AALBORG UNIVERSITY
DENMARK

Intelligence detection and prediction of energy at the device level

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Outline

- Project background
- State-of-the-art
- What has been done
- Papers
- Future plan
- PhD courses and teaching

Background

- Renewable energy sources (RES) are increasing
- Important component for the future power grids
- Renewable Energy Sources (RES) fulfill a major portion electricity demand in Nordic region.
  - 6% of total energy power generation from wind power.
  - Increasing at a rate of 4 TWh per year[1].
  - 39% of total electricity demand in Denmark (2014).

[1]N. E. R. (NordREG). Nordic market report 2014.

Background

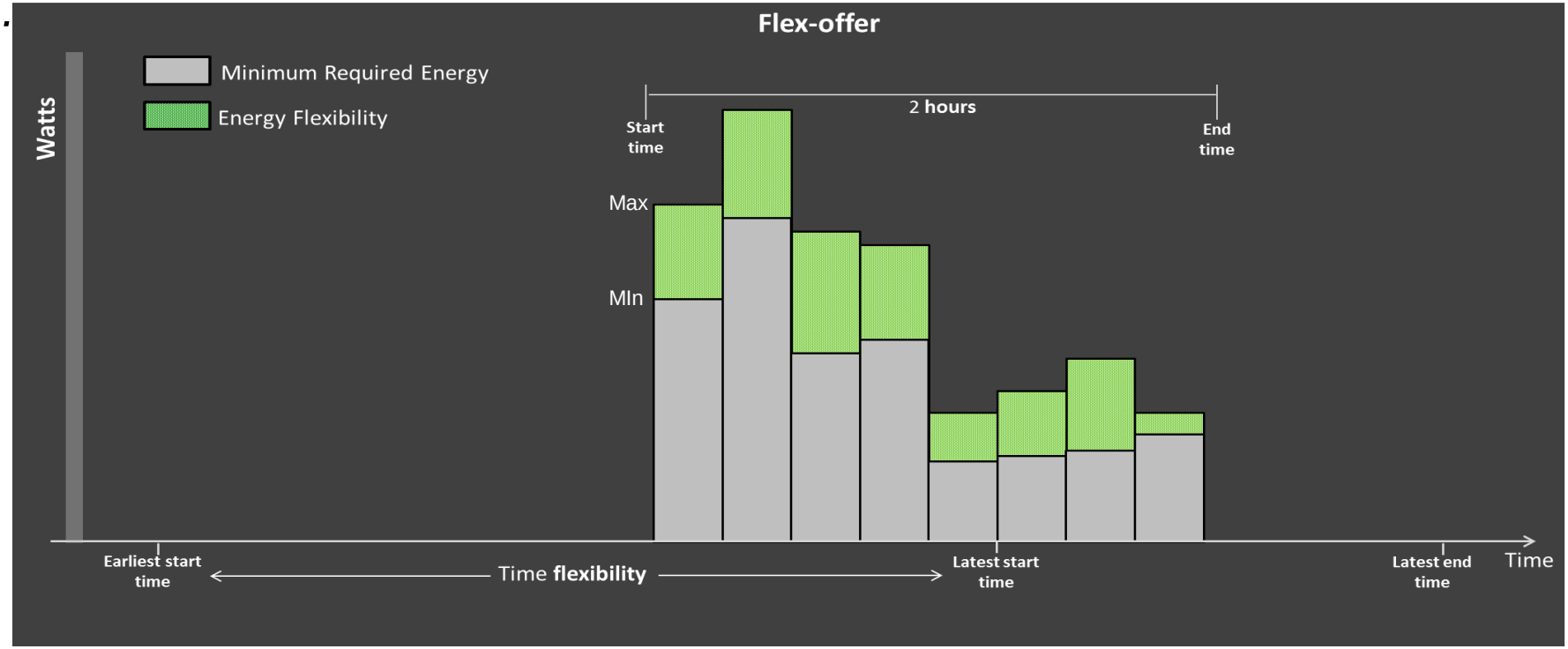
- Challenges due to fluctuating generation from RES
  - Often results in imbalance.
- Solution :
  - Utilizing the flexibility in energy consumption for demand management
  - TotalFlex[1] implements the concept of flex-offer[2]
  - Flex-offer: a flexible consumption (and production) offer.
- Benefits : demand management, minimize energy loss, better pricing for customer

[1]Totalflex Project, www.totalflex.dk/Forside/
[2]flex-offer, proposed in EU FP7 project MIRABEL, www.mirabel-project.eu

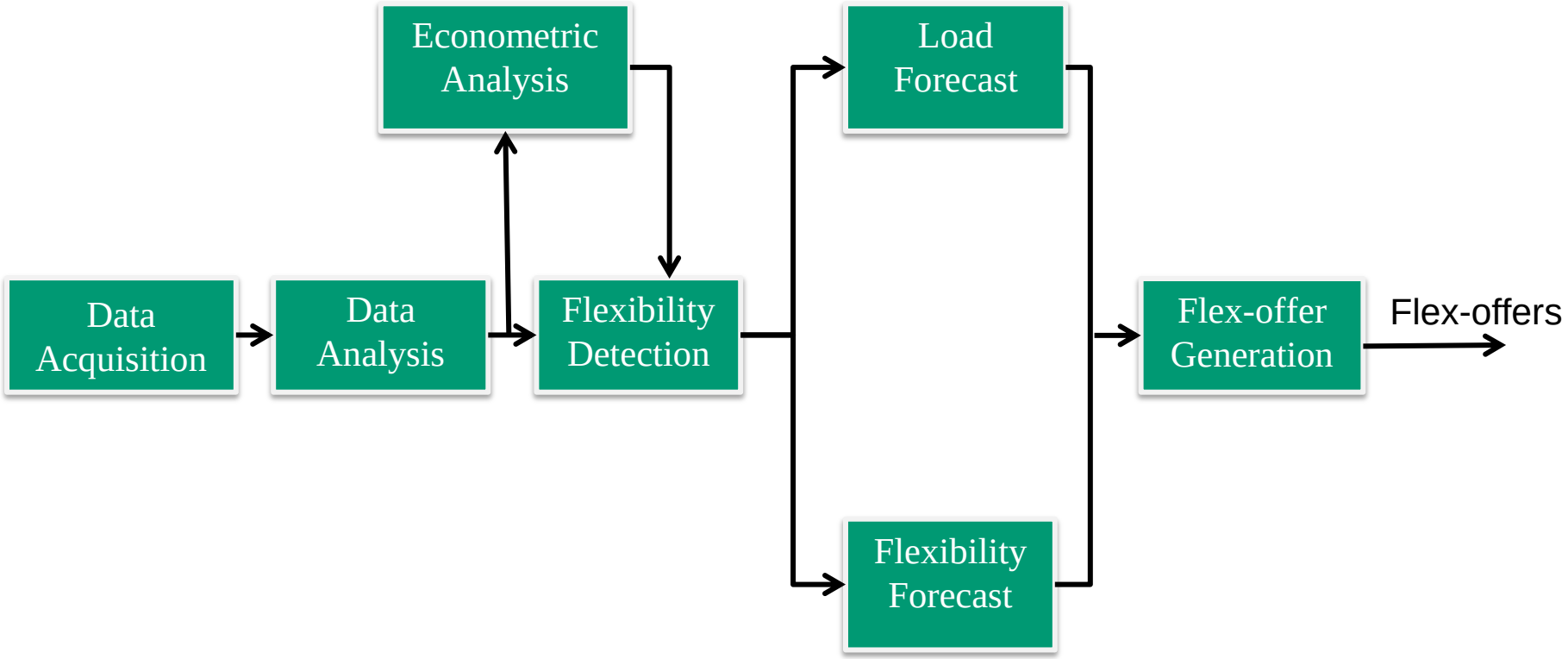
Flexibility

- *Time Flexibility* (TF) : preponing or postponing demand for energy.

- *Amount Flexibility* (AF): represents the range between maximum and minimum energy



Ph.D. Research Focus Area



Ph.D. Project Challenges

- Device level consumption data
- Noisy data
- Varying devices properties
- Stochastic device level usage patterns
- Limited literature related to device level consumption analyses

PhD. Project Contribution

- Comprehensive device level analysis (extraction of flexibility)
  - On real world energy consumption data
  - Massive time series dataset
  - Methods to confront challenges in cleaning device level data

- The state-of-the art forecasting model
  - For energy flexibility and demand at the device level
  - Model highly stochastic environment

PhD. Project Contribution

- Econometric analysis of flexibility
  - Effect on energy regulation market
  - Balance of RES production and demand

- Financial impact on energy market that are caused due to error in flexibility forecast.

- Flex-offer generation
  - Multidimensional (time and/or energy) flexibility
  - Atomic granularity (device level)
  - Device specific

What has been done so far

- Acquisition of device level datasets.
- Data analyses for consumption patterns. (Published)
- Econometric analysis of flexibility. (Published)
- Methods to forecast device activation time.
- eManage: graphical user interface for flexibility detection and forecast.
- Collaboration in the TotalFlex project.
- Designed OLAP application for bank data.

Published Papers

- Towards Flexibility Detection in Device-level Energy Consumption. (Paper 1)
  - Dare 2014, workshop

- Evaluating the Value of Flexibility in Energy Regulation Markets. (Paper 2)
  - ACM E-energy 2015, Conference

Towards Flexibility Detection…

- Acquisition of Datasets REDD[8] and ZENSE (project partner).

- REDD:
  - 3 sec. resolution
  - 6 household
  - 11-20 unique devices

- ZENSE:
  - 15 min. resolution
  - 10 household

Towards Flexibility Detection…

Flexibility: the amount of energy and the duration of time to which the device energy profile (energy flexibility) and/or activation time (time flexibility) can be changed.

- Evaluate devices based on the cost and benefit of utilizing it under the TotalFlex scenario.

  Cost: The loss of user-perceived quality caused by accepting flexibility.

  Benefit: The available time and energy flexibility for the device.

Towards Flexibility Detection…

Hypothesis and Results

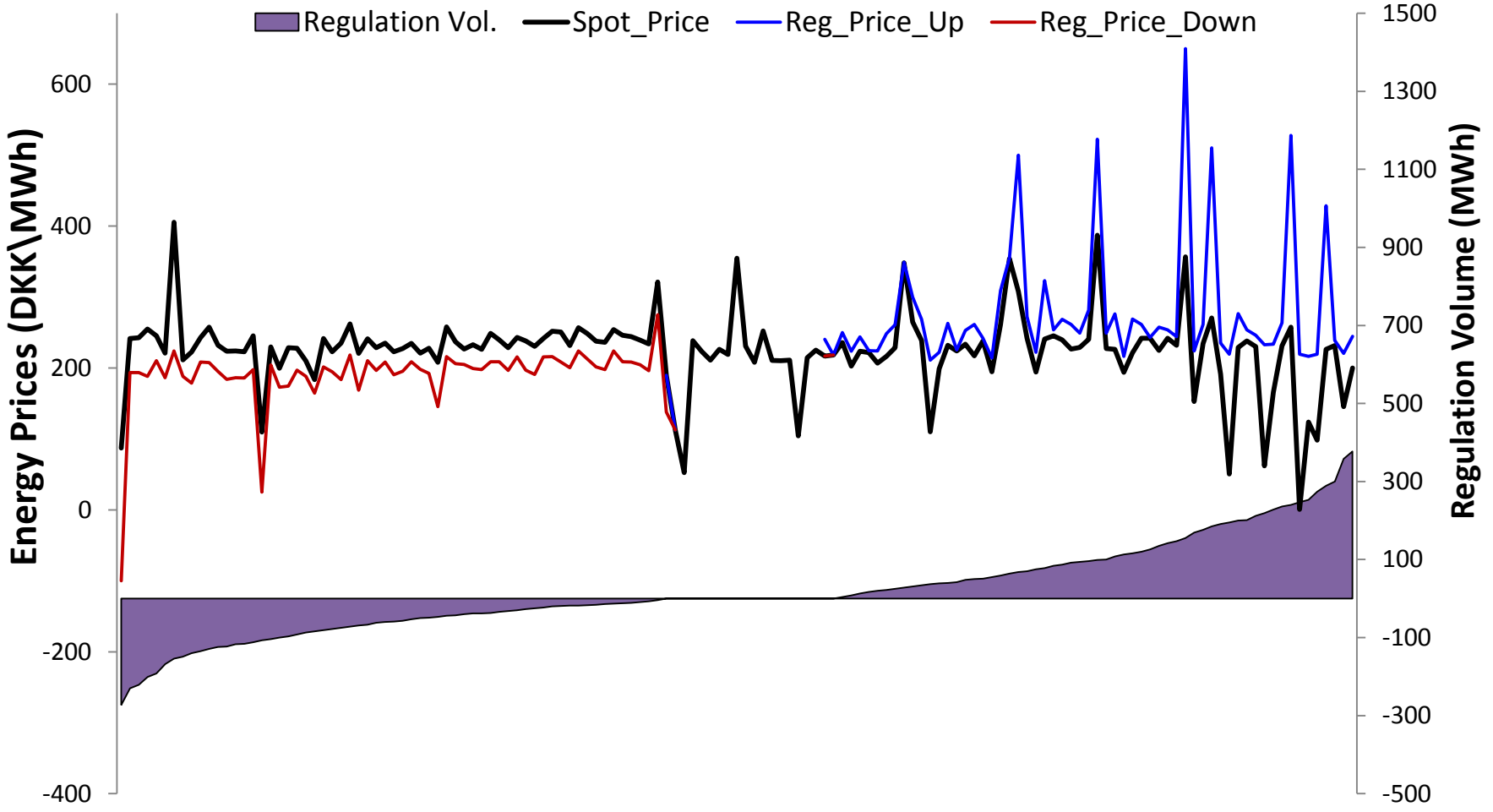
- 1) There exists detectable Intra-day and Inter-day patterns in device operation.
  - (a) Weekend and Weekdays patterns are different. ✓
  - (b) Houses exhibit general and specific intra-day and inter-day patterns. ✓
- 2. There exist time and energy flexibility in device operation.
  - (a) A major percentage of energy consumption comes from flexible devices. ✓
  - (b) An alteration in device energy profile is feasible. ✓
  - (c) Device activation time can be shifted by some duration. ✓

Towards Flexibility Detection…

- Some devices are correlated
  - (a) Highly correlated device are operated simultaneously or just after one another. ❌
  - (b) There is some fixed sequence of device operation. ✅

- This work is published as workshop paper at DARE'14 on June 20, 2014.

Evaluating the Value of Flexibility…



Evaluating the Value of Flexibility…

Econometric analysis on regulation market

- $$p_{u/d}(t) = 1.\, p_s(t) + 1_{v_u(t)<0}(-0.069 \cdot p_s(t) + 0.023 \cdot v_d\,(t) - 4.30) + 1_{v_u(t)>0}(0.028 \cdot p_s(t) + 0.042 \cdot\ v_u(t) + 13.07)$$

  Model from Literature

- $$p_{u/d}(t) = 1.\, p_s(t) + 1_{v_u(t)<0}(-0.5101 \cdot p_s(t) - 0.032 \cdot v_d\,(t) + 55.83) + 1_{v_u(t)>0}(0.0657 \cdot p_s(t) + 2.6157 \cdot\ v_u(t) - 12.28)$$

  Model from Literature fitted to latest dataset

- $$p_{u/d}(t) = 1.\, p_s(t) + 1_{v_u(t)<0}(-0.3362 \cdot p_s(t) + 0.0005\ (p_s(t) \cdot\ v_d(t)) + 1_{v_u(t)>0}(0.2378 \cdot p_s(t) + 0.0034\ (p_s(t) \cdot\ v_u(t))$$

  Model used in our experiments

Evaluating the Value of Flexibility…

Market Objective

- We optimize the total benefit of utilizing flexibility

$$C(X;\tau) = \max(t'_1, \dots, t'_n) \sum_{i=1}^{n} C(t_i, t'_i; \tau)$$

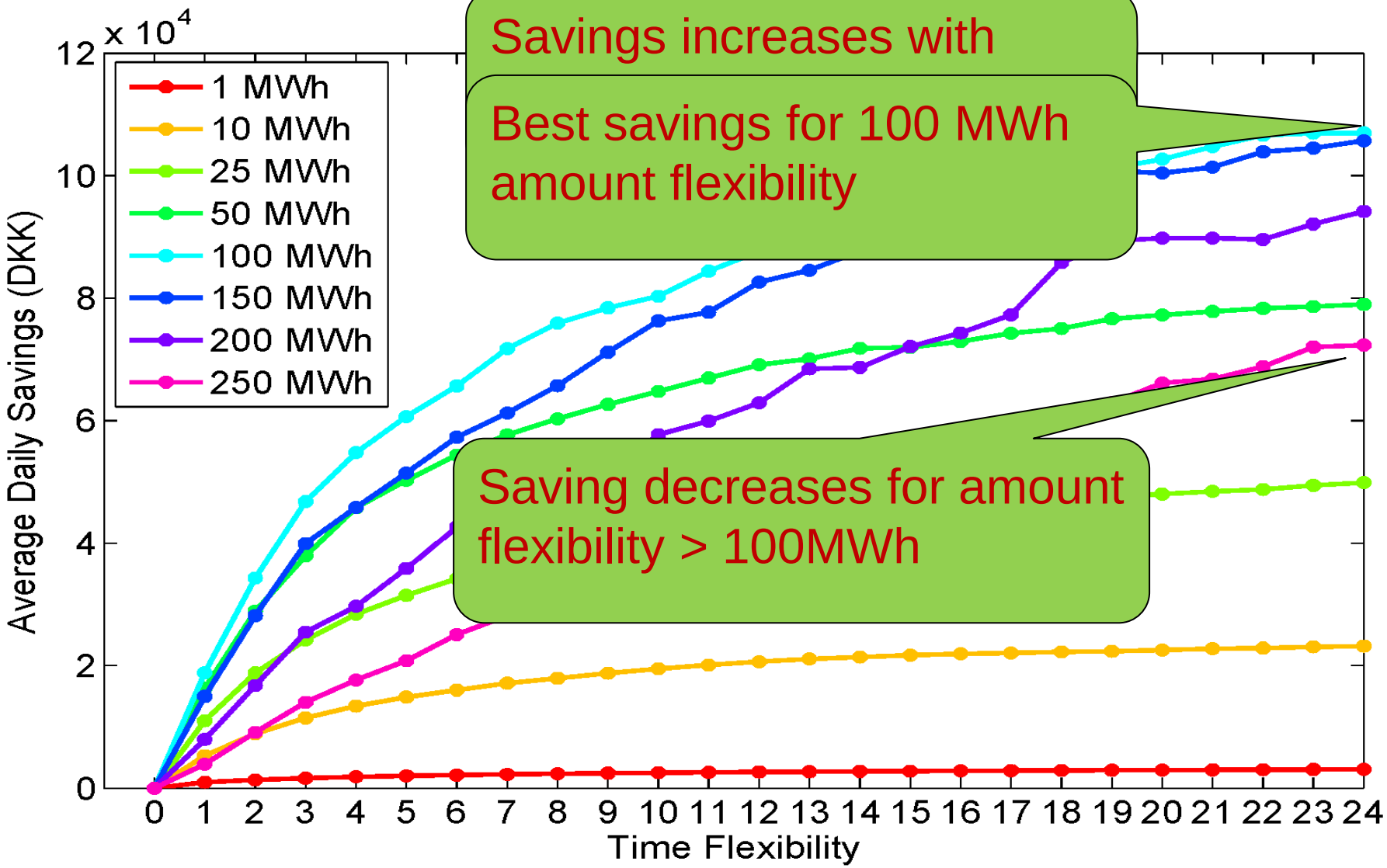
  - Minimizing regulation cost

$$C(t_i, t'_i; \tau) = \Delta R(t_i, t'_i; \tau)$$

  - Minimizing regulation volume

$$C(t_i, t'_i; \tau) = \left(v_{\overline{d}}^{u}(t) + v_{\overline{d}}^{u}(t')\right) - \left(v_{\underline{d}}^{u}(t) + \overline{v_{\overline{d}}^{u}(t')}\right)$$

Evaluating the Value of Flexibility…



Evaluating the Value of Flexibility…

Analysis

- Increase in total saving with a increase in time flexibility.
- Just 3.87% flexibility in the demand, can reduce the regulation cost and volume by up to 49% (107K) and 29.4% (442 MWh), respectively.
- Highest benefit is obtained for 100 MWh (48 % higher then 250 MWh).

Working Papers

- Financial Impact of Flexibility Forecast Error on the energy Market. (Paper 3)
  - Energy Economics Journal (Elsevier), September 2015.

- eManage: A Comprehensive Energy Management Using Flex-offer. (Paper 6)
  - Demo paper

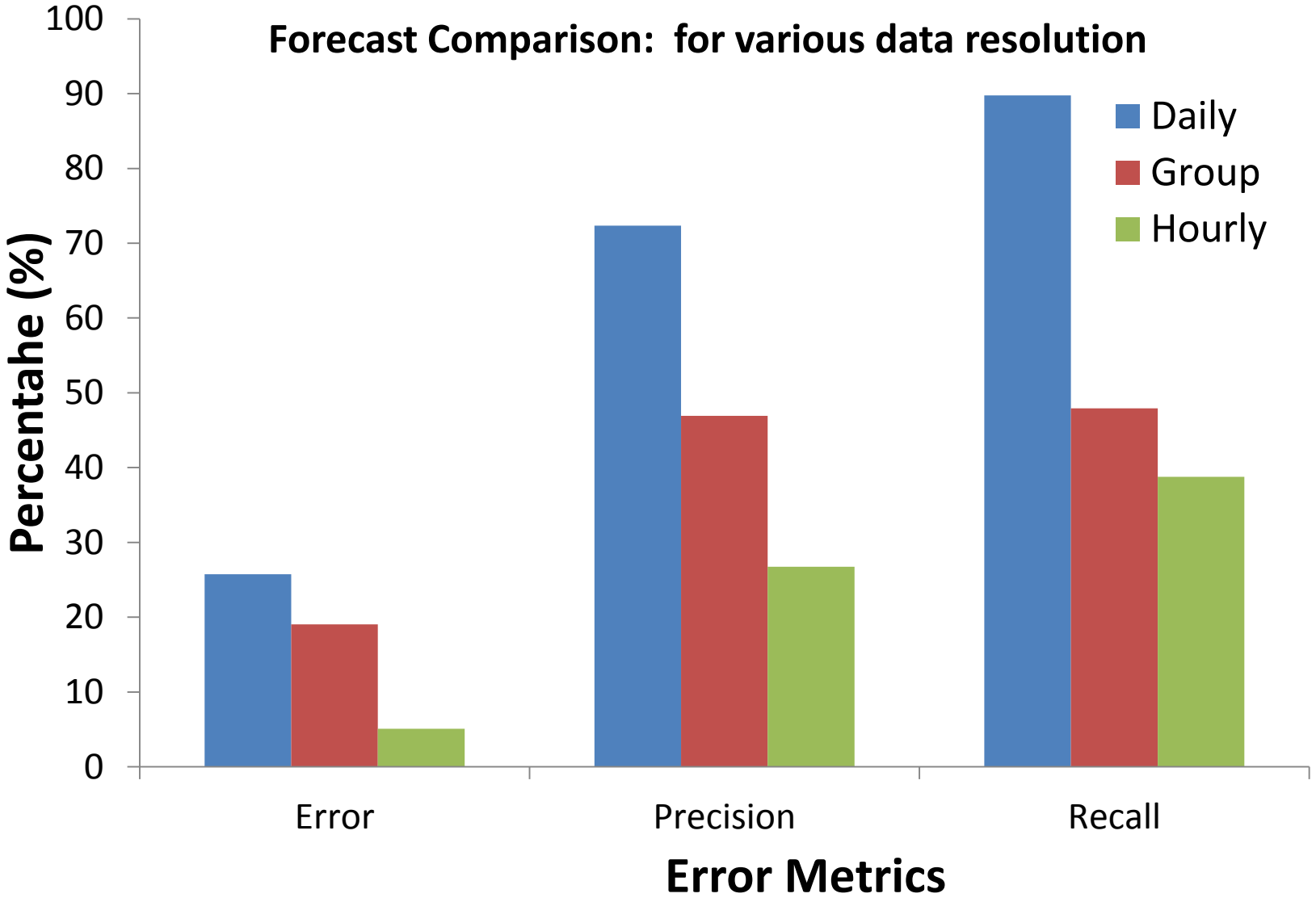
State-of-the-art/Forecast models

- There exist various forecast models focusing on different research domains
- Quantitative time series methods: ARIMA, Exponential smoothing, Moving Average, EGRV, HWT
- Machine Learning: SVM, ANN, Fuzzy Logic, Expert System

State-of-the-art/Forecast

- Most of the existing model are tailor made and tuned to specific domain, data or time-horizon.
- Device level data exhibits higher stochastic behavior compared to aggregated data.
- Accuracy decreases with increasing data resolution.
- Relationship between accuracy and forecast horizon.
- Imbalance class problem. (only 2-3% positive instance)

Financial Impact of Error …



Financial Impact of Error …

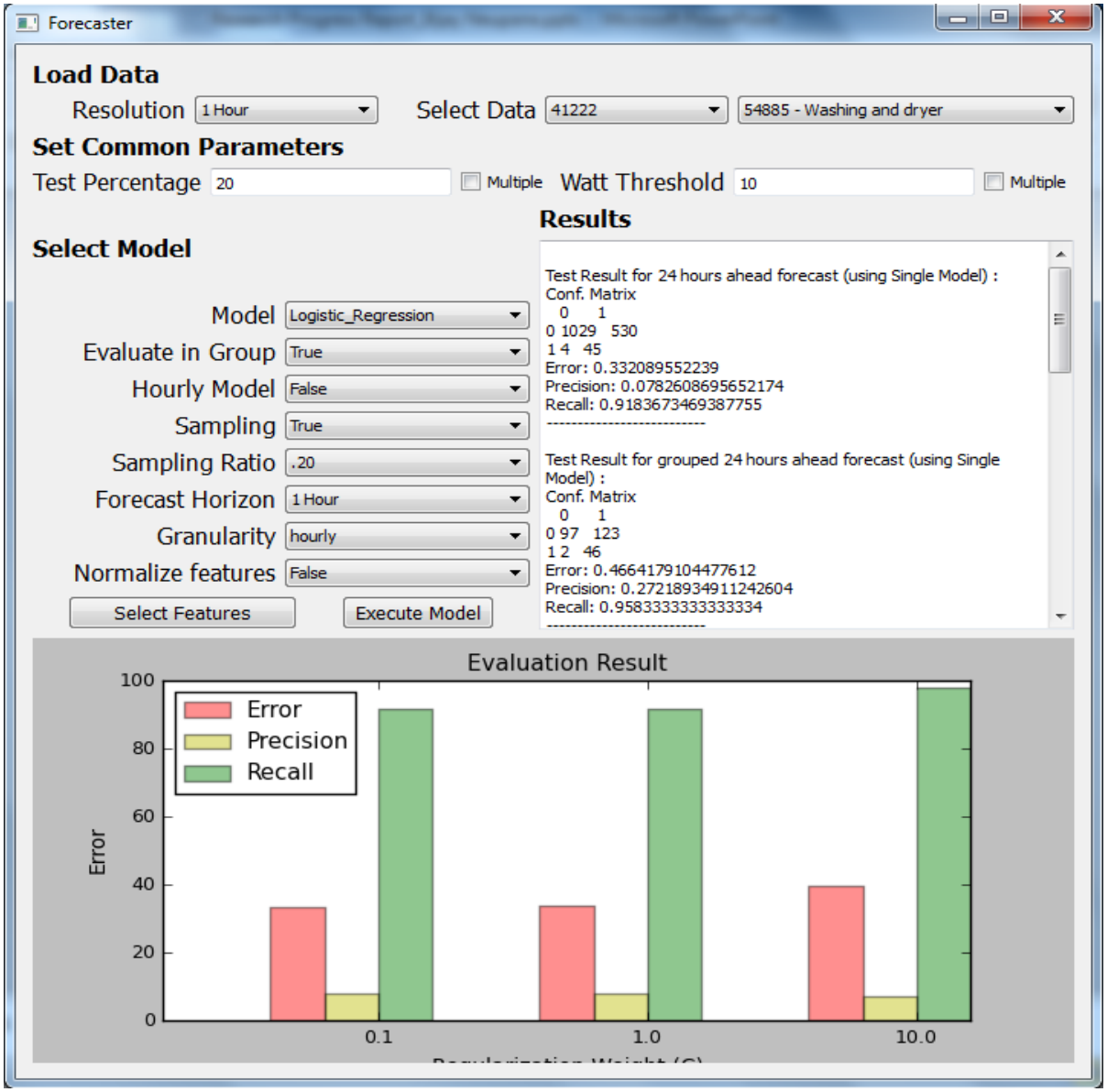
- Forecast device activation time
  - Analysis of various time series model.
  - Logistic regression (l1)
  - Feature generation

- Experimental evaluation of forecast model for various data resolution and forecast horizon.

- Analysis on the evaluation metrics for device level forecast models.

- Impact of forecast error (False Positive and False Negative) on flexibility market.

eManage…


Forecaster
Load Data
Resolution
1 Hour
Select Data
41222
54885 - Washing and dryer
Set Common Parameters
Test Percentage
20
Multiple
Watt Threshold
10
Multiple
Select Model
Model
Logistic_Regression
Evaluate in Group
True
Hourly Model
False
Sampling
True
Sampling Ratio
.20
Forecast Horizon
1 Hour
Granularity
hourly
Normalize features
False
Select Features
Execute Model
Results
Test Result for 24 hours ahead forecast (using Single Model) :
Conf. Matrix
0 1
0 1029 530
1 4 45
Error: 0.332089552239
Precision: 0.0782608695652174
Recall: 0.9183673469387755
Test Result for grouped 24 hours ahead forecast (using Single Model) :
Conf. Matrix
0 1
0 97 123
1 2 46
Error: 0.4664179104477612
Precision: 0.27218934911242604
Recall: 0.9583333333333334
Evaluation Result
Error
Precision
Recall
100
80
60
40
20
0
0.1
1.0
10.0

Future Papers

- Multi-dimensional Flexibility Detection for Flexible Objects.
  - ACM e-Energy January 2016 , conference.

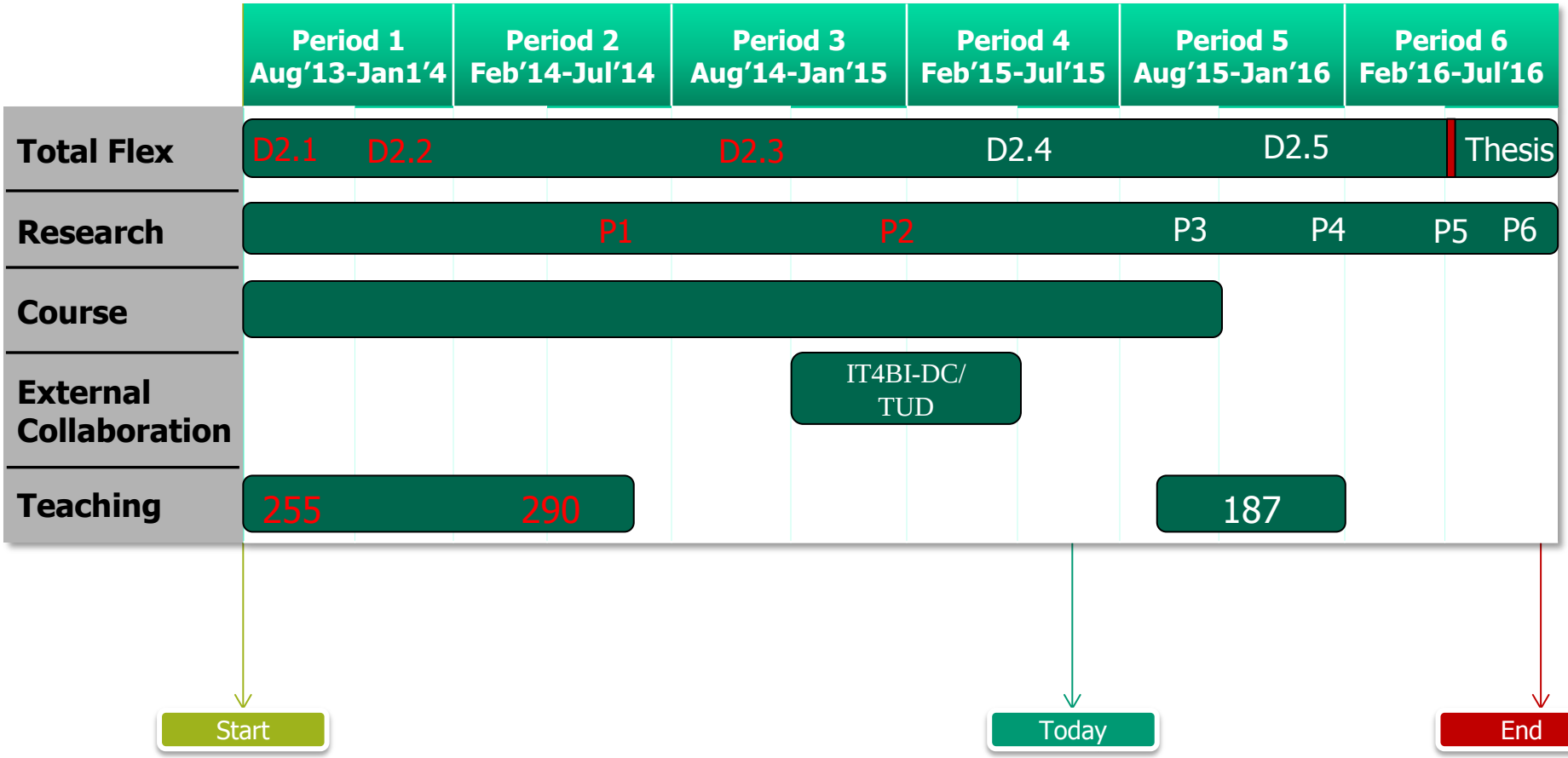
- A Comprehensive Device Level Analyses on Flex-forecast and Flex-offer Generation .
  - JAIR 2016 journal.

Courses Plan

Courses	Place	ECTS	General/Project	Status
Introduction to the Ph.D. study	AAU	1.0	General	Completed, Fall 2013
PBL in Engineering and Science - Development of Supervisor Skills	AAU	2.0	General	Completed, Fall 2013
Writing and Reviewing Scientific Papers	AAU	3.75	General	Completed, Spring 2014
Semantic Web Warehouse	AAU	2.0	Project	Completed, Spring 2014
European Business Intelligence Summer School	Berlin, Germany	2.0	Project	Completed, Summer 2014
Academic writing in English	AAU	3.0	General	Completed, Fall 2014
Good scientific practice	TUD	1.0	General	Completed, Spring 2015
Foreign Language (Danish)	AAU	2.0	General	Ongoing
Data Science: Concepts, Techniques and Systems	AAU	2.0	Project	Completed, Spring 2015
Doctoral Colloquium	ULB	2.0	Project	Summer 2015
Big Data Management Systems: Concepts, Architectures and Implementation	AAU	2.0	project	Enrolled, Fall 2015
Data Management and Integration on the Web	AAU	2.0	Project	Enrolled, Fall 2015
Artificial Intelligence, Machine Learning & Model Checking - Study Group	AAU	2.0	Project	Enrolled, Fall 2015
Deep Learning	AAU	1.0	Project	Enrolled, Fall 2015
Conference attendence	To be decided	2.0	project	Fall 2015
Project related courses	To be decided	1.0	project	Spring 2016
General Courses		**12.75**		
Project Cources		**18**		
Total		**30.75**		

- 18.75 credits earned, 12.75 general and 6 project related
- 7 credits enrolled, 2 credits Doctoral Colloquium
- 595 Teaching hours

Time Schedule



Completed

Planned

P = Paper
D = TotalFlex Deliverable
TUD = Technische Universität Dresden
Teaching in Hours, Total 732 hours