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On Incentive-Based Market Design for Incorporation of Renewable Energy Sources and Demand Response

Presentation “Frontiers in Energy Research”, ETH Zürich, Zürich, 05/26/2014

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Agenda

Introduction to Power Systems / Power Markets

Current Challenges

On Achieving Allocative Efficiency in Power Markets

Demand Response – Engineering vs. Economics

Conclusion

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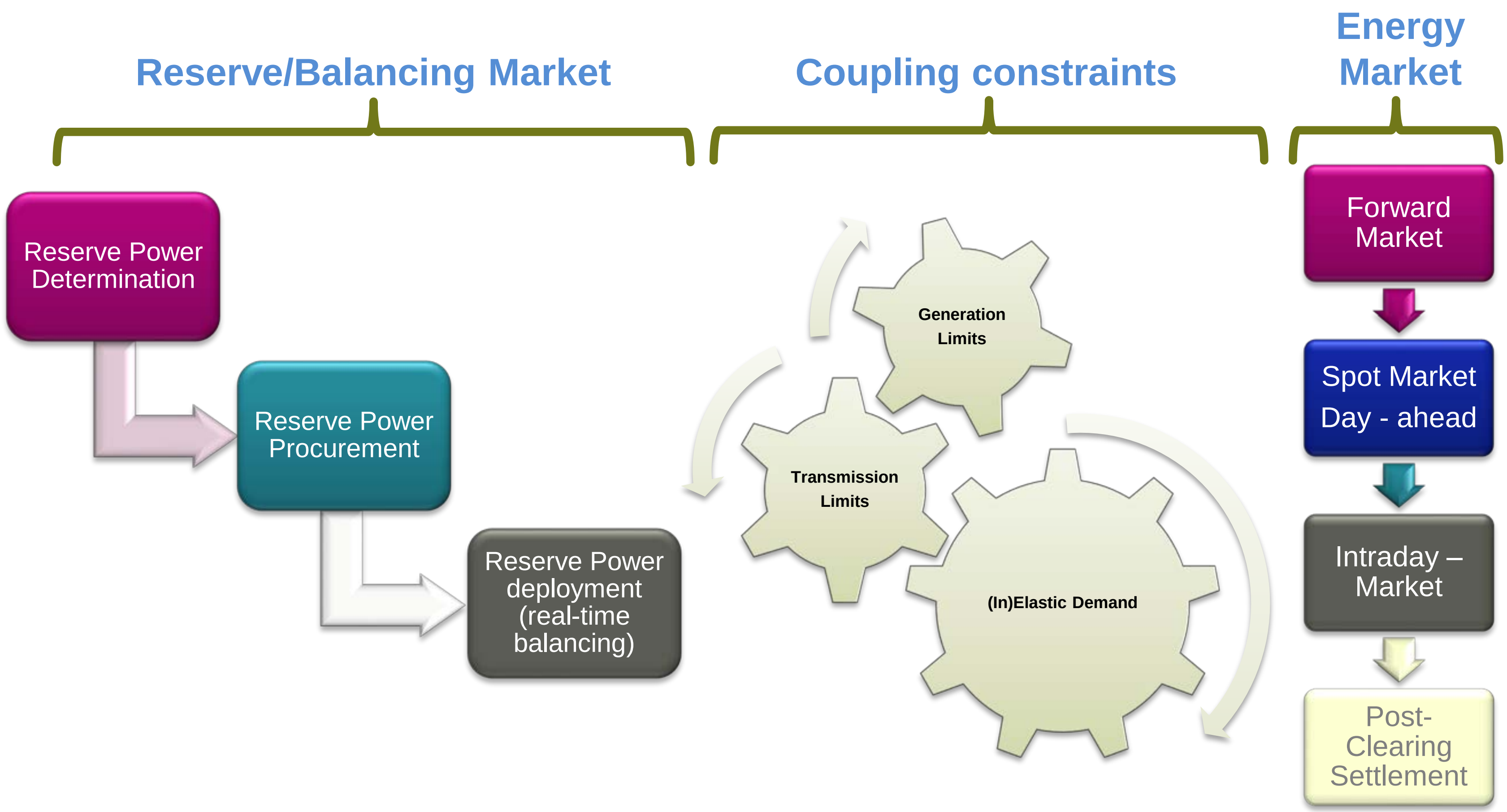
What is a power system?

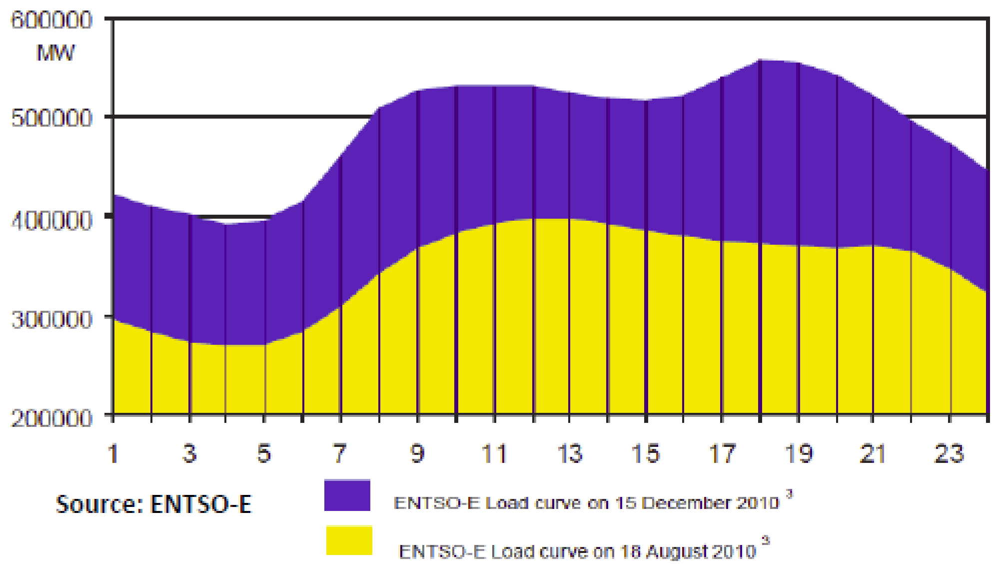
- Power System = Multi-Stage-Decision Making Process
- Economic interests vs. technical constraints



Power Systems in Comparison – Key Figures

Metrics (2010 Data)	EU+	Contiguous U.S.
Population	≈ 530 million	≈ 310 million
HV lines (≥220kV)	≈ 287,300 km	≈ 300,000 km
Peak load demand	≈ 550 GW in Winter ≈ 390 GW in Summer	≈ 652 GW in Winter ≈ 768 GW in Summer
Yearly load consumption	≈ 3300 TWh	≈ 4200 TWh

EU+: EU-27 + Balkans, Switzerland, Norway

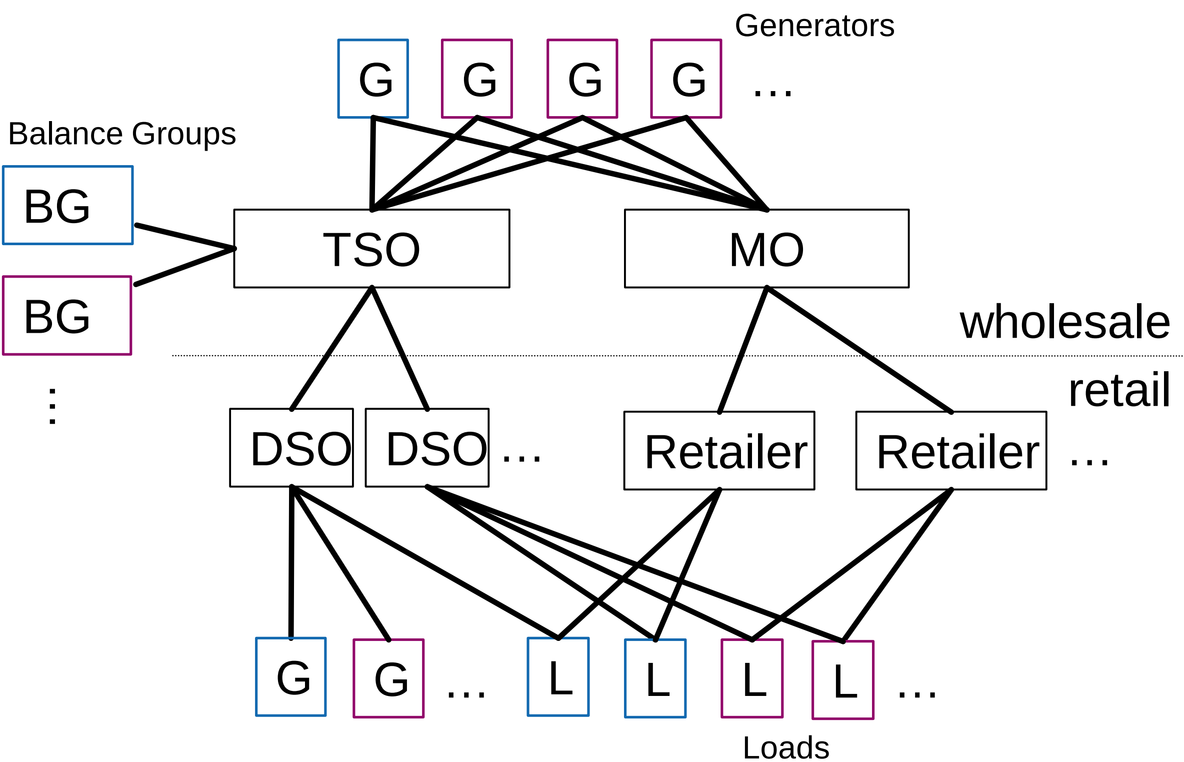


Source: ENTSO-E

Source: Ulbig (2012)

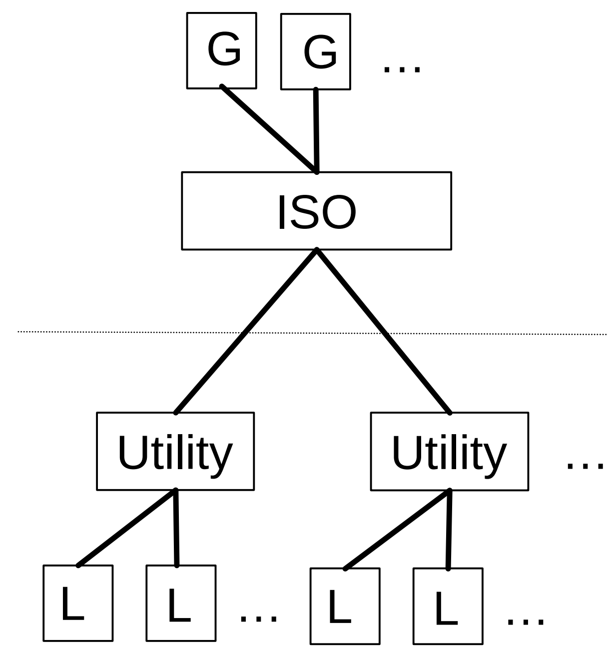
Power Systems in Comparison - Institutions

European Setup



TSO … Transmission System Operator
MO … Market Operator
DSO … Distribution System Operator

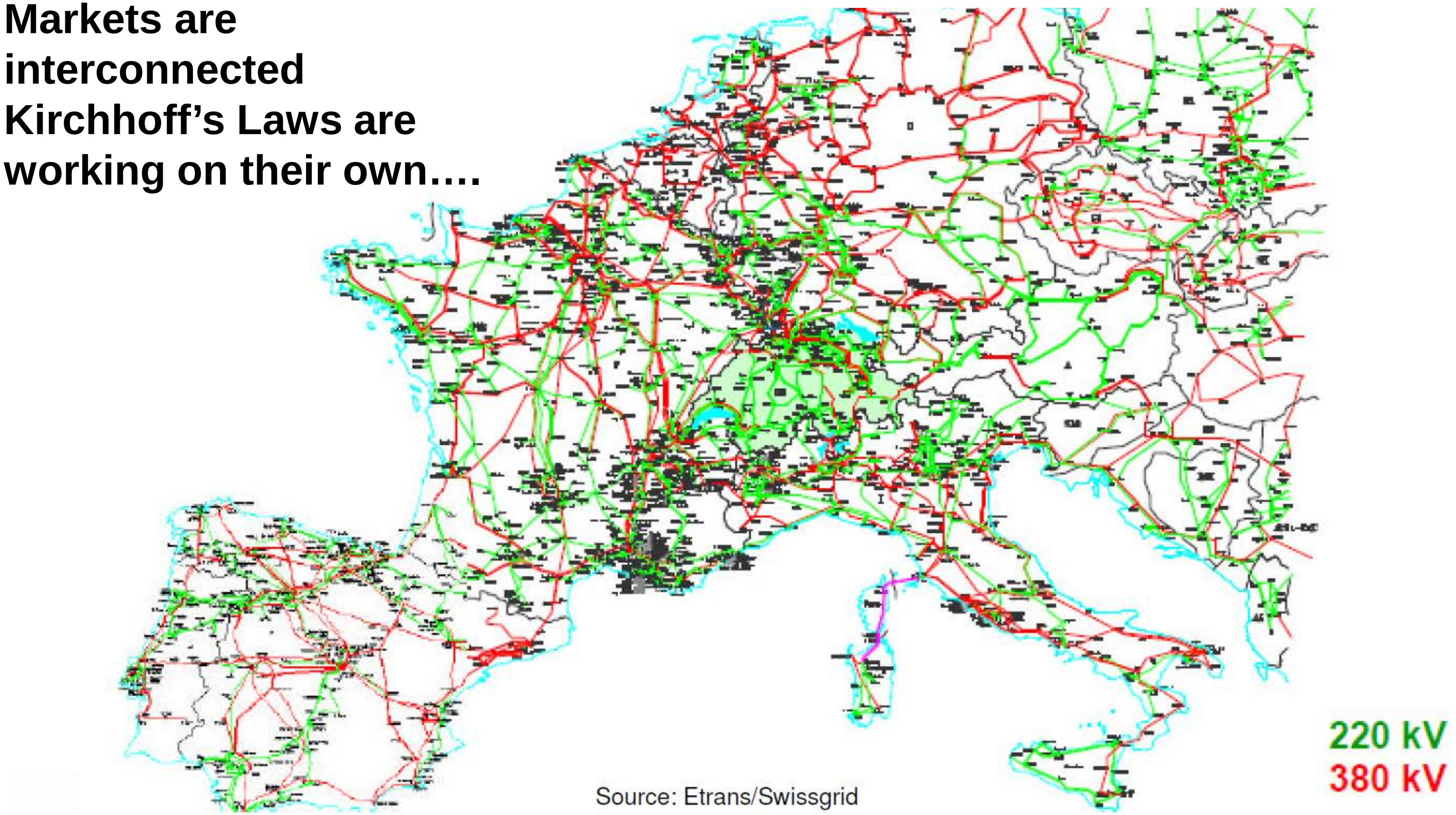
US Setup



«ISO = TSO + MO»

The Grid….

- **Markets are interconnected**
- **Kirchhoff's Laws are working on their own….**



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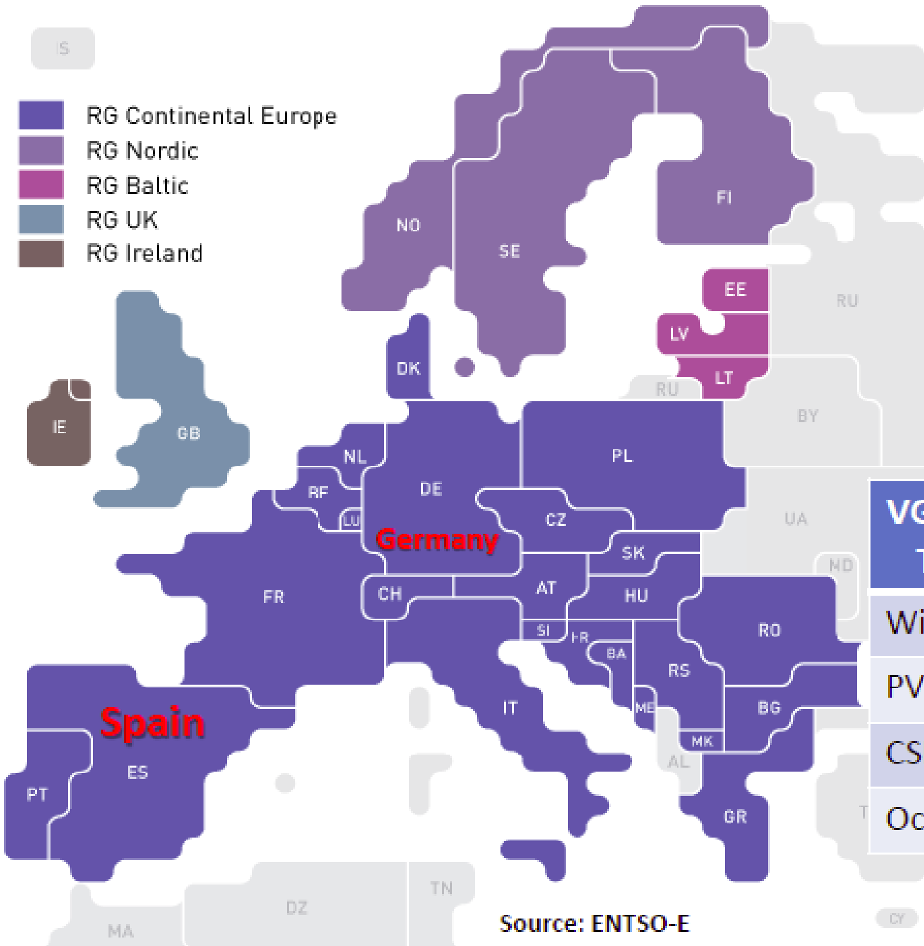
Renewable Energy Injection: An European perspective



Source: ENTSO-E

- ENTSO-E (European Network of Transmission System Operators for Electricity)
- 42 transmission system operators (TSOs) in 34 European countries
- www.entsoe.eu (official website)
- www.entsoe.net (transparency)

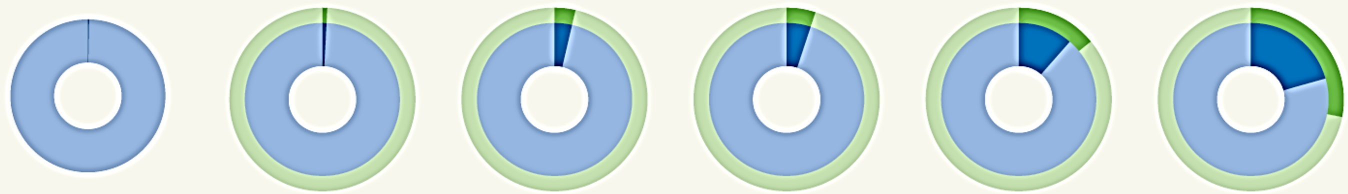
Comparision of VG Deployment (2010)

VG Generation Technology	EU	US
Wind	84 GW ↗	40 GW ↗
PV	29 GW ↗	2.5 GW ↗
CSP	0.6 GW ↗	0.5 GW
Ocean Power	0.3 GW	0 GW

REN21 Global Status Report 2011
(end-of year 2010 installed capacity)

Renewable Energy Injection: An European perspective

EWEA Report 2011- **“ Pure Power: EU Wind Energy Targets for 2020 and 2030**”

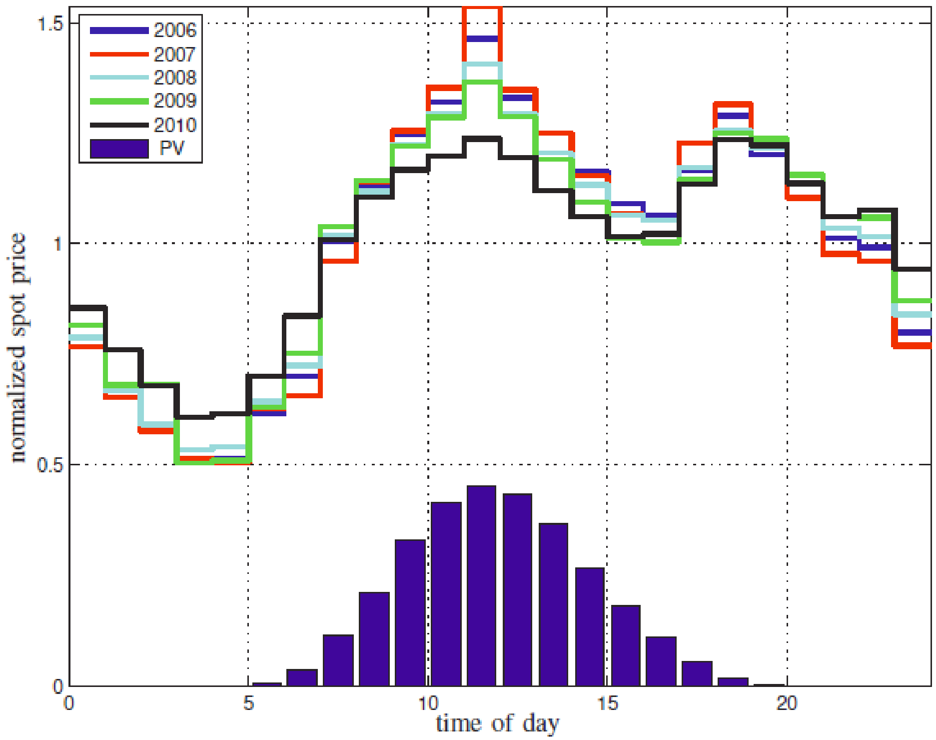


	1995	2000	2007	2010	2020	2030
Wind energy share (reference)	0.2%	0.9%	3.7%	5.0%	11.6%	20.8%
Wind energy (RE & eff. case)		0.9%	3.7%	5.2%	14.3%	28.2%
Wind power production (TWh)		23	119	176	477	935
Reference Electricity demand (TWh)*		2,577	3,243	3,554	4,107	4,503
RE & Eff, case Electricity demand (TWh)*		2,577	3,243	3,383	3,345	3,322

Renewable Energy Injection: An European perspective

Intermittent RES-infeed requires **more power system flexibility/operational reserves**:

- Pumped-Hydro, **but…..**
- Another solution: distributed storage and demand response, **but ….**

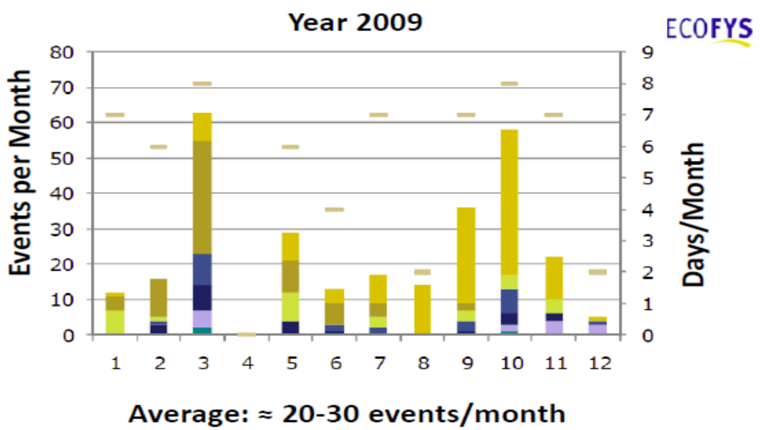


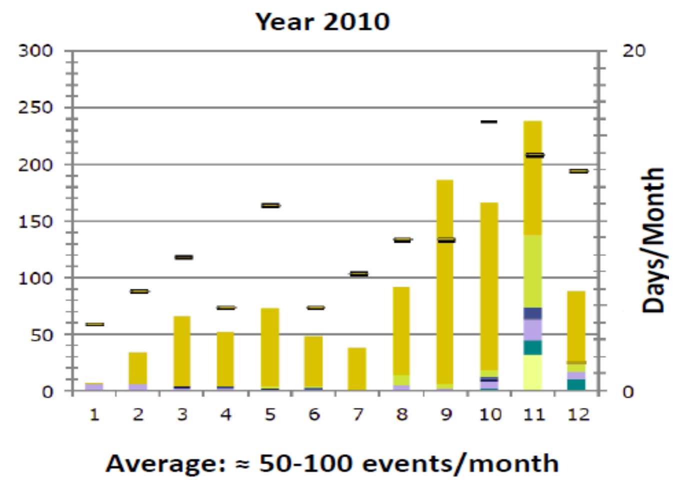
YEARLY PEAK BASE SPREAD ζ AND NET ARBITRAGE POTENTIAL Δ_{net}

Year	ζ	Δ_{net} $[\frac{€}{MWh}]$	P_{spot}^{base} $[\frac{€}{MWh}]$
2006	1.59	17.06	50.79
2007	1.64	15.00	37.99
2008	1.51	17.12	65.76
2009	1.46	8.09	38.85
2010	1.33	3.71	44.49

Source: Hildmann (2011)

Renewable Energy Injection: An European perspective





Source: Jens Bömer, Ecofys

Remote intermittent RES-infeed requires **transmission capacity**:

- Forced curtailment of wind power in-feed due to grid constraints (and other contingencies) on MV level → has risen with higher deployment of wind turbines
- WG are paid for the energy curtailed

Renewable Energy Injection: An European perspective

Response in the media:

- IEEE Spectrum, Sept 09, 2013: *German Energy Crisis*
- Bloomberg, Oct 11, 2013: *Europe Risks Energy Crisis From Green Subsidies*

- Bloomberg, Oct 13, 2013: *Clean Energy Investment Headed for Second Annual Decline*

How to improve desirable goals of sustaining electricity markets?

Key point: Efficiency in Cost Allocation (first part of the talk)

- In-Feed tariffs and Grid tariffs but…
  - → make **intermittent units and demand responsible** for their schedule
  - → **Cost allocation of reserves** based on socialization gives no incentives to reduce balancing requirements
  - → **Reliability at a price**

Key point: Efficiency in Production (second part of the talk)

- Demand Response can provide backup capacity for frequency regulation but….

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What can be done?

„Symphony“ vs. „Jazz“

↕ ↕ ↕

Market based Incentive mechanisms

“Develop market mechanisms which are proper to reduce costs and allocate the costs of different types of reserves?”

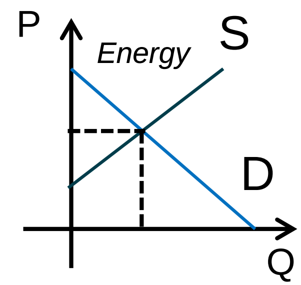
- Event-based reserves: Reserves needed with low probability (i.e. contingency)
- Non-Event based reserves: High probability of utilization (i.e. load following, ramping, etc.)

Cost Allocation Algorithm in a Centralized Market Setup (ISO)

1. Stage:

- Unit commitment for Lost - Opportunity Costs Calculation in Co-Opt Problem
- Unit Commitment → Includes Start-Up Costs and Costs of Operation
- No Reserve Scheduling so far.....

Input: Supply and Demand
Traded Energy



Mixed Integer Linear Program

Unit Commitment

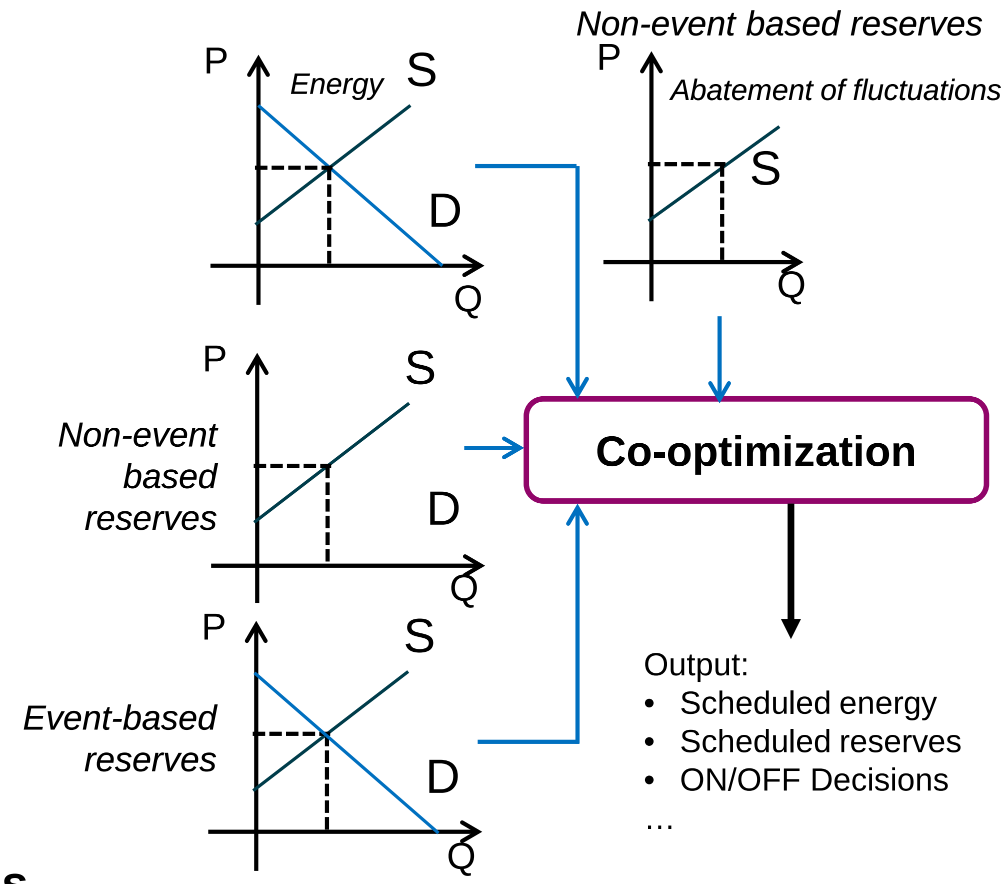
Output:
- ON/OFF Decision
- Dispatch Decision
- Ramping Rates
- Locational Marginal Pricing

…

Cost Allocation Algorithm in a Centralized Market Setup (ISO)

2. Stage:

- Co-Optimization for efficient clearing of energy and reserves
  - Demand for event-based reserves
  - Demand for non-event-based reserves
  - Marginal costs of abating the need for non-event reserves

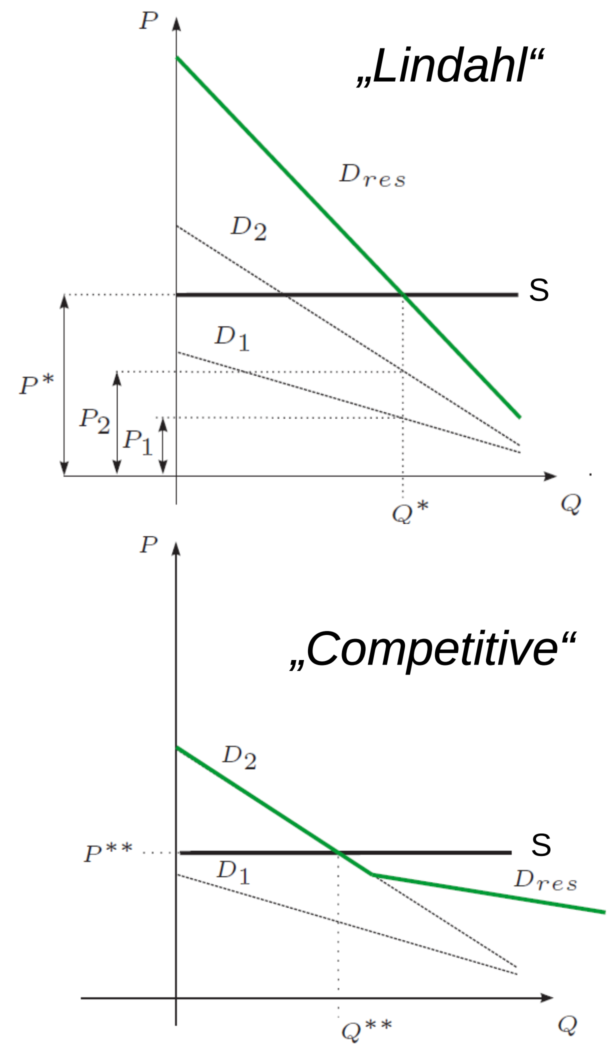


Principles:
- **Cost Causality**
- **Market = decentralized decisions**

- Event-based reserves: Low probability of utilization (i.e. contingency)
- Non-Event based reserves: High probability of utilization (i.e. load following, ramping, etc.)

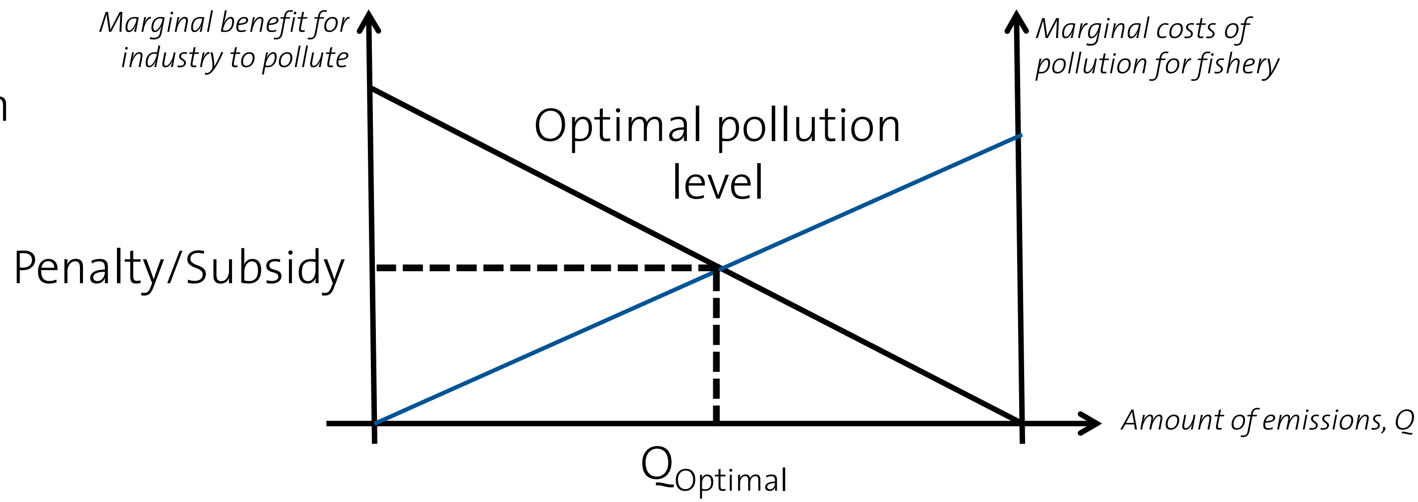
Cost allocation of event-based reserves:

- Consider Reserves as public goods:
  - Non rivalry
  - Non excludability
- Event-based reserve demand per node
  - i.e. interruptible load contracts + direct load control
  - "Vertical addition" of demand curves enables cost sharing → "Lindahl equilibrium"
  - Formal: Samuelson condition



Cost allocation of non-event based reserves

Illustrative Example:
- River pollution
- 2 parties with contradicting goals



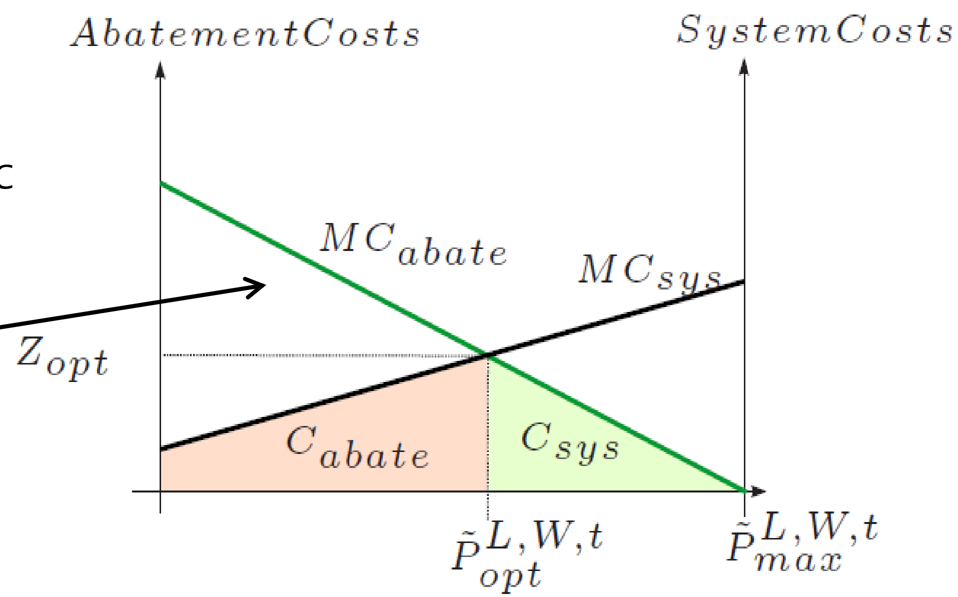
Power System:
- Non-event based reserves/actions:
  - Regulation, ramping, etc. = negative externalities
- Pareto Efficient allocation of costs
  - System costs: i.e. lost opportunity costs, reserve procurement, redispatch cost, ….
  - Abatement costs: i.e. storage reservation, transaction costs, …..

Cost allocation of non-event based reserves

- Sharing penalty/subsidy of avoiding reserve requirements
- Revelation of abatement costs → incentive mechanism necessary

Total injection/demand:

$$P_{total}^{L,W,t} = \underbrace{P_f^{L,W,t}}_{\text{deterministic}} + \underbrace{\tilde{P}^{L,W,t}}_{\text{stochastic}}$$

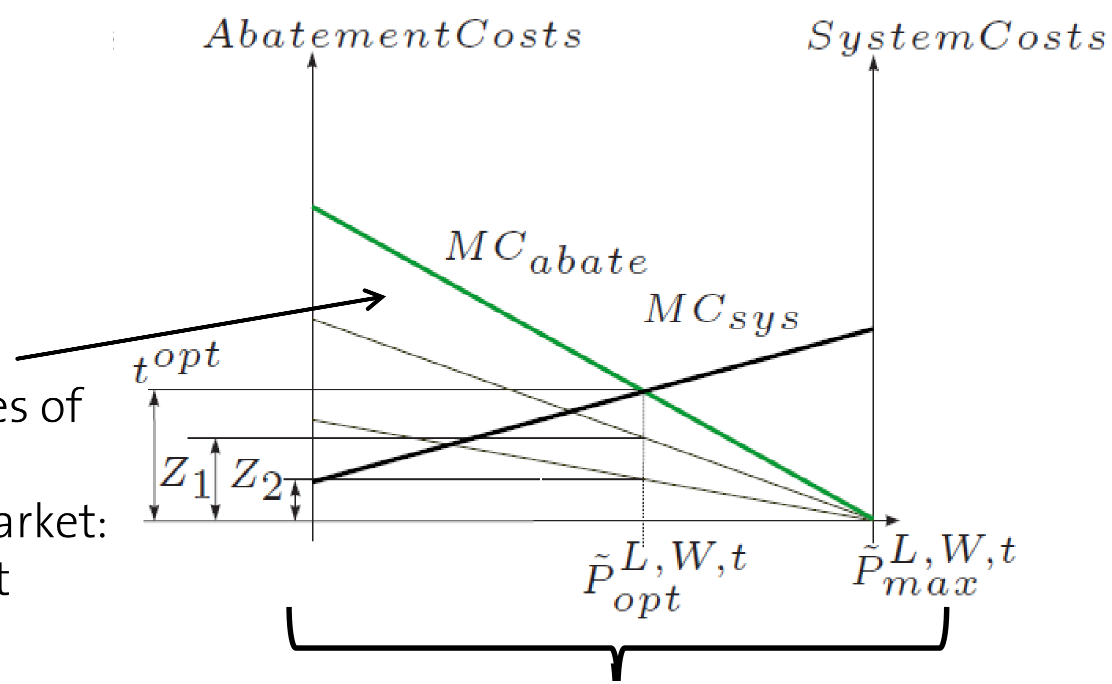


- Sum of cost curves of abatement
- In non-perfect market: incentive to cheat

Pricing of externalities

Cost allocation of non-event based reserves

- Sharing penalty/subsidy of avoiding reserve requirements
- Revelation of abatement costs → incentive mechanism necessary

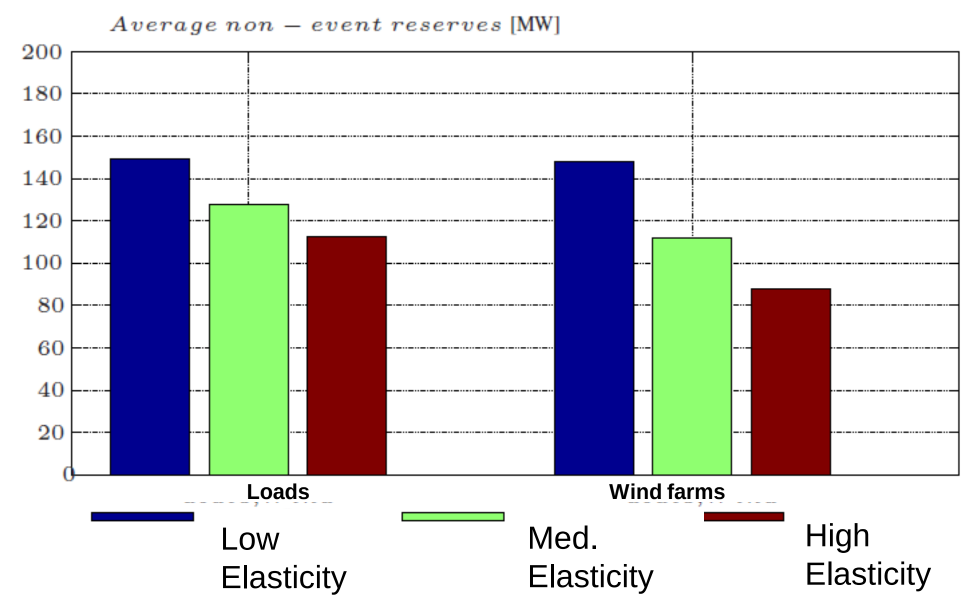


- Sum of cost curves of abatement
- In non-perfect market: incentive to cheat

Incentive compatible pricing of externalities

Assessment of policy: Where (load or wind-farm) does investment in elasticity give the highest leverage, i.e. reduced reserved capacity?

- Lowering marginal abatement costs of renewable in-feed more efficient (in this simulation)
- **Wealth is limited!**



….of Abatement Cost Curve

(in our conceptual simulations: IEEE 24 RTS)

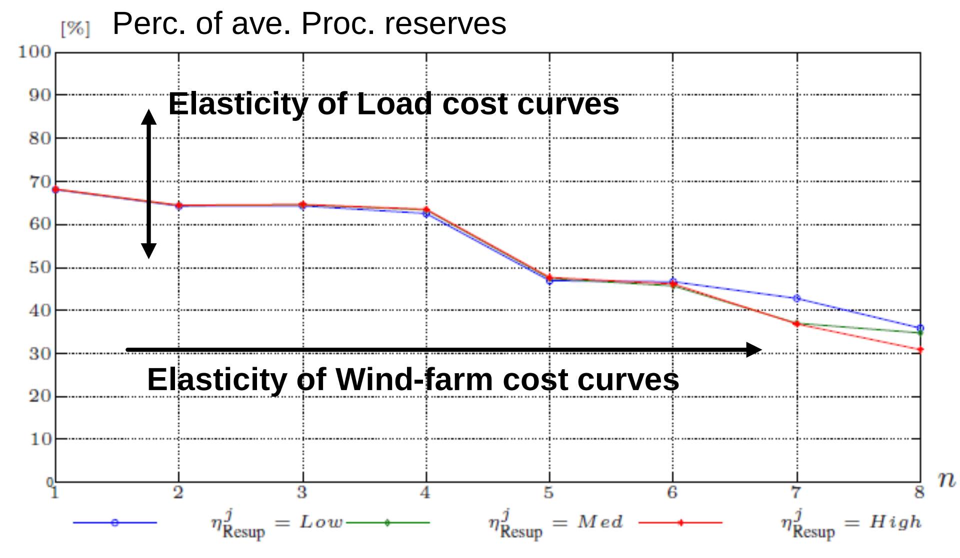
Assessment of policy: What technology helps in terms of ramping/avoiding balancing costs?

- Impact in balancing benchmark compared to ramping benchmark significant

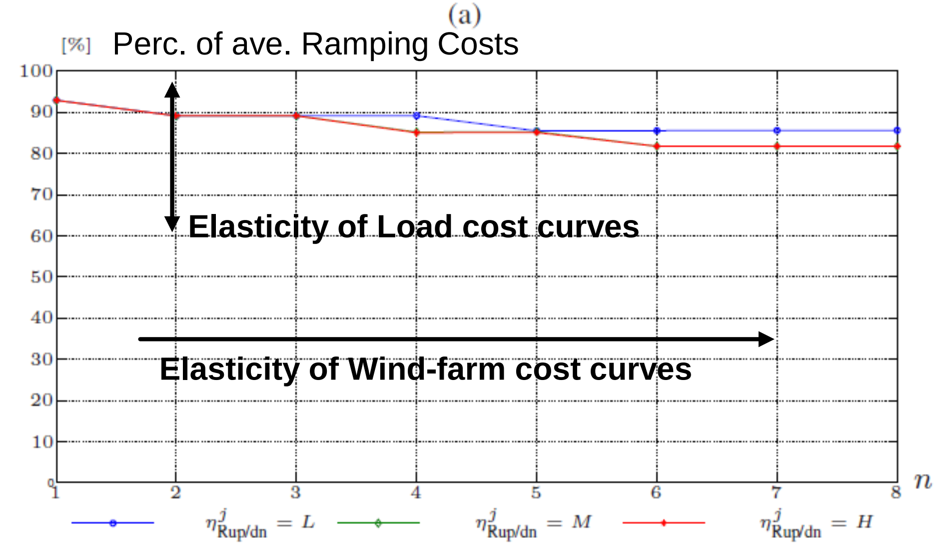
In our simulation example:

- Wind farm → balancing
- Loads → ramping

(in our conceptual simulations: IEEE 9 Bus)



(a)



(b)

Conclusions

Cost allocation of ancillary services

Pros:

- reduces significantly costs through reduced centralized procurement
- allows assessment of policies which ought to support demand response or renewable energy in-feed
- reduces welfare losses through the exploitation of scarcity conditions by the generators

Cons:

- Mispresentation of preferences is inherent
- Preference revelation mechanims:
  - Groves-Clarke has certain drawbacks
  - Preference revelation mechanims: probably complicated and computational effort may requires approximations

Principles may have problems on operational level but are useful on planning and regulatory level (alternative iterative auction designs for policy recommendations)

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The Engineer vs. The Economist?

- **So, what exactly is DR?**
  - A mechanism to improve electricity markets?
  - A new control variable that can enhance power system reliability and security?

Department of Energy (2006):

Demand response (DR) refers to the willingness of the consumer to respond to prices of electricity, or to receive incentive payments in times where grid reliability is jeopardized

- **How should we implement residential DR programs?**
  - Dynamic electricity prices?
  - Direct load control?

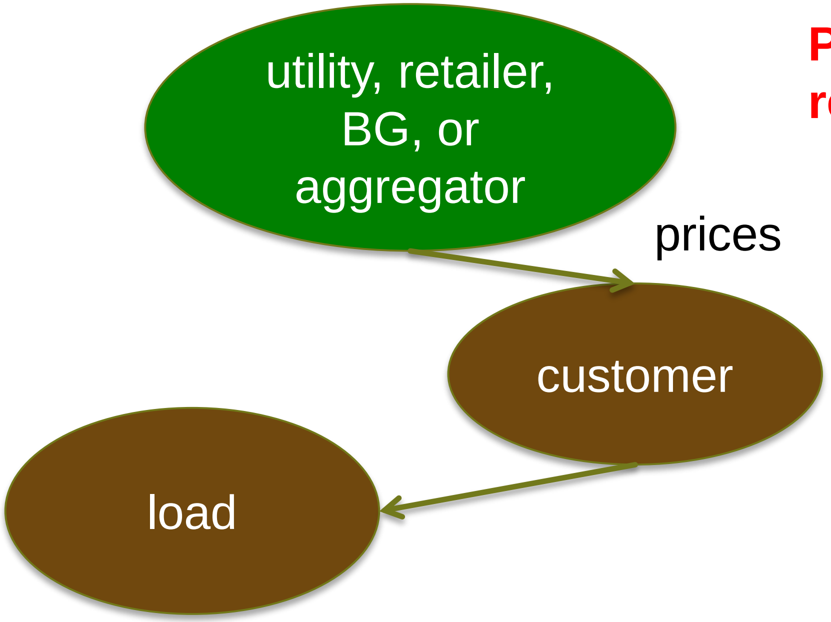
Does our view of DR affect our preference for DR program design?

- The **engineer's view**
  - The power system is hard to accurately model and control because it is complex:
    - Huge!
    - Nonlinear
    - Uncoordinated controls
    - Must operate given stochastic loads, intermittent generation, and contingencies
  - A new control knob to improve both power system planning and operation.

- The **economist's view**
  - Power markets suffer from several market failures:
    - Imperfect competition
    - Imperfect information
    - Externalities
    - Incomplete markets
    - *Reliable* electricity is a public good
  - Alleviate some of these market failures, making power markets more competitive and improving social welfare.

Example 1: Price signals from the utility, retailer, BG, or aggregator

- Prices formed based on outcome of wholesale markets, which settle based on past/forecasted demand (no demand-side bidding)
- Price could be updated hourly to practically instantaneously



Price Signals = unreliable response in real time

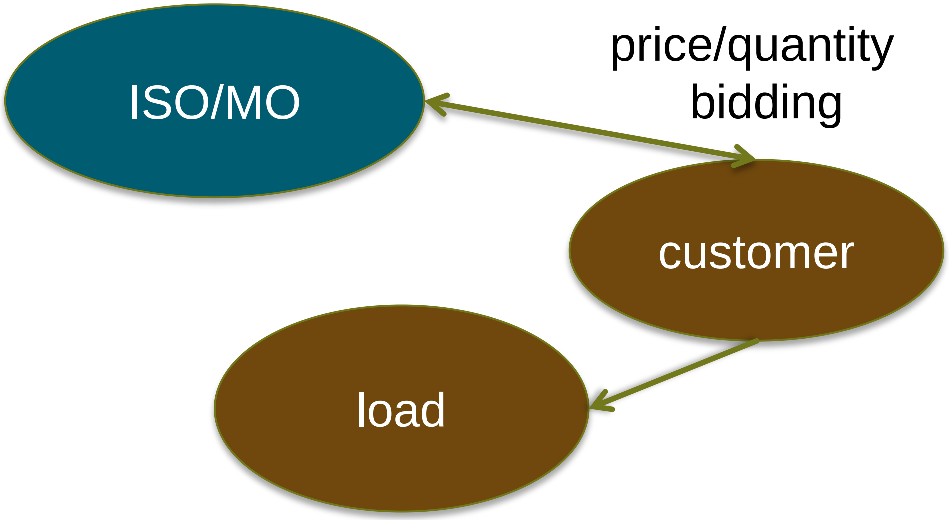
Example 1: Price signals from the utility, retailer, BG, or aggregator

- **Engineer's** perspective…
  - Pros
    - Individual modeling, control, & optimization
    - No baselines!
  - Cons
    - Uncertain customer behavior combined with long ramp times (minutes to hours) could lead to system inadequacies
    - Delays between price setting and price response resulting in possible volatility & instabilities

- **Economist's** perspective…
  - Pros
    - "Full-knowledge" optimization of consumption/investments
    - Customer autonomy in real-time
  - Cons
    - Financial risk to the customer; incomplete markets must be addressed
    - With location prices, perceptions of fairness
    - Uncertain behavior may lead to volatility, instabilities, etc.

Example 2: Price/Quantity bidding by individual customers into markets run by the ISO or MO

- Individual customers submit price/quantity bids into markets
- Bids are co-optimized against generator bids via an OPF
- The timescale of the markets could be days to practically instantaneously
- We do not consider aggregation here, because we are concerned with *customer* interaction with the system.



Scalability?

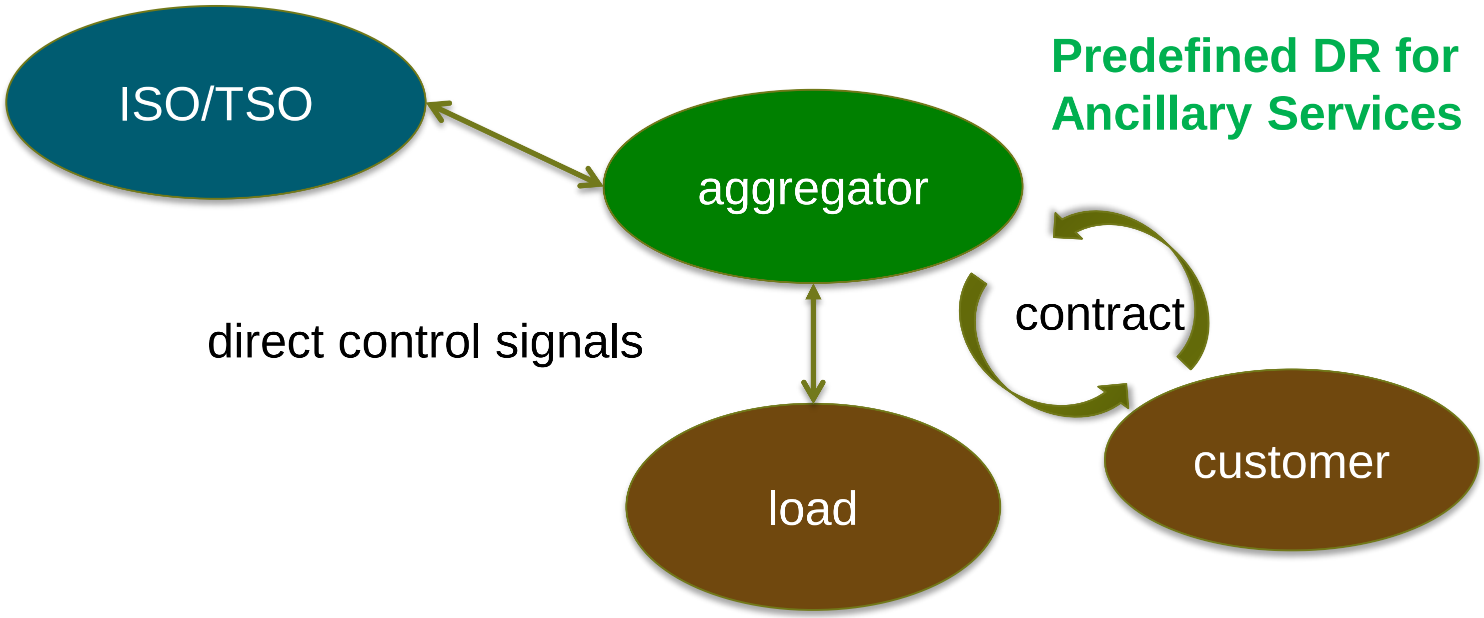
Example 2: Price/Quantity bidding by individual customers into markets run by the ISO or MO

- **Engineer's** perspective…
  - Pros
    - Individual modeling, control, & optimization
    - No baselines
  - Cons
    - Individual market bidding
    - Market optimization via an OPF non-tractable

- **Economist's** perspective…
  - Pros
    - "Full-knowledge" optimization of consumption/investments
    - Privacy
    - Customer autonomy in real-time
  - Cons
    - Financial risk to the customer; incomplete markets must be addressed
    - With fast-DR → high transaction costs!

Example 3: Direct load control via an aggregator providing some market based service to the ISO or TSO

- Customers enter contracts with centralized or decentralized aggregators (i.e. load coalitions)
- Direct control signals could be set point changes, power trajectories, switching commands, or even prices, so long as the response is known a-priori



Example 3: Direct load control via an aggregator providing some market based service to the ISO or TSO

- **Engineer's** perspective…
  - Pros
    - Controllability, observability, and stability can be checked a-priori
    - Benefits via coordination of diverse (possibly hybrid) resources
  - Cons
    - Baselines may be needed
    - Aggregated modeling, control, and optimization (either computationally complex or simplified resulting in non-optimal behavior)

- **Economist's** perspective…
  - Pros
    - Lower financial risk for all players
    - Simple for the customer – what's the value of simplicity?
  - Cons
    - No real-time customer autonomy
    - Privacy issues due to two-way communication

Demand Response: An European perspective

Small Customers:

- Not many choices……
- Liberalization brought freedom to choose retailer
- Retailers offer electricity contract with „green portfolio“
- Two part tariff + Ripple control

Large Customers:

- Several institutions:

e.g. „VIK – Verband der industriellen Energie- und Kraftwirtschaft e. V. „(~members cover 80% of industrial energy consumption in Germany)

- Electric arc furnace (~80MW) versus 40 000 washing machines (~2kW)

What can be done?

- Due to inherent power system limitations (ramp rates, little storage, etc.), we recommend direct load control for fast, reliable DR, but......

We have to consider ....

- *Market products*
- *Contract design: privacy vs. efficiency*
- *Role of competition: retail and wholesale* level

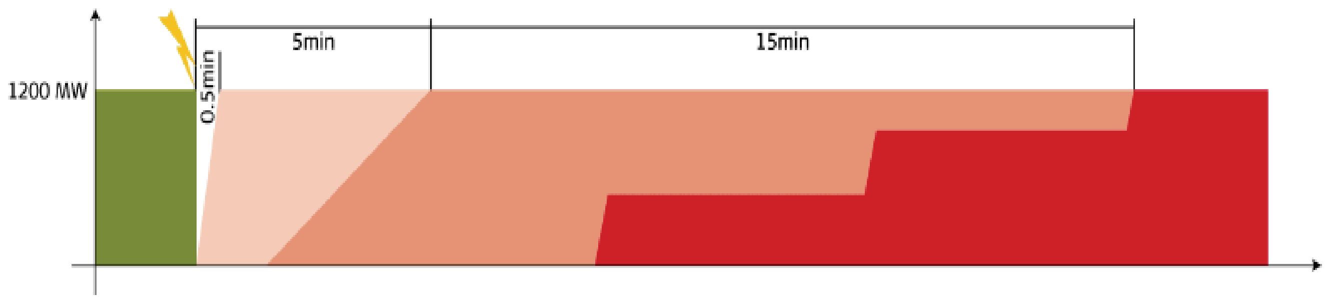
Market Products

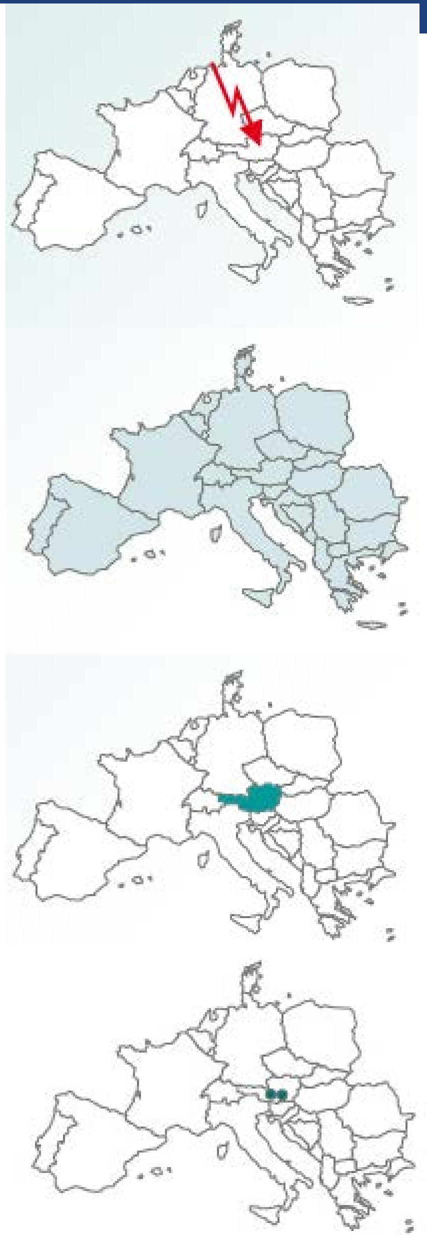
Example:

Continental Europe Setup for frequency control

- Primary Control (Frequency Containment)
- Seconday Control Frequency Restoration)
- Tertiary Control (Manually Activated)

- Quickness of response versus energy content





Market Products

Secondary frequency control (AGC) in Switzerland:

- Always activated:
  - Compensate for continously arising small imbalances
  - Compensate for unit outages until the activation of tertiary control
- PI controller regulates the Area Control Error to zero
- Market based procurement – symmetric 400 MW
- **Same Signal independent of possibilities of generation units**

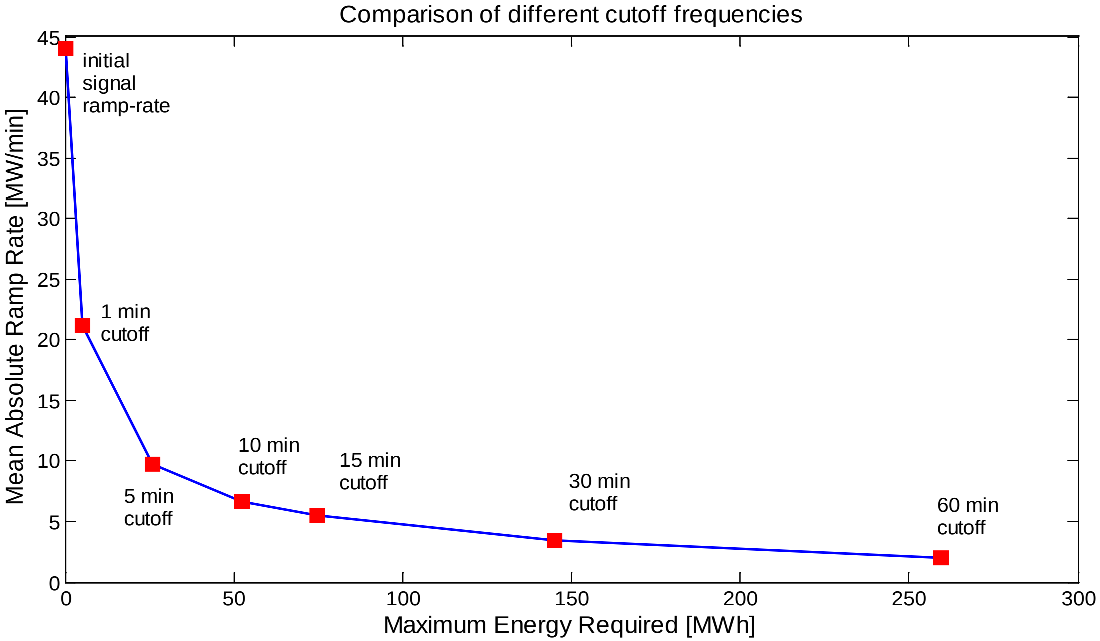
PJM regulation signal

- Slow signal (blue) ➔ ramp-limited units
- Fast signal (green) ➔ fast moving units

Market Products

- Split AGC - Signal via digital Filters:
  - Real-time implementation → only causal filters
  - Trade off between delay produced by higher filter order and frequency rolloff
- Filters examined
  - Lowpass
  - Highpass
  - Exponential weighted moving average (1st order)

Market Products



Ramp Rate / Energy Requirements

- the lower the ramp-requirement of the smooth signal
- the higher the energy storage requirement of the volatile signal

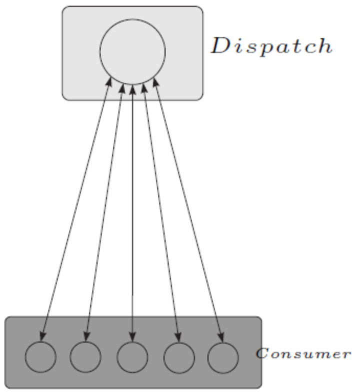
Number-of-changes in direction within 1 hour:

- Lower frequencies➔smoother signal
- Slow-changing less changes than the initial

Period	Lowpass	Highpass	EWMA
1 h	4	60	103
30 min	5	72	117
15 min	10	87	134
10 min	15	96	141
5 min	27	111	154
1 min	106	162	191
Optimizer	138		
Initial AGC	233		

Contract Design – The role of intermediaries

«Central»



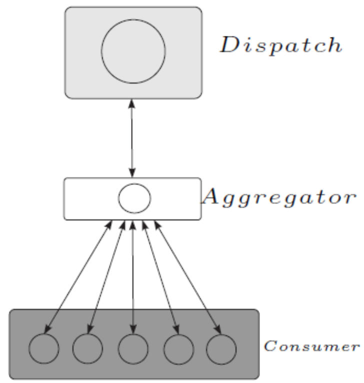
$$\min_{x \in X, y \in Y} F(x,y)$$

subject to

$$H_i(x,y) \leq 0, for i \in 1,2,...,I$$

F ... Cost minimization of dispatch
H_i ... Constraints related to dispatch and consumer contracts

«Central» with third party aggregator



$$\min_{x \in X, y \in Y} F(x,y)$$

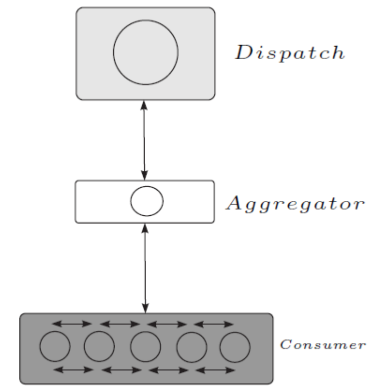
subject to

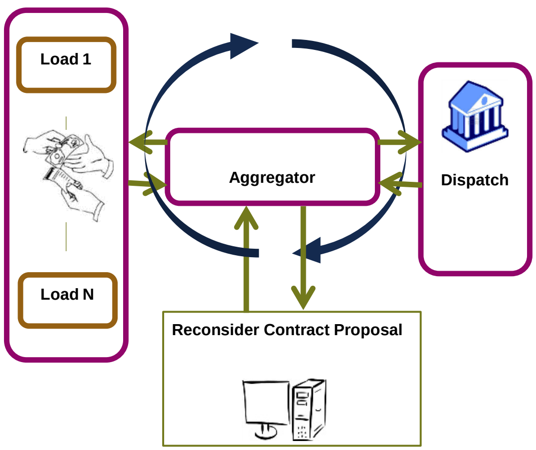
$$G_i(x,y) \leq 0, \ \ for \ i \ \in 1,2,...,I$$

$$y \in \underset{z \in Y}{argmin}\{f(x,z) : g_j(x,z) \leq 0, j \in \{1,2,...,J\}\}$$

x, y ... Decision vector of aggregator, dispatch F ... Profit maximization of aggregator
f ... Cost minimization of dispatch
G_i ... Constraints related to consumer contracts (*Individual Rationality, Incentive Compatibility*)
g_j ... Constraints related dispatch constraints (generator limits, grid, etc.)

«Decentral» with consumer cooperative

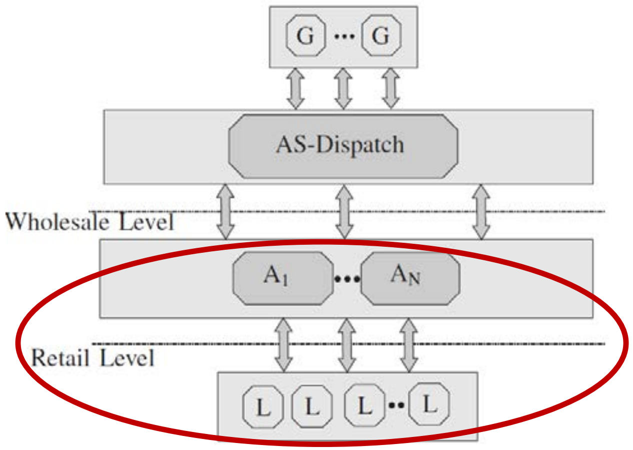




Contract Design – Example: Third Party Aggregator

- Upper level problem: Maximize aggregator profit

$$\max_{\boldsymbol{\vartheta_2}} . f(\boldsymbol{\vartheta_2}) = \sum_{a=1}^{N_A} \sum_{j=1}^{N_L} \Bigg(\sum_{t=1}^{N_t} p^{j,a} (\zeta^{t}_{\text{Cap,Up}} D^{j,t,a}_{\text{Cap,Up}} + \zeta^{t}_{\text{Cap,Dn}} D^{j,t,a}_{\text{Cap,Dn}} - \kappa^{j,t,a}_{\text{Cap,Up}} - \kappa^{j,t,a}_{\text{Cap,Dn}}) \Bigg) + \sum_{s=1}^{N_S} \omega_s \Bigg\{ \sum_{a=1}^{N_A} \sum_{j=1}^{N_L} \Bigg(\sum_{\tau}^{N_\tau} p^{j,a} (\zeta^{\tau,s}_{\text{En,Up}} D^{j,\tau,a,s}_{\text{En,Up}} + \zeta^{\tau,s}_{\text{En,Dn}} D^{j,\tau,a,s}_{\text{En,Dn}} - \kappa^{j,t,a,s}_{\text{En,Up}} - \kappa^{j,t,k,a,s}_{\text{En,Dn}} \Bigg) \Bigg\}$$



subject to:

- Storage and other limitations
- Individual rationality of payments
- Incentive compatibility of payments

Contract Design – Example: Third Party Aggregator

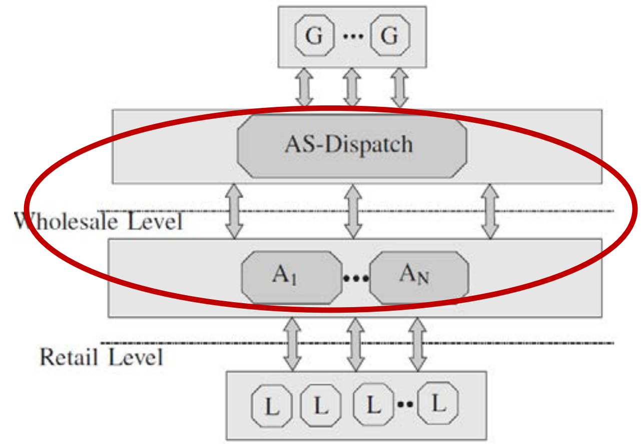
- Lower level problem: minimize costs of dispatch

$$\min_{\vartheta_3} . f(\vartheta_3) = \sum_{t}^{N_t} \sum_{i}^{N_G} \left(MC^{i,t}_{\text{Cap,Up}} G^{i,t}_{\text{Cap,Up}} + MC^{i,t}_{\text{Cap,Dn}} G^{i,t}_{\text{Cap,Dn}}\right) +$$

$$\sum_{a}^{N_A} \sum_{j}^{N_L} p^{j,a} \left(\alpha^{j,t,a}_{\text{Cap,Up}} D^{j,t,a}_{\text{Cap,Up}} + \beta^{j,t,a}_{\text{Cap,Dn}} D^{j,t,a}_{\text{Cap,Dn}}\right) + \sum_{s=1}^{N_S} \omega_s \bigg\{ \sum_{\tau}^{N_\tau} \bigg(\sum_{i=1}^{N_G} \bigg($$

$$MC^{i,\tau}_{\text{En,Up}} G^{i,\tau,s}_{\text{En,Up}} + MC^{i,\tau}_{\text{En,Dn}} G^{i,\tau,s}_{\text{En,Dn}}\bigg) + \sum_{a}^{N_A} \sum_{j}^{N_L} p^{j,a} (\gamma^{j,\tau,a,s}_{\text{En,Up}} D^{j,\tau,a,s}_{\text{En,Up}} +$$

$$\delta^{j,\tau,a,s}_{\text{En,Dn}} D^{j,\tau,a,s}_{\text{En,Dn}})\bigg)\bigg\}$$



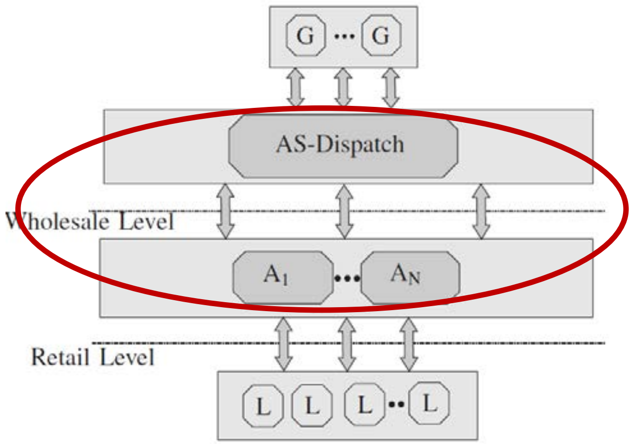
subject to:

- Limits generation

Contract Design – Example: Third Party Aggregator

- Lower level problem: minimize costs of dispatch

$$\min_{\vartheta_3} . f(\vartheta_3) = \sum_{t}^{N_t} \sum_{i}^{N_G} (MC^{i,t}_{\text{Cap,Up}} G^{i,t}_{\text{Cap,Up}} + MC^{i,t}_{\text{Cap,Dn}} G^{i,t}_{\text{Cap,Dn}}) +$$
$$\sum_{a}^{N_A} \sum_{j}^{N_L} p^{j,a} (\alpha^{j,t,a}_{\text{Cap,Up}} D^{j,t,a}_{\text{Cap,Up}} + \beta^{j,t,a}_{\text{Cap,Dn}} D^{j,t,a}_{\text{Cap,Dn}}) + \sum_{s=1}^{N_S} \omega_s \Big\{ \sum_{\tau}^{N_\tau} \Big(\sum_{i=1}^{N_G} \Big($$
$$MC^{i,\tau}_{\text{En,Up}} G^{i,\tau,s}_{\text{En,Up}} + MC^{i,\tau}_{\text{En,Dn}} G^{i,\tau,s}_{\text{En,Dn}}) + \sum_{a}^{N_A} \sum_{j}^{N_L} p^{j,a} (\gamma^{j,\tau,a,s}_{\text{En,Up}} D^{j,\tau,a,s}_{\text{En,Up}} +$$
$$\delta^{j,\tau,a,s}_{\text{En,Dn}} D^{j,\tau,a,s}_{\text{En,Dn}}) \Big) \Big\}$$



Price bids of generators

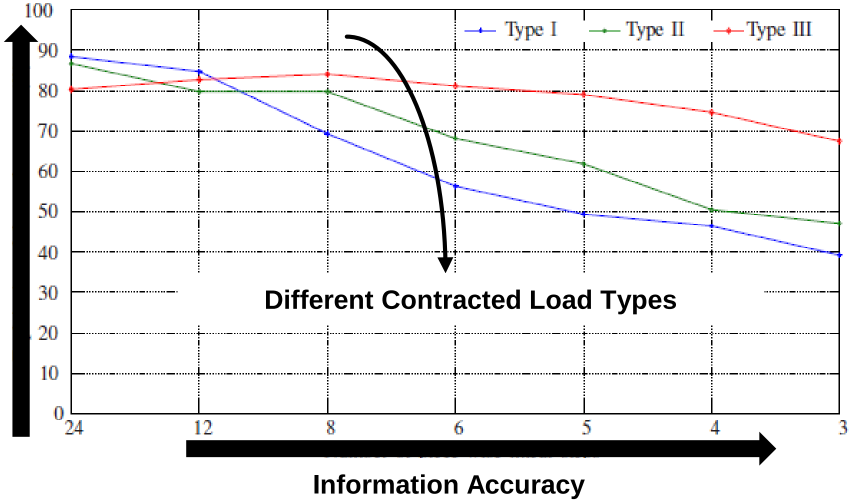
subject to:

- Limits generation

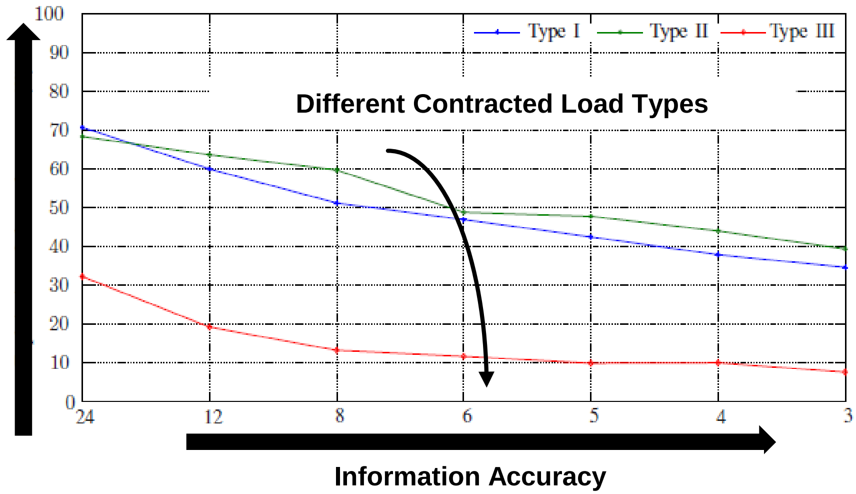
Lower level problem can be transformed into KKT conditions and integrated in upper level problem (i.e. Conejo (2009), Bart (1998))

Contract Design – Example: Third Party Aggregator

DR exploitation without incentive compatibility in % of Benchmark



DR exploitation with incentive compatibility in % of Benchmark



- Incentive compatibility results in significant reduction of total exploitation
- inaccurate Information (i.e. resolution of metering) influences exploitation

The role of competition

- Wholesale Level: Do wholesale auction provide enough revenue? → active DR

- Retail Level: Role of competition unclear → passive DR models

- Prisoners Dilemma and Public Goods

- Complexity of retail market designs (billing, reliability issues) indicate their success → Combination of price signals and contracts? DR fatigue.....

Agenda

Introduction to Power Systems / Power Markets

Current Challenges

On Achieving Allocative Efficiency in Power Markets

Demand Response – Engineering vs. Economics

Conclusion

Conclusion

- Power Systems Research regained significant importance
- Market Designs for integration of renewable should follow first principles:
  - Productive Efficiency
  - Allocative Efficiency

  } **Can be Contradicting Issues!**
- Presented Examples:
  - Cost Allocation of Ancillary Services to improve renewable energy support
  - Incorporation of demand side needs careful implementation with regards to information exchange and business cases
- Not Treated in this presentation:
  - Revenue Sufficiency for conventional generators
  - Other aspects of governmental/regulatory intervention

References

- A. Ulbig, Y. Makarov, Update on Recent European Experiences with Grid Integration of Wind and Solar Power , WECC Variable Generation Sub-Committee, 2012
- M. Hildmann, A.Ulbig, G. Andersson, Revisiting the Merit-Order Effect of Renewable Energy Sources, Working paper - version date 30 June 2013., arXiv:1307.0444
- V. Lenzi, A. Ulbig and G. Andersson, Impacts of Forecast Accuracy on Grid Integration of Renewable Energy Sources, Presented at the IEEE Powertech Conference, Grenoble, France, 2013.
- M. Hildmann, A.Ulbig and G.Andersson, Electricity Grid In-feed from Renewable Sources: A Risk for Pumped-Storage Hydro Plants?, European Energy Markets (EEM) 2011, Zagreb, Croatia, May 2011..
- N. Associates, L. B. N. Laboratory, and P. N. N. Laboratory, Benefits of demand response in electricity markets and recommendations for achieving them," Department of Energy Report to the US Congress, Tech. Rep., 2006. [Online]. Available: http://www.oe.energy. gov/DocumentsandMedia/congress1252d.pdf
- T. Haring and G. Andersson, Cost allocation in Ancillary Service Markets, Proceedings Hawaii International Conference on System Sciences 2014
- T. Haring, D.S. Kirschen and G. Andersson, Efficient Allocation of Balancing and Ramping Costs, accepted Power Systems Computation Conference, Wroclaw, Poland, 2014
- J.L. Mathieu, T. Haring, J. O. Ledyard, and G. Andersson, Residential Demand Response Program Design: Engineering and Economic Perspective, Proceedings European Energy Market Conference (EEM 2013)
- T. Haring, J.L. Mathieu and G. Andersson, Demand Response for Ancillary Services via multi-agent Contract Design, Proceedings European Energy Market Conference (EEM 2013)
- J.L. Mathieu, T. Haring, and G. Andersson, Harnessing Residential Loads for Demand Response: Engineering and Economic Considerations, Proceedings of the Interdisciplinary Workshop on Smart Grid Design & Implementation hosted by the University of Florida Laboratory for Cognition & Control in Complex Systems, Gainesville, FL, 7-8 Dec 7-8, 2012
- C.Ruiz and A. Conejo, Pool strategy of a producer with endogeneous formation of locational marginal prices, IEEE Transaction on Power Systems, vol. 24, no. 4, 2009.
- J.F.Bard, Practical bilevel optimization: Algorithms and applications,Springer, 1998.

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Thank you for your attention!

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