Our Energy Informatics Agenda: Putting Bits in Energy

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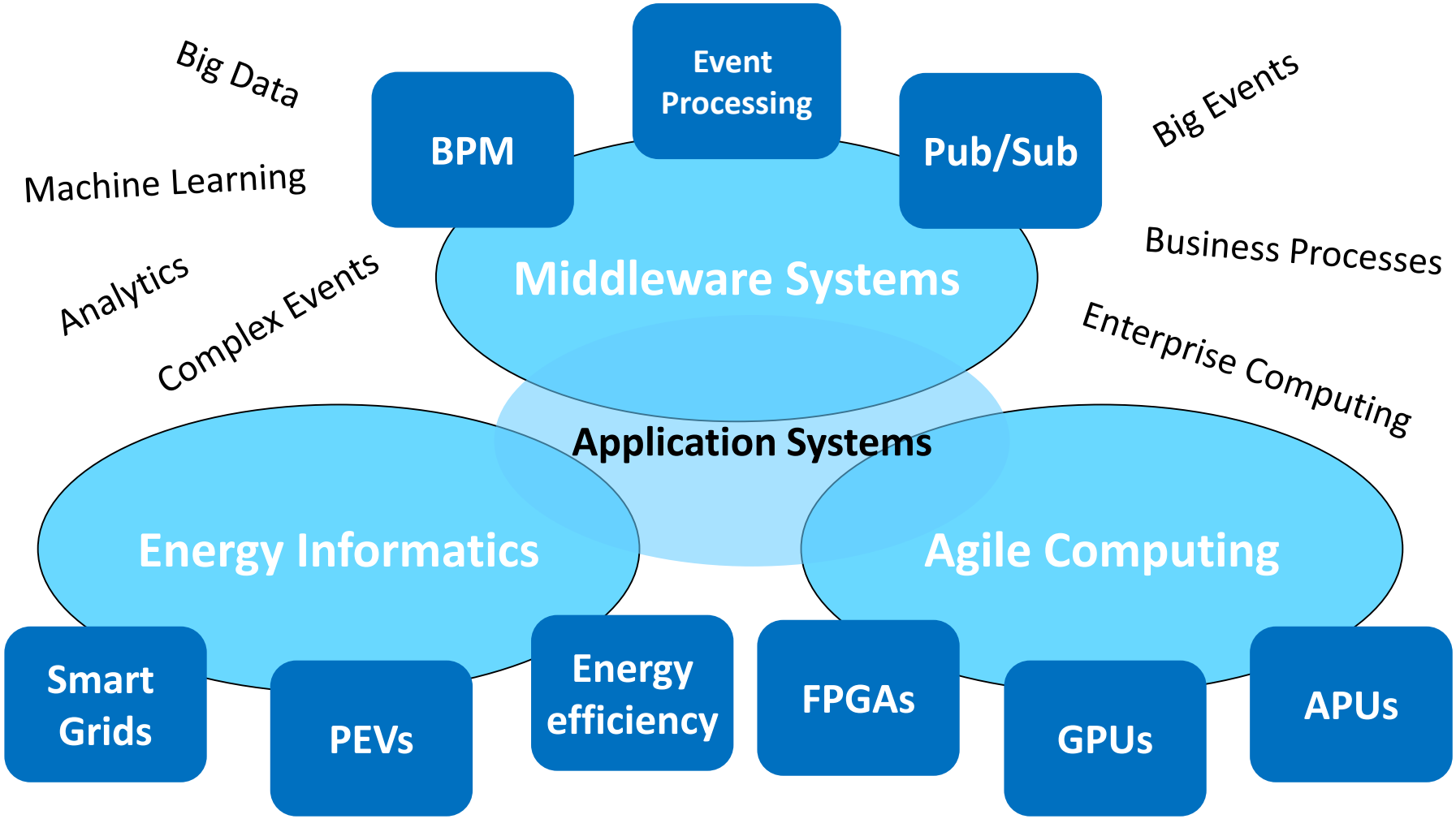
Agenda

- Where we are coming from
- What is energy informatics
- Energy informatics teaching
- Selected research projects

Our Research Scope



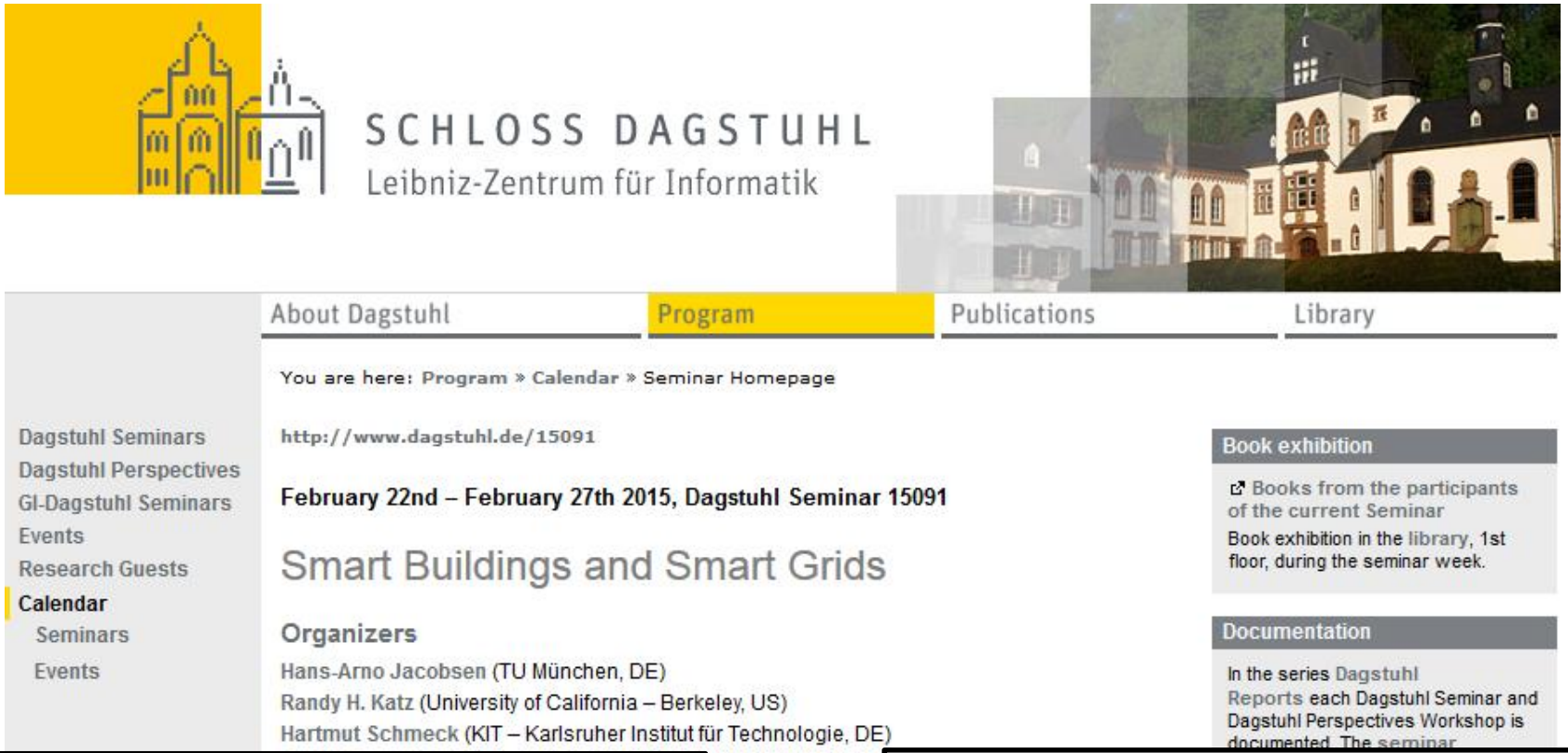
Energy Informatics (EI)

- Emerging **interdisciplinary** area
  - Interdisciplinary research involving among others electrical, mechanical, civil & computer engineering
  - Acquisition of new competences (energy conversion, power systems, etc.)

- Two perspectives
  - Develop systems that **manage energy more sustainably**
  - Develop more **sustainable computer systems**

- Evaluate systems based on **realistic models and data**

Dagstuhl Seminar & Community Building

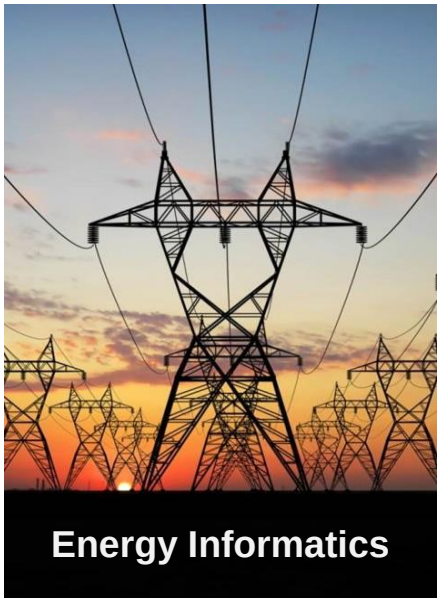


Stay tuned for forthcoming report on the seminar.

C. Goebel, H.-A. Jacobsen, ***et al.*** **Energy Informatics – Current and Future Research Directions. BISE 2013**.

Our Energy Informatics Teaching

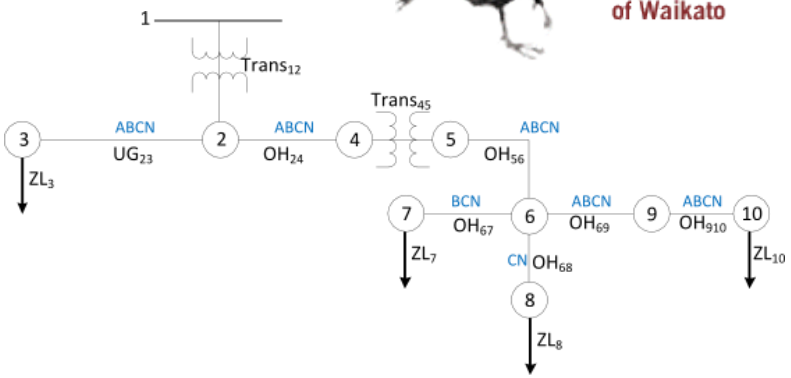
- Lecture (IN2280, 5 ECTS)
  - Big Data and data analysis in the energy domain
  - High performance computing for power systems
  - Electricity market design
  - Modeling and simulation of renewable energy resources and energy storage
  - Information age demand-response
  - Smart buildings and smart grids

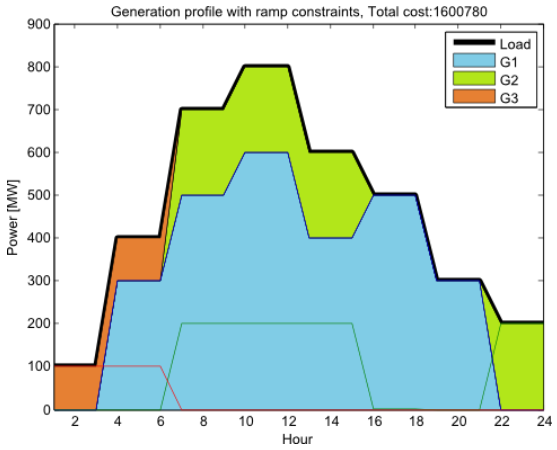


- Seminar (IN4725, 4 ECTS)
  - Supervise students in research on EI topics
  - Literature review, empirical studies, and prototyping

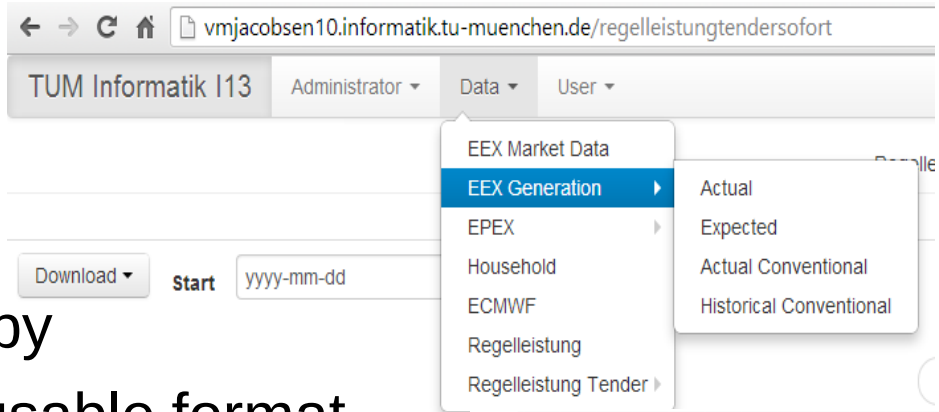
Energy Informatics Lab

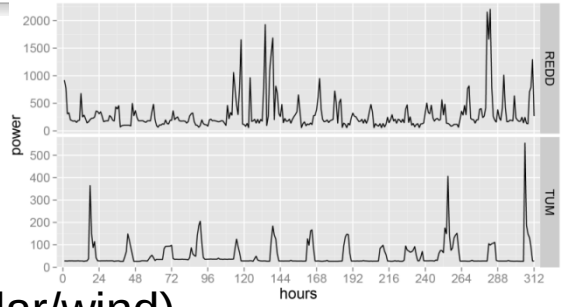
- Household demand forecasting (machine learning using WEKA)
- Wind power forecasting (machine learning using Python libraries)
- Distribution grid simulations (using GridLab-D)
- Optimal power flow and unit commitment optimization (using Matlab)





EI Database





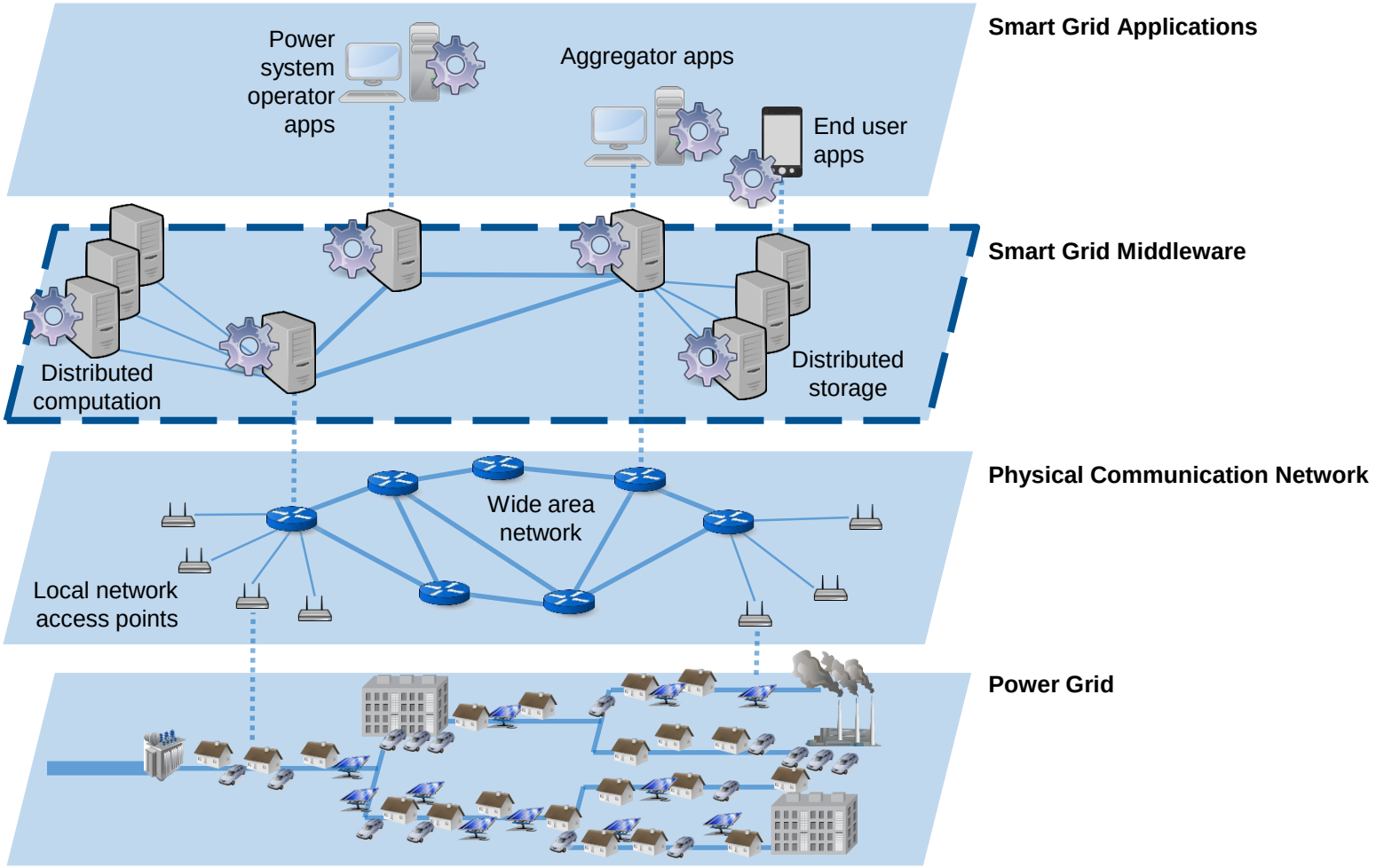
- **Problem:** Data supporting EI research hard to come by
- **Solution:** EI database in usable format
  - Available data sets to date:
    - Household electricity consumption traces
    - EEX Day Ahead
    - EEX Generation (actual/expected conventional/solar/wind)
    - EPEX Spot Market (intra-day and auction)
    - Ancillary services (demand and tenders)
    - ECMWF (wind 10 meter, temp 2 meter, solar radiation, …)
  - Continuously updated and extended

Research Partnerships

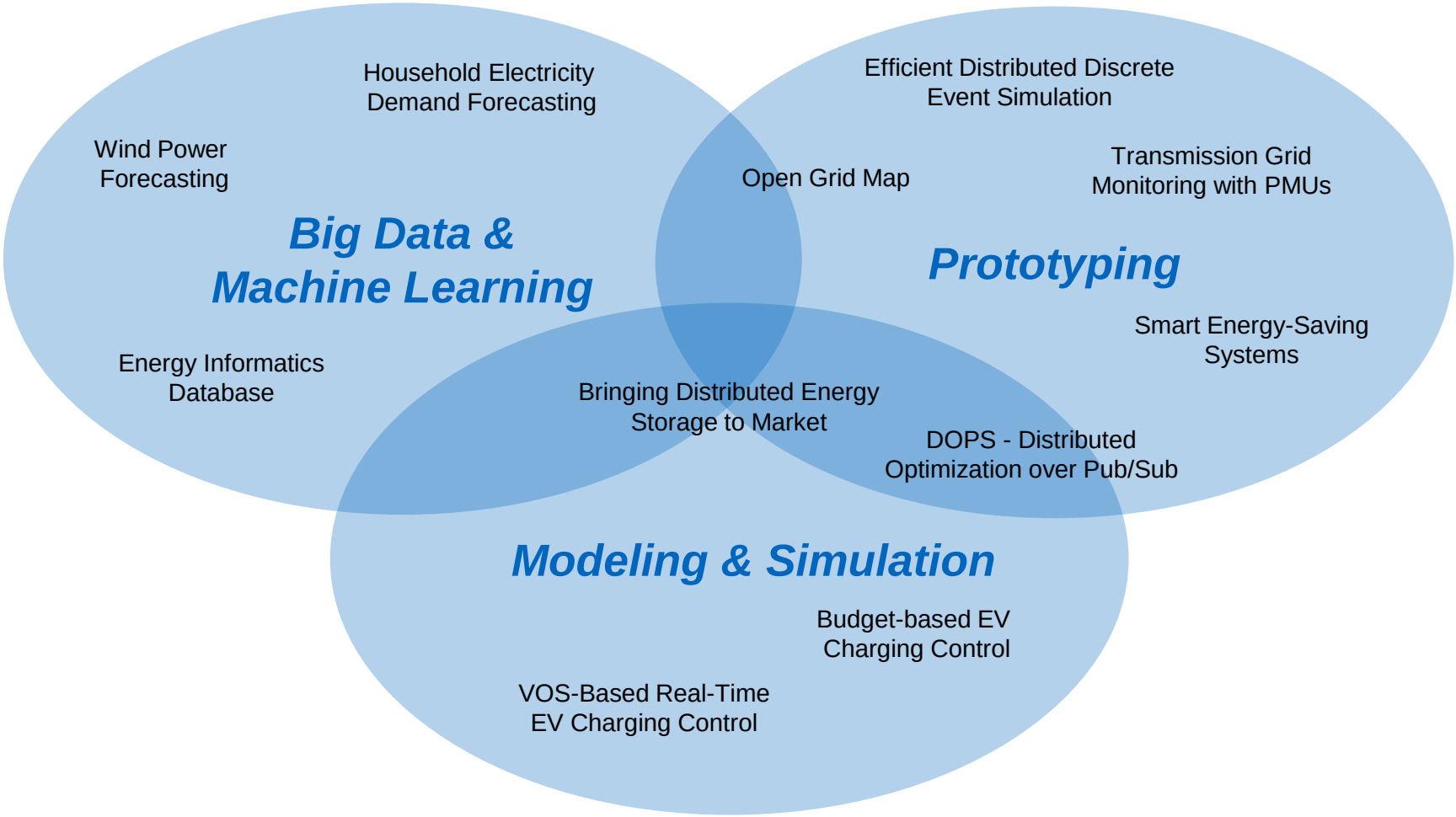
Academia

Industry

Smart Grid Middleware Vision



Projects Overview

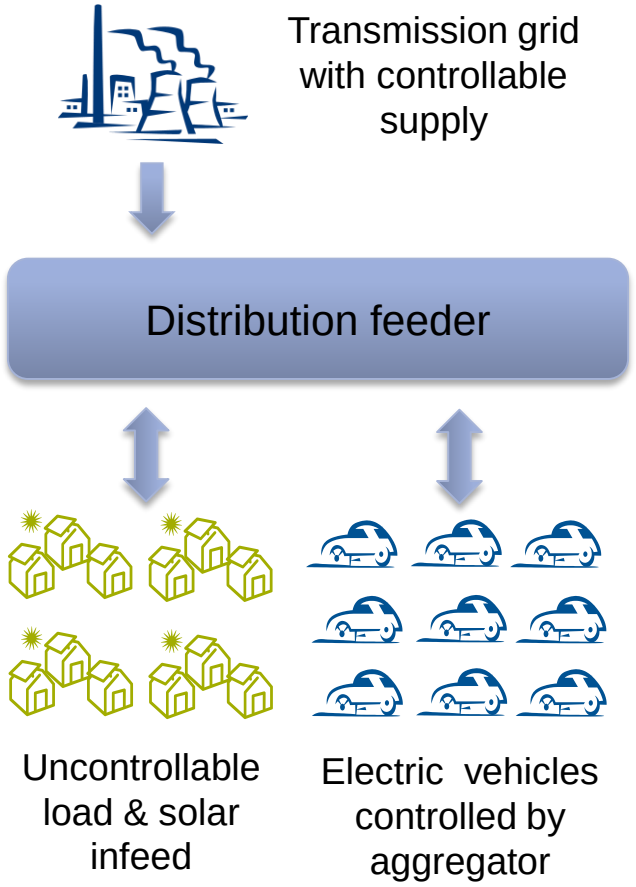


Real-Time EV Charging Control

- **Problem:** Find fast and scalable method for near-optimal real-time control of EV (dis)charging

- **Challenges:**
  - Complex optimization problem
  - Real-time requirement
  - Dynamic influences: Variable non-EV load, renewable power, and EV (dis)charging availability

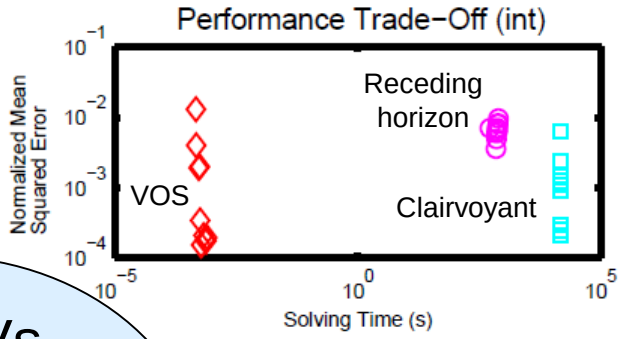
- **State-of-the-art**:
  Centralized optimization based on full state information



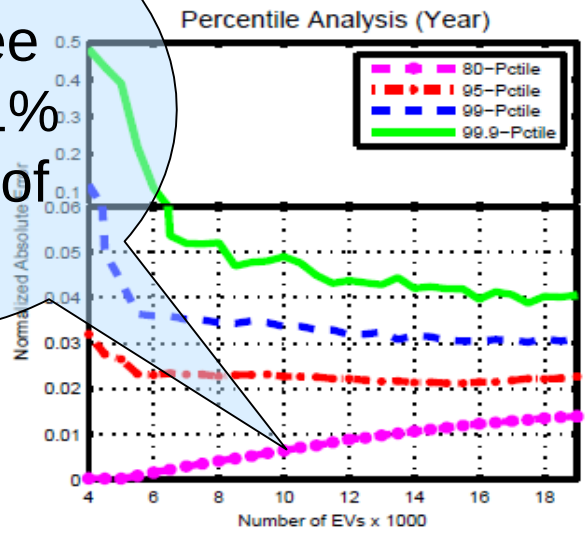
[IEEE ISGT'2013, IEEE SmartGrid Comm'2014, EI'2014]

VOS-Based Real-Time EV Charging Control

- **Solution: VOS**
  - **Vehicle-Originating-Signals** (VOS): Encode EV state as *need-for-charge* & *willingness-to-supply* signals
  - Computation of real-time controls by aggregator



10K EVs, guarantee errors < 1% for 80 % of cases



- **Advantages:**
  - Real-time availability of controls
  - Increased privacy
  - Low dependency on predictions
  - Decoupled EV complexity
  - Faster than optimizing with comparable results

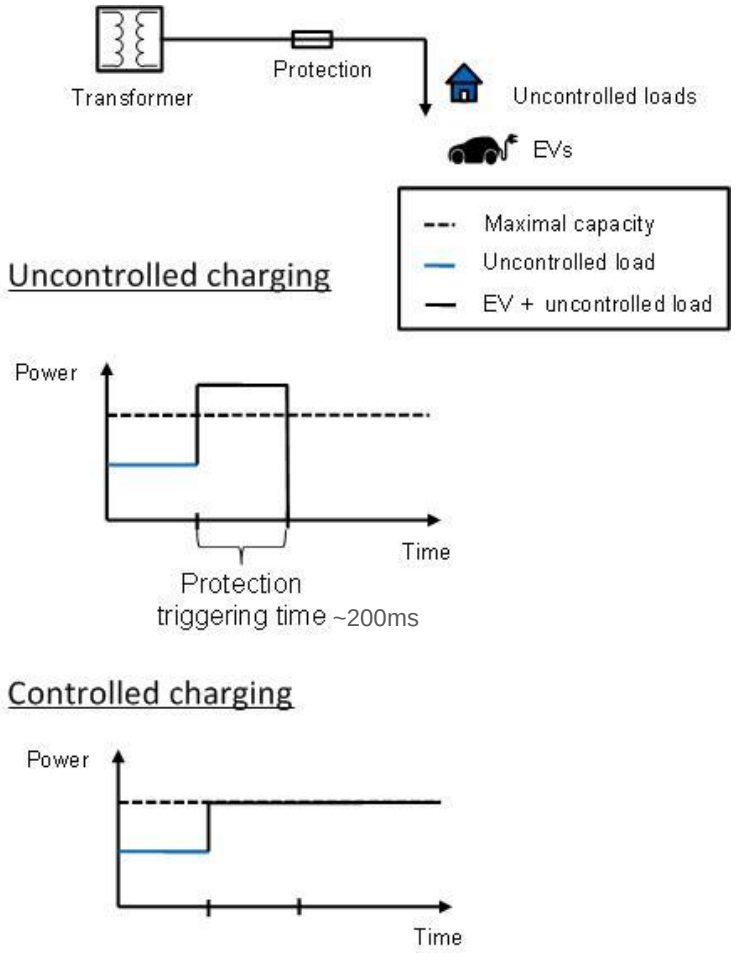
[IEEE ISGT'2013, IEEE SmartGrid Comm'2014, EI'2014]

EV Charging Control

- **Problem:** Control EV charging to avoid grid overload and make optimal use of the available infrastructure

- **State-of-the-art:**
  - Direct control: Not scalable & no data privacy
  - Incentive-based control: Not fast enough

- **Challenge:**
  Define a distributed optimization algorithm that can cope with real-time requirements

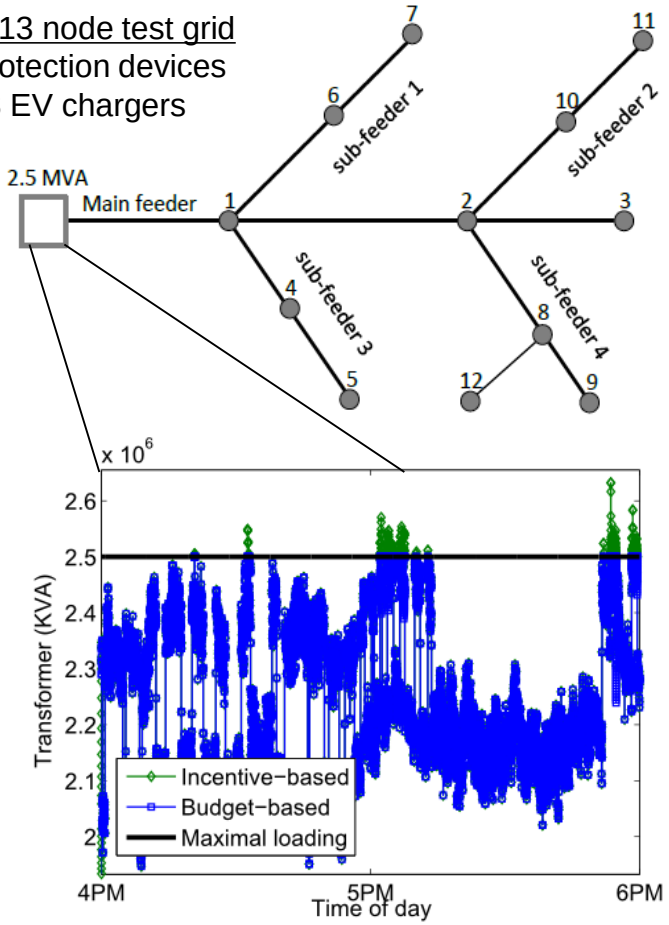


[IEEE CDC'13 & CDC'2014]

Budget-based EV Charging Control

- **Solution:**
  - Budget-based control
  - Protection IEDs define a maximal charging rate for EVs based on the grid state

- **Advantages:**
  - Optimal use of the infrastructure
  - Anytime algorithm allows real-time response



[IEEE CDC'13 & CDC'2014]

Bringing Distributed Energy Storage to Market

- **Problem:** How to control a large number of stationary batteries for flexible and concurrent participation in energy and reserve markets

- **Challenges:**
  - Enabling multi-market participation
  - Develop efficient data structures for market & storage schedules
  - Design of services that translate aggregator requests/controls into individual storage requests/controls
  - Design fast planning and optimization algorithms that scale

Approach:

- Effective schedule representation
- Flexible and scalable resource control according to market rules
- Several techniques for solving dispatch problem

[IEEE Trans PS'2014]

Household Electricity Demand Forecasting with Complex Event Processing

- **Problem:** Identify effective solutions for disaggregated electricity demand forecasting (smart meter & device level)

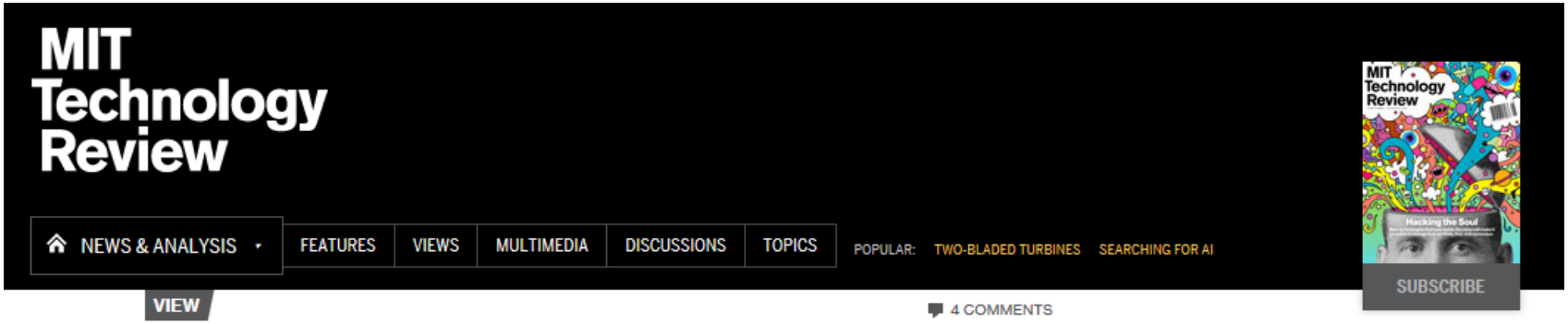
- **Challenges:**
  - Highly individual, uncertain and variable demand on household level
  - Many existing forecasting techniques
  - High computational cost of applying existing techniques

Data	Forecast	MAE Weekdays	MAE Weekends	RMSE Weekdays	RMSE Weekends
HH1	Avg.	143%	133%	296%	319%
	Pers.	53%	63%	112%	131%
	SVMs	42%	53%	81%	117%
HH2	Avg.	132%	122%	207%	332%
	Pers.	57%	38%	137%	115%
	SVMs	33%	25%	85%	40%
HH3	Avg.	112%	101%	148%	124%
	Pers.	33%	43%	55%	128%
	SVMs	19%	17%	26%	25%
Avg.	Avg.	129%	119%	217%	258%
	Pers.	48%	48%	101%	125%
	SVMs	31%	32%	64%	60%

Source: Siemens.com

[IEEE SmartGrid Comm'2013]
[ACM Middleware'2013; ACM E-Energy'2014]

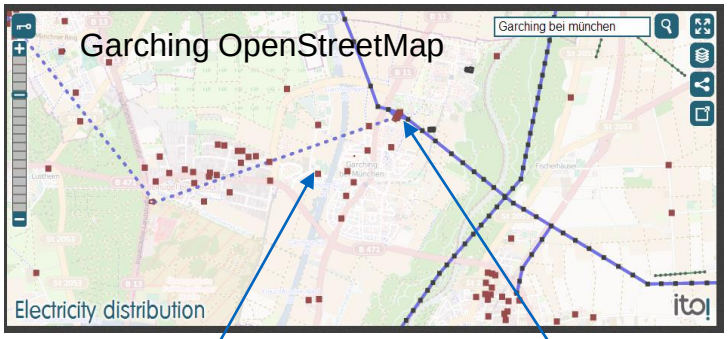
At least someone got excited

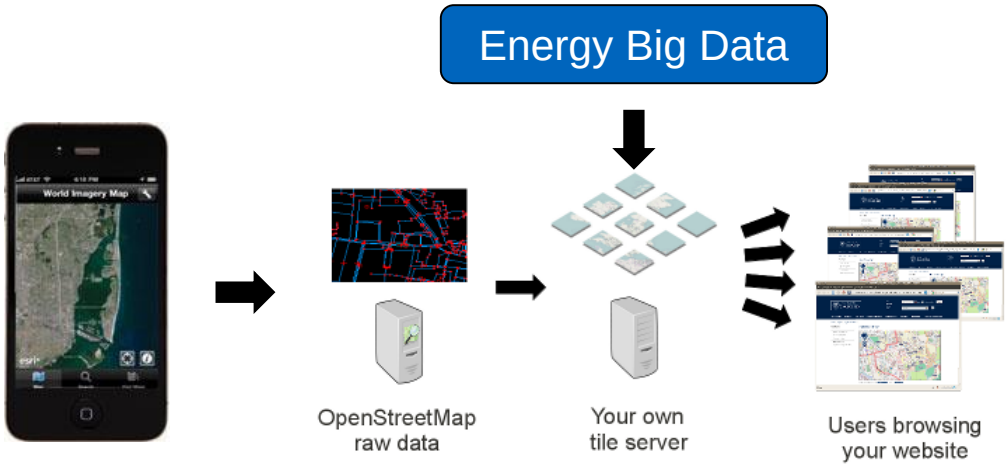


Open Grid Map

Partner: SIEMENS

- **Problem:** Distribution grid information is often not available (even to DSO)
- **Solution:** Infer grid's structure from available and geo-tagged information collected via crowd-sourcing





Our Energy Informatics Team

Dr. Christoph Goebel

Principal Researcher

Experienced IS researcher (KIT, EPFL, CMU, Humboldt, UC Berkeley, TUM)

José Rivera, Dipl.-Ing.

Doctoral Student

Electrical engineer, studied at TUM, Master's thesis (with Siemens) on electric mobility, visiting student at MIT

Christoph Doblander, Mag.

Doctoral Student

Experienced software engineer (5+ years of industy experience), studied at FH Kufstein, previously worked in gas trading

Mathias Kahl, MSc.

Doctoral Student

Electrical engineer, manages our Non-invasive Load Monitoring project; computer science background

Victor del Razo, MSc.

Doctoral Student

Experienced telecommunications engineer (5+ years of industy experience), studied at University of Helsinki

Anwar Ul HAQ, MSc.

Doctoral Student

Electrical Engineer, studied at Hanyang University, Korea, Master's thesis on Game Theory applied to Smart Grids

Conclusions

- Energy Informatics is an emerging area

- Recommendations to funding agencies
  - Establish **open data set archives**
    - The Internet trace archive of energy systems
  - Establish **smart grid test beds**
    - The PlanetLab of power grids
  - Establish **smart building test beds**
    - The EmuLab of smart buildings

Energy Informatics Papers I

1. C. Goebel, H.-A. Jacobsen, et al. Energy Informatics – Current and Future Research Directions. *Business and Information Systems Engineering (6:1): 25-31.* 2013.
2. C. Goebel, D. Callaway. Using ICT-Controlled Plug-in Electric Vehicles to Supply Grid Regulation in California at Different Renewable Integration Levels. *IEEE Transactions on Smart Grid (4:2): 729-740.* 2013.
3. C. Goebel. On the Business Value of ICT-Controlled Plug-in Electric Vehicle Charging in California. *Energy Policy (53:3): 1-10.* 2012.
4. H. Ziekow, C. Doblander, C. Goebel, H.-A. Jacobsen. Electricity Demand Forecasting with Complex Event Processing: Insights from a Prototypical Solution. In Proceedings of the *13th ACM International Middleware Conference, Beijing, China.* 2013.
5. H. Ziekow, C. Goebel, J. Strüker, H.-A. Jacobsen. The Potential of Smart Home Sensors in Forecasting Household Electricity Demand. In Proceedings of the *4th IEEE International Conference on Smart Grid Communications (SmartGridComm2013), Vancouver, Canada.* 2013.
6. J. Rivera, P. Wolfrum, S. Hirche, C. Goebel, Hans-Arno Jacobsen. Alternating Direction Method of Multipliers for Decentralized Electric Vehicle Charging Control. *52nd Conference on Decision and Control (CDC2013), Florence, Italy.* 2013.
7. C. Goebel, M. Voß. Forecasting Driving Behavior to Enable Efficient Grid Integration of Plug-in Electric Vehicles. *IEEE Online Conference on Green Communications (GreenCom)*. 2012.
8. V. del Razo, C. Goebel, H.-A. Jacobsen. Benchmarking a Car-Originated-Signal Approach for Real-Time Electric Vehicle Charging Control. Submitted to *5th Innovative Smart Grid Technologies Conference, Washington, DC., USA.* 2013.
9. C. Goebel, D.S. Callaway, H.-A. Jacobsen. The Impact of State of Charge Management When Providing Regulation Power With Energy Storage. *IEEE Transactions on Power Systems (29:3): 1433-1434.* 2013.
10. C. Goebel, H.-A. Jacobsen. Multi-Market Sourcing of EV Charging Energy. *IEEE Transactions on Smart Grid (under revision)*

Energy Informatics Papers II

11. S. Rusitschka, C. Doblander, C. Goebel, H.-A. Jacobsen. Adaptive Middleware for Real-time Prescriptive Analytics in Large-scale Power Systems. In Proceedings of the *13th ACM International Middleware Conference, Beijing, China.*
12. J. Rivera, C. Goebel, H.-A. Jacobsen. Distributed Real-time Control of EV Charging in Congested Distribution Feeders: A Solution based on Dynamic Budgets. *Working paper*. 2014.
13. V. del Razo, C. Goebel, H.-A. Jacobsen. Benchmarking a Car-Originated-Signal Approach for Real-Time Electric Vehicle Charging Control. In Proceedings of the *5th PES Innovative Smart Grid Technologies Conference (ISGT2013), Washington, D.C., USA.*
14. A. Veit, C. Goebel, R. Tidke, C. Doblander, H.-A. Jacobsen. Household Electricity Demand Forecasting: Benchmarking State-of-the-Art Methods. In Proceedings of the *5th ACM International Conference on Future Energy Systems (ACM e-Energy 2014), Cambridge, UK. 2014.*
15. J. Rivera, M. Jergler, A. Stoimenov, C. Goebel, H.-A. Jacobsen. Publish/Subscribe Middleware for Distributed EV Charging Optimization. Submitted to *5th Conference on Energy Informatics (EI2014), Zurich, Switzerland.*
16. C. Goebel, H.-A. Jacobsen. Bringing Distributed Energy Storage to Market. *IEEE Transactions of Power Systems*. (*under revision).* 2014.
17. V. del Razo, C. Goebel, H.-A. Jacobsen. On the Effects of Signal Design in Electric Vehicle Charging using Vehicle-Originating-Signals. Submitted to *5th Conference on Energy Informatics (EI2014), Zurich, Switzerland.*
18. C. Doblander, T. Rabl, H.-A. Jacobsen. Processing Big Data Events with Showers and Streams. *Third Workshop on Big Data Benchmarking*. 2013.
19. J. Rivera, H.-A. Jacobsen. A Distributed Anytime Algorithm for Network Utility Maximization with Application to Real-time EV Charging Control. *53nd Conference on Decision and Control (CDC2014), Los Angeles, CA, USA.* 2014.
20. V. del Razo, C. Goebel, H.-A. Jacobsen. Reducing Communication Requirements for Electric Vehicle Charging using Vehicle-Originating-Signals. Submitted to *5th IEEE International Conference on Smart Grid Communications (SmartGridComm2014), Venice, Italy.*