# Smart Energy Systems

Manolis Vavalis
University of Thessaly & CERTH

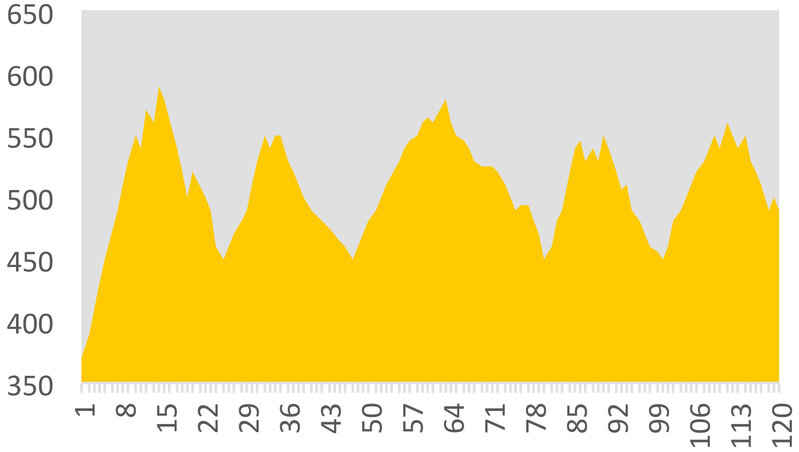
SummerSoC
Service Oriented Computing

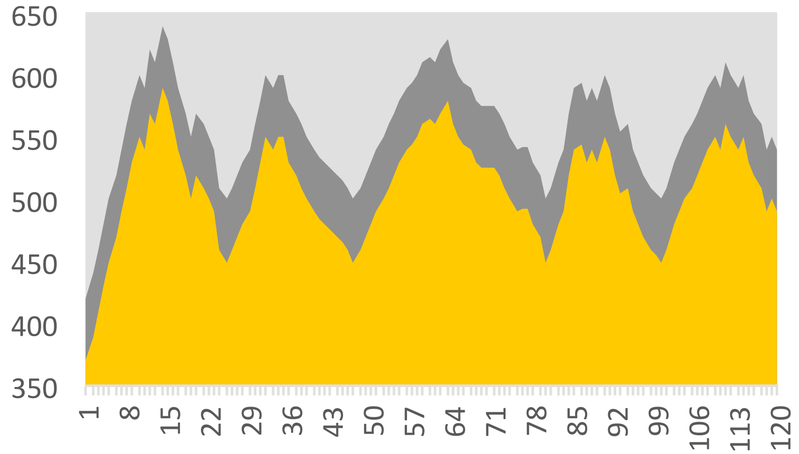
# Electricity

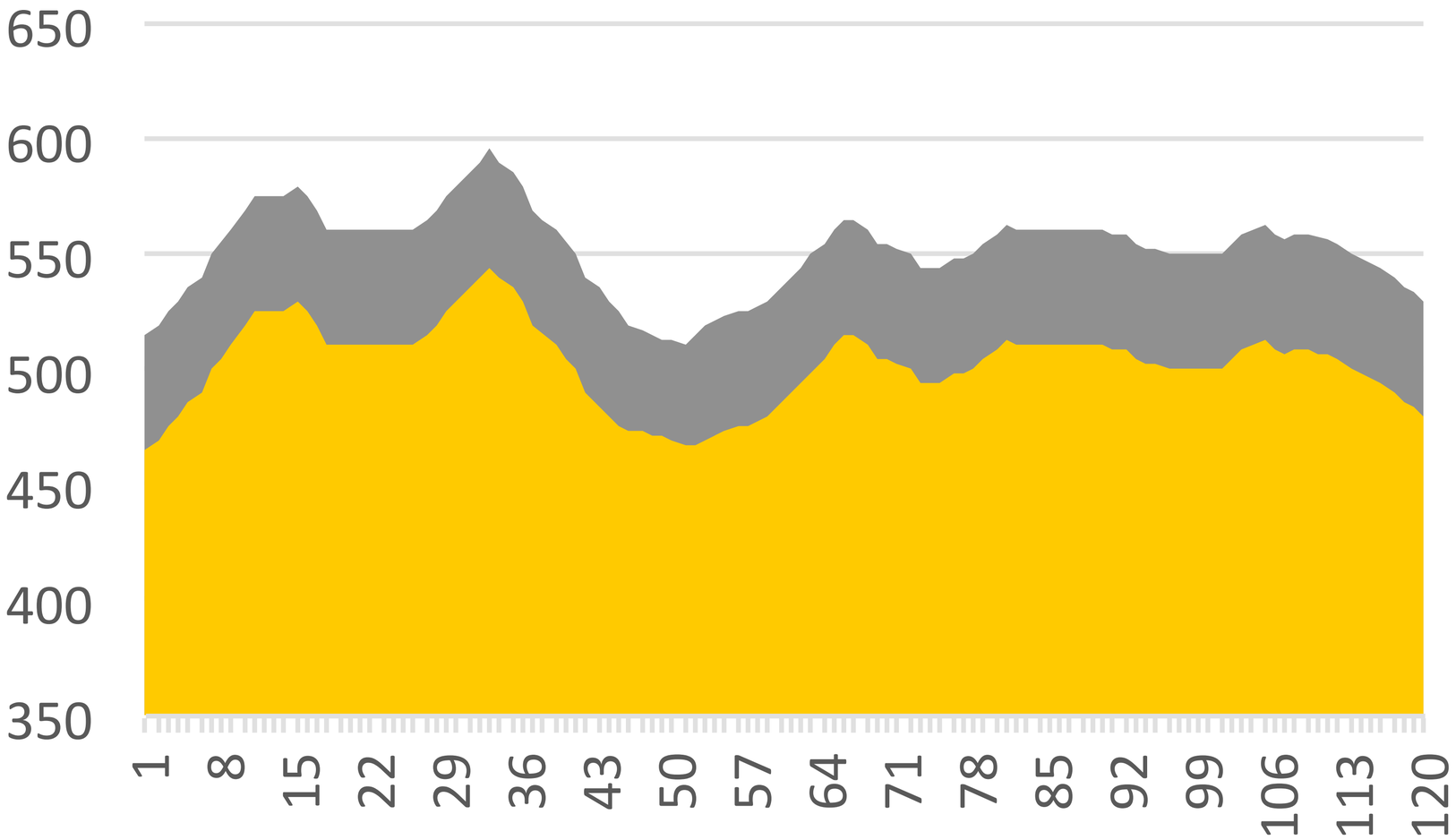
- Travels at the speed of light
- Can not be practically stored
- It is a commodity, or perhaps a service?

**Energy is enough, but expensive!**

# Demand/Response & Price Elasticity



# Clearing Price

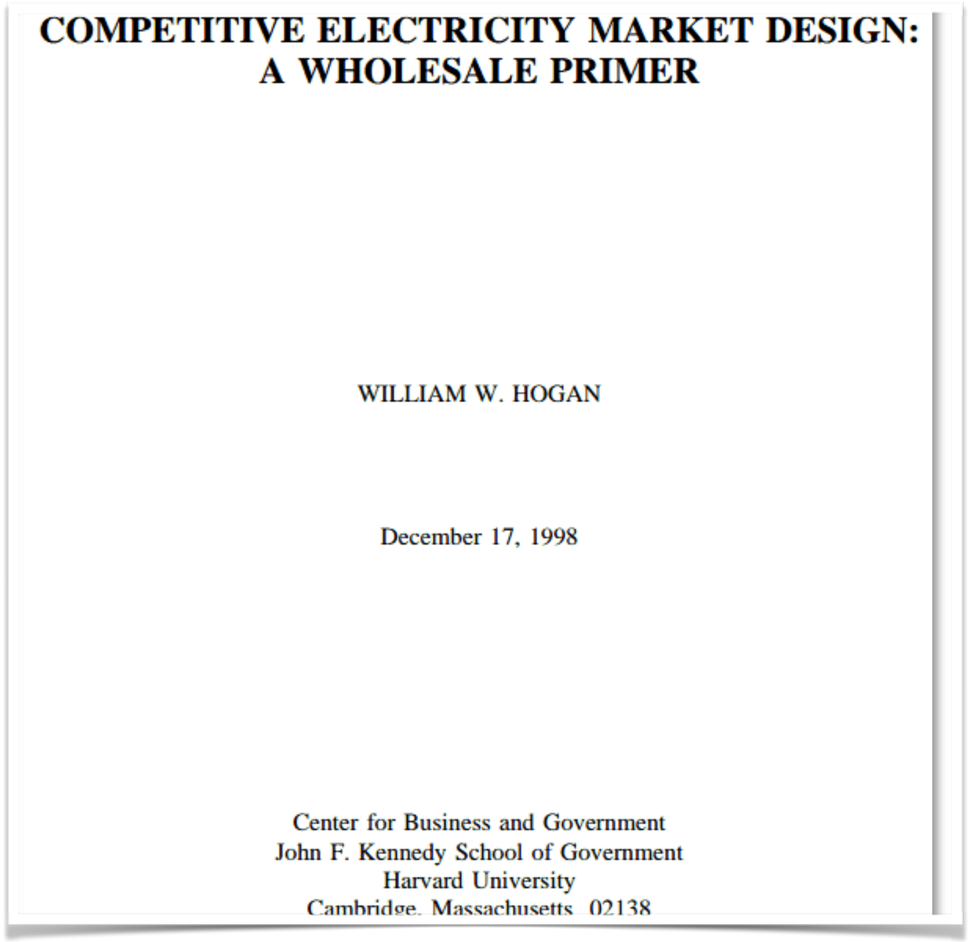

# Smooth Functioning of Electricity Market

depends on:

- electricity generators;
- power exchanges;
- transmission system operators (TSOs);
- distribution system operators (DSOs);
- regulators;
- customers.

# Energy Market Reform

- Spot market transactions at market clearing locational prices
- Two settlement system
  - Day ahead
  - Real time
- Bilateral transactions among local markets
- Price volatility hedges
  - Contract for differences
  - Transmission congestion contracts



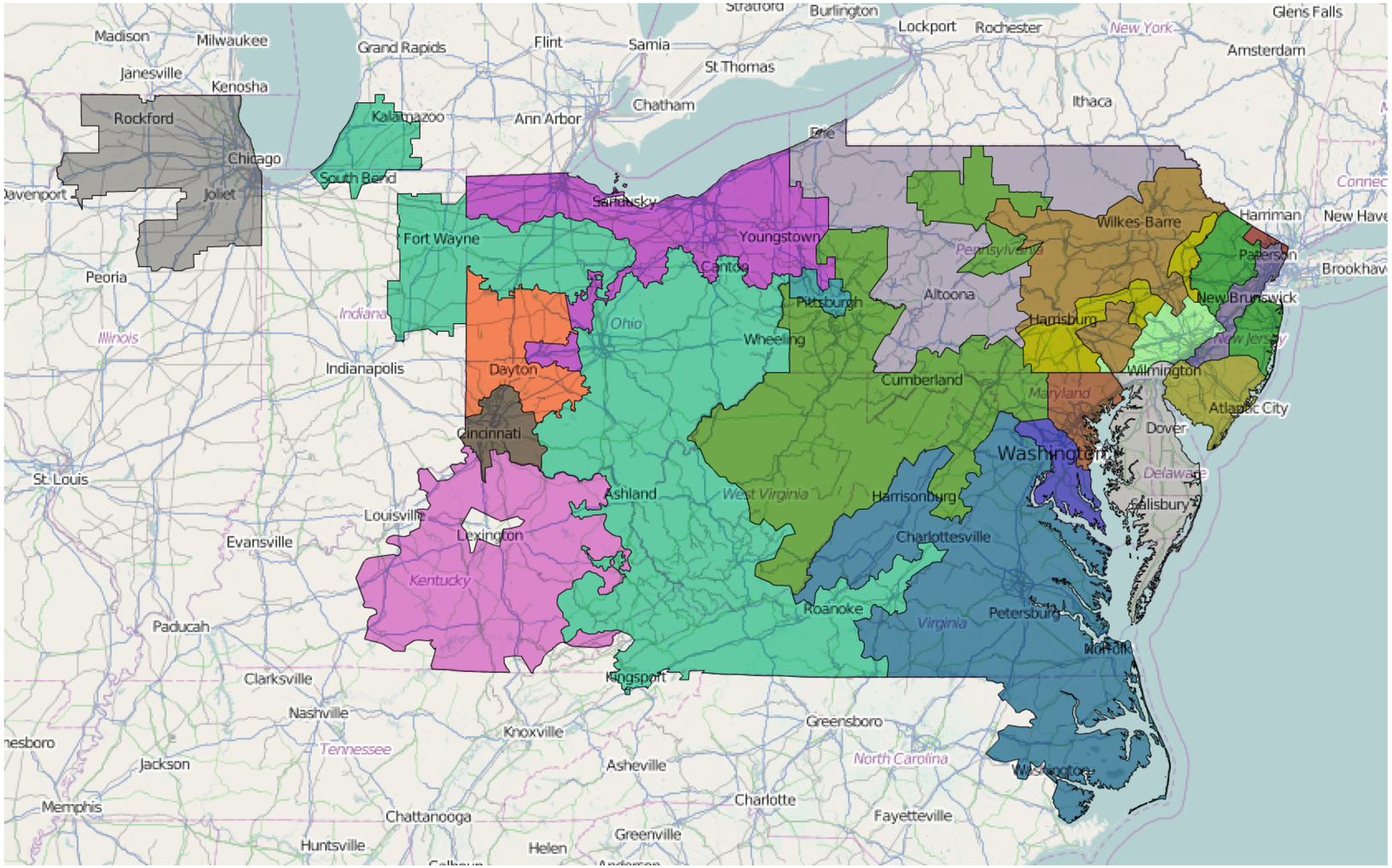
COMPETITIVE ELECTRICITY MARKET DESIGN:
A WHOLESALE PRIMER

WILLIAM W. HOGAN

December 17, 1998

Center for Business and Government
John F. Kennedy School of Government
Harvard University
Cambridge, Massachusetts 02138

# PJM Regional Operator



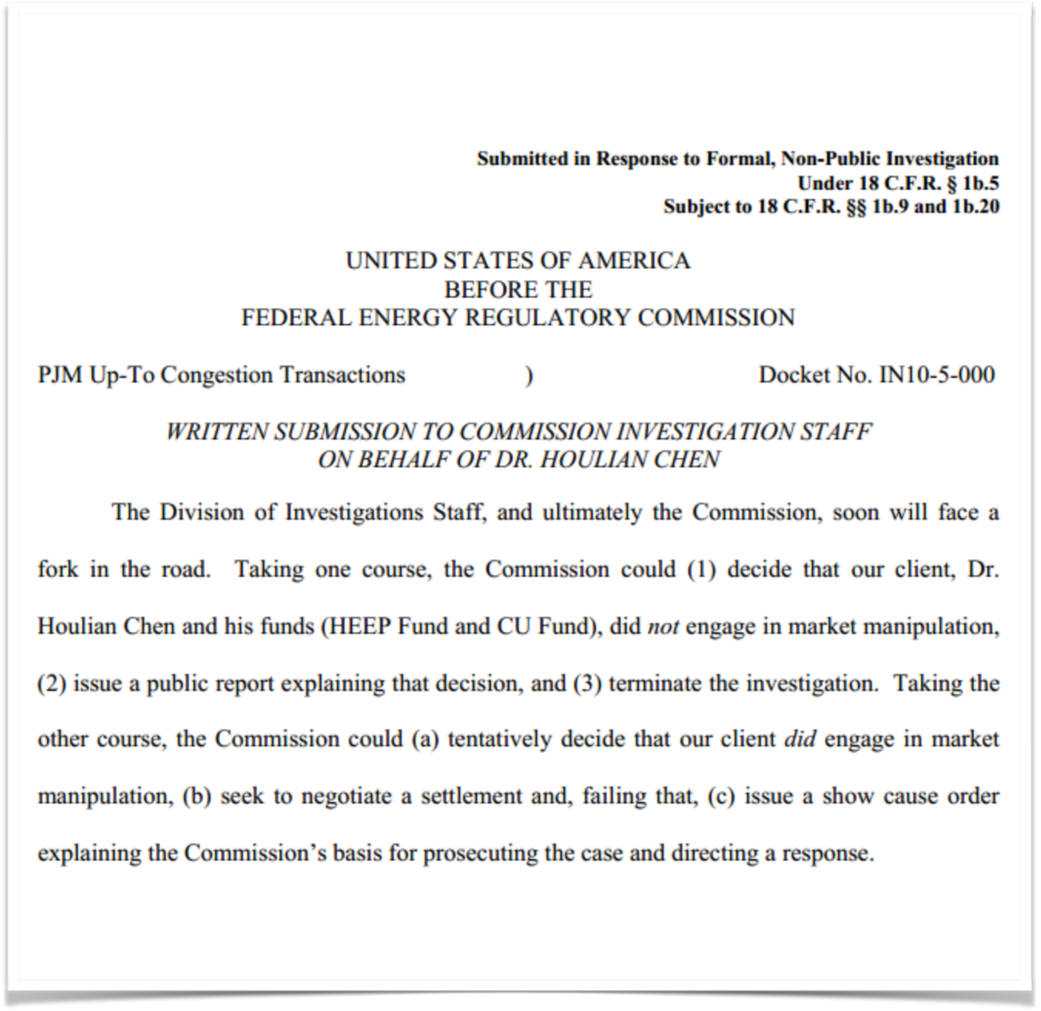

- Allegheny Power Systems
- American Electric Power Co., Inc.
- American Transmission Systems, Inc.
- Atlantic Electric Company
- Baltimore Gas and Electric Company
- ComEd
- Dayton Power and Light Co.
- Delmarva Power and Light Company
- Dominion
- Duke Energy Ohio and Kentucky
- Duquesne Light
- Eastern Kentucky Power Cooperative
- Jersey Central Power and Light Company
- Metropolitan Edison Company
- PPL Electric Utilities
- PECO Energy
- Pennsylvania Electric Company
- Potomac Electric Power Company
- Public Service Electric and Gas Company
- Rockland Electric Company

# Nevertheless

Several

energy market issues

need to be elucidated



**Submitted in Response to Formal, Non-Public Investigation**
**Under 18 C.F.R. § 1b.5**
**Subject to 18 C.F.R. §§ 1b.9 and 1b.20**

UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

PJM Up-To Congestion Transactions ) Docket No. IN10-5-000

*WRITTEN SUBMISSION TO COMMISSION INVESTIGATION STAFF*
*ON BEHALF OF DR. HOULIAN CHEN*

The Division of Investigations Staff, and ultimately the Commission, soon will face a fork in the road. Taking one course, the Commission could (1) decide that our client, Dr. Houlian Chen and his funds (HEEP Fund and CU Fund), did *not* engage in market manipulation, (2) issue a public report explaining that decision, and (3) terminate the investigation. Taking the other course, the Commission could (a) tentatively decide that our client *did* engage in market manipulation, (b) seek to negotiate a settlement and, failing that, (c) issue a show cause order explaining the Commission's basis for prosecuting the case and directing a response.

# Hephaestus Excellence Project

- started 01/01/2013
- 3 years
- 500K euros
- 5WPs, 12 deliverables



# Theoretical Components

- Energy Grid System
  - Power flow equations (Kirchhoff laws, thermal limits, congested lines, …)
  - Power generator equations
- Market Modeling
  - Differential Equations
  - Optimization Problems
- Solvers
  - Game theory
  - Newton's method for non-linear equations
  - …

- To minimize cost of operation,

$$C_T = \sum_{i=1}^{m} C_i(P_{Gi})$$

- Subject to:
  - Power flow equation

$$f(P_{Gi}) = \sum_{i=1}^{m} P_{Gi} - \sum_{i=1}^{n} P_{Di} - P_{loss}(P_{G2}, P_{G3}, \ldots, P_{Gm}) = 0$$

  - Generation limit

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}$$

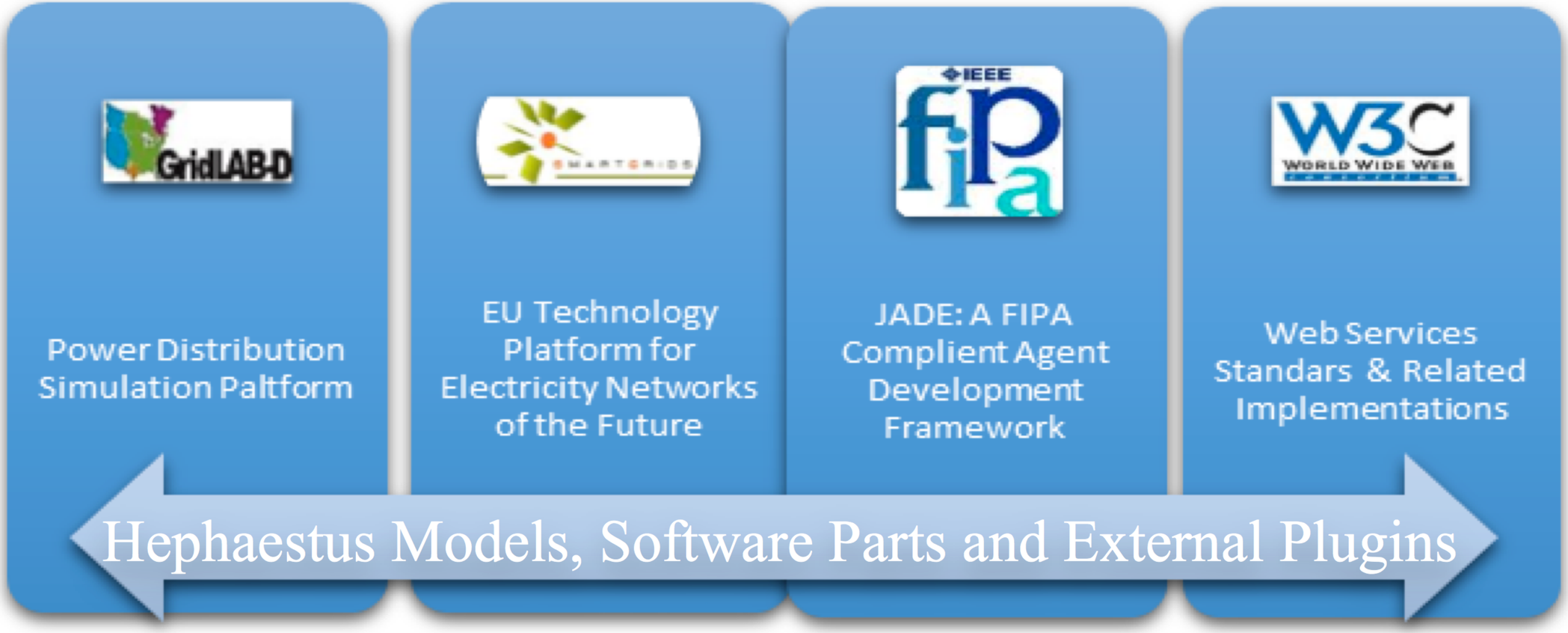
  - Voltage limit

$$|V_i|^{\min} \le |V_i| \le |V_i|^{\max}$$

  - Line flow limit

$$|P_{ij}| \le |P_{ij}|^{\max}$$

Results in an optimization problem "Nonlinear programming"




# Enabling Technologies

considered

# Basic Assumption I

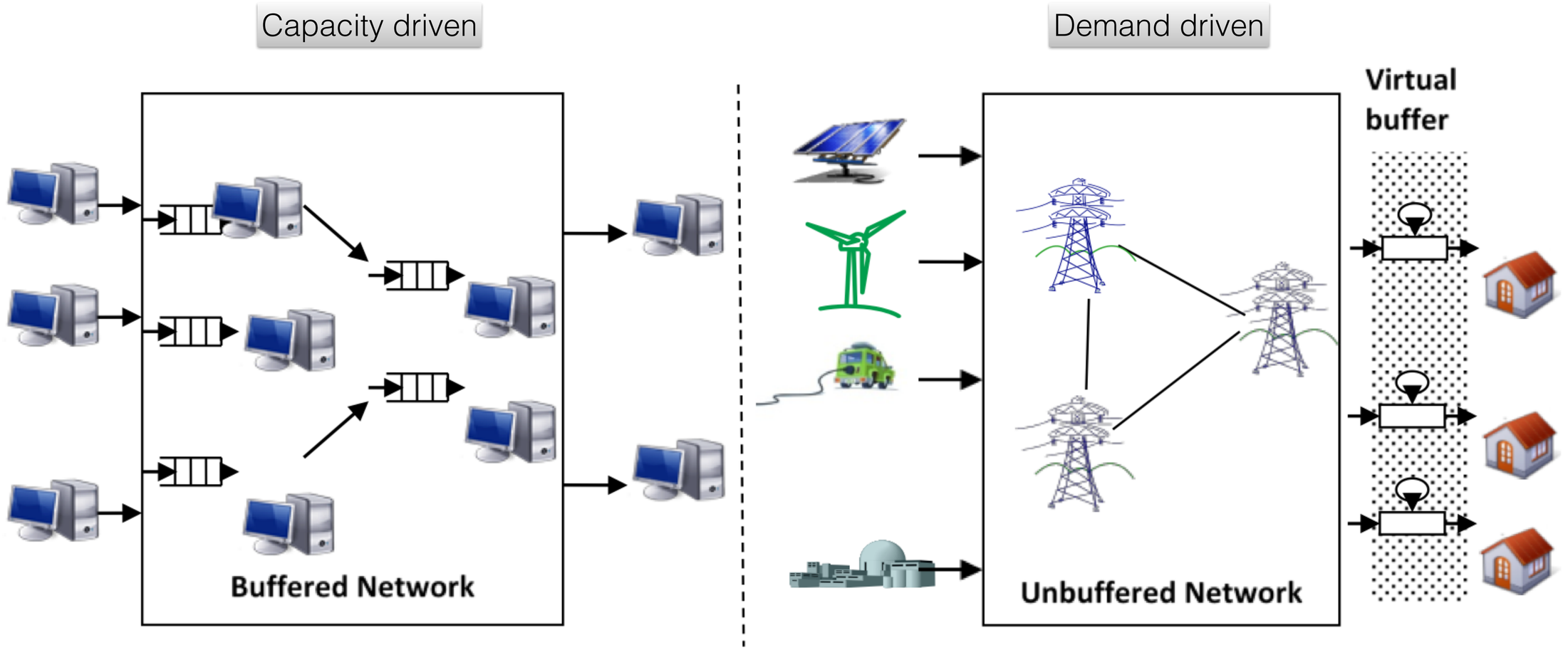
Intelligent management

+

sharing of information

=

virtual energy storage




# Internet & Power Grid

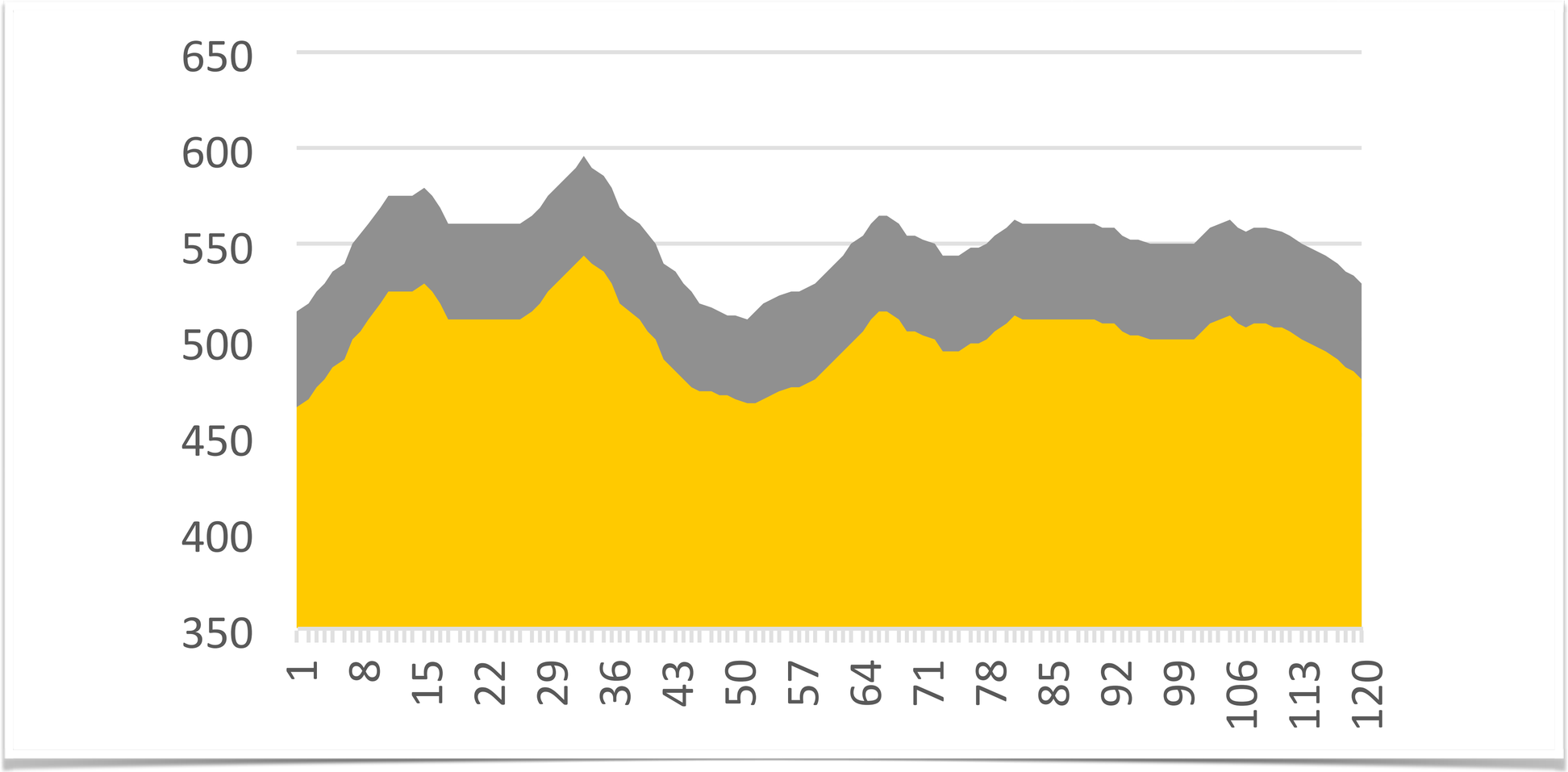
Buffering

# Basic Assumption II

Price elasticity

can manage

stochasticity




# Pricing Signals

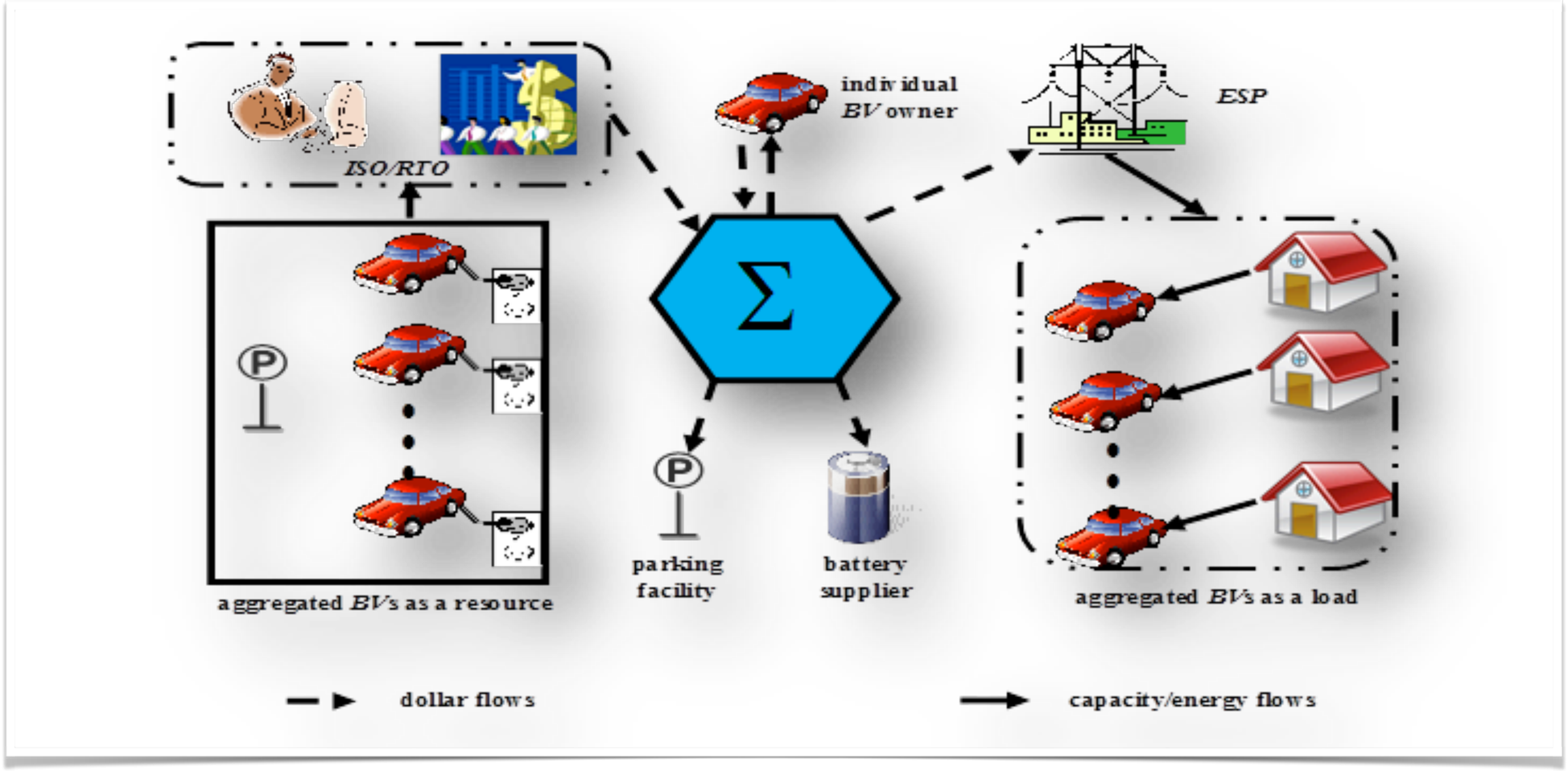
fill the gaps

# Basic Assumption III

Integration of physical storage

stabilizes

smart energy systems




# Aggregated BVs as storage

and release of power in an price-incentivized architecture

# Implementation

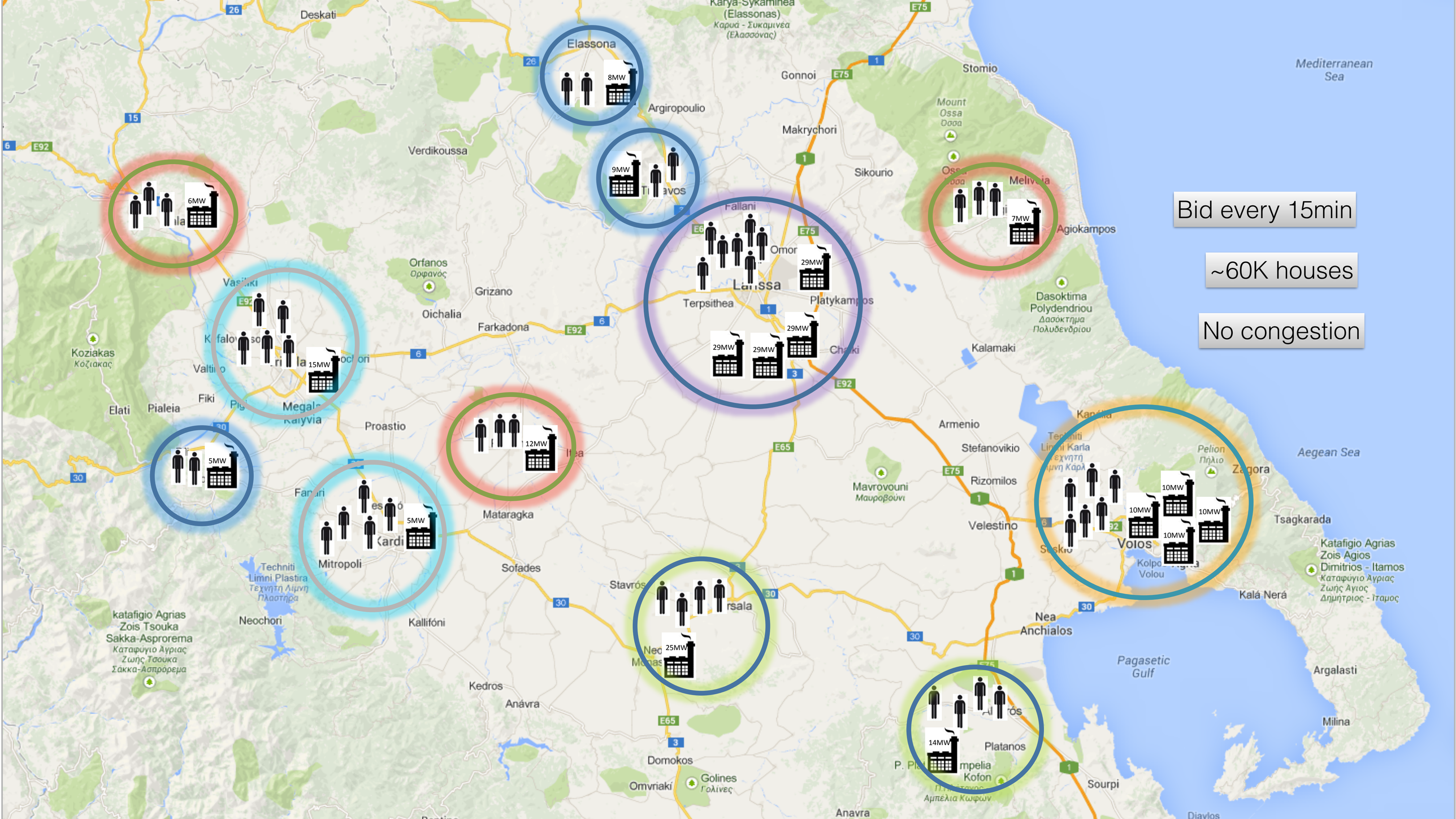
- Forecasting Models
- Agent Platform
- Intelligent Information Management
- Integration & Testing

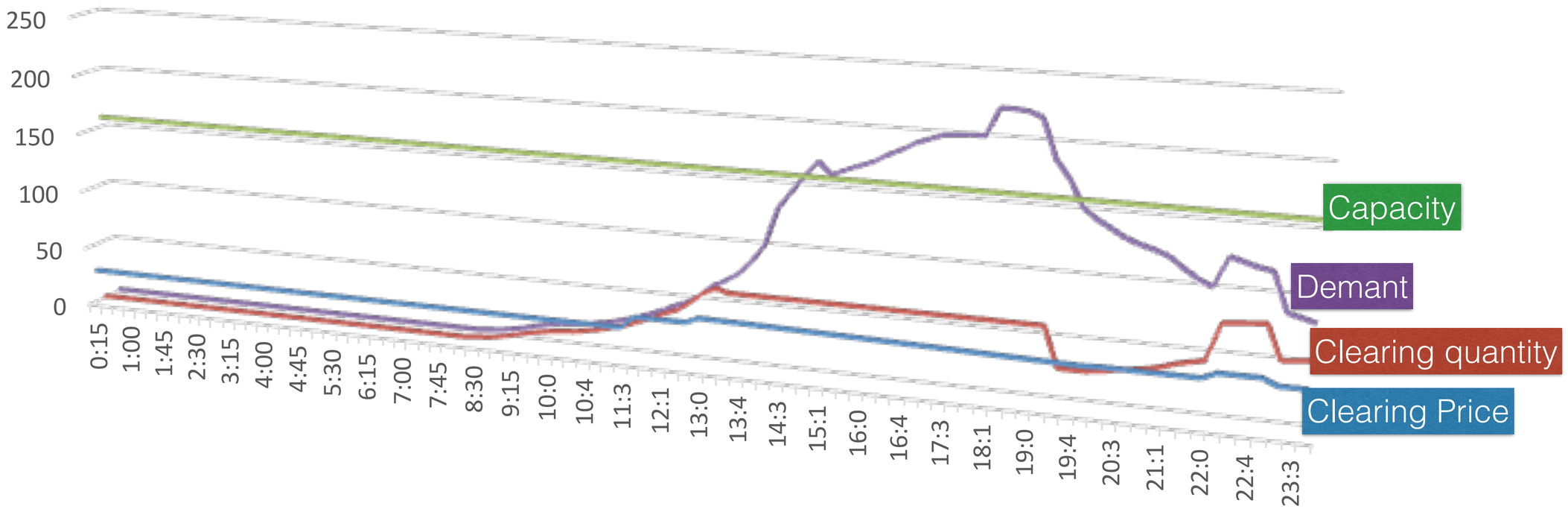

# IoT Social Ability

in practice



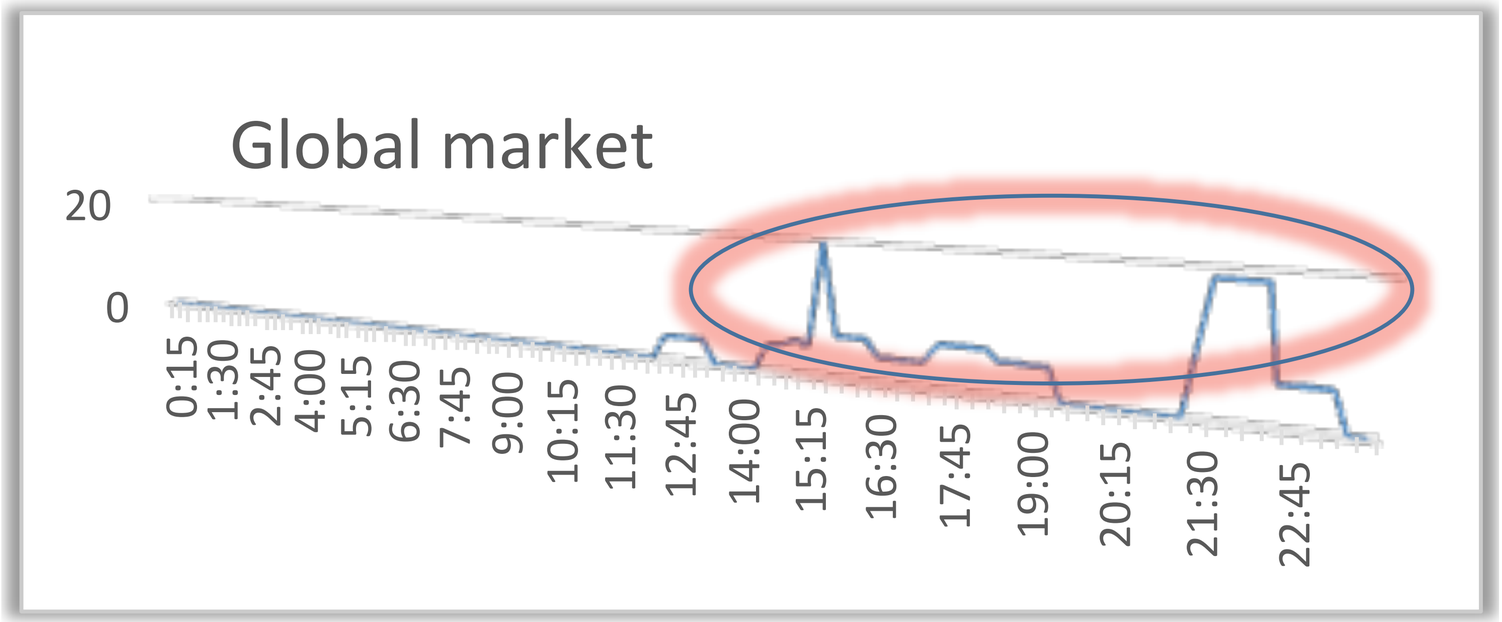

# Just install in breaker panel

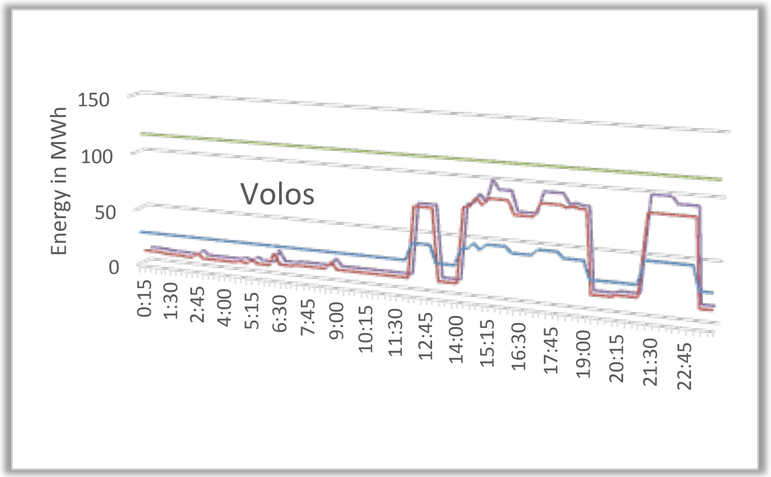

Bid every 15min
~60K houses
No congestion
6MW
8MW
9MW
29MW
29MW
29MW
29MW
7MW
15MW
12MW
5MW
5MW
25MW
14MW
10MW
10MW
10MW
10MW
Deskati
Elassona
Karya-Sykaminea (Elassonas)
Καρυά - Συκαμινέα (Ελασσόνας)
Argiropoulio
Gonnoi
Stomio
Mediterranean Sea
Mount Ossa
Όσσα
Makrychori
Sikourio
Verdikoussa
Fallani
Larissa
Terpsithea
Platykampos
Agiokampos
Dasoktima Polydendriou
Δασόκτημα Πολυδένδριου
Orfanos
Ορφανός
Grizano
Oichalia
Farkadona
Koziakas
Κοζιάκας
Kalamaki
Elati
Pialeia
Fiki
Proastio
Armenio
Stefanovikio
Rizomilos
Mavrovouni
Μαυροβούνι
Aegean Sea
Pelion
Πήλιο
Zagora
Tsagkarada
Velestino
Volos
Katafigio Agrias Zois Agios Dimitrios - Itamos
Καταφύγιο Αγριας Ζωής Άγιος Δημήτριος - Ίταμος
Kalá Nerá
Mataragka
Sofades
Techniti Limni Plastira
Τεχνητή Λίμνη Πλαστήρα
Mitropoli
Kallifóni
Neochori
katafigio Agrias Zois Tsouka Sakka-Asprorema
Καταφύγιο Αγριας Ζωής Τσούκα Σάκκα-Ασπρόρεμα
Stavros
Nea Anchialos
Pagasetic Gulf
Argalasti
Milina
Kedros
Anávra
Domokos
Omvriaki
Golines
Γολίνες
Platanos
Kofon
Sourpi
Anavra

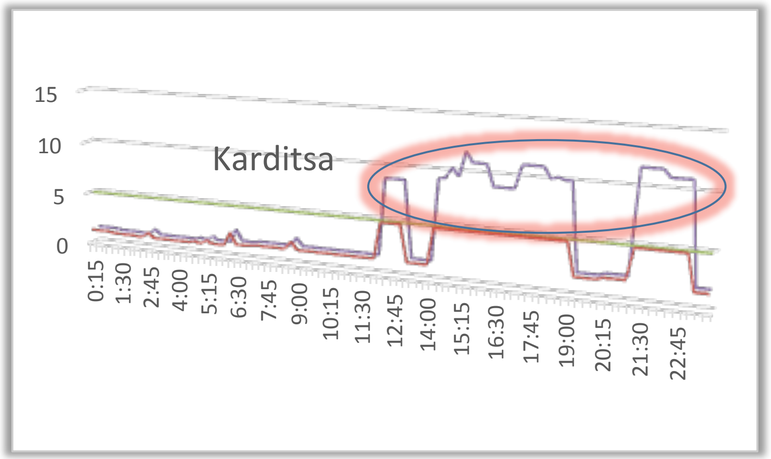



# Market 1: Demand Response, Global Pool

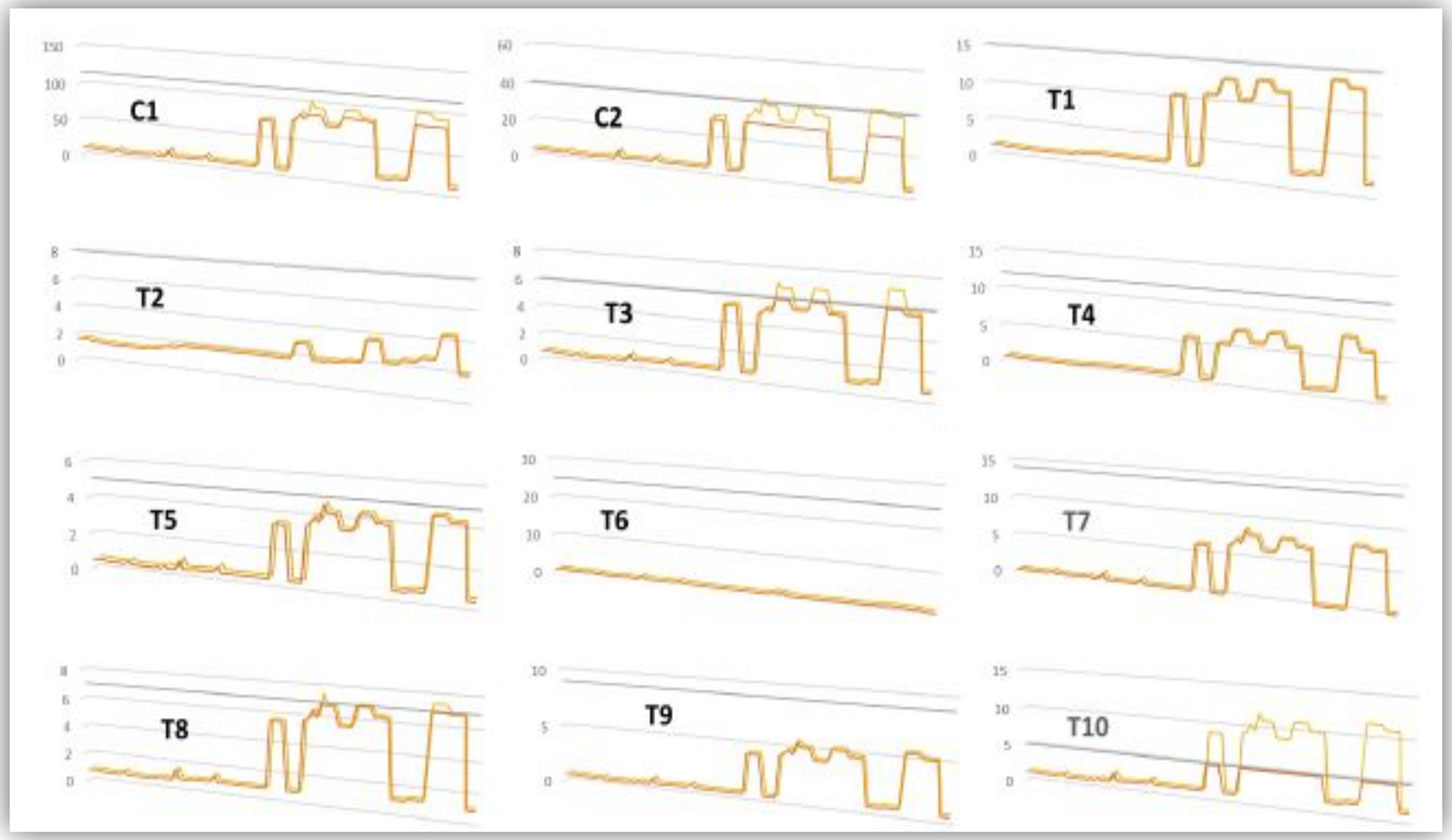
Volos




# Market 2: Demand Response, Two Levels


C1
C2
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10

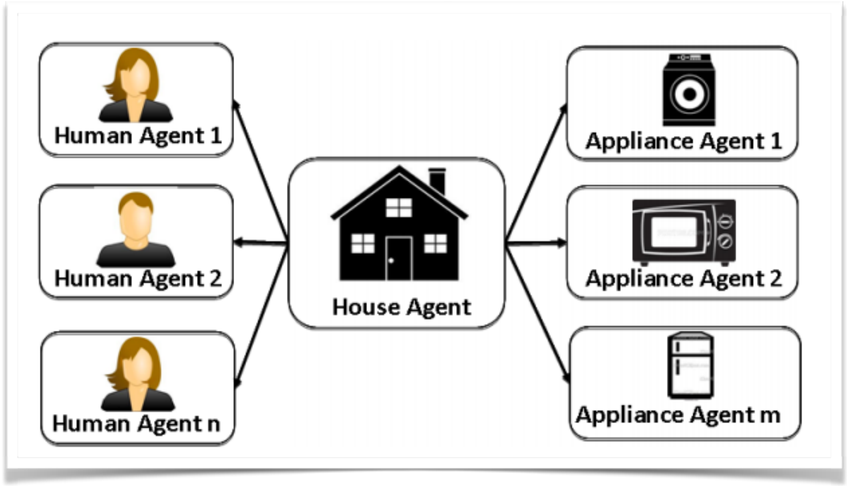
# SoA and Web Services

**No common enterprise service/information bus may easily developed**

Utilize WS for

- Service level agreements for long term contracts
- Biding for short term (1min?) auctions
- Weather data
- Market trends
- Neighborhood behavior
- …

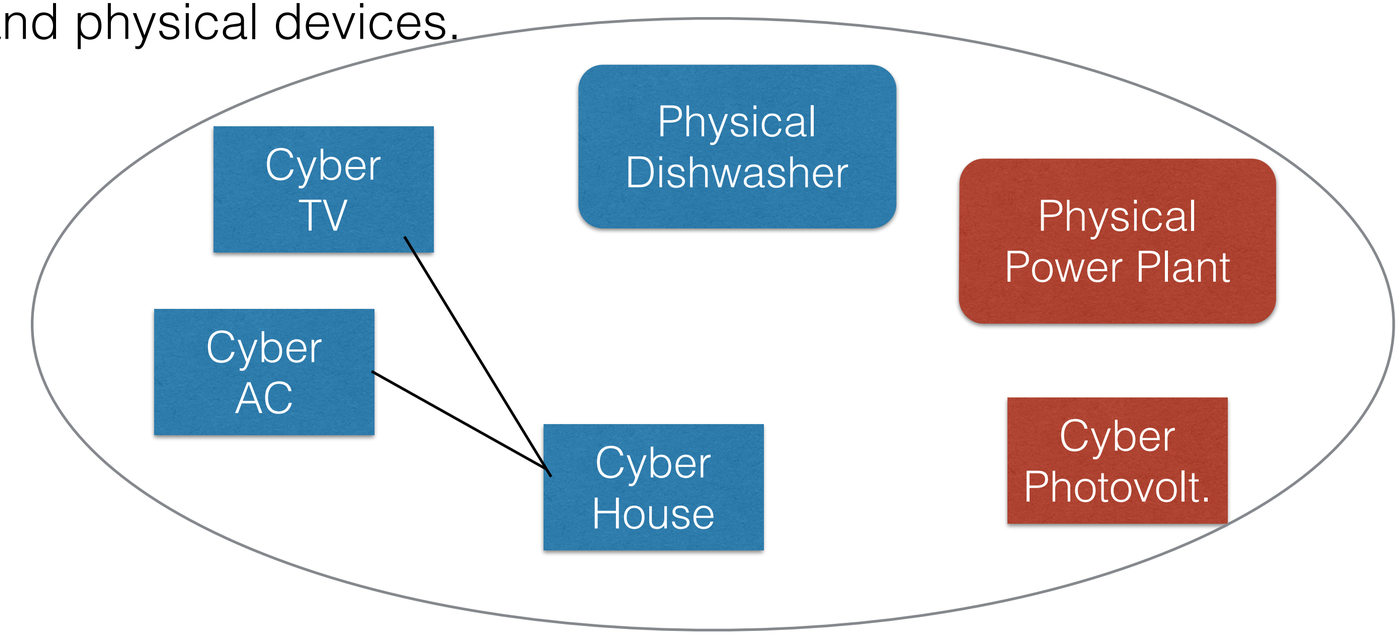
# Cyber-Physical Systems




Recently proposed

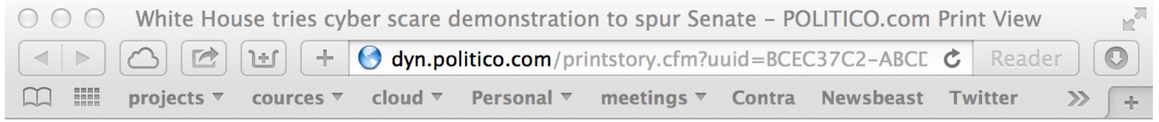
IoT approach

- Virtual houses equipped with virtual devices.
- Virtual houses equipped with both virtual and physical devices.
- Both virtual and physical houses equipped with both virtual and physical devices.



# Crucial issues r

- Security
- Anonymity
- Acceptability


POLITICO

## White House tries cyber scare demonstration to spur Senate

By: Jennifer Martinez
March 8, 2012 07:24 PM EDT

The White House orchestrated a simulated cyberattack on New York City's power supply during a summer heat wave late Wednesday to illustrate not only potential human and economic casualties, but to tee up support for Senate passage of a sweeping cybersecurity bill.

During a classified briefing in the Office of Senate Security, Homeland Security Secretary Janet Napolitano and White House counterterrorism adviser John Brennan showed lawmakers how a hacker could breach control systems of the city's electric system and trigger a ripple effect throughout the population and private sector, according to a source familiar with the scenario.

"The fact that we could be subject to a catastrophic attack under the right circumstances and we now know some of the things that would help us to protect against such an attack, that's why it's important now for the Congress to take this up," Napolitano said in an interview with POLITICO.

Such an attack could lead to mass casualties or strike a devastating blow to the U.S. economy, Napolitano said.

Yet the aim of the cyber exercise wasn't just to scare senators straight, but also build support for the Senate to act on a sweeping cybersecurity bill that includes government requirements on private sector operators of the nation's "critical infrastructure" — such as power grids and water supplies.

The bill, backed by Sens. Joe Lieberman (I-Conn.), Susan Collins (R-Maine), Jay Rockefeller (D-W.Va.) and Dianne Feinstein (D-Calif.), has been challenged in recent days by a rival plan that leaves out industry mandates.

During the simulation, the hacker gains access to the electric supply's control system through a simple "spearphishing" attack, in which a worker merely clicks on a link in an email that appears to be from someone they know.

A who's who of law enforcement and Defense officials also participated, including FBI Director Robert Mueller, National Security Agency Director Gen. Keith Alexander and Chairman of the Joint Chiefs of Staff Martin Dempsey.

Noting the prominent lineup of officials at the briefing, Napolitano said, "I think the message given out was: This could happen now."

Ήφαιστος

http://ireteth.certh.gr/hephaestus/