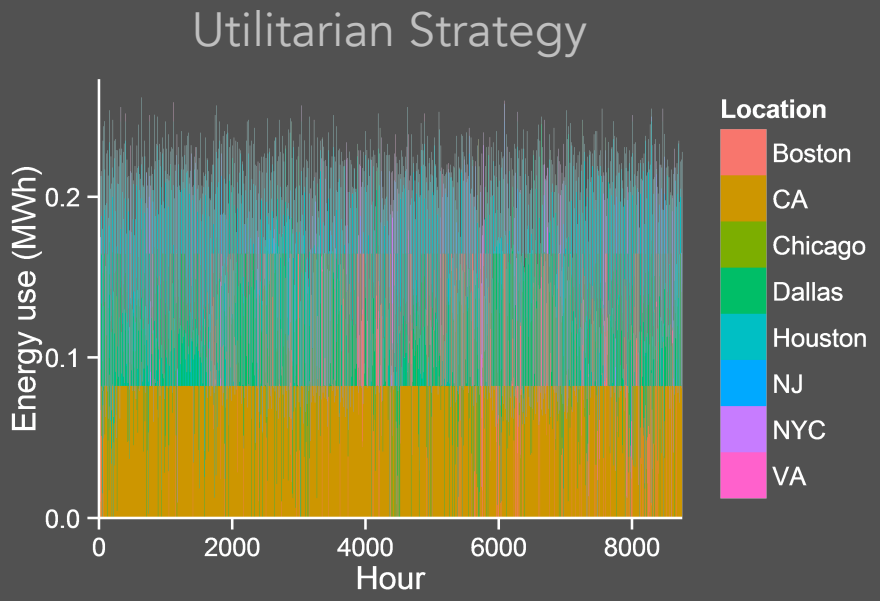
- Capitalistic: minimize private cost (LMP)
- Green: minimize external cost (marginal damages)
- Utilitarian: minimize total social cost
- (Baseline): level load

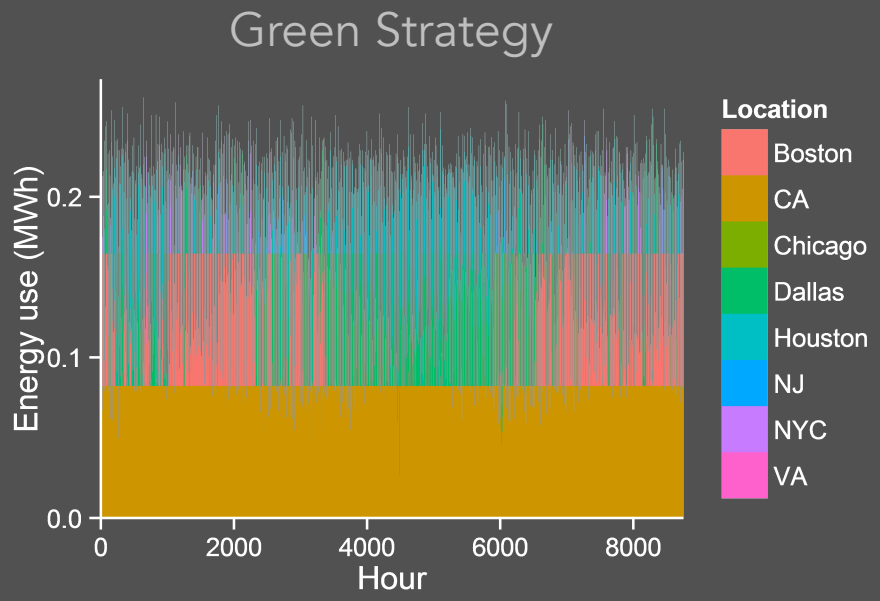
Green strategy shifts load to cleaner power





Utilitarian strategy gets “best of both worlds”

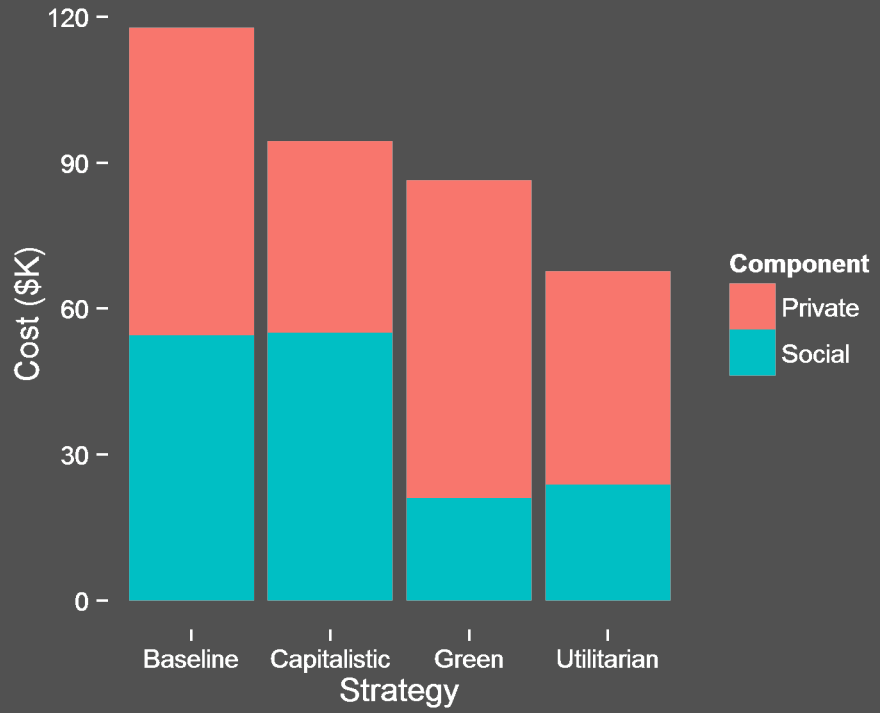




The utilitarian strategy reaps most of external savings and much of private savings

Savings vs. Baseline

	Cost		
Strategy	Private	External	Total
Baseline	--	--	--
Capitalistic	38%	-1%	20%
Green	-3%	61%	27%
Utilitarian	31%	56%	43%



Preliminary Conclusions

- Load shifting offers immediate private savings
- Compelling middle ground: reducing private savings by ~7%-pts reduced external costs by ~half (in this scenario)
- Extent of realized savings is sensitive to capacities of individual data centers

Policy impact:

What would be the ramifications of a carbon price (or other externality pricing) on cost-aware load shifting strategies?

Model additions needed

- Bandwidth and/or latency costs (95th percentile constraint)
- Improve energy use model
- Improve traffic simulation
- Explore sensitivities (capacity, traffic profiles)

Possible excursion

- Add on-site renewable generation option
- Compare LCOE with value of avoided damages

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Thanks for listening!

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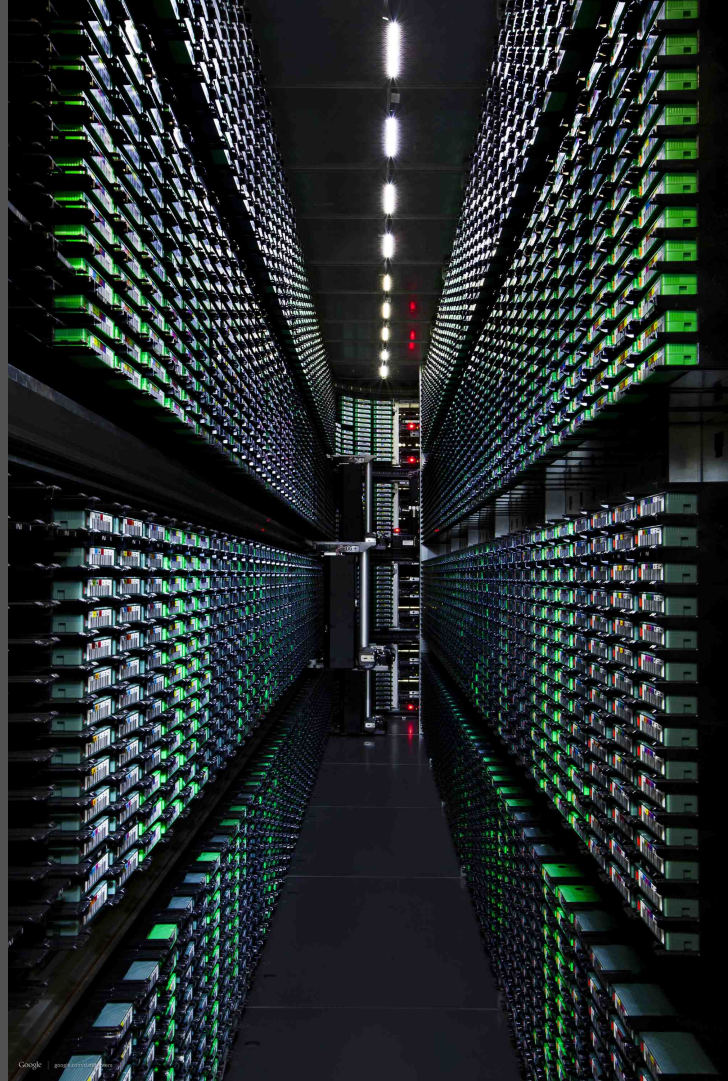

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