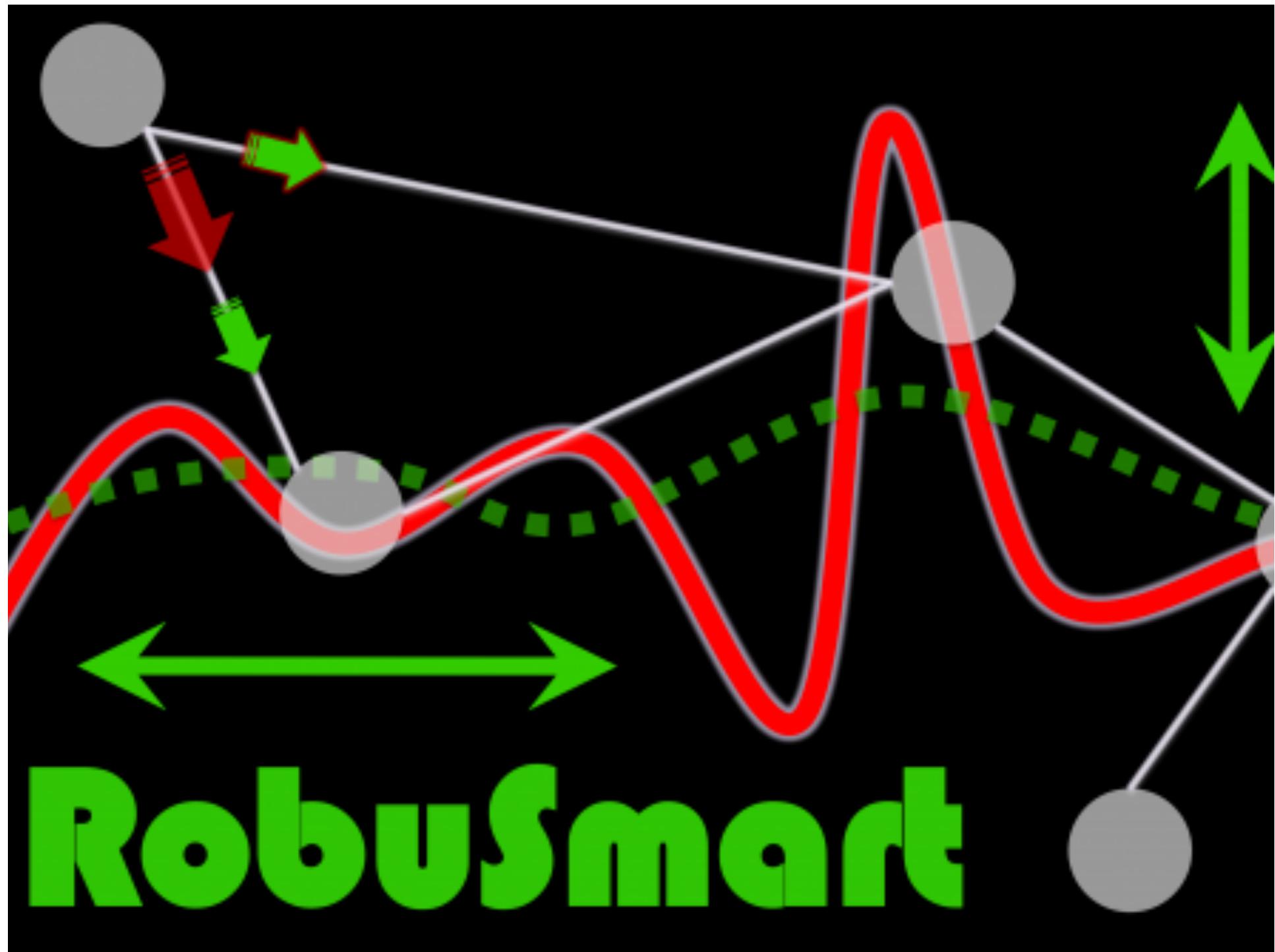




Socio-technical Trade-offs in Self-regulating Smart Grids

Evangelos Pournaras, Matteo Vasirani, Robert E. Kooij, Karl Aberer







Real-time Regulation of Smart Grids

Robustness

Matching supply and demand



Real-time Regulation of Smart Grids

Robustness

Matching supply and demand

via...

demand planning

load-shifting

load-adjustment



Real-time Regulation of Smart Grids

Robustness

Matching supply and demand

via...

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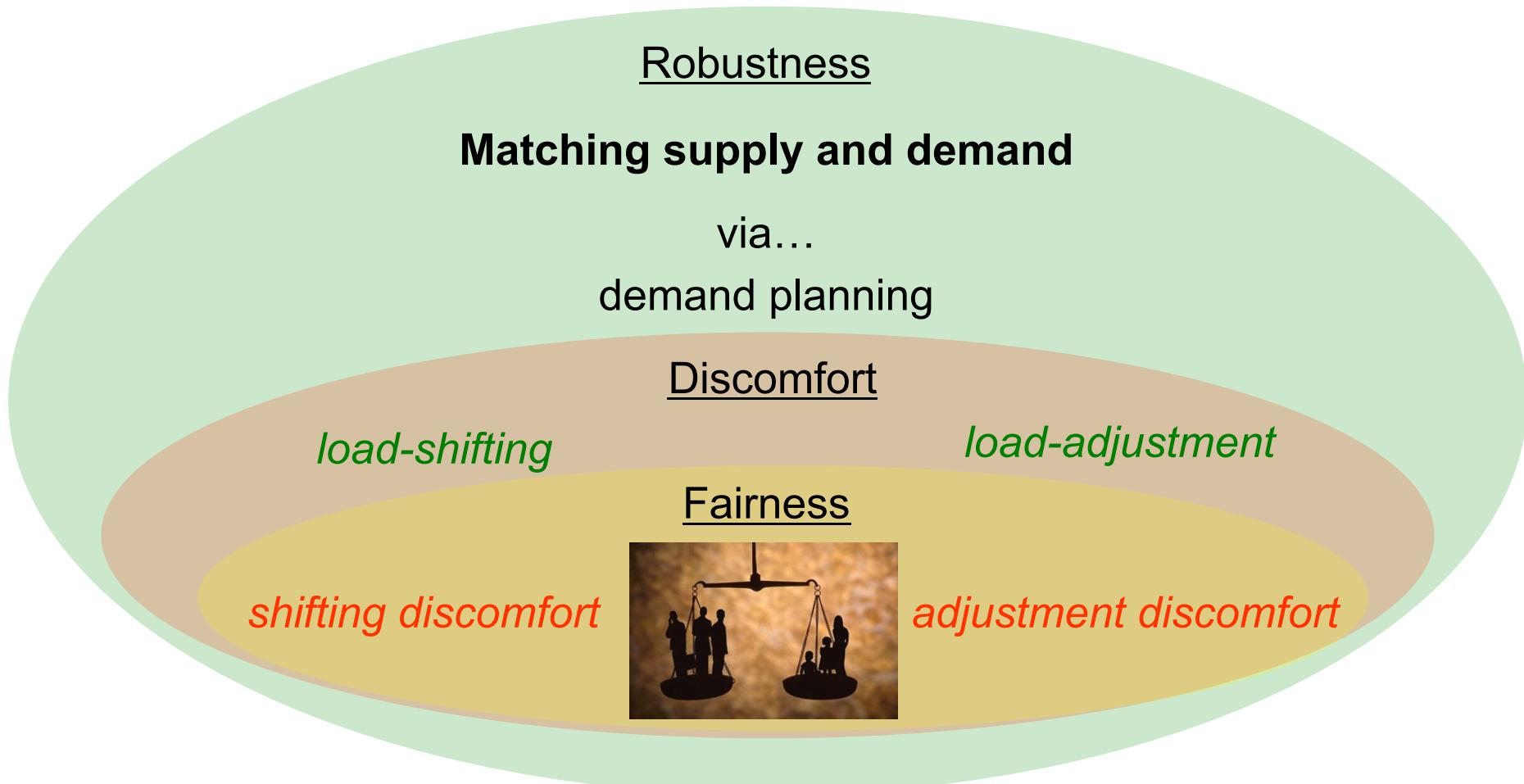
load-shifting

load-adjustment

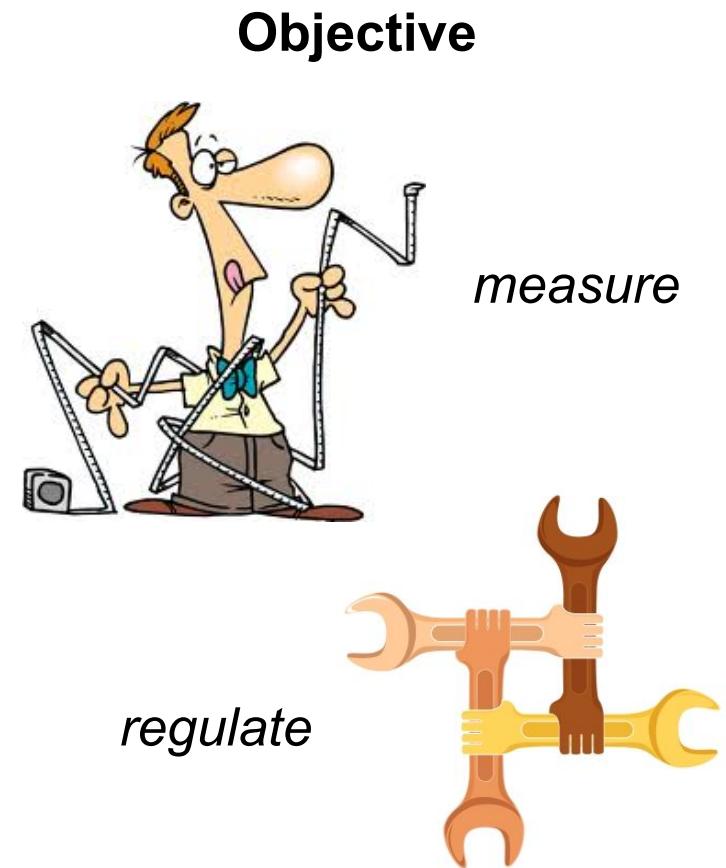
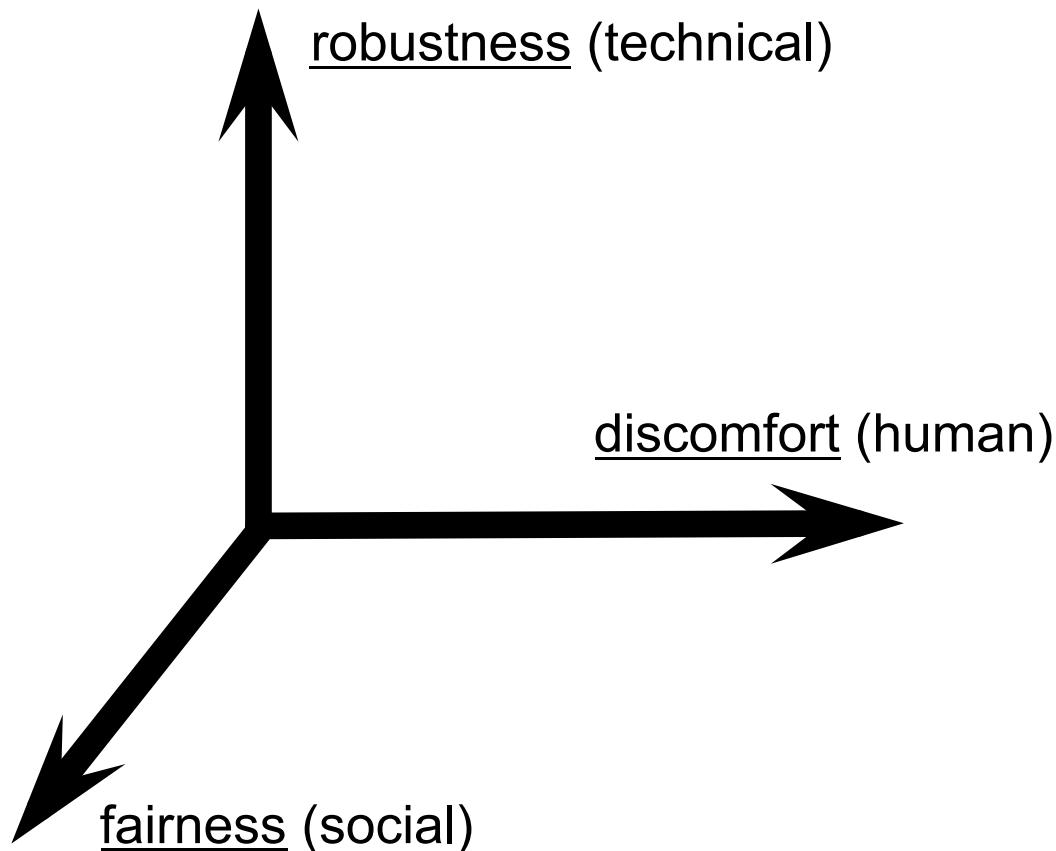
shifting discomfort



Real-time Regulation of Smart Grids



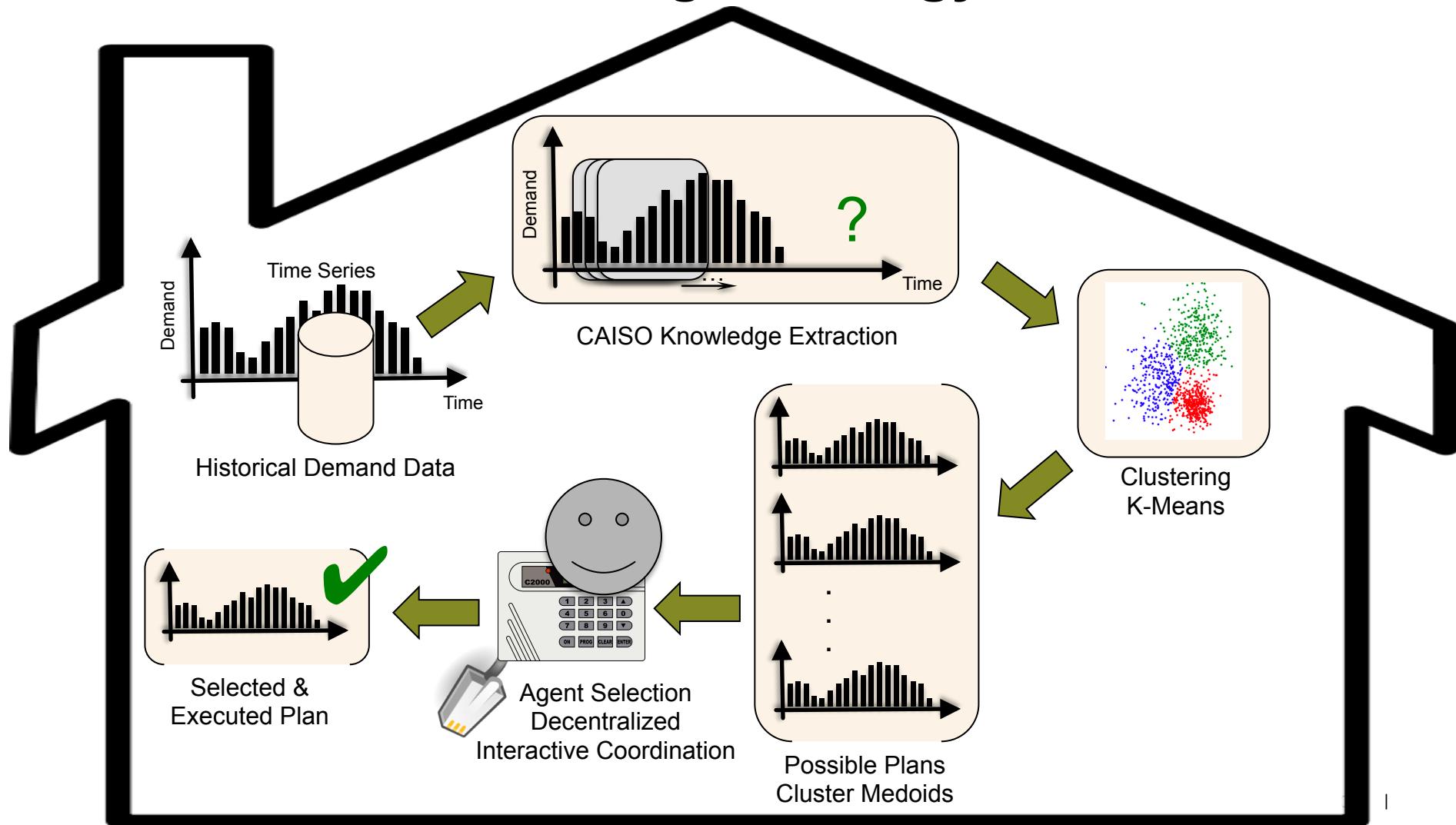
Socio-technical Trade-offs



Research Question

*How to **measure & regulate** socio-technical trade-offs
under **decentralized planning** of energy demand in Smart Grids?*

Decentralized Planning of Energy Demand



1. Measuring Socio-technical Trade-offs

Robustness: distance metric

Relative error of demand volatilities

Discomfort: distance metric

Weighted root mean square error

Survey questions – user preferences

Data-driven a posteriori measurements - *planned demand vs. actual demand*

Data from **real-world** operational Smart Grids

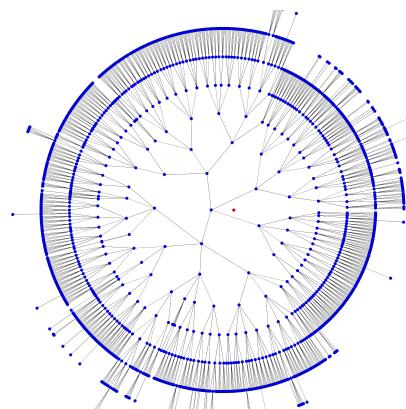
Fairness: dispersion metric

Standard deviation of discomfort

2. Self-regulation of Energy Demand

EPOS – Energy Plan Overlay Self-stabilization¹

A fully decentralized coordination algorithm



Reconfigurability via **plan generation & selection functions**

1. E. Pournaras, M. Warnier and F.M.T. Brazier, *Local Agent-based Self-stabilisation in Global Resource Utilisation*, International Journal of Autonomic Computing, Vol. 1, Nr. 4, pp. 350-373, 2010

Selection Functions

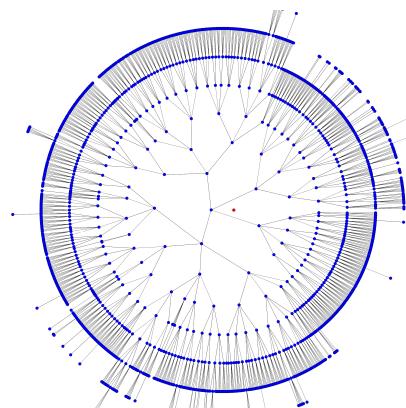
	Selection Function	Definition
Local Selections	RANDOM:	$\arg \min_{j=1}^l \text{rand}(\mathbf{p}_i^j)$
	MIN-DEMAND:	$\arg \min_{j=1}^l \{\text{avg}(\mathbf{p}_i^j)\}$
	MAX-DEMAND:	$\arg \max_{j=1}^l \{\text{avg}(\mathbf{p}_i^j)\}$
	MIN-INTERVENTIONS:	$\arg \min_{j=1}^l (I_j)$
Coordinated Selections	MIN-DEVIATIONS:	$\arg \min_{j=1}^{l^c} \{\sigma(\mathbf{a}_i + \mathbf{c}_i^j)\}$
	MIN-RELATIVE-DEVIATIONS:	$\arg \min_{j=1}^{l^c} \left\{ \frac{\sigma(\mathbf{a}_i + \mathbf{c}_i^j)}{\text{avg}(\mathbf{a}_i + \mathbf{c}_i^j)} \right\}$
	MAX-LOAD-FACTOR:	$\arg \max_{j=1}^{l^c} \left\{ \frac{\text{avg}(\mathbf{a}_i + \mathbf{c}_i^j)}{\max(\mathbf{a}_i + \mathbf{c}_i^j)} \right\}$
	MAX-ENTROPY *:	$\arg \max_{j=1}^{l^c} \left(- \sum_{t=1}^T u_i^t \log u_i^t \right)$

* $u_i^t = \frac{a_i^t + c_i^t}{\sum_{t=1}^T (a_i^t + c_i^t)}$ is the demand utilization at planning time t .

Self-regulation

EPOS – Energy Plan Overlay Self-stabilization¹

A fully decentralized coordination algorithm



Reconfigurability via **plan generation & selection functions**

It is this reconfigurability that makes socio-technical trade-offs possible!

1. E. Pournaras, M. Warnier and F.M.T. Brazier, *Local Agent-based Self-stabilisation in Global Resource Utilisation*, International Journal of Autonomic Computing, Vol. 1, Nr. 4, pp. 350-373, 2010

Experimental Evaluation

1. Electricity Customer Behavior Trial project

782 consumers in Ireland from 01/2010 to 12/2010

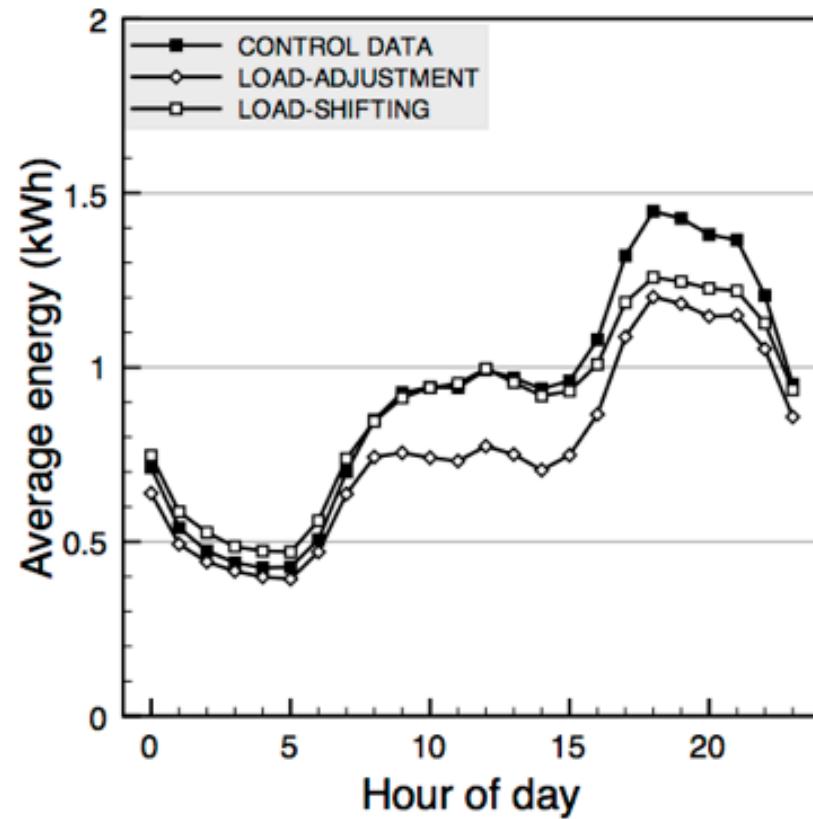
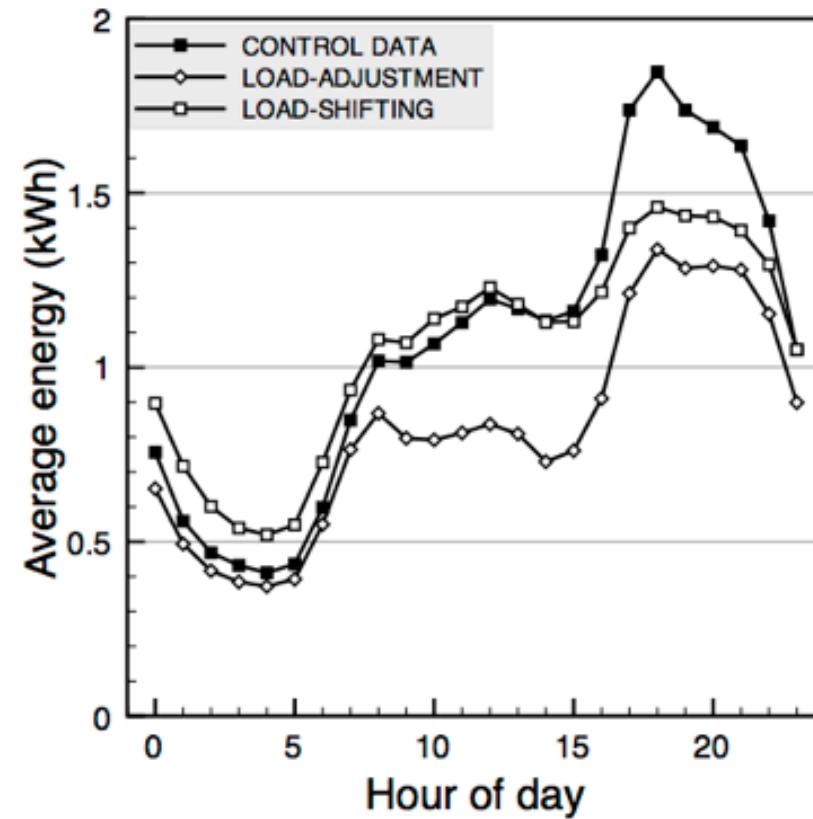
2. Olympic Peninsula Smart Grid Demonstration project

27 consumers in the USA from 11/2006 to 03/2007

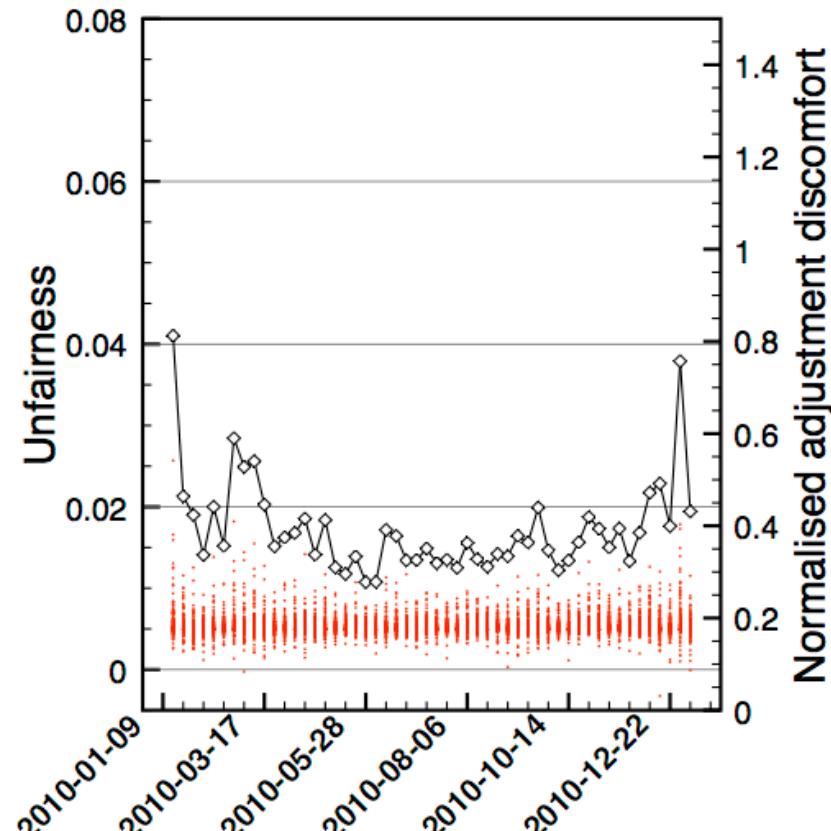
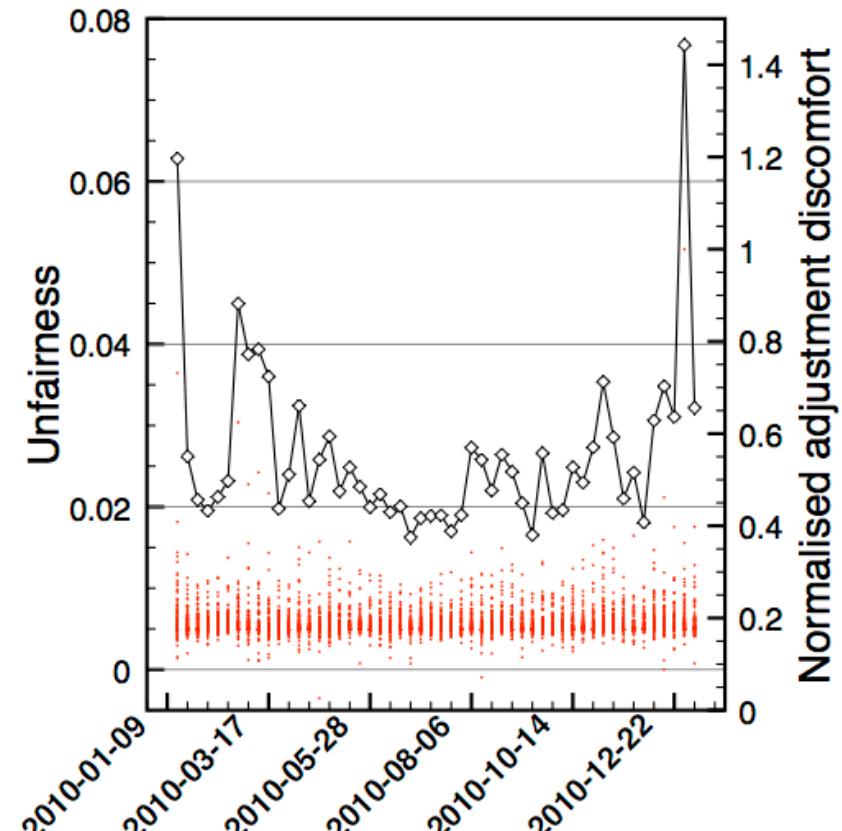
Self-regulation tests

1. Different selection functions
2. Different number of generated plans

Load Curves

(a) $l = 2$.(b) $l = 4$.

Fairness

(a) $l = 2$.(b) $l = 4$.

Conclusion

higher robustness = higher discomfort = lower fairness

Key contribution

Beyond empirical observations

Proof-of-concept

Measurable and controllable socio-technical trade-offs in Smart Grids

lower robustness = lower discomfort = higher fairness

Questions?

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www.evangelospournaras.com

<http://evangelospournaras.com/project/robusmart/>

<http://evangelospournaras.com/project/epos/>

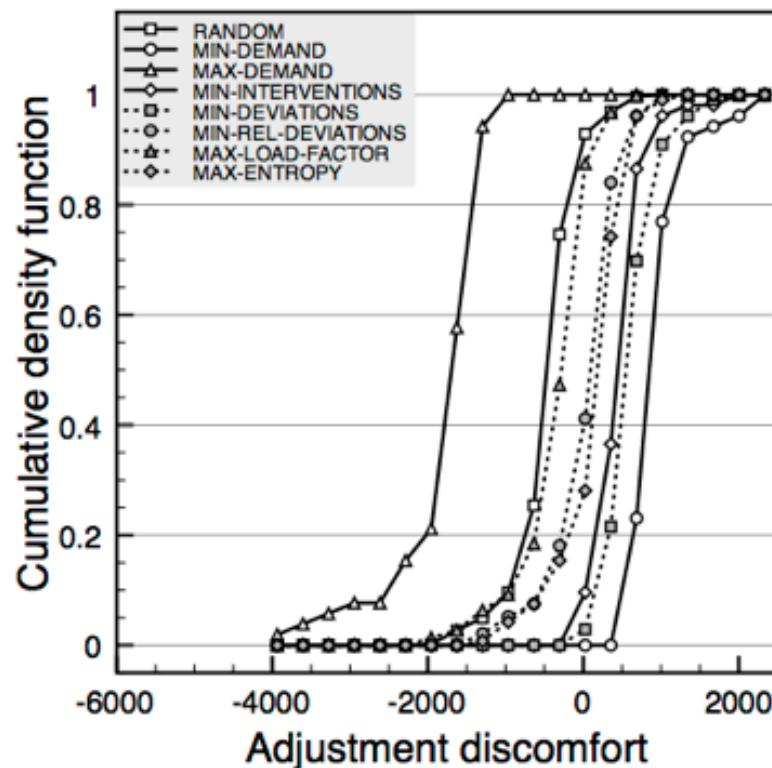
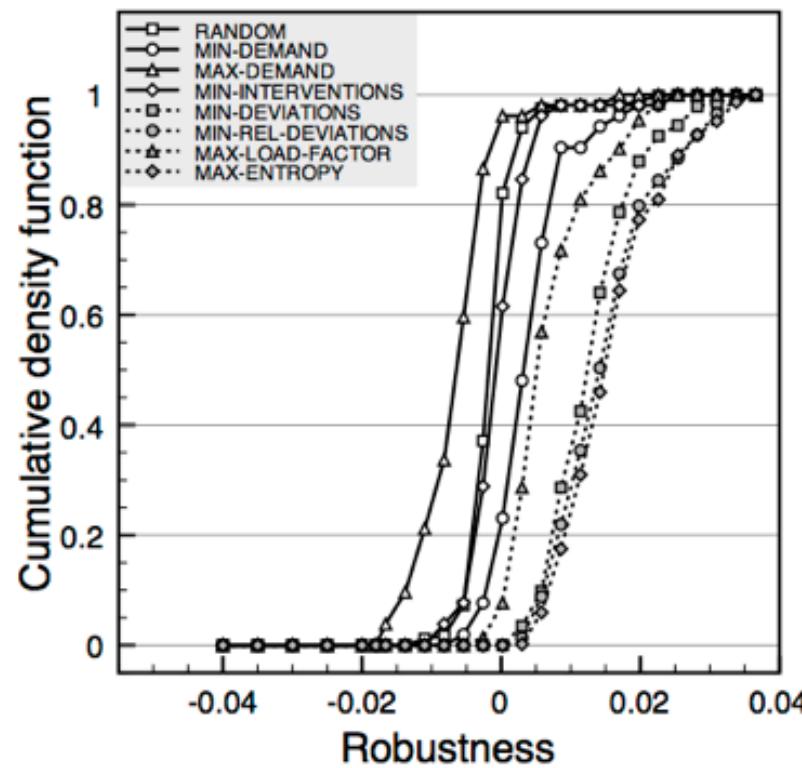
Key publications

E. Pournaras, M. Vasirani, R.E. Kooij and K.Aberer, *Decentralized Planning of Energy Demand for the Management of Robustness and Discomfort*, IEEE Transactions on Industrial Informatics, Vol. 10, Nr. 4, pp. 2280-2289, 2014 © IEEE

E. Pournaras, M. Vasirani, R.E. Kooij and K. Aberer, Measuring and Controlling Unfairness in Decentralized Planning of Energy Demand, in the proceedings of the IEEE International Energy Conference-EnergyCon 2014, Dubrovnik, Croatia, May 2014. © IEEE

E. Pournaras, M. Warnier and F.M.T. Brazier, *Local Agent-based Self-stabilisation in Global Resource Utilisation*, International Journal of Autonomic Computing, Vol. 1, Nr. 4, pp. 350-373, 2010

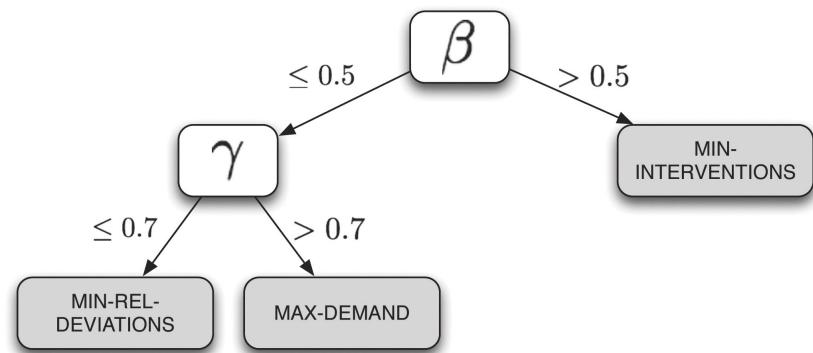
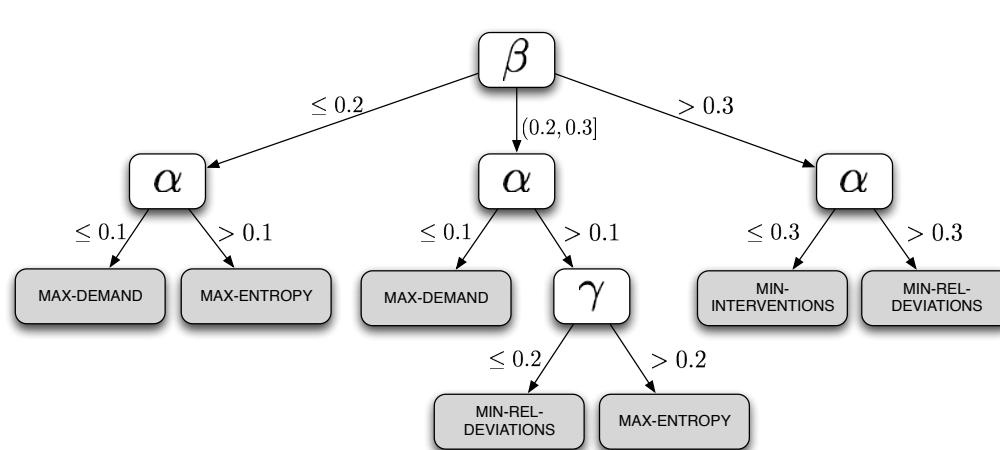
Robustness and Discomfort



**Cumulative density functions for
ranking the performance of selection functions!**

Choosing a Selection Function

1. Rank the performance of selection functions
2. Assign relative weights to robustness, discomfort & fairness
3. Choose selection function using decision trees – C4.5 algorithm



Olympic Peninsula Smart Grid
Demonstration Project