Karlsruhe Institute of Technology

e-Energy - IT based management of energy efficiency

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Karlsruhe Service Research Institute (KSRI)

@ CEEM, UNSW, Sydney

19th of March 2009

Gas Markets on the Move…

WELT ONLINE

EU's Barroso complains to Putin over gas shortage
The Associated Press - vor 1 Stunde gefunden
Russia cut off **gas** supplies to Europe on Wednesday amid a pricing dispute with neighboring Ukraine. Russia restarted **gas** flows to Europe on Tuesday morning, ...
Germany warns **gas shortage** imminent Financial Times
Russia pledges to resume natural **gas** flow Ukrainian Journal (subscription)
Europeans 'afraid of tomorrow' BBC News

Russia's Putin says 'era of cheap gas' is over
AFP - Dec 23, 2008
MOSCOW (AFP) — Russian Prime Minister Vladimir Putin warned consumers on Tuesday that the "era of cheap gas" is coming to an end, in a keynote speech to a ...

Telegraph.co.uk

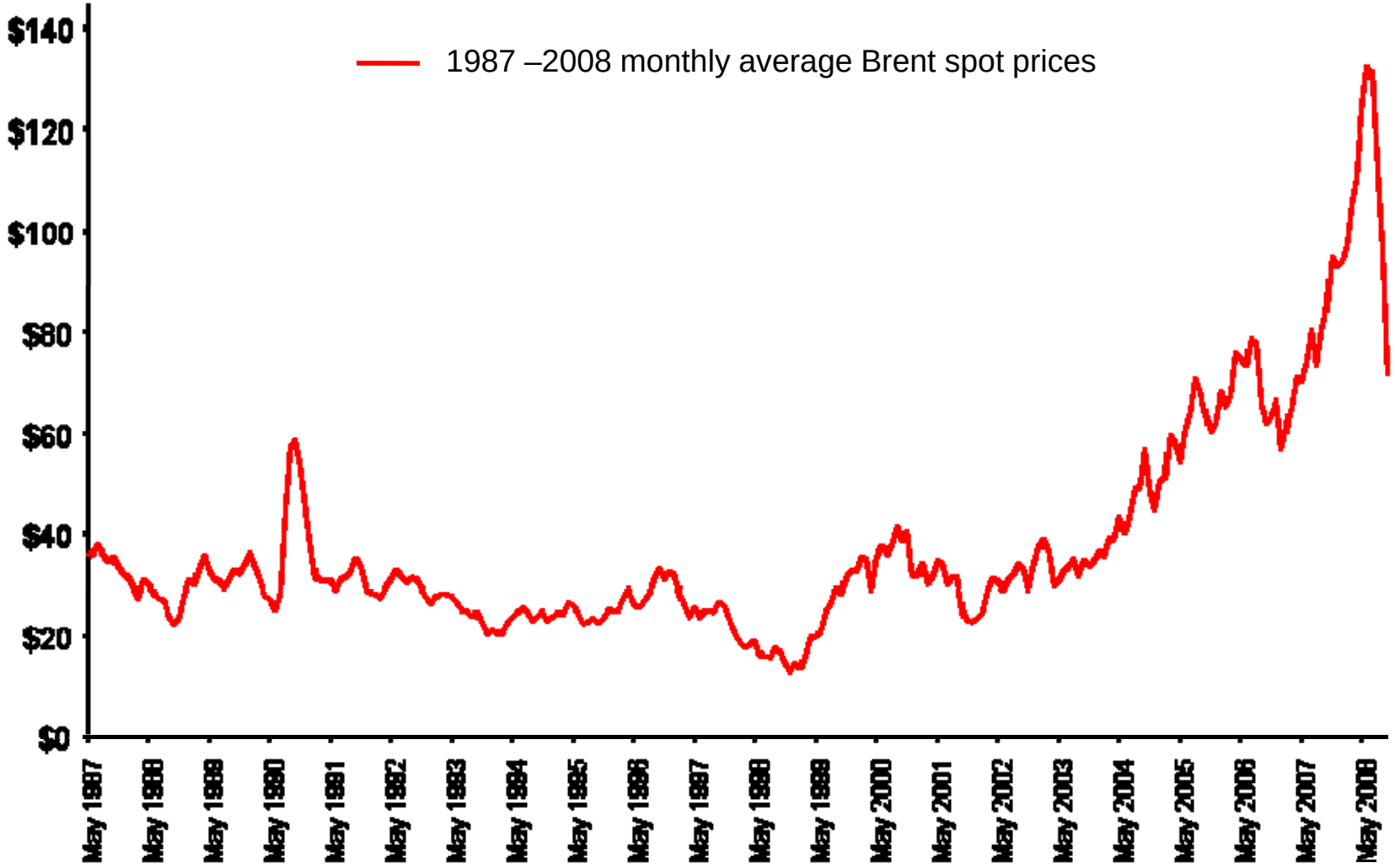
The new cold war
Scotland on Sunday - 10. Jan. 2009
"In the UK we're now more, not less, **dependent** on **gas**," he says. "This spat will up the pressure to address the whole question of **dependency** on **gas**. ...
Peter Ainsworth: The planet has to pay for every boiling kettle Independent

CTV.ca

Slovaks to restart nuclear unit due to gas shortage
Reuters - 10. Jan. 2009
Bratislava declared a state of emergency on Tuesday after the flow of Russian **gas** stopped, and the government said the 440 MW unit at the older nuclear ...
Slovakia to order V1 launch if **gas** contract not signed today-Fico Czech Happenings
Slovakia Re-Starts Nuclear Reactor to Avoid Blackout Deutsche Welle
Nuclear fears as danger plant is reopened in **gas** war with Russia Times Online

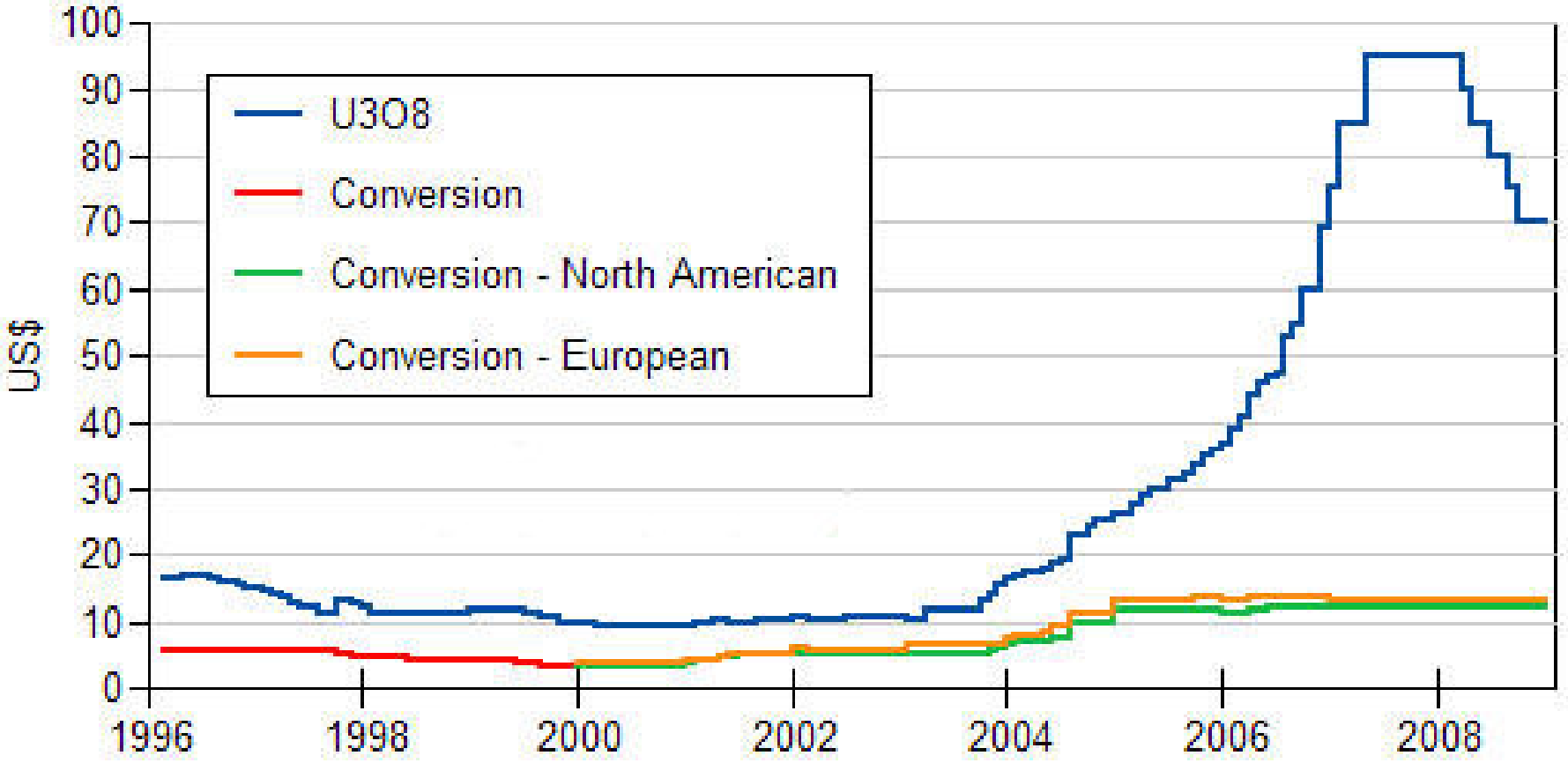
[Source: Google News]

Oil Markets on the Move…



[Sources: Energy Information Administration and Bureau of Labor Statistics]

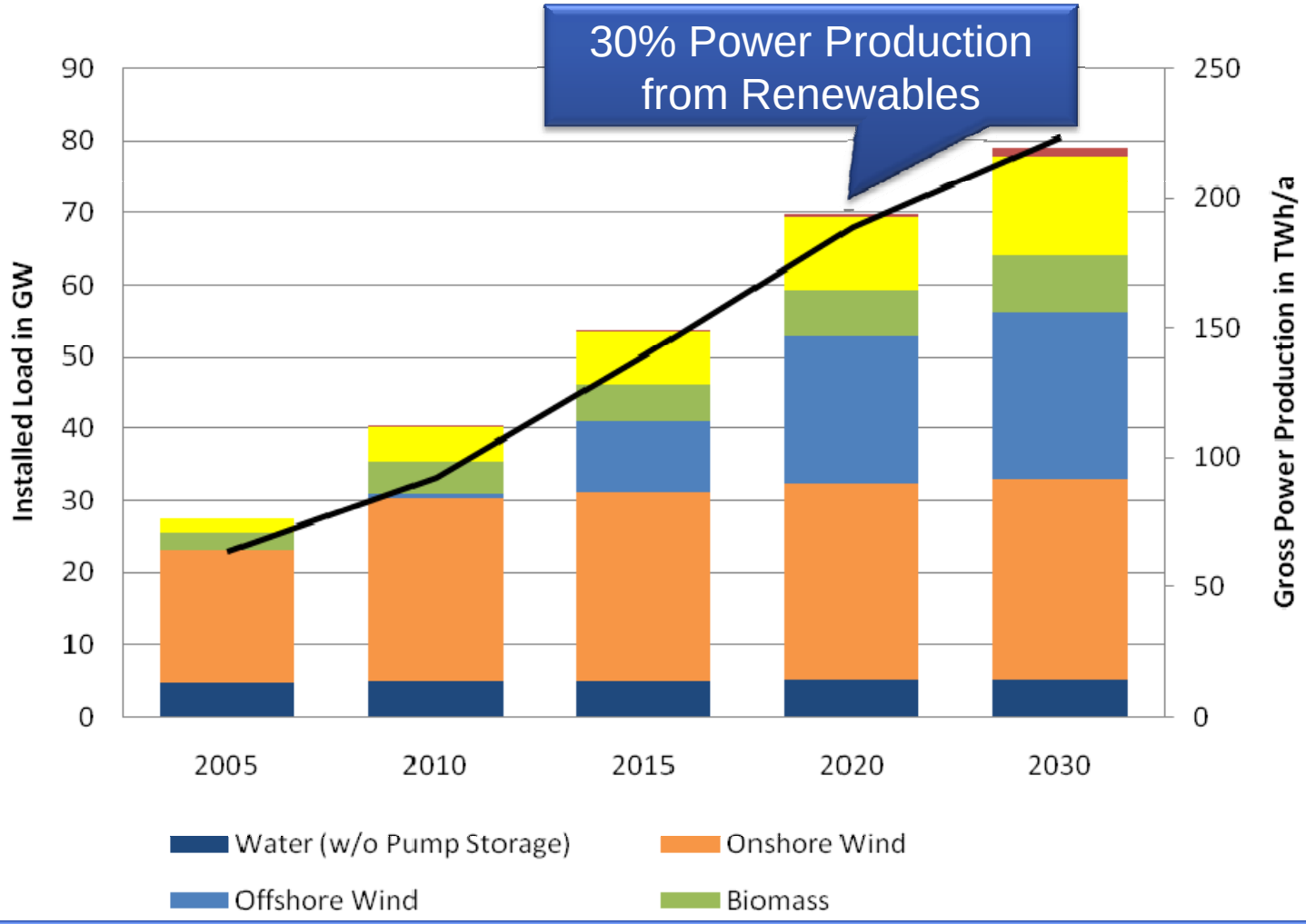
Uranium Markets on the Move…



[Source: TradeTech]

What is an answer to that?

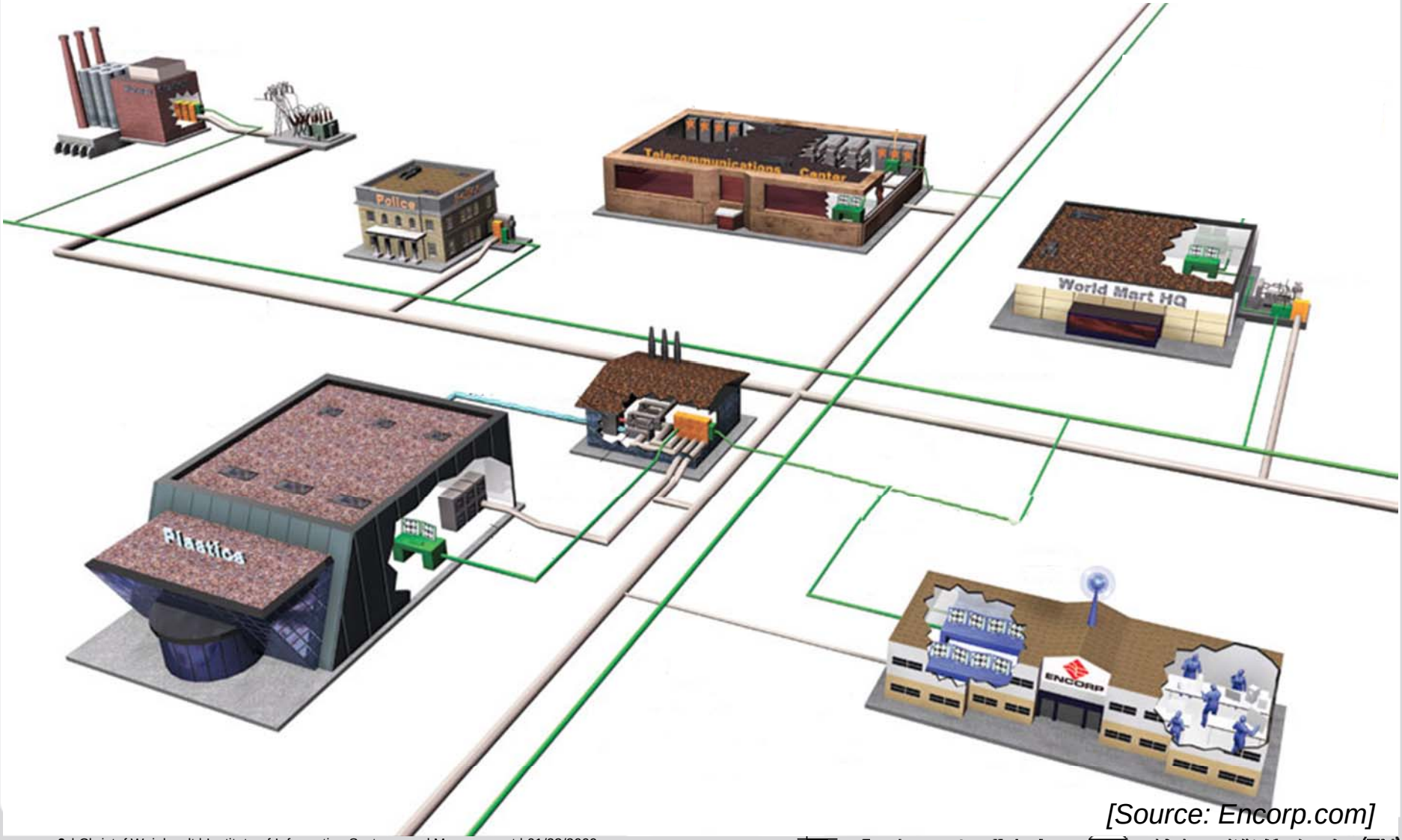
Diversification



But diversification also means decentralization!

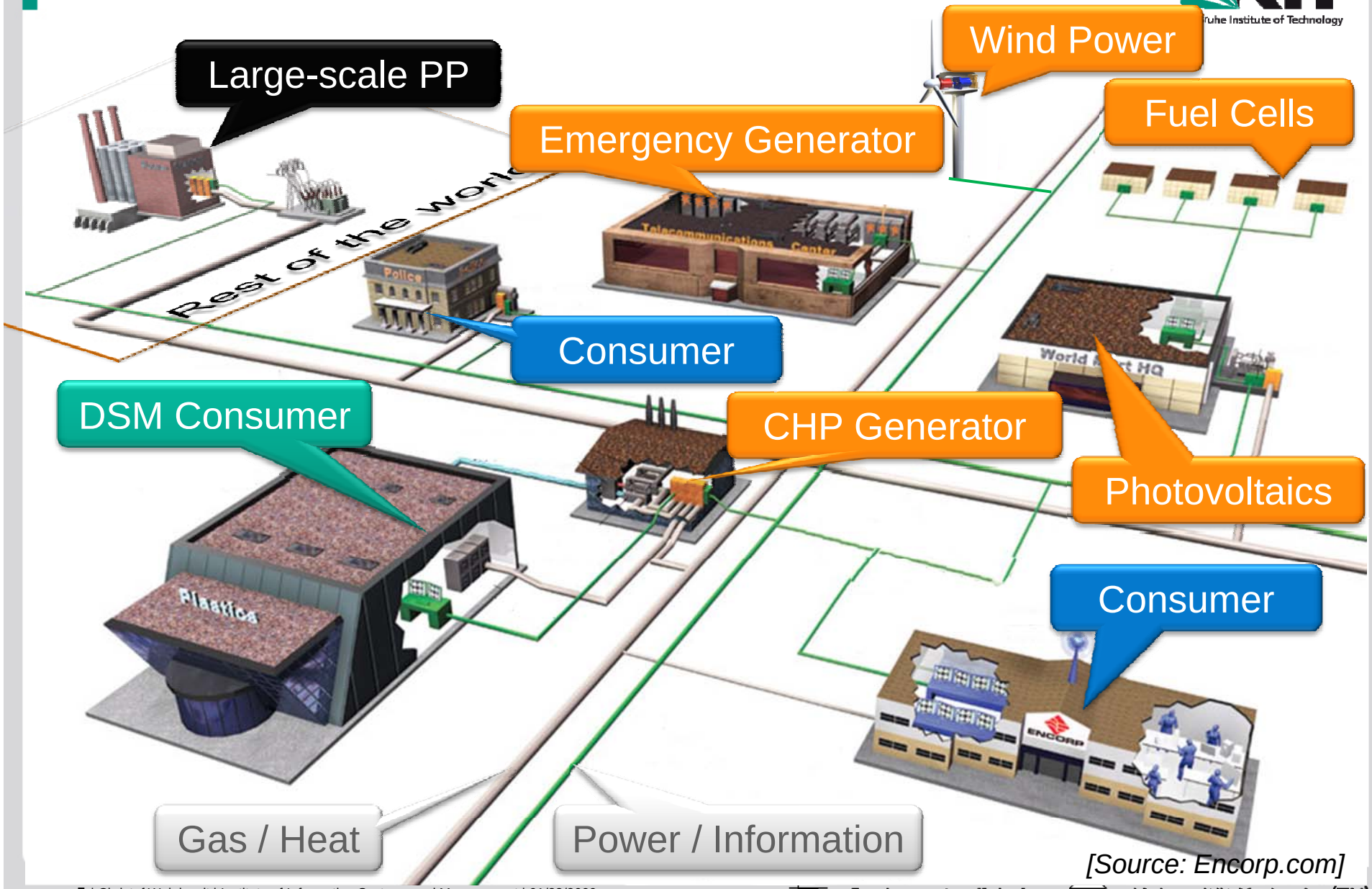
[Source: BMU 2007]

The Energy Infrastructure will change…



[Source: Encorp.com]

The Energy Infrastructure will change…



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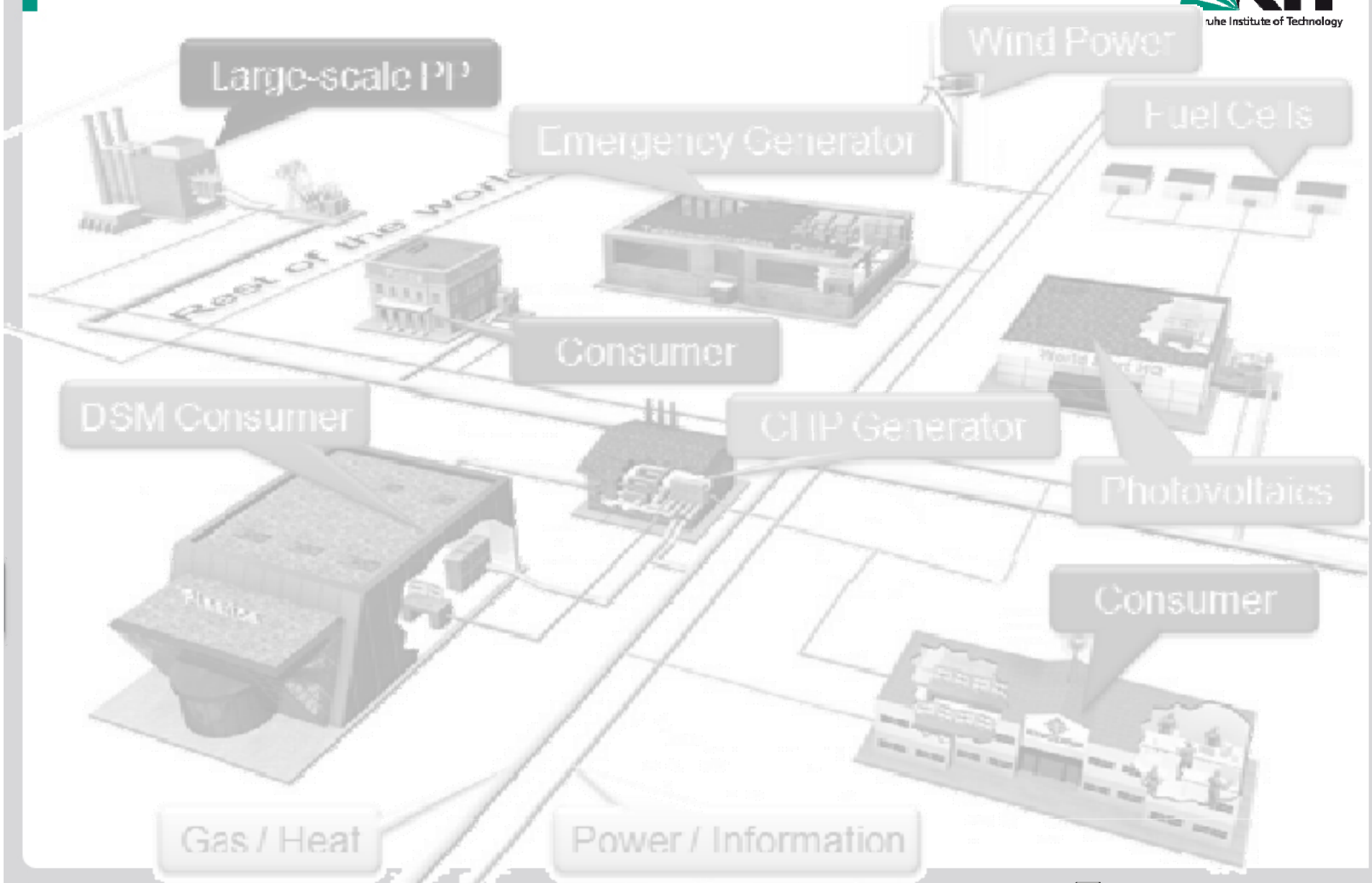


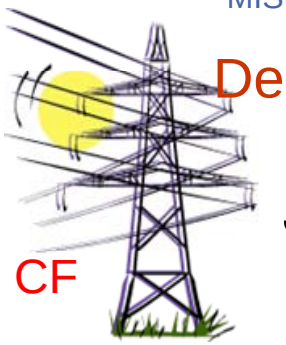
Agenda

- Motivation
- Service Innovation in Energy Markets
- Engineering Future Energy Markets
  - Example: Agent-Based Trading in Micro Grid Markets
  - Example: An Economic Energy Storage Model
- Some more Services…
- TODOS for an Energy Efficient Future

From Energy Grids to Energy Service Grids
The *eOrganisation* perspective

Supply (traditional)

MISNR



Demand

CF

Coordination of autonomous units

- human and technical actors
- decentralized decision-making
- self-organization

Supply

CF

ABC

Services: Accounting, Billing, Contracting

MISNR

Demand (traditional)

ABC

Supply

Collaboration / Group Formation

- Common objectives
- Local objectives/ optimization (e.g. internal discounts)

Co-opetition

- Spontaneous change of roles
- Dynamic pricing / contracting

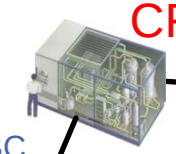
Additional Services:

- **M**onitoring, **I**ndividualization of tariffs, **S**ecurity, **N**ego/Markets, **O**ptimization, **C**ommunity **F**ormation

CF

ABC

ABC



ABC

N

SN

CF

MIR

SNR

ABC

IT links the Energy Grid to the Service Layer

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Regional Energy Markets | Virtual Power Plants | Intelligent Consumers | Energy Dimensioning / Management | Energy Certificates

Services

Service Middleware

Energy Grid Infrastructure

IT Links the Energy Grid to the Service Layer

Karlsruhe Institute of Technology

IT Links the Energy Grid to the Service Layer

MICRO GRIDS

Regional Energy Markets

Virtual Power Plants

Intelligent Consumers

Energy Dimensioning / Management

Energy Certificates

Services

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Energy Grid Infrastructure

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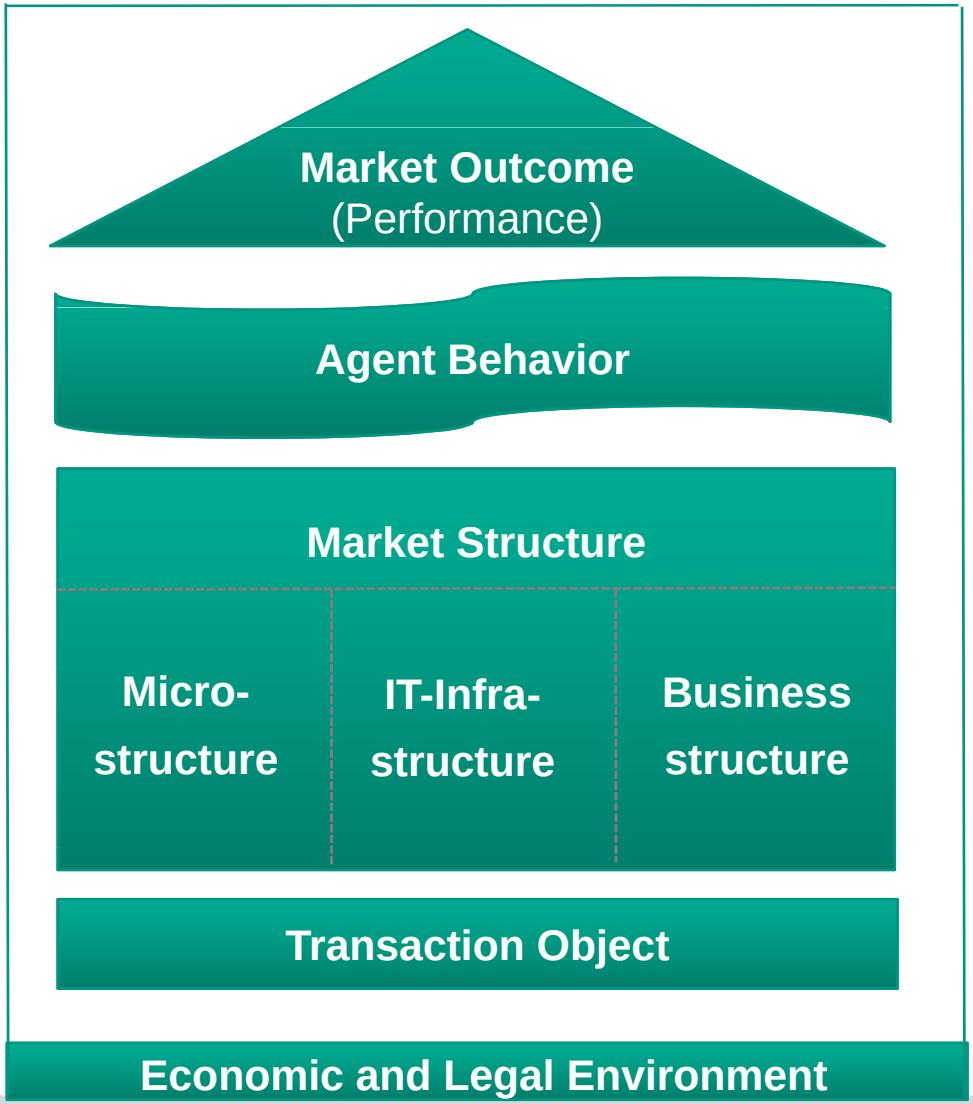
Market Engineering – the basic idea



- **Operation & Monitoring**
- **Introduction & Training**
- **Evaluation**
  (simulations, experiments, business game analysis...)
- **Conceptualization & Implementation**
- **Requirements analysis**
  (customer & product)
- **Customer identification**
- **Product design**

MEREGIO: Bulding a pilot region that uses real-time market-based energy allocation

Energy Technology

- Smart Metering
- Hybrid Generation
- Demand Side Management
- Distribution Grid Management

Energy Market

- Decentralized Trading
- Price incentives at the power plug
- Premium Services
- System Optimization

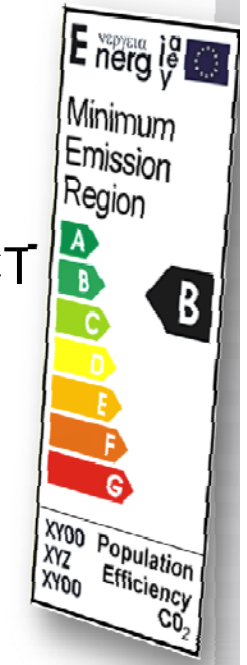
Information and Communication Technology

- Real-time measurement
- System Control & Billing
- Safety & Security
- Non Repudiable Transactions

Facts about Project MEREGIO

Objectives:

- Optimize energy generation & usage from producers to end consumers
- Intelligent combination of new generator technology, DSM and ICT
  - → Price signals for efficient energy allocation
  - → Combined Heat and Power
- Pilote Region with ~ 1000 Participants (Freiamt + Göppingen)
- MEREGIO-Certificate: Best practice + information dissemination



Status: *Granted (consortium agreement + working)*

Initator: Federal Ministry of Economics and Technology

Budget: Approx. 23 Mio EUR

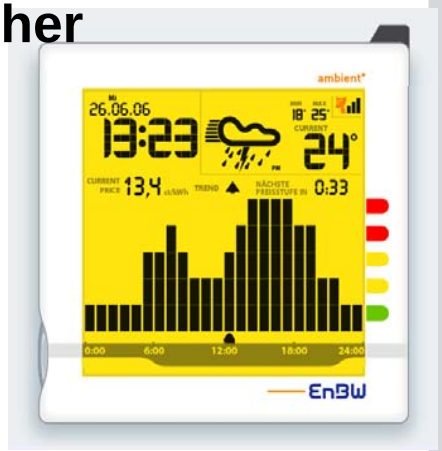
Start: 01.11.2008

Project Consortium:

Pilot Region: Karlsruhe/Stuttgart

- **1000 participants**
  (~800 consumers, ~ 150 generators, ~ 50 energy storages)
  - **private HHs and medium sized c ompanies**
  - **decentral energy genaration plants**
    (Photo Voltaic, Fuel Cells, Micro-CHP, …)

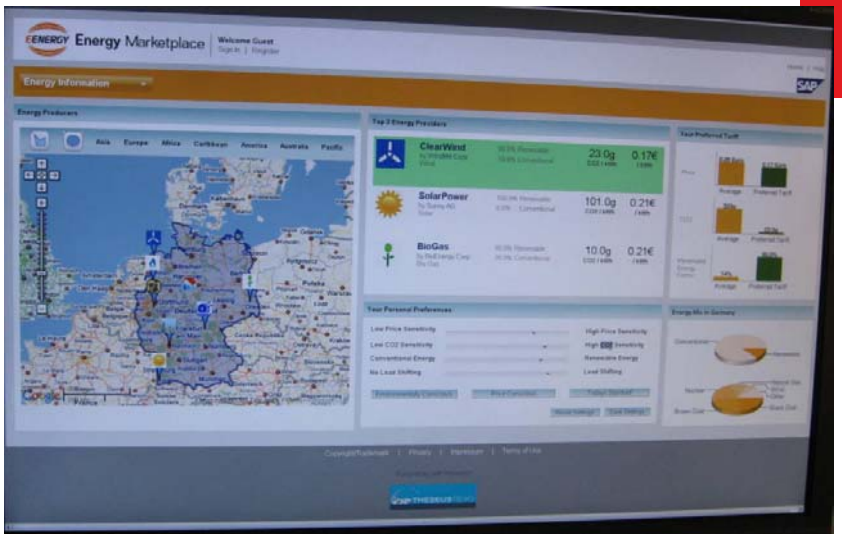
- **…physically und virtually linked among each other**
  - **majority on same low and middle voltage grid**
  - **remote participants virtually integrated**



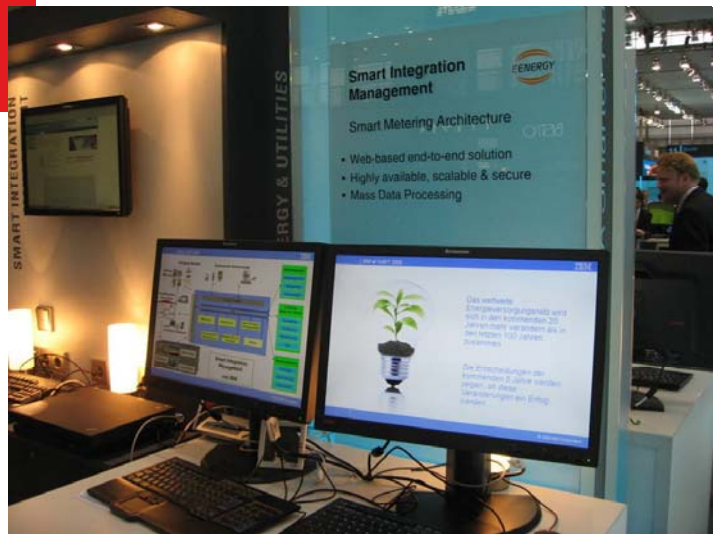
- **…equipped with most currently available ICT**
  - **remote readable, smart multi utility meters**
  - **devices for demand side and demand response management (e.g. switchable power sockets)**
  - **additional secundary technology in municipal grid stations**

MEREGIO: First Impressions from CeBIT 2009

CeBIT
3.-8. MÄRZ 2009
IN HANNOVER

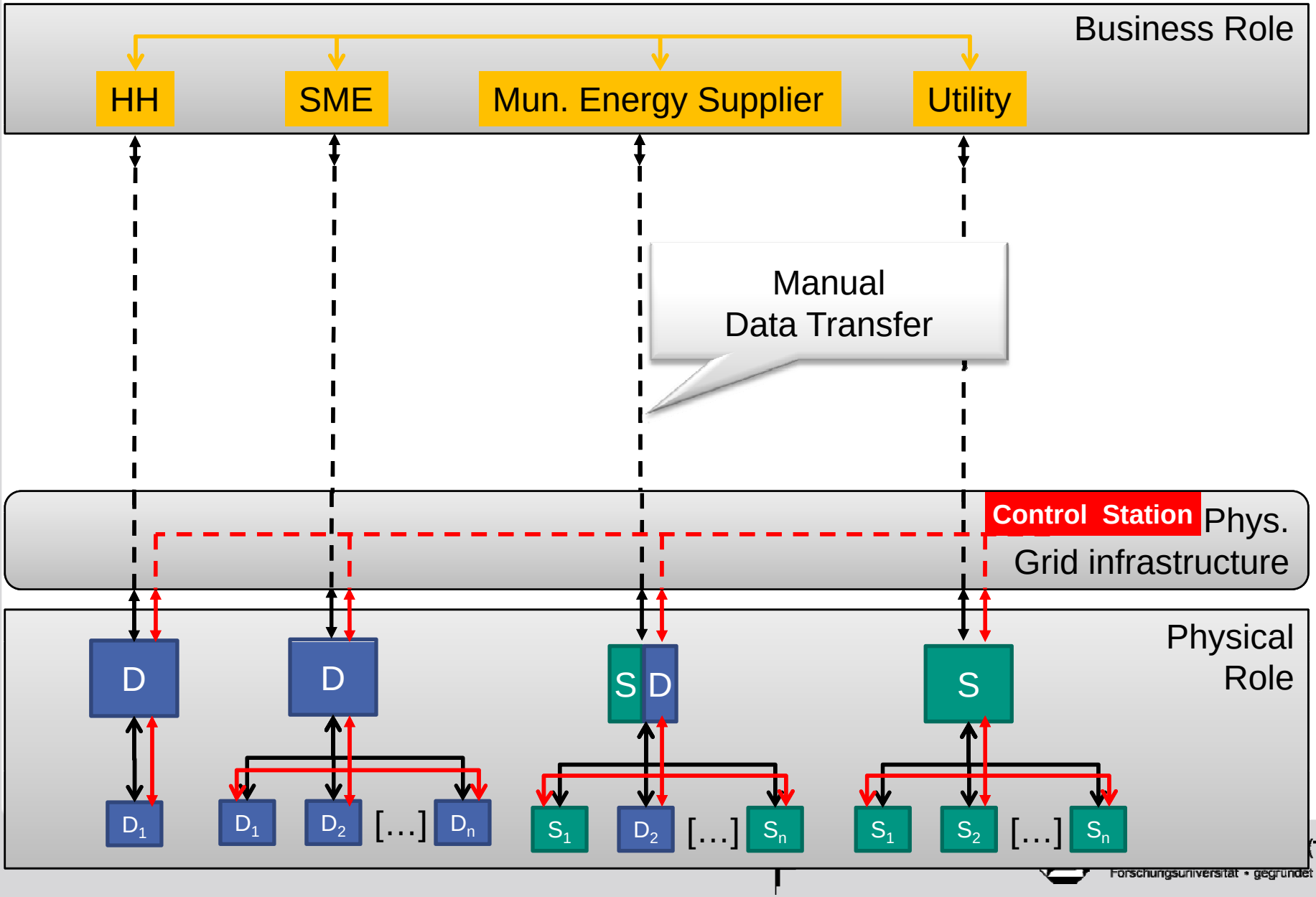


Scale World & Energy Market Place (SAP)

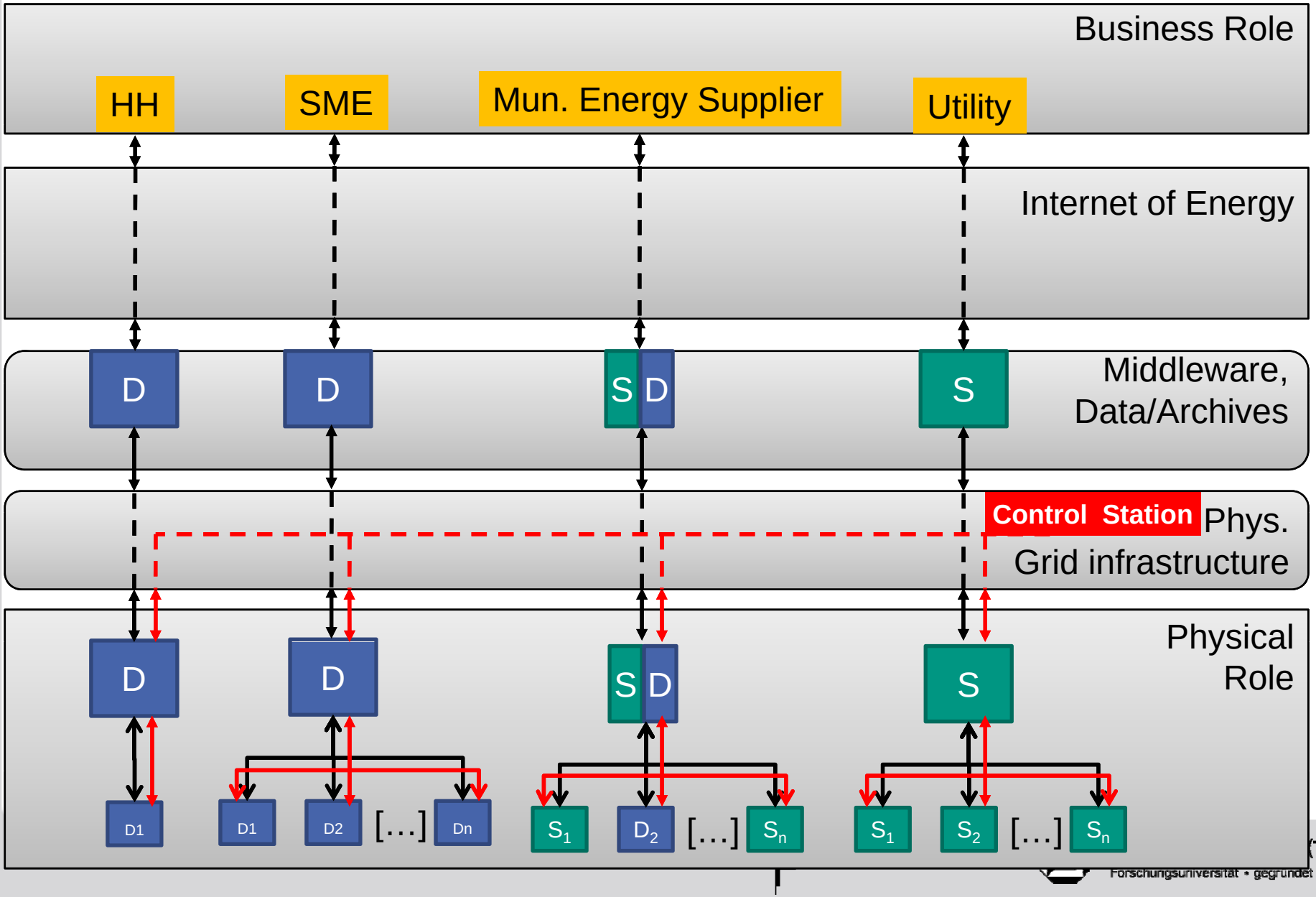


Meter Data Management (IBM)

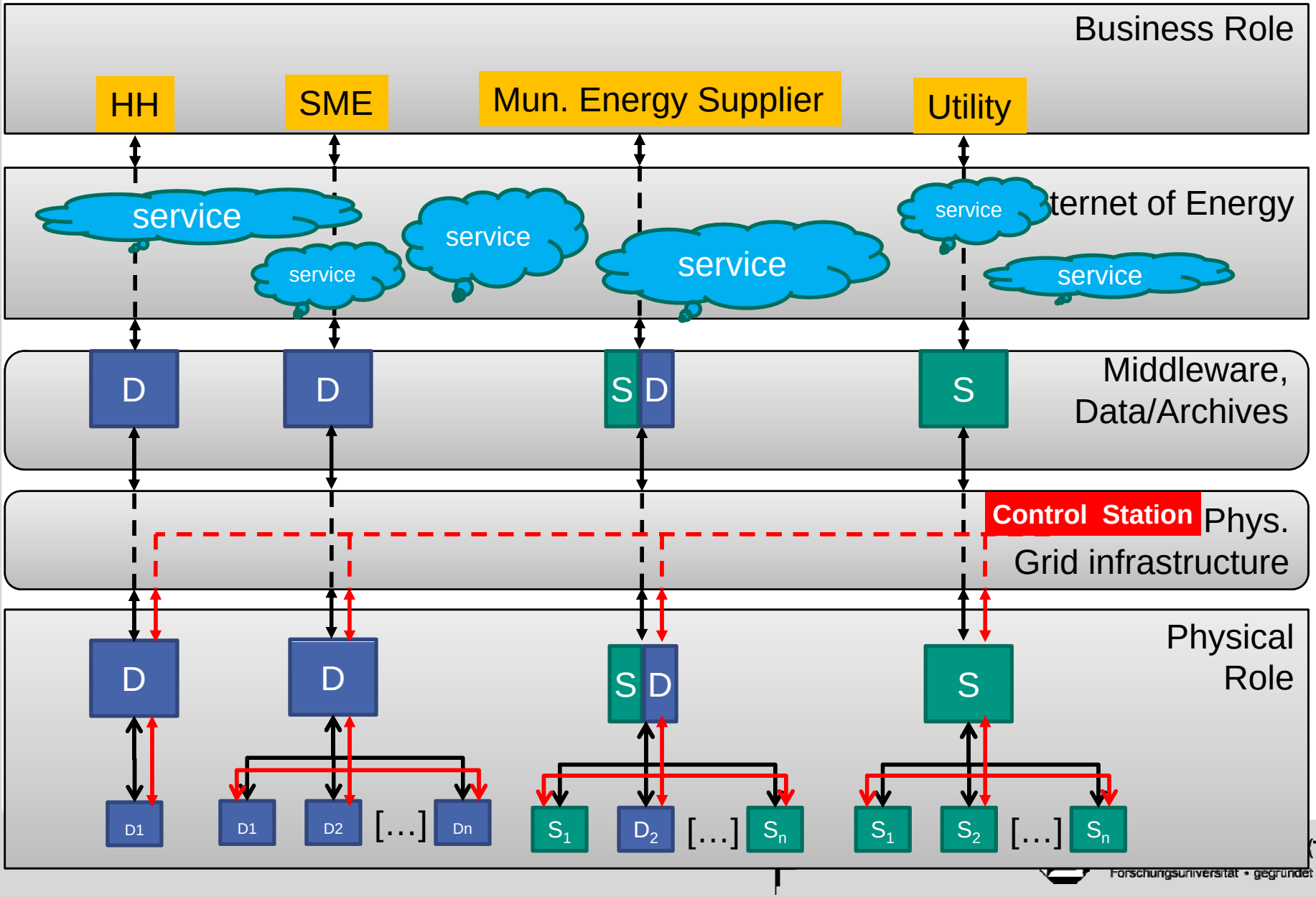
MEREGIO – The Situation today



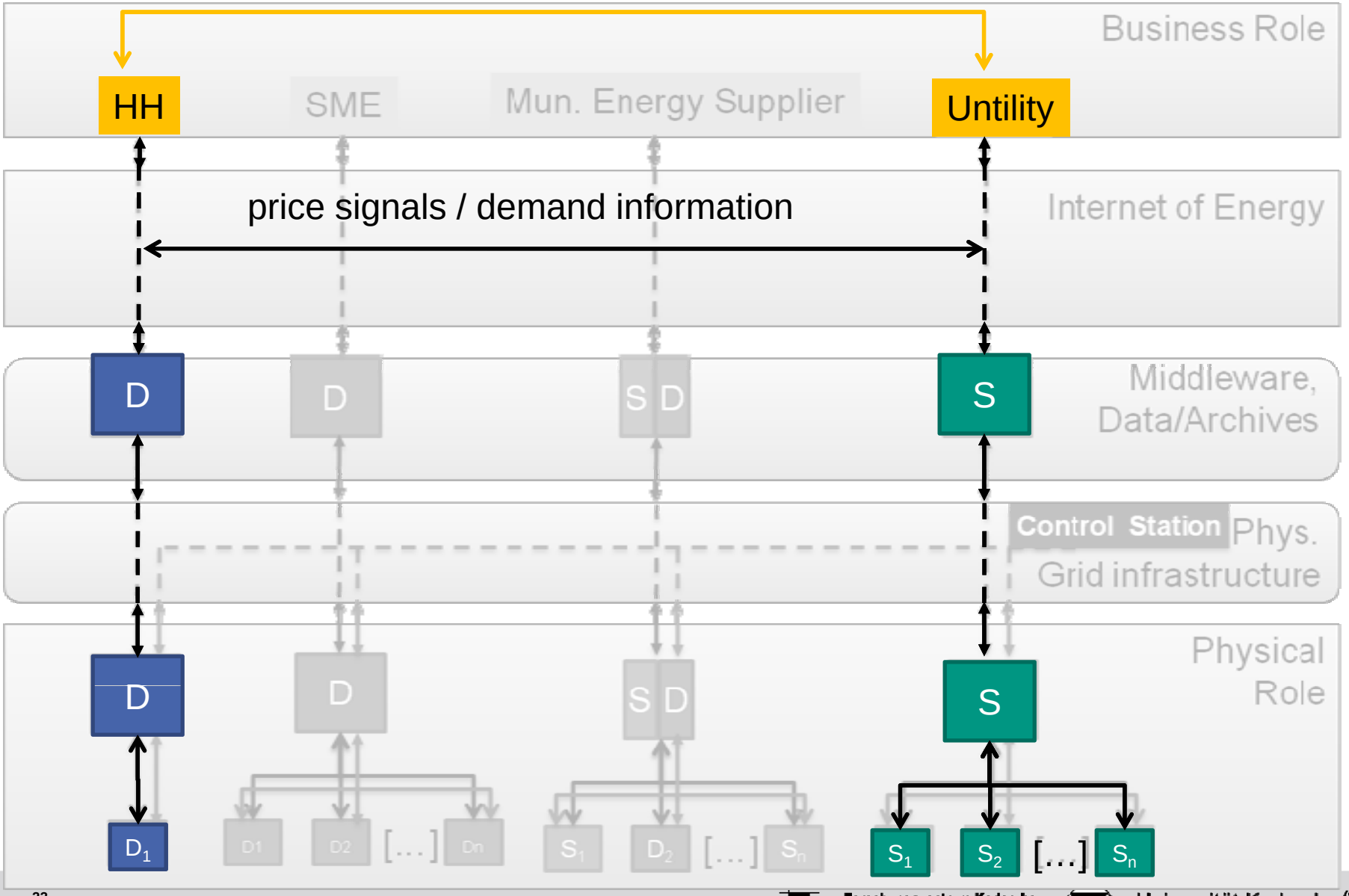
MEREGIO – The Future Infrastructure



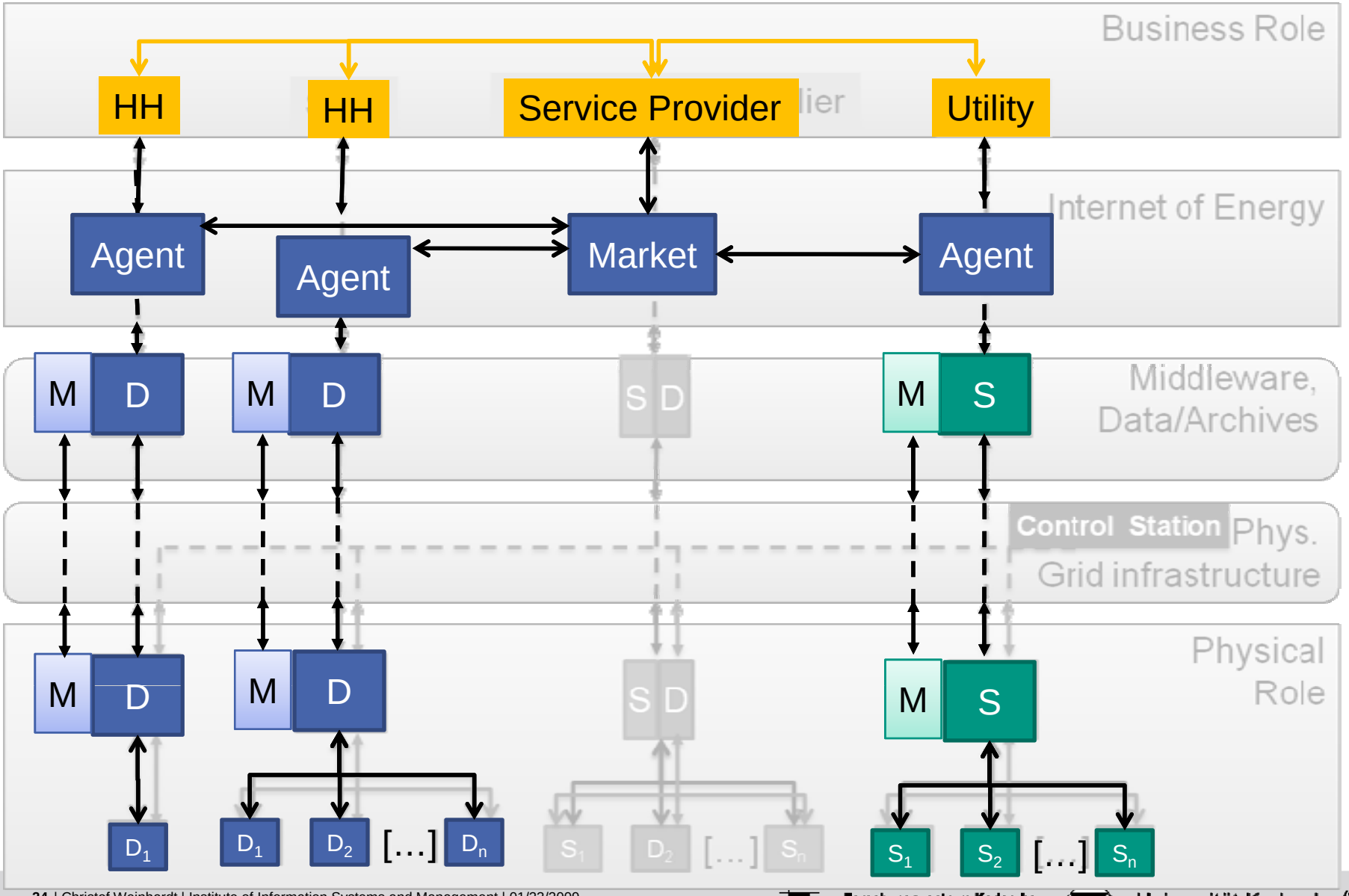
MEREGIO – The Future Infrastructure



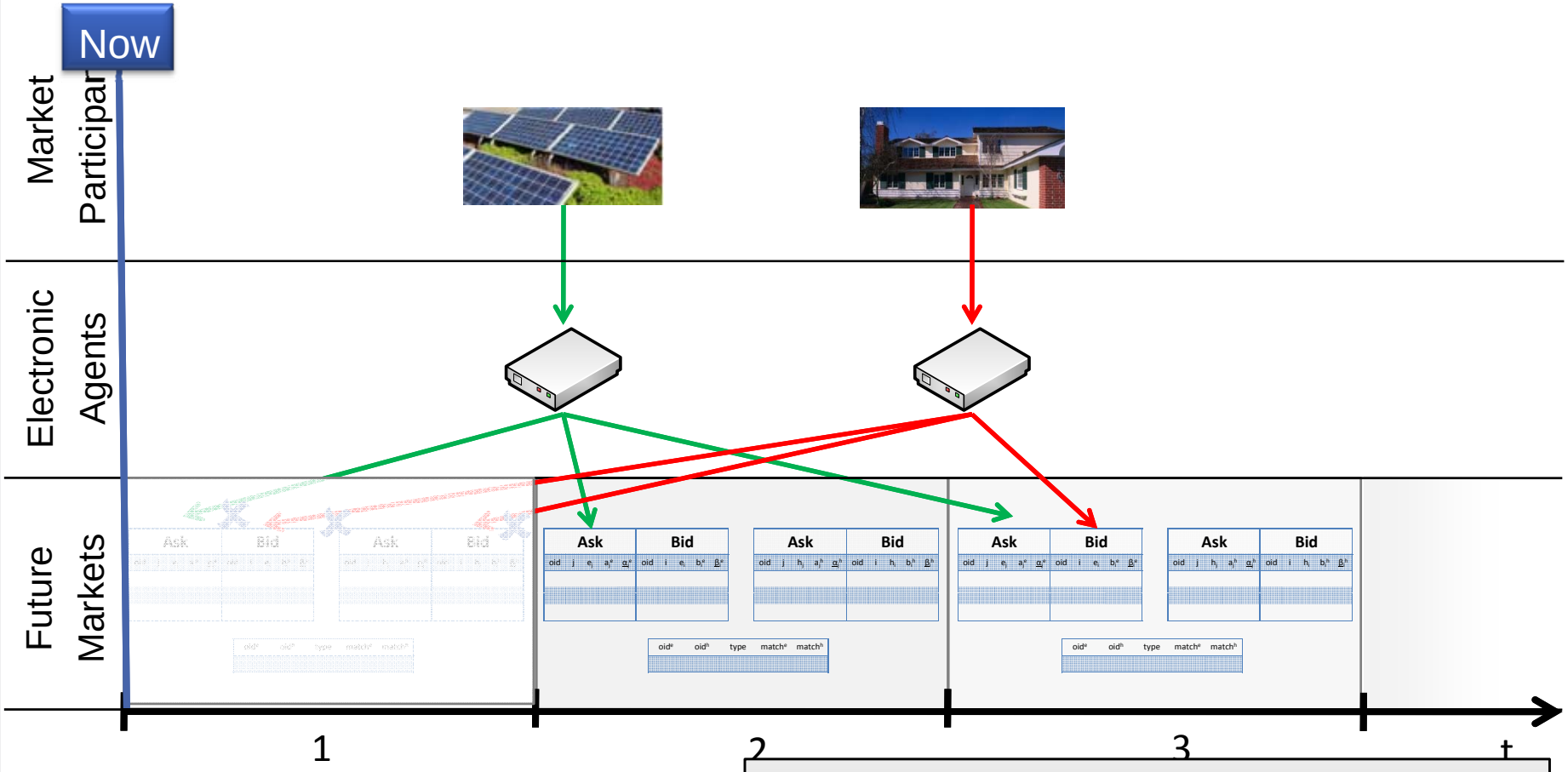
MEREGIO – Scenario „Variable Tariff“



MEREGIO – Scenario „Market“



Technical Control and Market-Based Planning in Micro CHP Grids for stable and efficient operation (Carsten Block)



Price balancing power > market price:

Incentive for agents to trade demand and supply in advance on the market

Winner Determination Model (WDP)

- **Standard WDP Formulation (c.f. Xia et al. 2005, Sandholm 2002):**

$$max \quad V^* = \sum_{j=1}^{n} p_j x_j$$

Maximize total welfare

$$s.t. \sum_{j=1}^{n} a_j^i x_j = 0 \quad \forall i \in M$$

Balanced Demand & Supply for all items (no free disposal)

$$l_j \leq x_j \leq u_j \quad \forall j \in 1, \ldots, n$$

Feasibility Constraints

- **Legend:**

p_j	limit price per bundle
x_j	allocated bundles (optimization variable)
$a_j = (a_j^1, \ldots, a_j^i, \ldots, a_j^m)$	share of each item in the bundle
l_j	lower bound for x_j (min. allocation constraint)
u_j	upper bound for x_j (max . allocation constraint)

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Feasibility Constraints

Note: lower bound violates Efficiency

- **NP Complete (c.f. Sandholm 2001, …)**
- **Equivalent Formulation to Knapsack problems**
- **But special cases exist that can be solved efficiently:**
  - **Rothkopf et al. 1998:** Cardinality-based structure for solving WDP with at most two items in polynomial time (*single unit case)*.
  - **Tennenholtz 2000:** Proof of tractability of optimal algorithm for two goods and multi-unit case *(no min allocation constraints)*

Extended WDP with order splitting

$$maxV^* = \sum_{j=1}^{n} p_j u_j x'_j + p_j x''_j$$

Maximize total welfare

$$s.t. \sum_{j_1}^{n} a_j^i u_j x'_j + a_j^i x''_j = 0 \quad \forall i \in M$$

Balanced Demand & Supply for all items (no free disposal)

$$x''_j - x'_j \leq 0 \quad \forall j \in 1, \ldots, n$$

Coupling Constraints

$$0 \leq x''_j \leq u_j - l_j \quad \forall j \in 1, \ldots, n$$

Feasibility Constraints

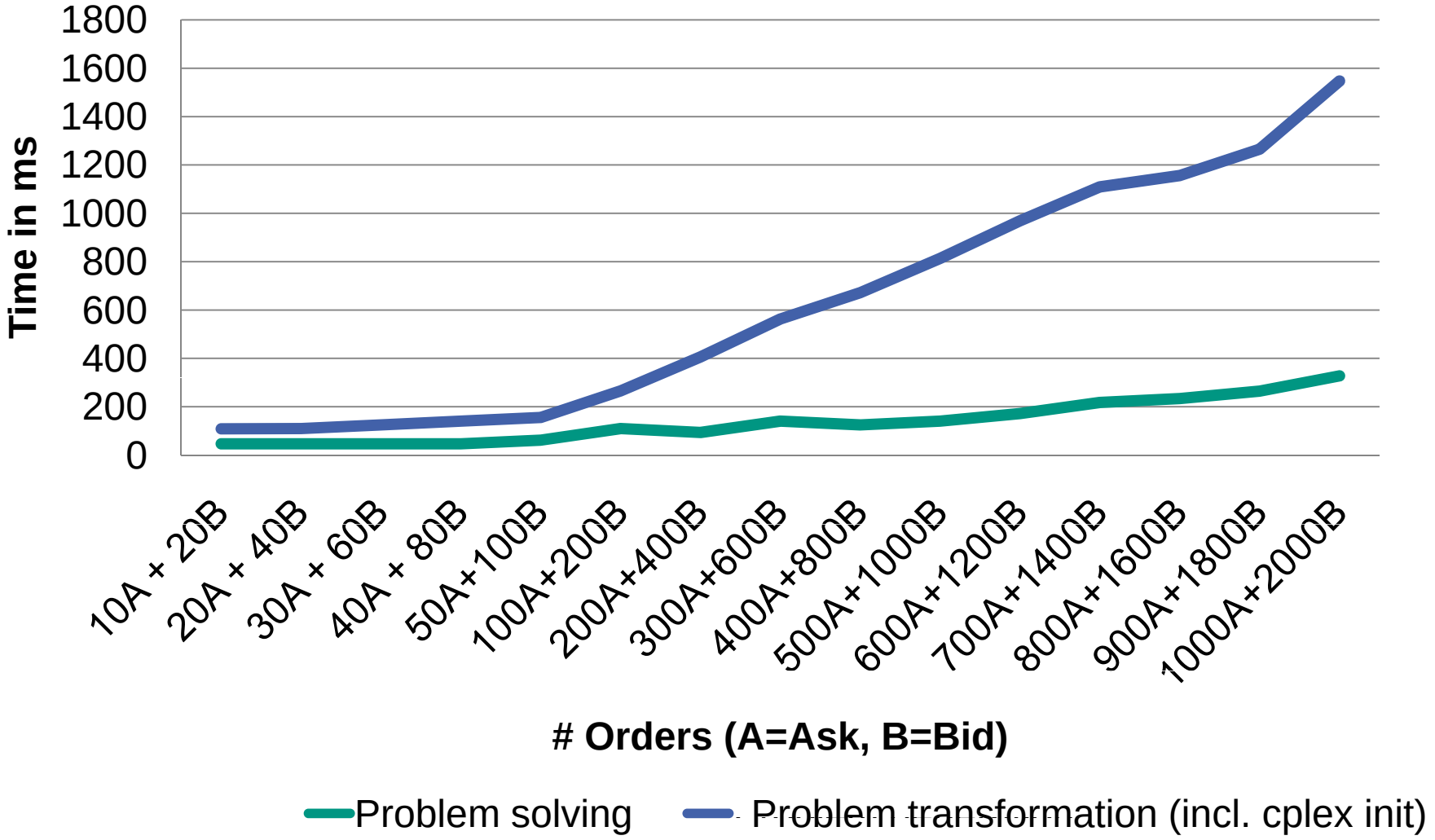
$$x'_j s \in 0, 1 \quad \forall j \in 1, \ldots, n$$

→Allows for order allocations x_j to be either {0} or within the interval $[l_j, u_j]$

→Mechanism allocative efficient

→Computational complexity manageable up to 2000+ orders in an order book

Computational Complexity of Extended WDP



Designing a Pricing Model for CHP Trading

- **Desired economic mechanism properties:**
  - Allocative Efficiency (AE)
  - Budget Balance (BB)
  - Individual Rationality (IR)
  - Incentive Compatibility (IC)
  - [Computational Tractability] (CT)
  - [„Understandibility“ / Acceptance of the matchmaking results]
- **Myerson Satterthwaite (1983):**
  - Impossible to find mechanism that ist BB, AE, IR, and IC

➢ **Idea:**

- ➢ BB and IR as *MUSTS*
- ➢ Find Pricing Scheme that is

  “as IC as possible “ given the BB constraint → **IC‘**

Vickrey Pricing Scheme for CHP Trading

- Use V^* from WDP and compute all Vickrey Discounts $(V_{-j})^*$
- Goal: Award price discount Δ_j to each winning participant *j**
- Δ_j = welfare that participant j adds to the society: $V^* - (V_{-j})^*$
- But $V^* < \sum_{j \in N}(V^* - (V_{-j})^*)$ usually holds → BB violated
- ***Solution: Find set of „roughly" IC discounts that guarantee BB:***

$$min_{\Delta} \quad L(\Delta, \Delta_{vick})$$

$$s.t. \sum_{j=1}^{n} \Delta_i \leq V^* \quad (BB)$$

$$\Delta_j \leq \Delta_{vick,j}, \quad \forall j \in 1, \ldots, n \quad (VD)$$

$$\Delta_i \geq 0, \quad \forall j \in 1, \ldots, n \quad (IR)$$

This pricing is only IC' but still budget balanced because of reduced Vickrey Discount payments ⟶ c.f. Parkes 2001

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Energy Market Prototype as Open Source

Microgrid Market

- Allocation and pricing mechanisms for combined heat and power trading in micro grids
- Market coupling through electronic "arbitrage agents"
- Trading automation through electronic agents (e.g. for CHP Gensets)

- IISM source code released under Apache 2 open source license at http://microgridmarket.sourceforge.net/

[Source: Block et. al. 2008; Deindl et. al. 2008]

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IT Links the Energy Grid to the Service Layer

Regional Energy Markets | Virtual Power Plants | Intelligent Consumers | Energy Dimensioning / Management | Energy Certificates

Services

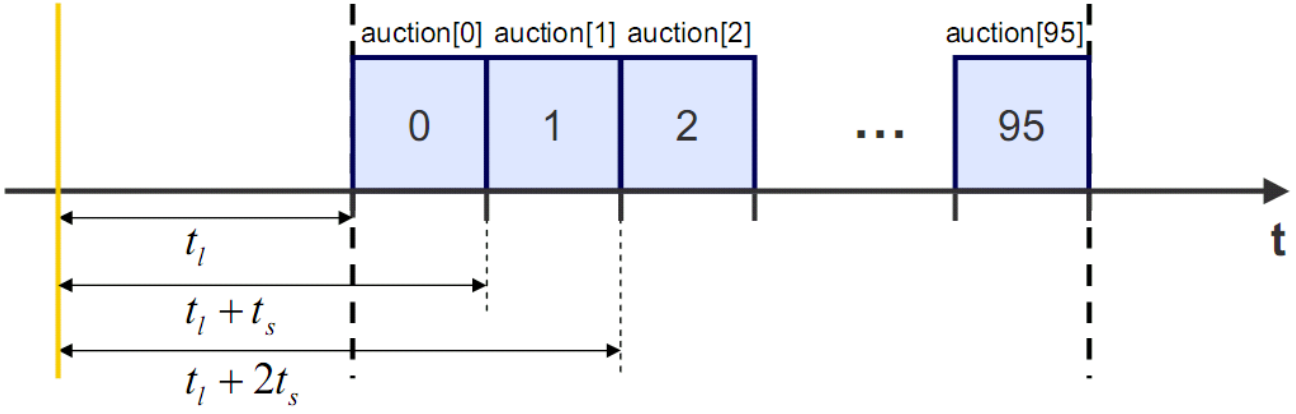
Service Middleware

Energy Grid Infrastructure

Agent Based Demand Side Management

- **Idea:**
  - **Electronic agents employed to buy energy on behalf of consumers (households)**
  - **Agent‘s objective: Meet energy demands for all timeslots at minimum cost**

- **Assumptions:**
  - **Single good (electrictiy) to procure at different (given) quantitites for each timeslot**
  - **Trading on a call market, limit orders only, bid & ask quotes available**
  - **Trading possible until the beginning of a timeslot is reached**



Intuition of Trading Strategy on the demand side

- **Three main environmental factors taken into account :**
  - **Success rate:** $S_{i,\tau}(t) = \gamma\sigma_{i,\tau}(t-1) + (1-\gamma)S_{i,\tau}(t-1)$
  - **Profit Margin:** $\mu_{i,\tau}(t) = \frac{|p_{i,\tau}(t) - \lambda_\tau|}{\lambda_\tau}$
  - **Desperation:** $D(t) = \frac{\epsilon^r_{i,\tau}}{\epsilon^t_{i,\tau}}\left(\frac{t^t_\tau(t) - t^r_\tau(t)}{t^t_\tau(t)}\right)$

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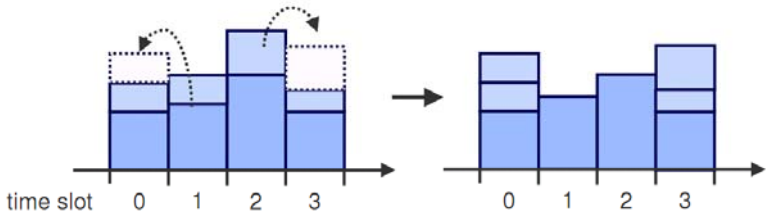
- **Load Shifting:**
  - **Agents can shift certain limited amounts of load from one time slot to another**



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- **Fuzzy rules used to update trading strategy (prices and quantities):**

Fuzzy rule set for bid price updates in t

		Success Rate S		
		Low	Medium	High
Profit Margin μ	Low	Decrease	NoChange	IncreaseMuch
	Medium	Decrease	NoChange	IncreaseMuch
	High	DecreaseMuch	NoChange	NoChange

Fuzzy rule set for bid quantity updates in t

		Desperation D		
		Low	Medium	High
Profit Margin μ	Low	VeryLow	Medium	High
	Medium	Medium	High	VeryHigh
	High	VeryHigh	VeryHigh	VeryHigh

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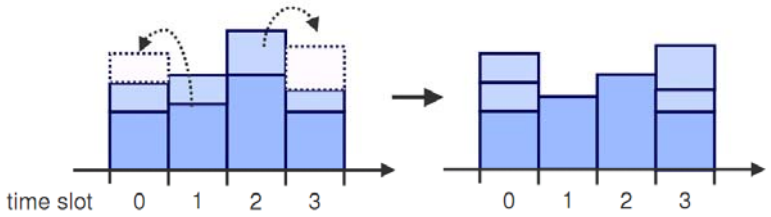
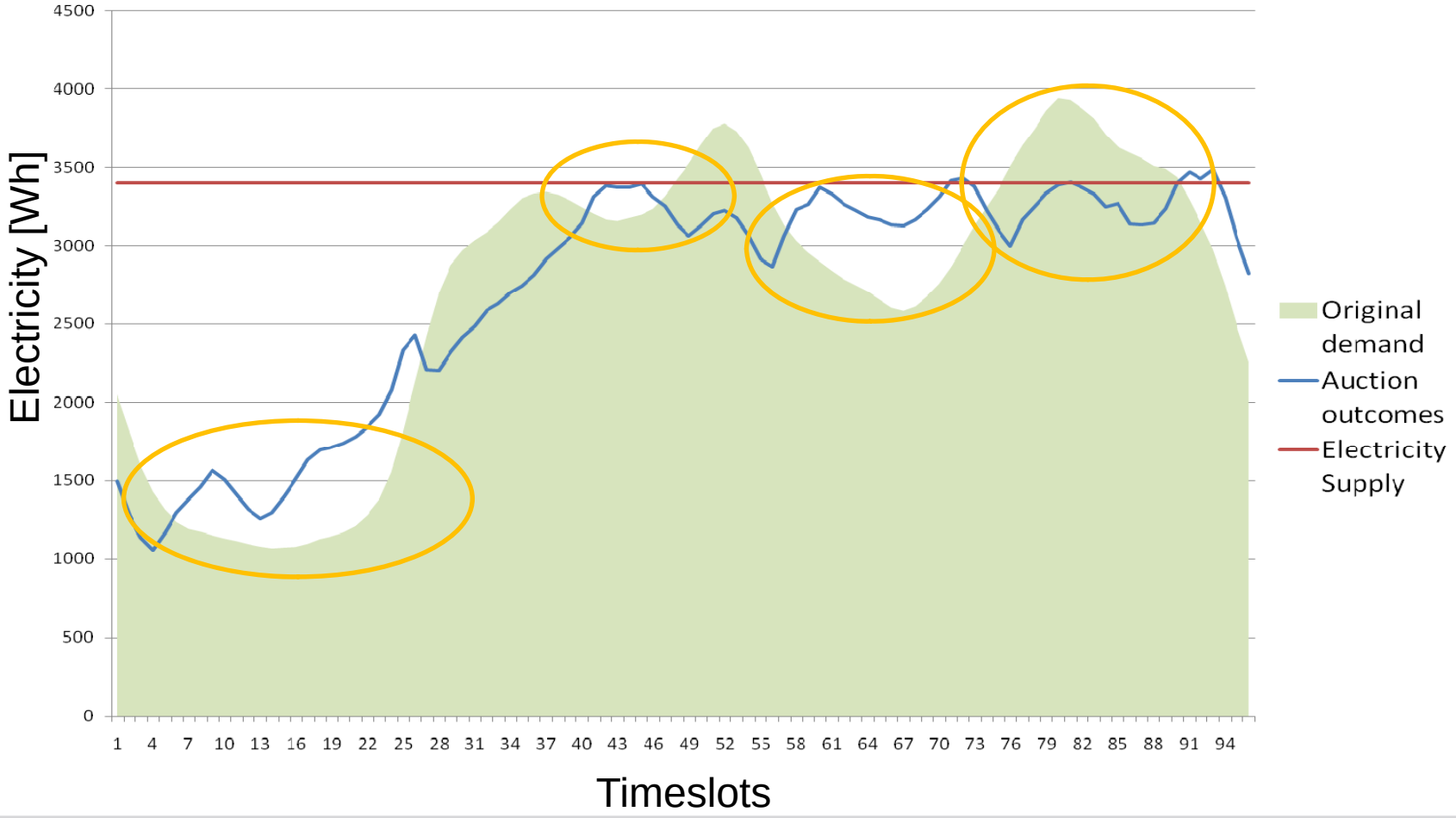


First Results from Load Shifting simulations

Setup:

- 20 Consumer Agents with given VDEW H0 Load Profiles
- Load shifting limited to +/- 15% of the original load

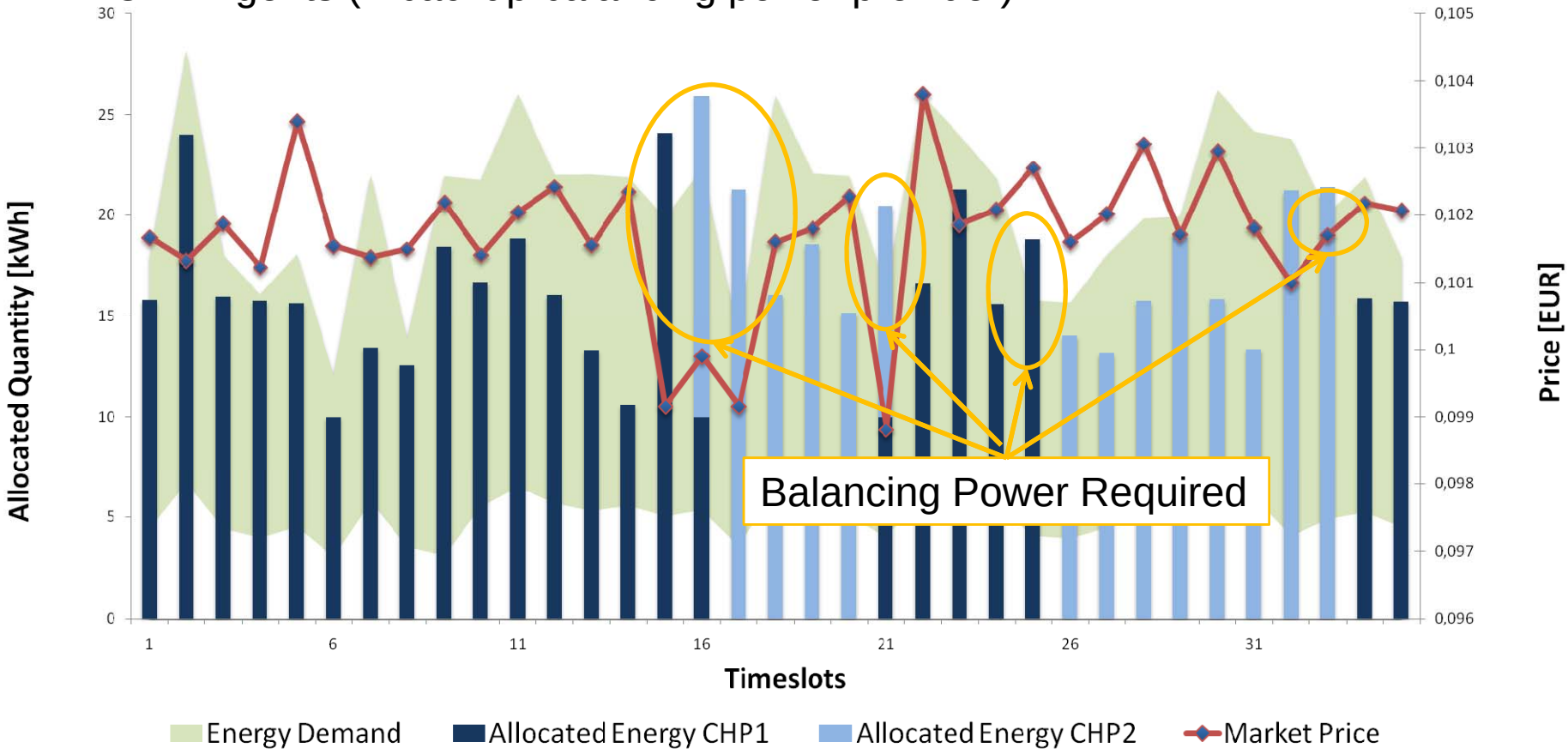


First Results from Market Simulations

Sample Setup:

[Research in Progress]

- 20 consumer agents with volatile (random) load profiles
- 2 CHP Agents (+ backup balancing power provider)



→Preliminary Finding: Market is self-balancing most of the time

First Results from Market Simulations

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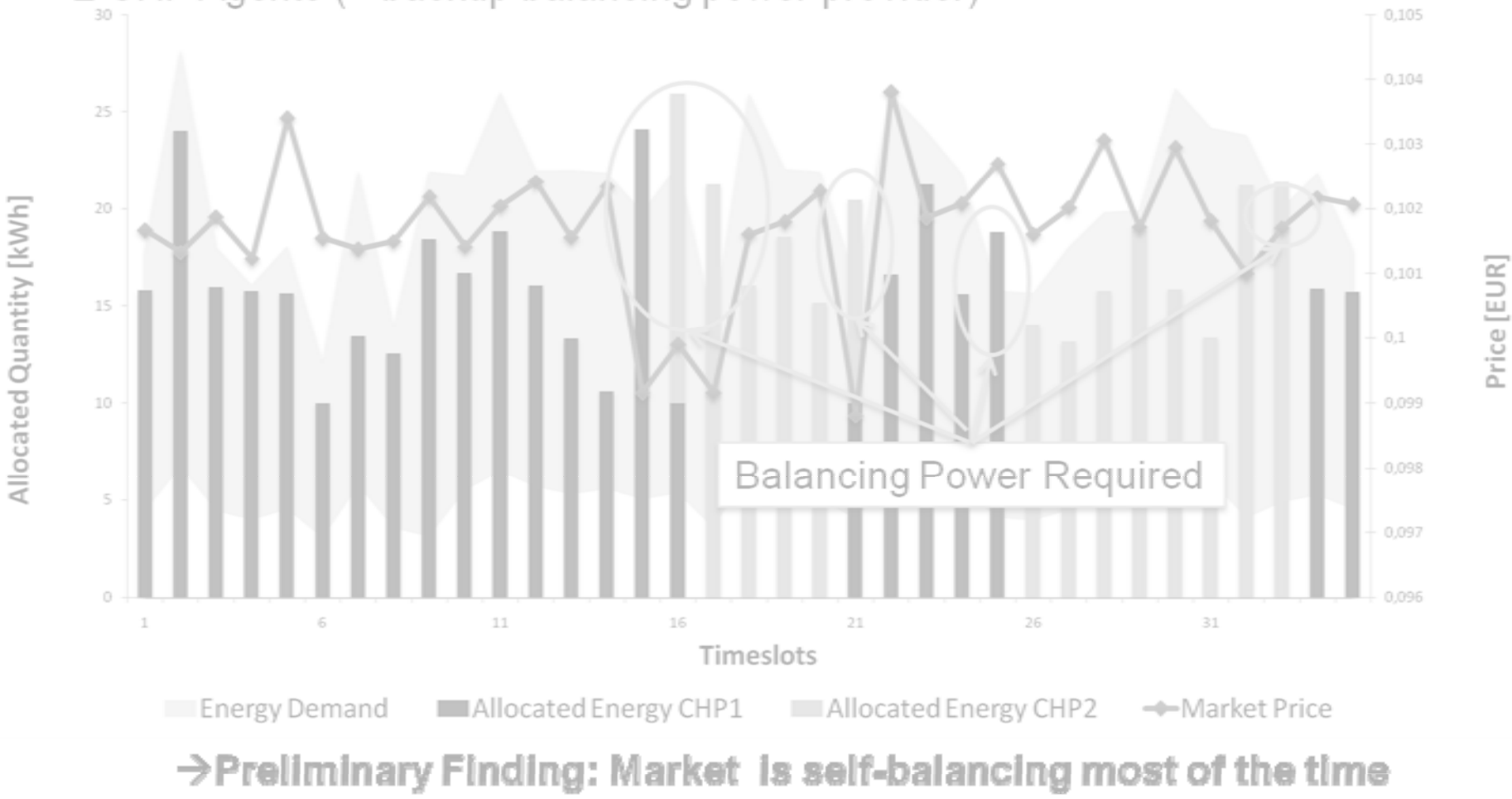

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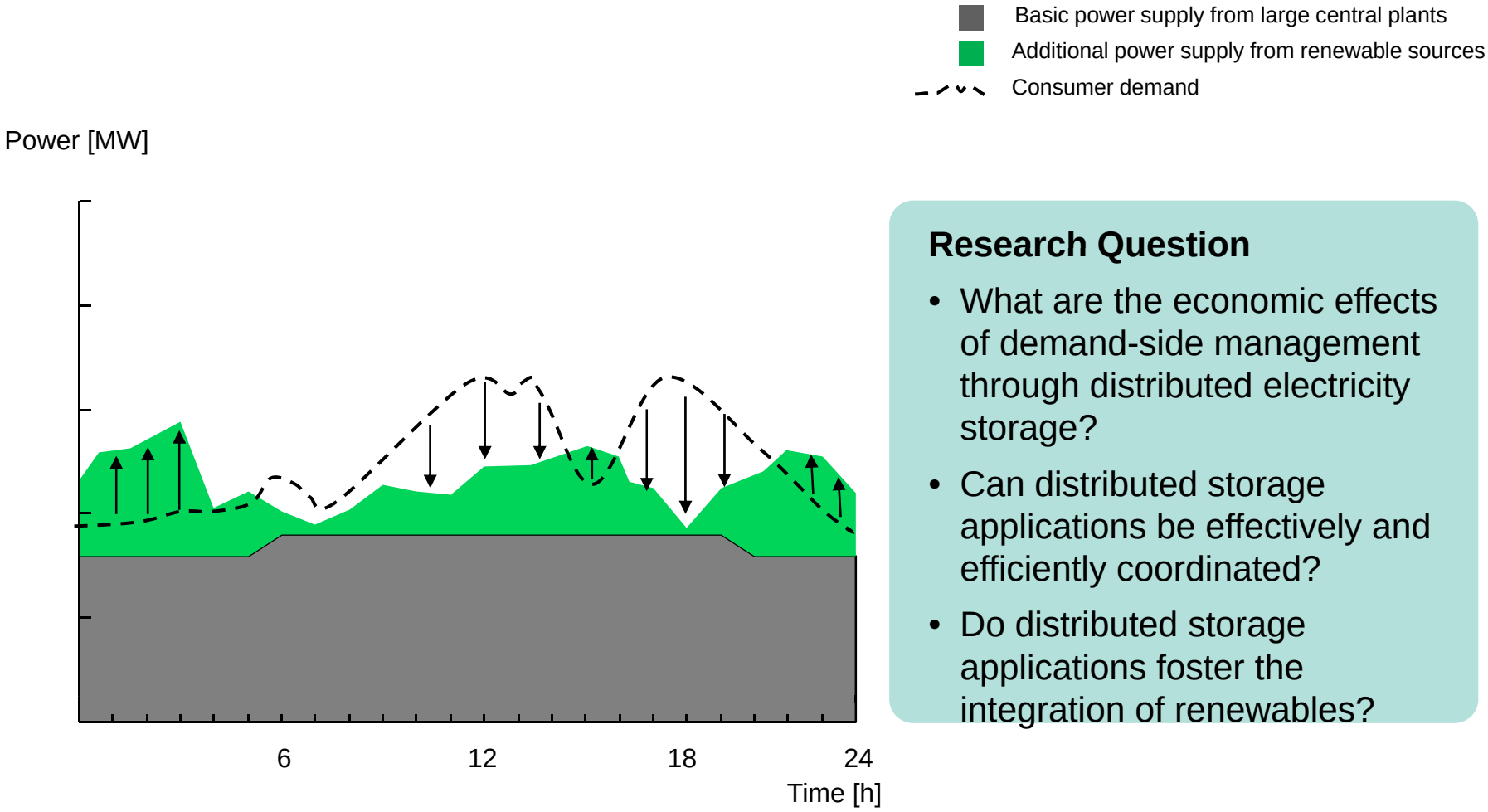
Increasing flexibility of power demand will lead to greater utilization of renewable energy sources

ILLUSTRATIVE

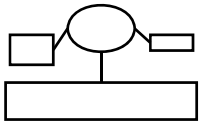


Research Question

- What are the economic effects of demand-side management through distributed electricity storage?
- Can distributed storage applications be effectively and efficiently coordinated?
- Do distributed storage applications foster the integration of renewables?

Analyzing a Storage System has several Dimensions

(Klaus Henning Ahlert)



Analysis and assessment of economic benefits

- Benefits through arbitrage accommodation
- Dependency of results from single input variables

Market Parameters

- Price curve granularity
- Price curve distribution
- Average market price
- Interest rate

Consumer Parameters

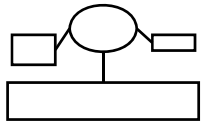
- Annual demand
- Load curve distribution

Storage System Parameters

Capacity	*Power*	*Efficiency*	*System Life Time*
Max. storage capacity	Input power (rectifier)	Rectifier efficiency	Peripherals' life time
Cost rate per capacity unit	Output power (inverter)	Storage efficiency	Average depth of discharge
Max. charging speed	Cost rates per power unit	Storage self-discharge	System temperature
Maintenance cost	Maintenance cost	Inverter efficiency	

Source: Built on Kowal and Sauer, 2007

Data Sources and Assumptions



Market prices are hourly prices with a distribution as on the EEX in 2007

lysis and assessment f economic benefits

- Benefits through arbitrage accommodation
- Dependency of results from single input variables

Market Parameters

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- Price curve distribution
- Average market price
- Interest rate

Consumer Parameters

- Annual demand
- Load curve distribution

Single household with 2000kWh annual consumption and a demand profile according to the VDEW standard profile

Storage System Parameters

Capacity	*Power*	*Efficiency*	*System Life Time*
Max. storage capacity	Input power (rectifier)	Rectifier efficiency	Peripherals' life time
Cost rate per capacity unit	Output power (inverter)	Storage efficiency	Average depth of discharge
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Source: Built on Kowal and Sauer, 2007

Formulation of the Linear Optimization Model
➡ CPLEX Simuation

1.

$$\min \rightarrow K^{fix} + \sum_{t=1}^{T} K_t^{variable}$$

2.

$$K^{fix} = K^{peripherals\_depreciation} + K^{capital\_cost} + K^{maintenance}$$

3.

$$K_t^{variable} = \underbrace{K_t^{market\_supply} - K_t^{storage\_supply} + K_t^{storage\_charging}}_{state-independent} + \underbrace{K_t^{storage\_depreciation}}_{state-dependent}$$

3.1

$$K_t^{market\_supply} = p_t \cdot \ell_t$$

$$K_t^{storage\_supply} = p_t \cdot q_t^{out} \cdot \lambda_t$$

$$K_t^{storage\_charging} = p_t \cdot q_t^{in} \cdot \varphi_t$$

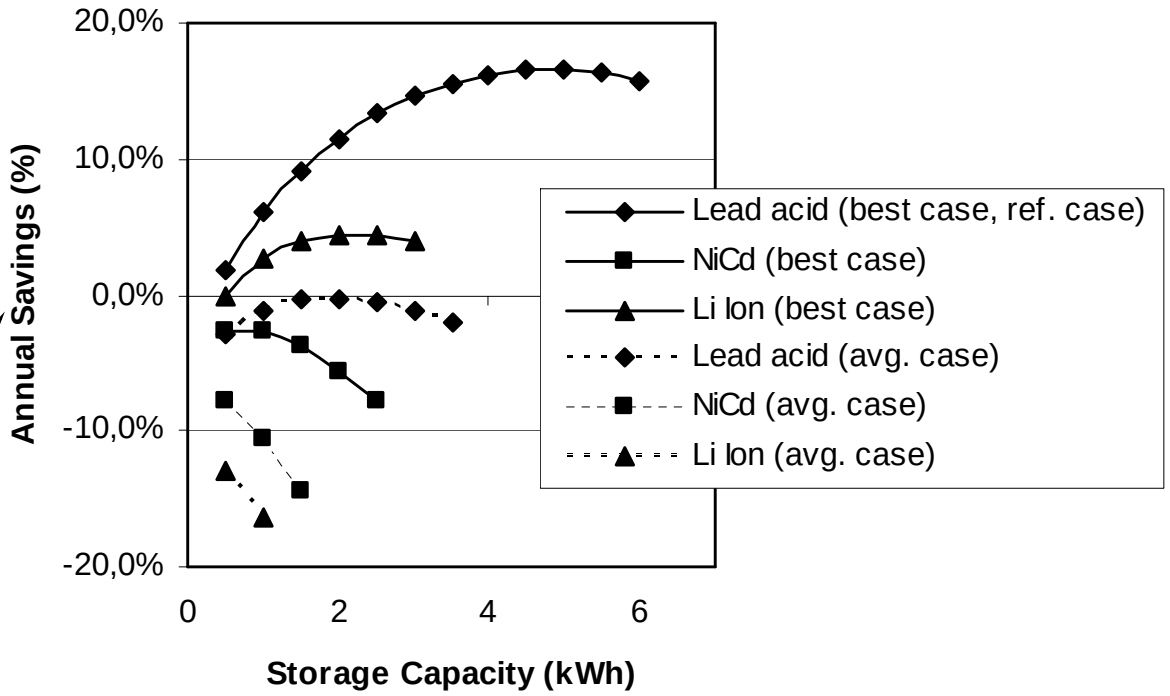
$$K_t^{storage\_depreciation} = \frac{C \cdot \kappa}{\gamma_t} \lambda_t$$

3.2 Potential charge and discharge volumes

$$q_t^{out} = \min\left(\ell_t; \min\left(C; \frac{P^{out}}{T^h}\right)\right) \qquad q_t^{in} = \frac{C}{\eta^{in} \cdot \eta^{store} \cdot v}$$

φ_t : Charge
λ_t : Discharge
p_t : Price
ℓ_t : Load
C : Capacity
κ : Price/capacity unit
P^{out} : Power capacity
η : Efficiency
v : Charging speed
γ_t : Expected charge cycles
T^h : Timeslots/hour

Comparison of different Storage Technologies



calculated versus a baseline case **without** a storage device (VDEW load profile + EEX prices)

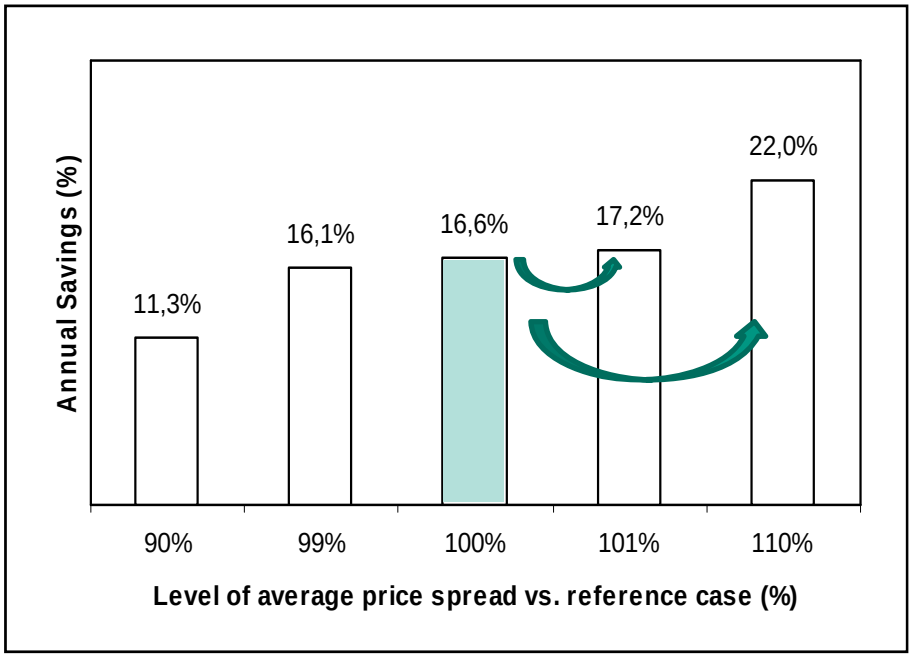
Scenario:
- EEX market prices constant
- Consumer profile constant

- Storage Technologies varied, size of the storage system (capacity) varied

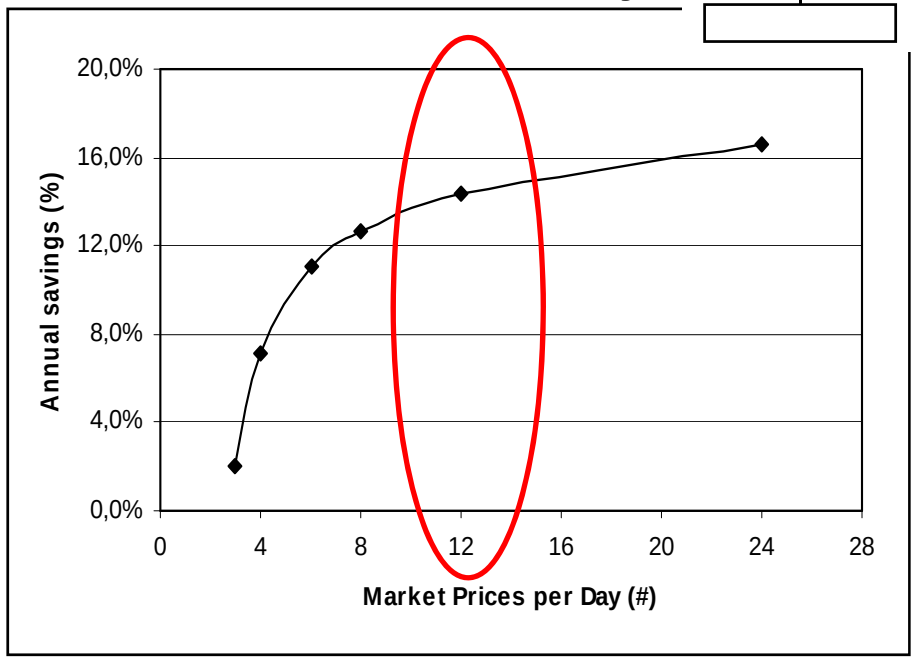
- Lead-acid technology shows best performance
- Arbitrage accommodation leads up to 17% annual savings
- Storage cost seem to be the most important parameter

Price Curve Characteristics impact Results significantly

Average Price Curve Spread



Price Curve Granularity

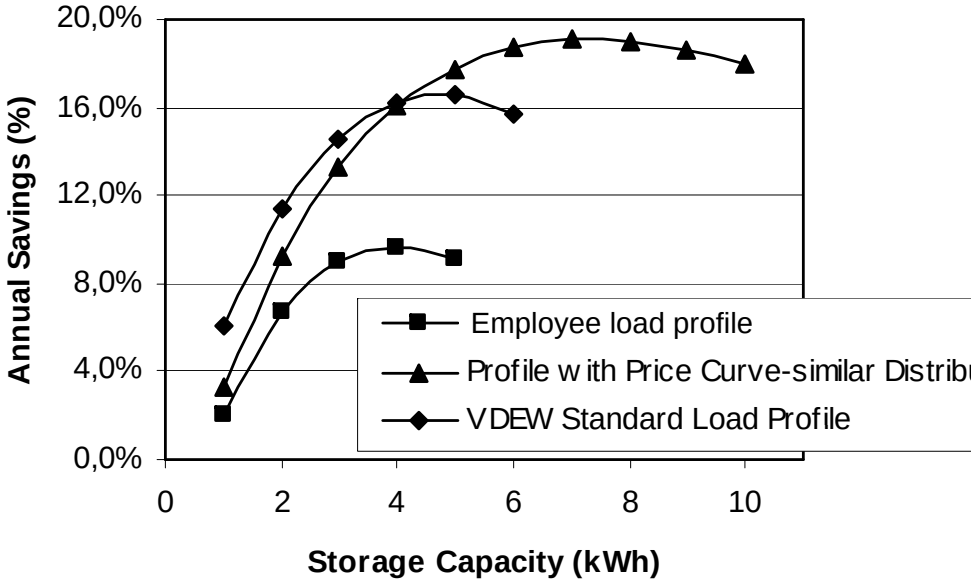


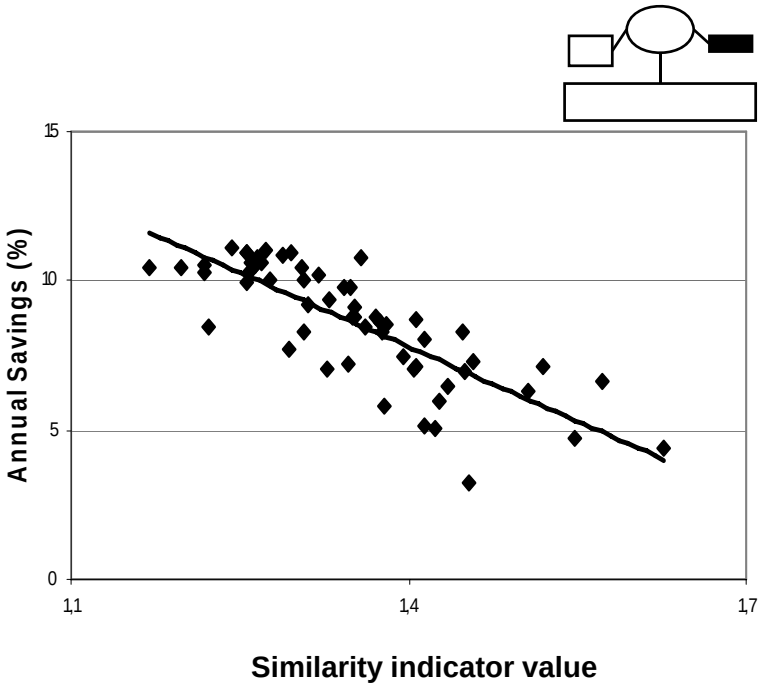
Scenario:

- Consumer profile constant
- Storage Technology constant (reference case with best case of lead-acid battery)
- EEX market prices varied

- Price spread and price granularity variations have a significant impact on the annual savings
- If the share of renewable energy sources increases (expected), price volatility also increases, e.g., spreads will increase
- In Germany, utilities must offer time-dependent or load-flexible tariffs from 2011 onwards (§40 (3) EnWG) – but price granularities are not yet described!

Load Curve Variations





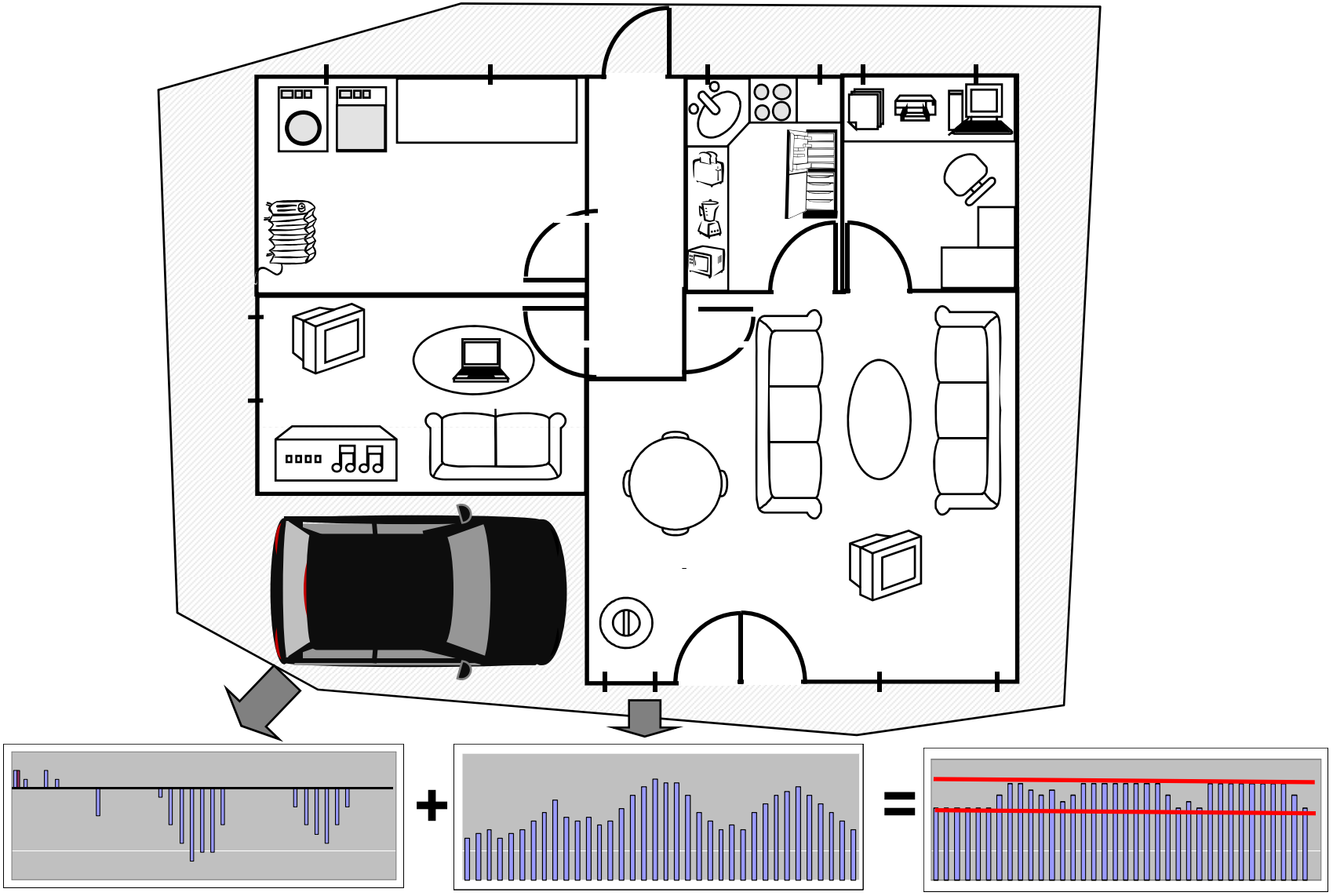
Scenario:
- EEX market prices constant
- Storage Technology constant (reference case with best case of lead-acid battery)
- Consumer profiles varied

- Achievable annual savings depend on load distribution
- Load curves with similar distribution to the price curve distribution lead to highest savings
- Savings actually correlate with degree of similarity

Further Research – Next Steps

- Presented model operated on ex-ante known data for load and price curves: **Are the required forecasts available** in sufficient quality? What forecast quality level is required?
- Switching from a single user model to a multi user model, i.e., from a market price as an exogenous variable to an endogenous variable: How to **design a mechanism providing a coordination signal** that efficiently allocates the market?
- What is the tipping point until storage capacity on the grid can economically be added?
- What potential can be seen in storage within Electric Vehicles vs stationary storage systems?

MEREGIOmobil: Integration of mobile storage



Agenda

- Motivation
- Service Innovation in Energy Markets
- Engineering Future Energy Markets
  - Example: Agent-Based Trading in Micro Grid Markets
  - Example: An Economic Energy Storage Model
- Some more Services...>>> >
- TODOS for an Energy Efficient Future

IT links the Energy Grid to the Service Layer

Regional Energy Markets

Virtual Power Plants

Intelligent Consumers

Energy Dimensioning / Management

Energy Certificates

Services

Service Middleware

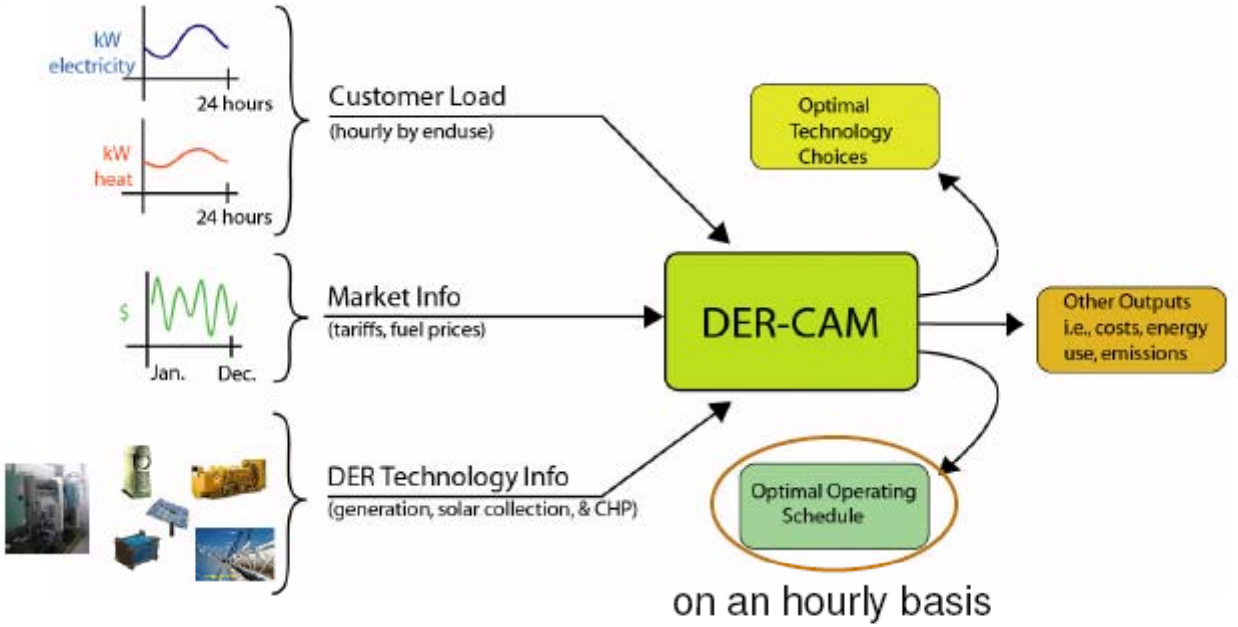
Energy Grid Infrastructure

A central planning concept

(Lawrence Berkeley National Laboratories, C. Marney, M. Stadler)

DER-CAM Concept

Distributed Energy Resource Customer Adoption Model
for Building Energy Use Optimization

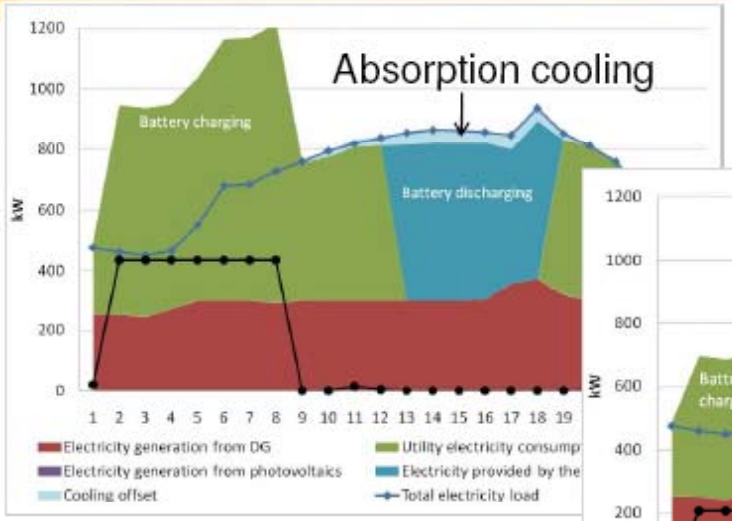


Environmental Energy Technologies Division

A central planning concept

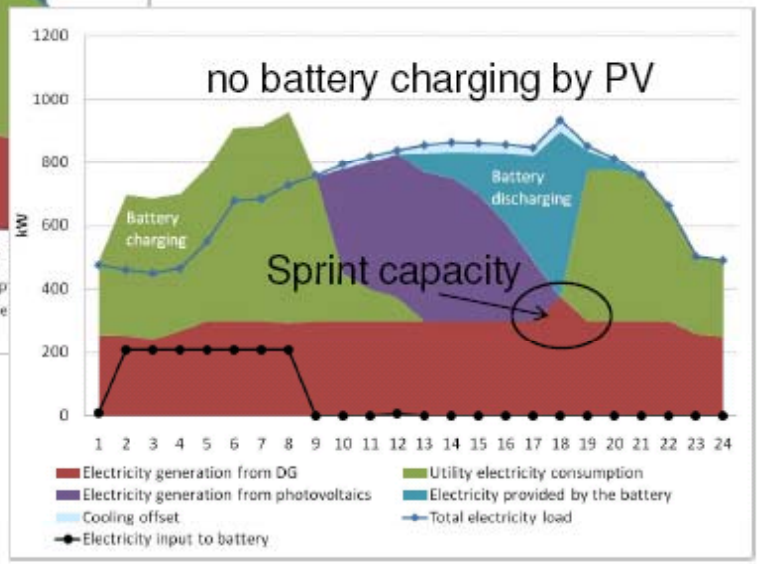
(Lawrence Berkeley National Laboratories, C. Marney, M. Stadler)

CA Nursing Home



Case C: Diurnal Electricity Pattern for the CA Nursing Home on a July Weekday

Case E: Diurnal Electricity Pattern for the CA Nursing Home on a July Weekday

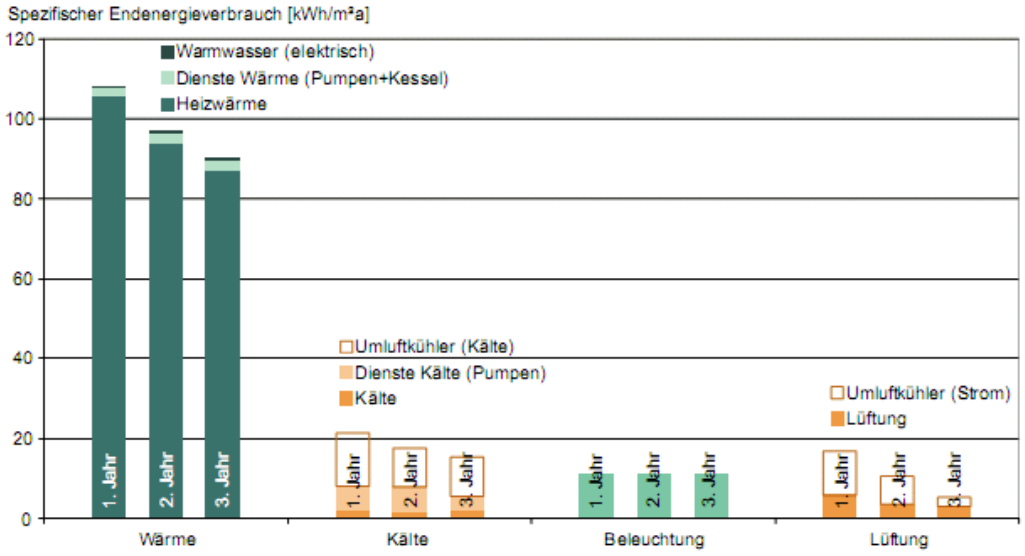


Environmental Energy Technologies Division

Optimal Dimensioning of Micro Energy Grids

Carsten Block

- DER-CAM Model as the underlying optimization model
- First pilot case study currently under investigation *(by Alexander Schuller)*
- KfW Ostarkaden (Mixed office & living, Frankfurt / Main)
  - Hourly consumption profiles available for 2003 – 2005
  - Energy concept developed by ftba (KIT/Uni Karlsruhe)
  - Average energy consumption by energy type:

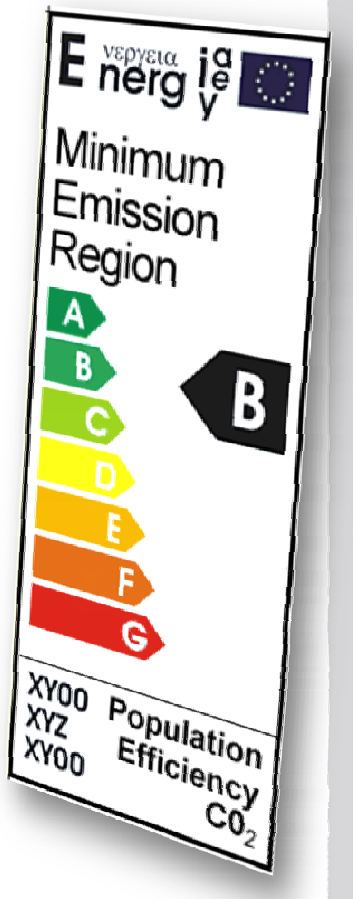


Optimization Service

MEREGIO: Regional Emission Certification:
A Decentralized Incentive Mechanism

Minimum Emission Region Certification

- Certification of demo regions as blueprint for others
- Audit and certification process
  ….provides regions with concrete measures on how to reduce their energy footprints



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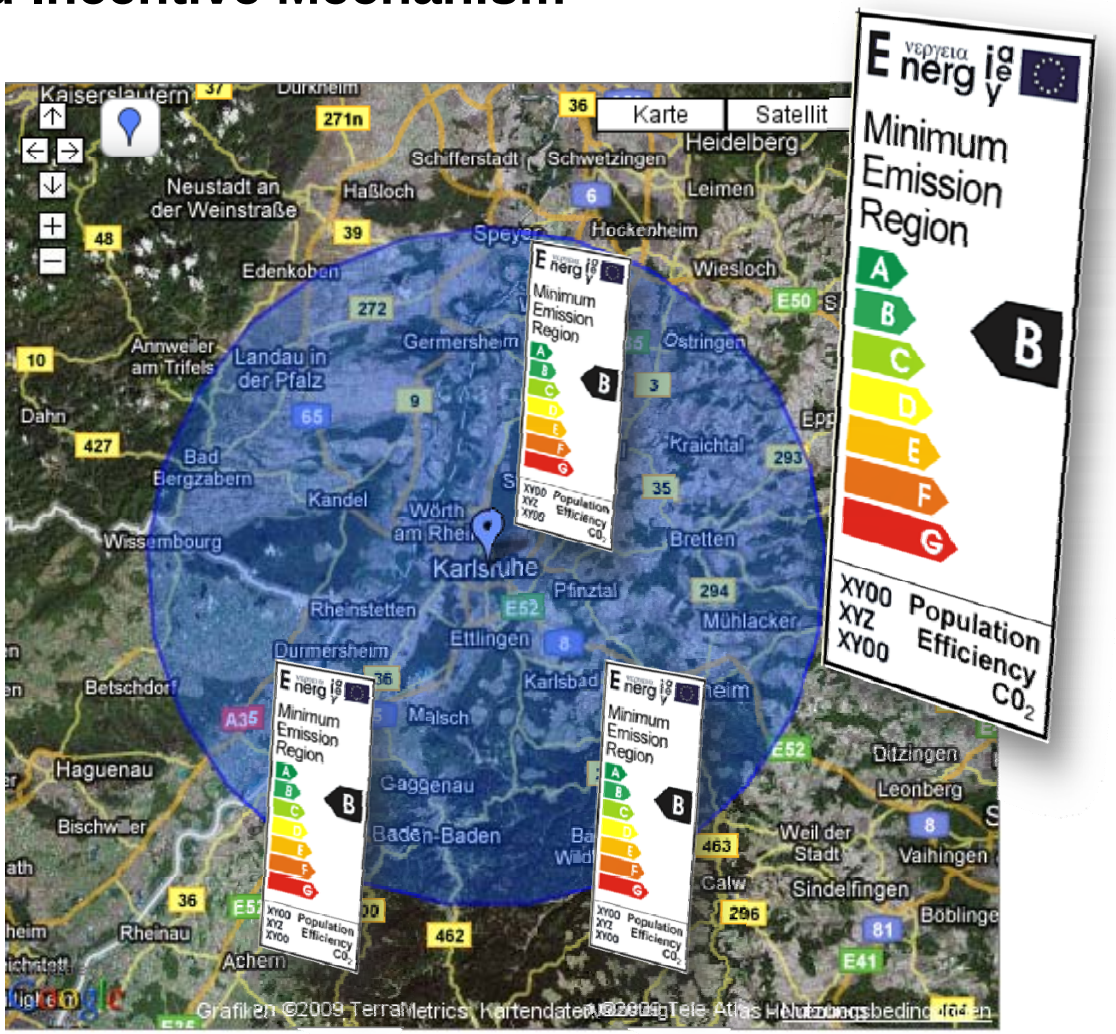

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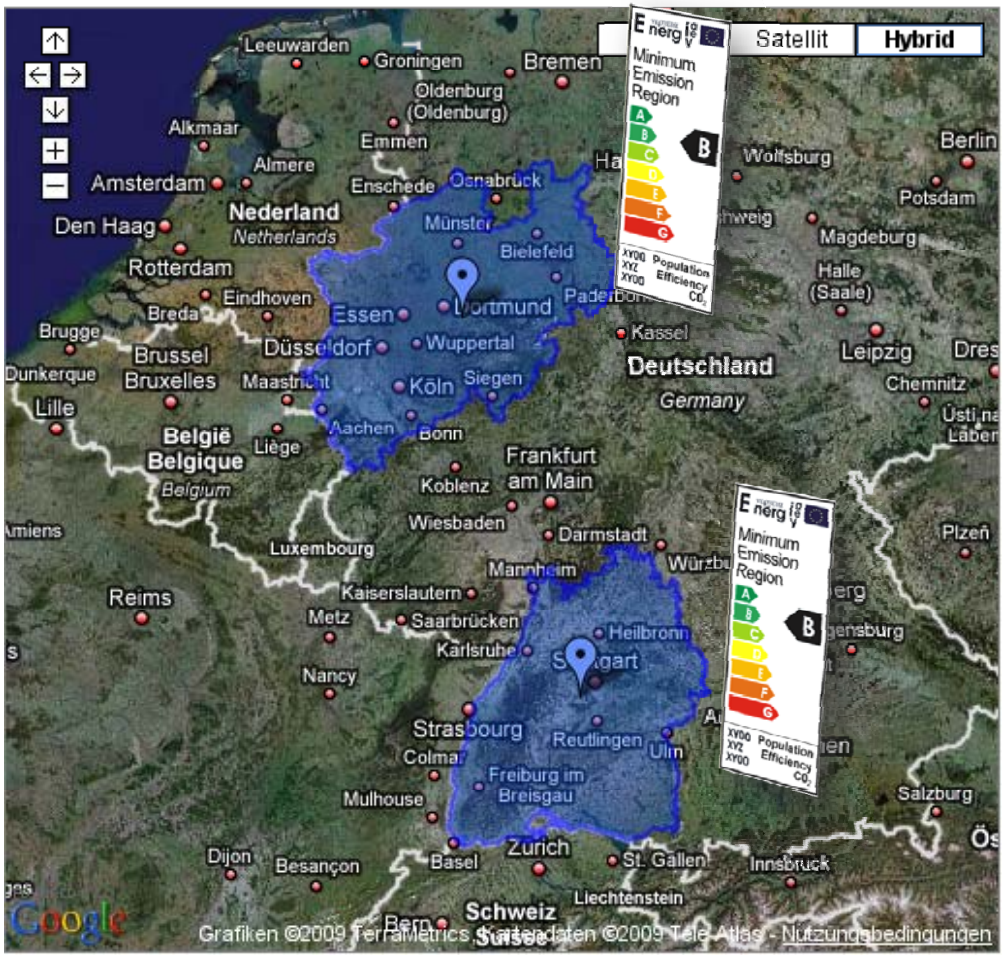

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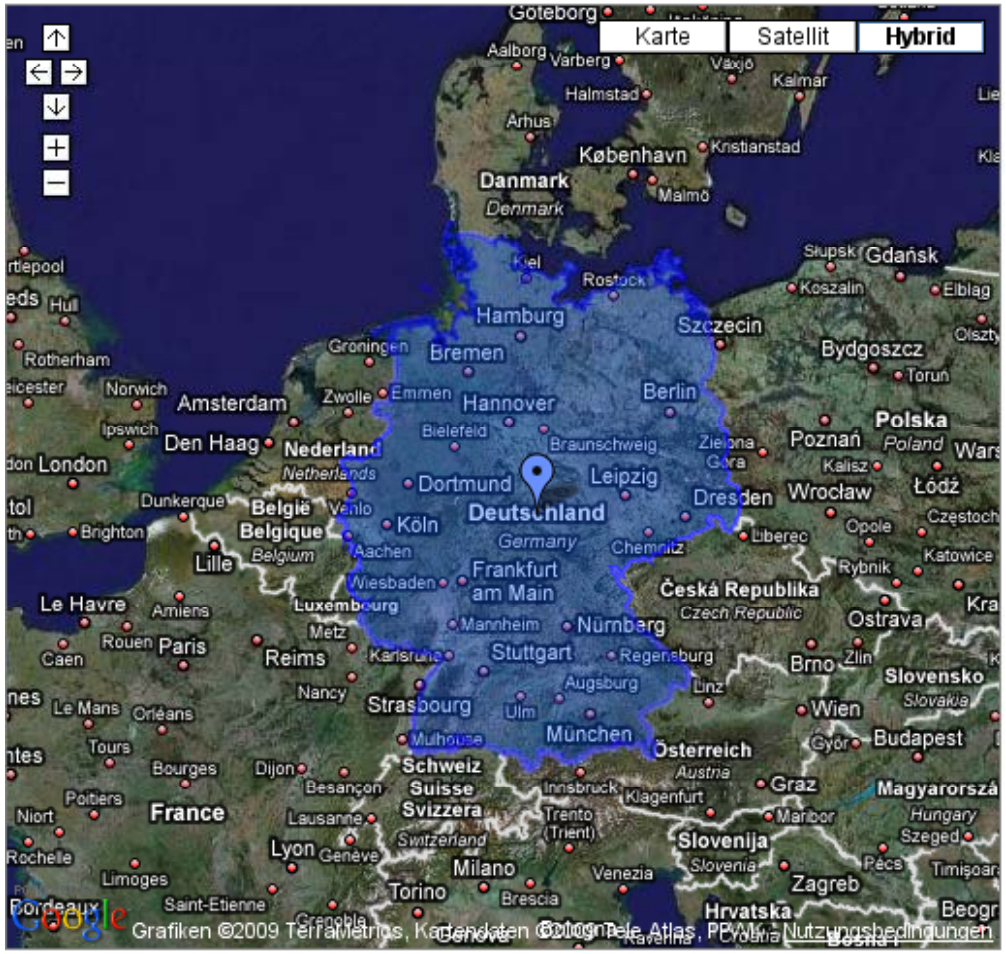

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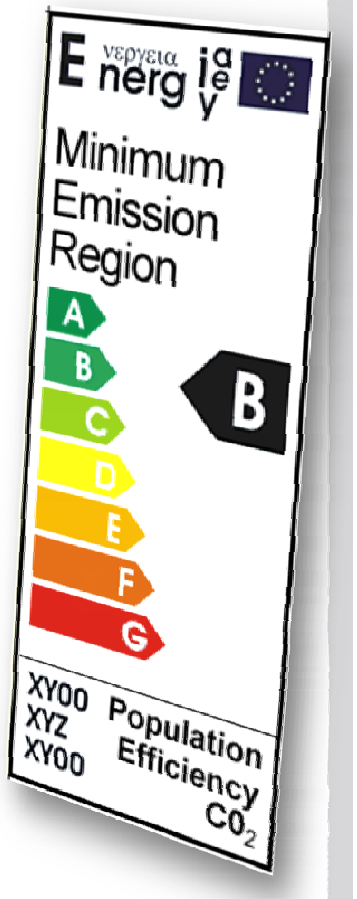
  ….provides regions with concrete measures on how to reduce their energy footprints
- The regional certification
  - … helps regions attract people and businesses
  - … an opportunity for the legislator to introduce targeted funding / taxation schemes
  - … fosters an “energy efficiency competition”
  - … ultimately leads to overall better efficiency



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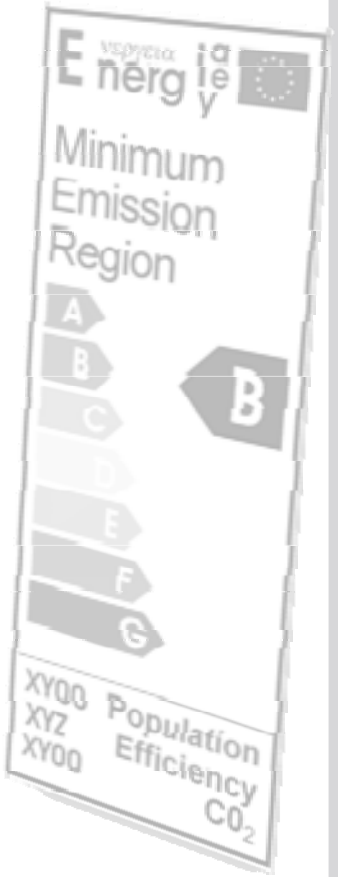

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TODOS for an Energy Efficient Future

TODOS for an Energy Efficient Future

Factors	Leverage	Initiatives
	•De-/Centralized Planning •Market of regional Markets •Regional Certification •…	•Klimaschutz-kommune 2009 •MEREGIO •…
	•Dynamic Community Formation - geographically - Demand/Supply profiles •Dyn. Pricing/Contracting •Regulated Self-Regulation	•SESAM •Powermatcher •…
	•Open Service Interfaces •Open ~~Handset~~ Energy Alliance •…	•BDI Initiativ •CISE, Oldenburg •…
	•Smart Metering •End-To-End Connectivity •…	•Figawa / ZVEI •Cenelec •…

TODOS for an Energy Efficient Future

Thanks for Your Attention

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