Greening multi-tenant data center demand response with parameterized supply function bidding

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2 stories about energy and data centers

Typical story: data centers are energy hogs

Emerging story: data centers are valuable resources

Idea: use data centers for demand response (DR)

Data centers have great potential for DR

~$5 million cost!

20 MW Data Center with 20% flexibility	=	700 kWh fast charging, optimally placed storage [Liu et al 2014]

Current practice: turn on diesel generator upon utility's request – costly and inefficient!

This talk: Efficient DR in Multi-tenant Data Centers

Multi-tenant (colocation) data centers

Multiple tenants house and manage their own servers independently in **shared** space

Data center operator is mainly responsible for facility support (e.g., power supply, cooling)

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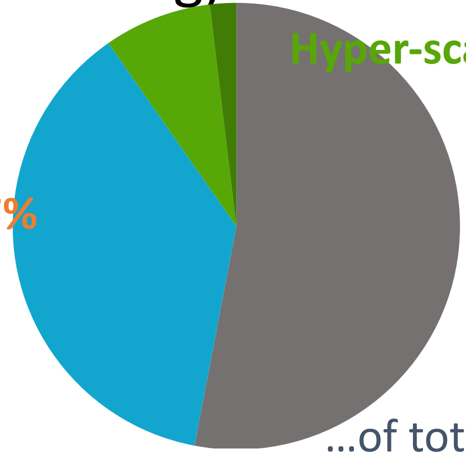


Why target multi-tenant data center for DR?

Most multi-tenant data centers are in metropolitan areas

– Downtown Los Angeles, New York, Silicon Valley, etc.

This is where demand response is **most** needed!

Example: On July 22, 2011, **hundreds of multi-tenant colocation data centers** participated in *emergency* demand response and contributed by cutting their electricity usage before a nation-wide blackout occurred in the U.S. and Canada.

--- A. Misra, "Responding Before Electric Emergencies."

CoreSite's "One Wilshire" (Photo: CoreSite)

Our contribution: a simple and provably efficient mechanism to incentivize tenants' reduction

Goal: $\min \; \alpha \cdot y + \Sigma_i c_i(s_i)$

s.t. $y + \Sigma_i s_i = \delta$

cost of local generatio

cost of load reduction

meets energy reduction target

Operator's challenge:

1. No direct control of tenants' reduction s_i
2. Tenants' private cost c_i unknown

Our proposal: use supply function bidding

Why supply function bidding?

1. VCG type mechanisms are problematic in energy settings
   [Zhang et al 2015] [Rothkopf 2007]

Thirteen Reasons Why the Vickrey-Clarke-Groves Process Is Not Practical

Michael H. Rothkopf

among them:

– tenants required to submit complex bid

– allocation problem for operator is NP hard

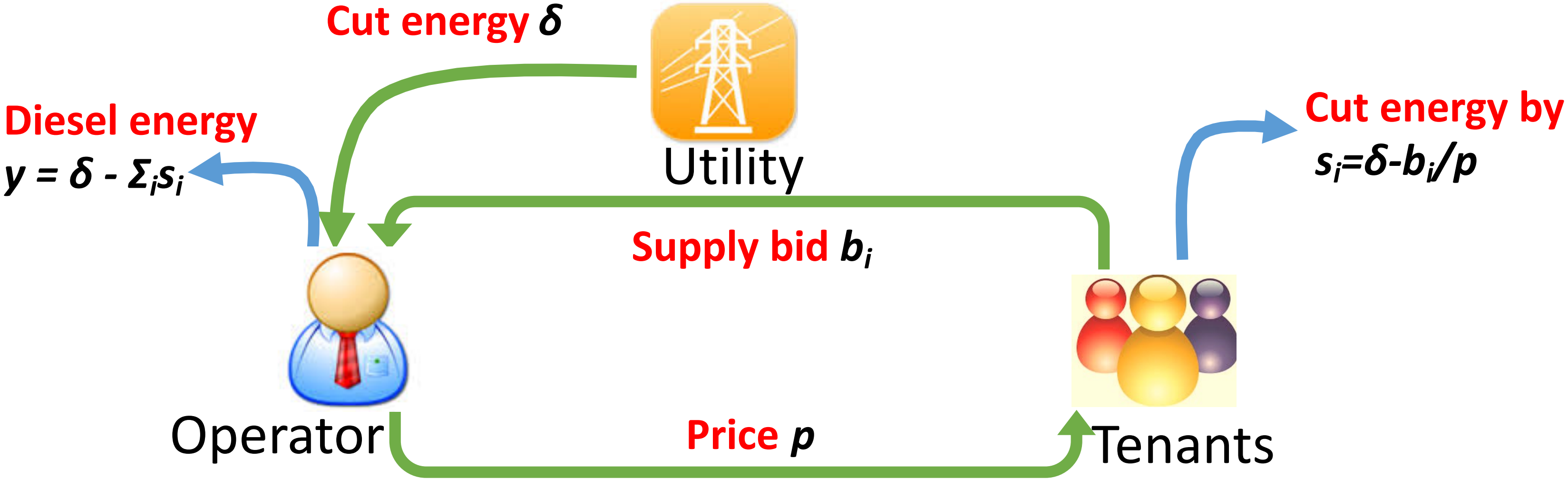
– price differentiation …

Why supply function bidding?

1. VCG type mechanisms are problematic in energy settings
   [Zhang et al 2015] [Rothkopf 2007]
2. Supply function bidding is widely used in electricity market
   [Baldick et al 2004] [Day et al 2002] [David and Wen 2000]
3. Prior work on supply function bidding
   [Klemperer and Meyer 1989] [Niu et al 2005] ← Unconstrained supply function, no performance guarantee
   [Johari and Tsitsiklis 2011] [Xu et al 2015] ← parameterized supply function, good performance guarantee

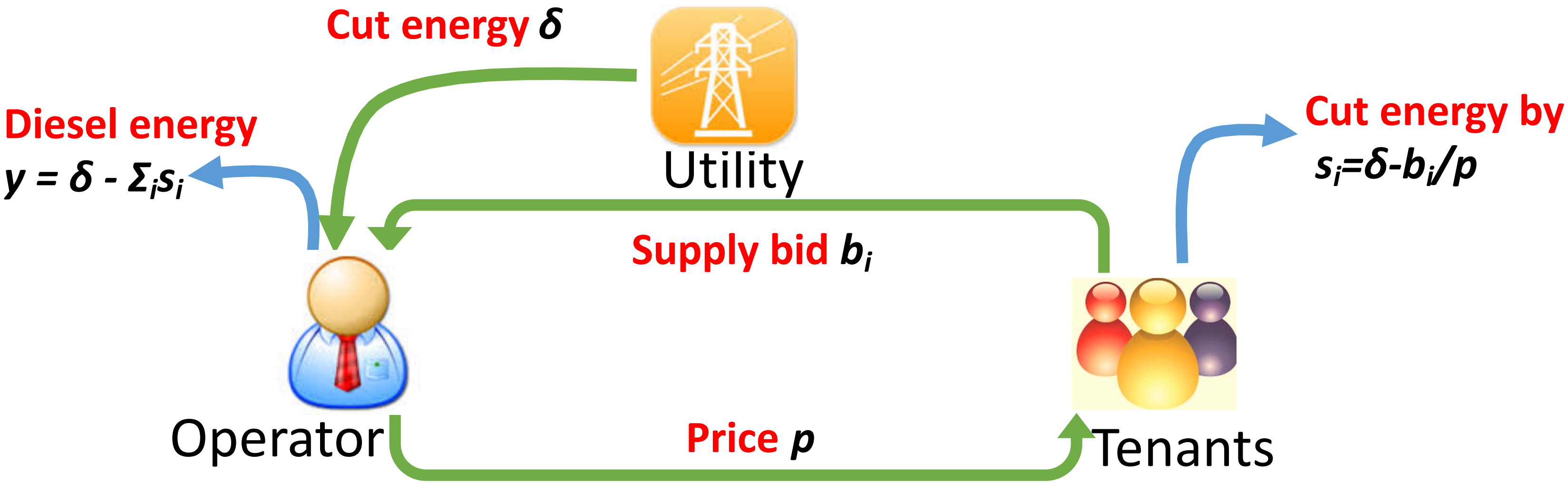
Key difference with our work: we consider operator has a backup supply option

A parameterized supply function mechanism



1. Operator announces supply function $s(b, p) = \delta\text{-}b/p$
2. Tenant i submits bid b_i
3. Operator sets market price p to minimize it own cost (payment to tenants plus diesel cost)
4. DR is exercised

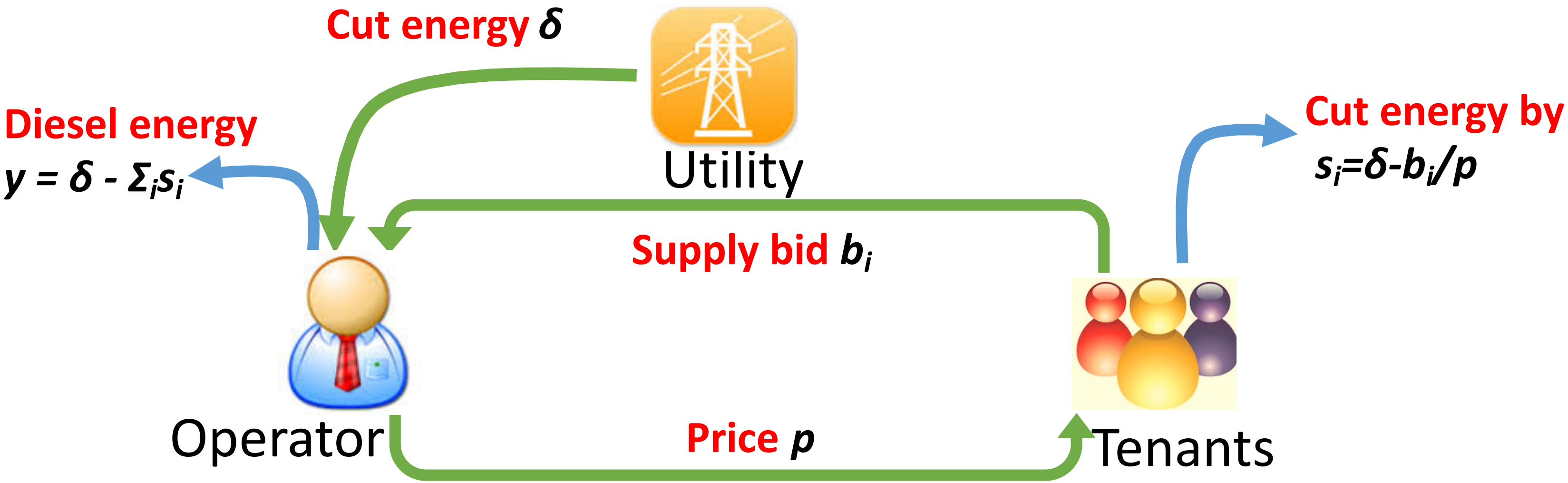
A parameterized supply function mechanism



How does operator set ***p*** and ***y***?

- $\min_{p,y} \boldsymbol{p(\delta\text{-}y) + \alpha y}$ subject to $\Sigma_i\ \boldsymbol{(\delta\text{-}\ b_i/p)+y = \delta}$
- equivalent to quadratic minimization problem, have closed form solution

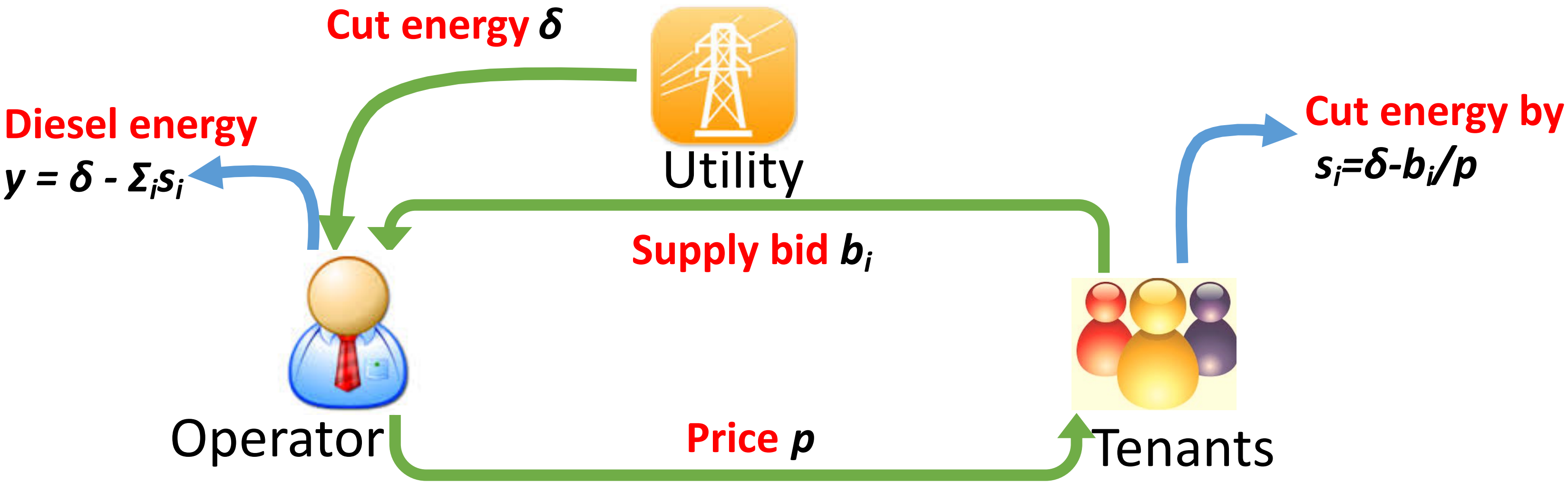
A parameterized supply function mechanism



How does tenant ***i*** bid b_i?

- **price-taking** $\max_{b_i} \; p \cdot S_i(b_i, p) - c_i(S_i(b_i, p))$
- **price-anticipating** $\max_{b_i} \; p(\mathbf{b}) \cdot S_i(b_i, p(\mathbf{b})) - c_i(S_i(b_i, p(\mathbf{b})))$

A parameterized supply function mechanism



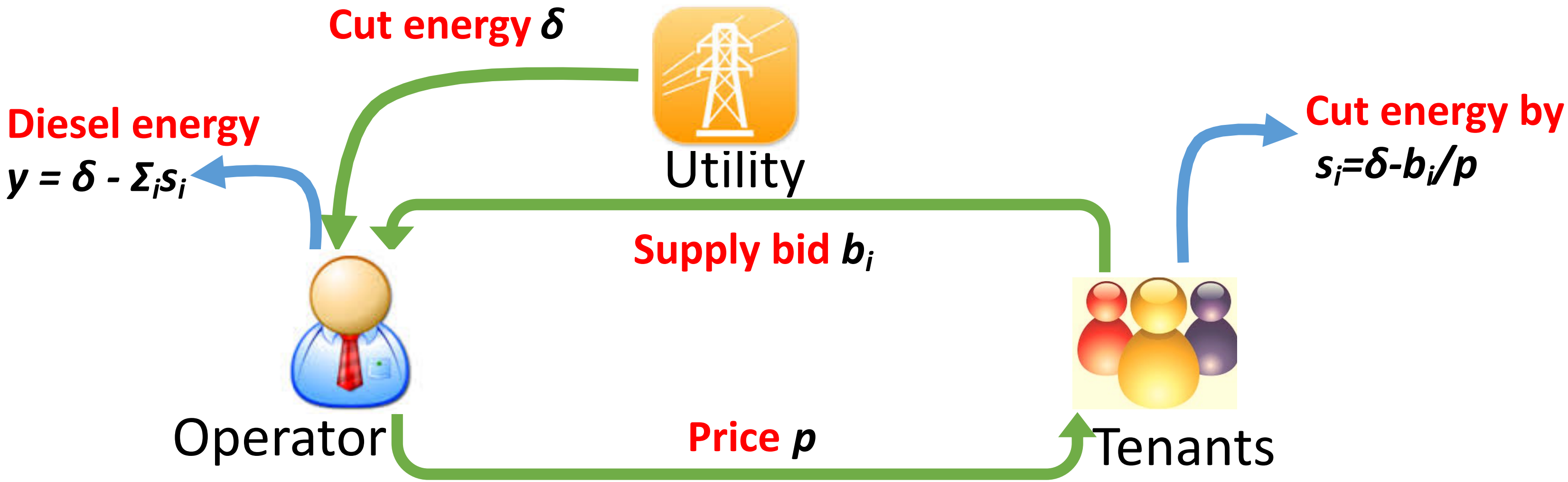
Simple: tenant only need to communicate one parameter

Fair: no price differentiation

Cost saving for operator: cost of dispatch decrease compared to diesel only

Equilibrium: always exists and unique

A parameterized supply function mechanism



Applicable to any problem of satisfying an inelastic demand $\boldsymbol{\delta}$ with $\boldsymbol{N}$ suppliers with an (expensive) backup option

Characterizing the equilibrium

Theorem: When tenants are **price-taking**, the market equilibrium is unique and characterized by

$$\min_{s,y} \Sigma_i c_i(s_i) + \frac{\alpha}{2N\delta}(y + (N-1)\delta)^2$$

$$\text{s.t. } \Sigma_i s_i + y = \delta$$

Due to strategic behavior of operator

Characterizing the equilibrium

Theorem: When tenants are **price-anticipating**, the market equilibrium is unique and characterized by

$$\min_{s,y} \Sigma_i \hat{c}_i(s_i) + \frac{\alpha}{2N\delta}(y + (N-1)\delta)^2$$

$$\text{s.t. } \Sigma_i s_i + y = \delta$$

Strategic behavior of tenants

Strategic behavior of operator

where

$$c_i(s_i) \le \hat{c}_i(s_i) \le c_i(s_i) + s_i\alpha/2N$$

How good is the equilibrium?

1. What is the social cost?
2. What are tenants' costs?
3. What is operator's cost?
4. What is the reduction in diesel usage?

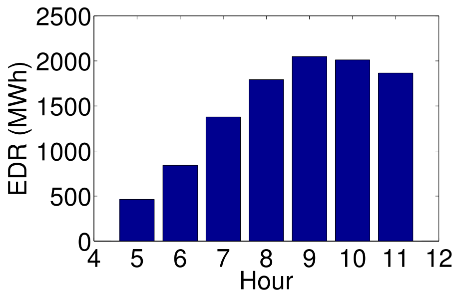
We answer these questions with both theoretical guarantees and trace-based simulations

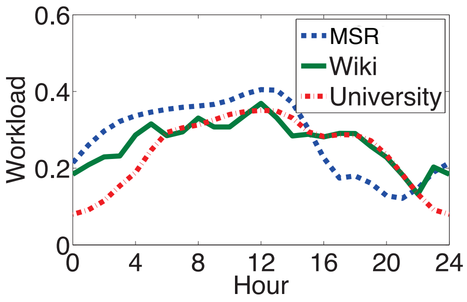
What are we comparing to?

Benchmark: Centrally controlled social cost minimization (SCM)

$$\min \ \alpha \cdot y + \Sigma_i c_i(s_i)$$
$$\text{s.t.} \ \ y + \Sigma_i s_i = \delta$$

Case study: DR signals issued by PJM on January 7, 2014, due to cold weather.





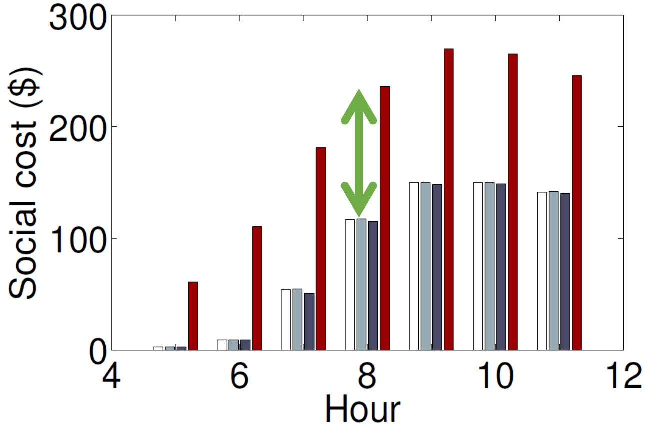
1. What is the social cost?

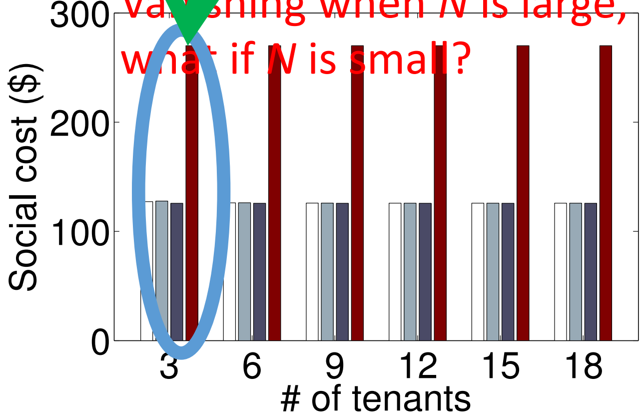
Theorem: For both **price-taking** and **price-anticipating** tenants,

$$\text{cost}(\text{ColoDR}) \leq \text{cost}(\text{SCM}) + \alpha\delta/N$$

…ear optimal
…hen N is small

Va…shing when *N* is large,
wh… if *N* is small?





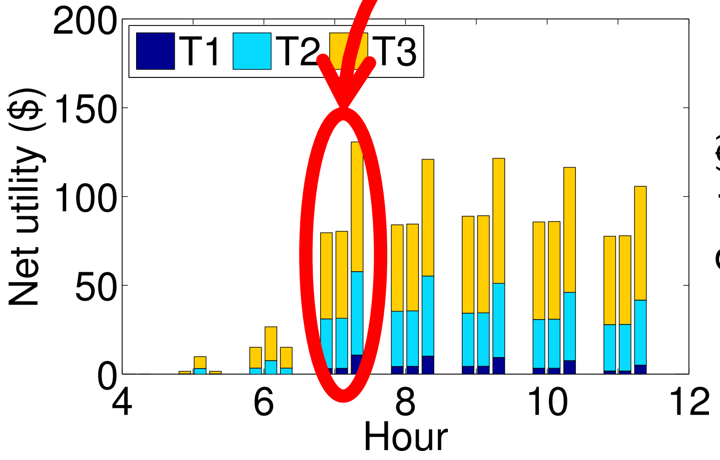
➔ ColoDR(price-taking) ColoDR(price-anticipating) SCM Diesel-only

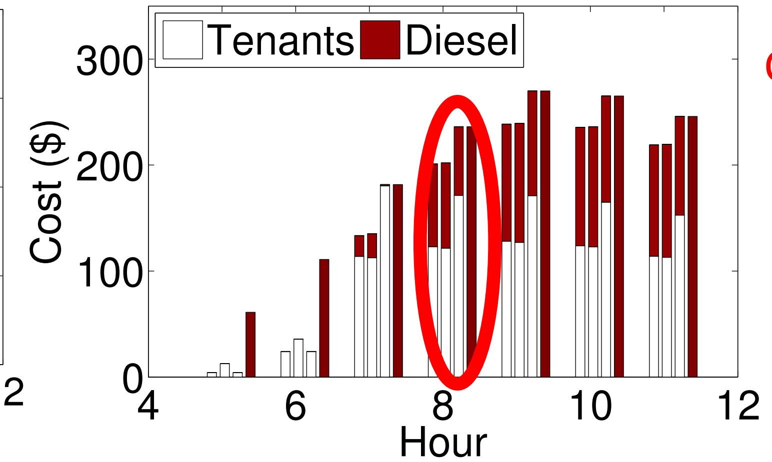
2&3. What are tenants' and operator's costs?

Theorem: For both **price-taking** and **price-anticipating** tenants,

$$\mathrm{cost_t(ColoDR)} \le \mathrm{cost_t(SCM)} + 2\alpha\delta/N$$
$$\mathrm{cost_o(ColoDR)} \ge \mathrm{cost_o(SCM)} - \alpha\delta/N$$

Higher utility for tenants with larger flexibility





CM

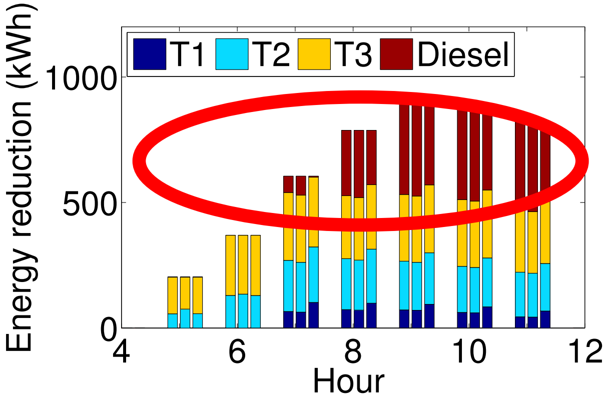
➔	ColoDR(price-taking)	ColoDR(price-anticipating)	SCM	Diesel only

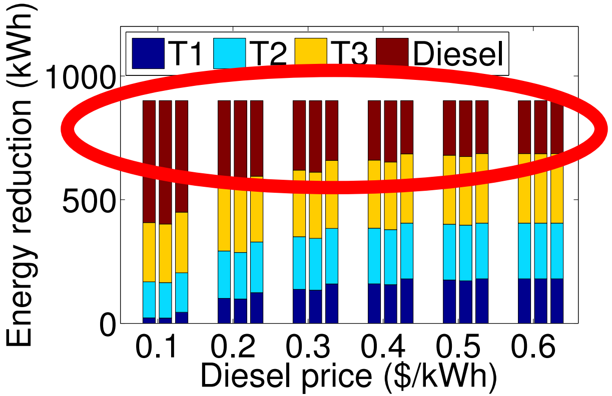
4. What is the reduction in diesel usage?

Theorem: For **price-taking** tenants, $y^t < y^* + \delta/2$

For **price-anticipating** tenants, $y^a \le y^* + \delta$

In worst case, ColoDR may use a lot more diesel than optimal





➔ ColoDR(price-taking) ColoDR(price-anticipating) SCM

How good is the equilibrium?

1. Social cost

$$\text{cost}(\text{ColoDR}) \leq \text{cost}(\text{SCM}) + \alpha\delta/N$$

2. Tenants' cost

$$\text{cost}_\text{t}(\text{ColoDR}) \leq \text{cost}_\text{t}(\text{SCM}) + 2\alpha\delta/N$$

3. Operator's cost

$$\text{cost}_\text{o}(\text{ColoDR}) \geq \text{cost}_\text{o}(\text{SCM}) - \alpha\delta/N$$

4. Diesel reduction

$$y^t \leq y^* + \delta/2 \qquad y^a \leq y^* + \delta$$

Key Message

Multi-tenant data center demand response can be "green" by incentivizing tenants' cooperation

– Our supply function bidding mechanism achieve this goal with a provably-efficient outcome