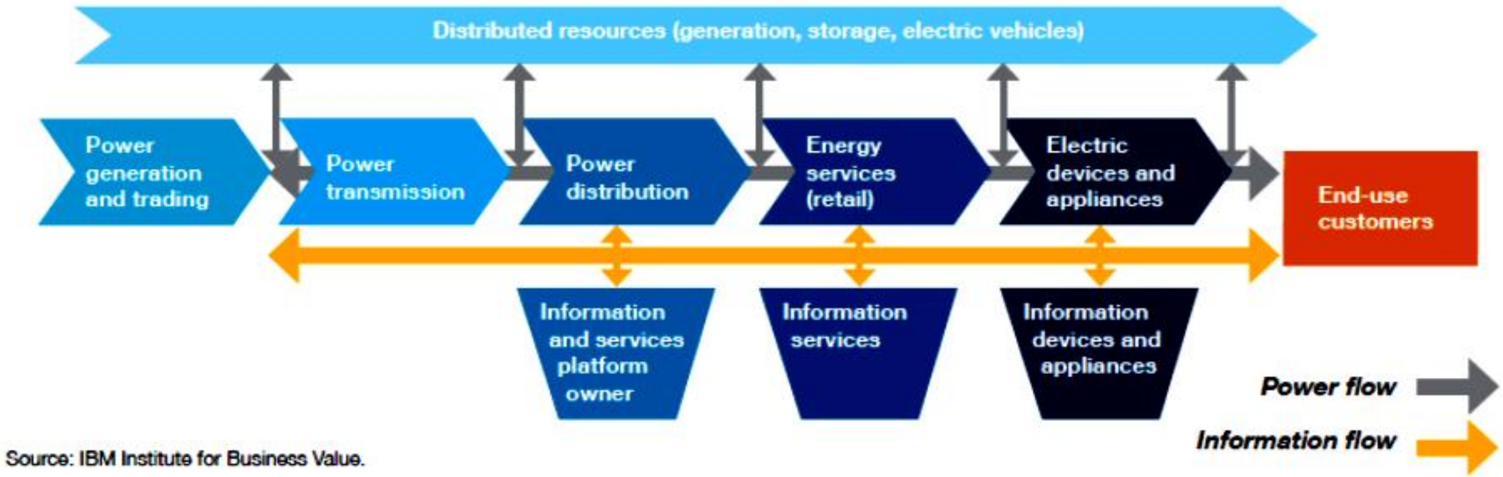
METHODOLOGY FOR MANAGING COST-EFFECTIVE DEMAND RESPONSE CAMPAIGNS BASED ON DEMAND ELASTICITY PROFILES

Angeliki Anastopoulou, Costas Kalogiros, George D. Stamoulis
Athens University of Economics and Business
Department of Informatics,
Services, Technologies, and Economics group (STEcon)
(*http://nes.aueb.gr*)

ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

Smart Grid Value Chain



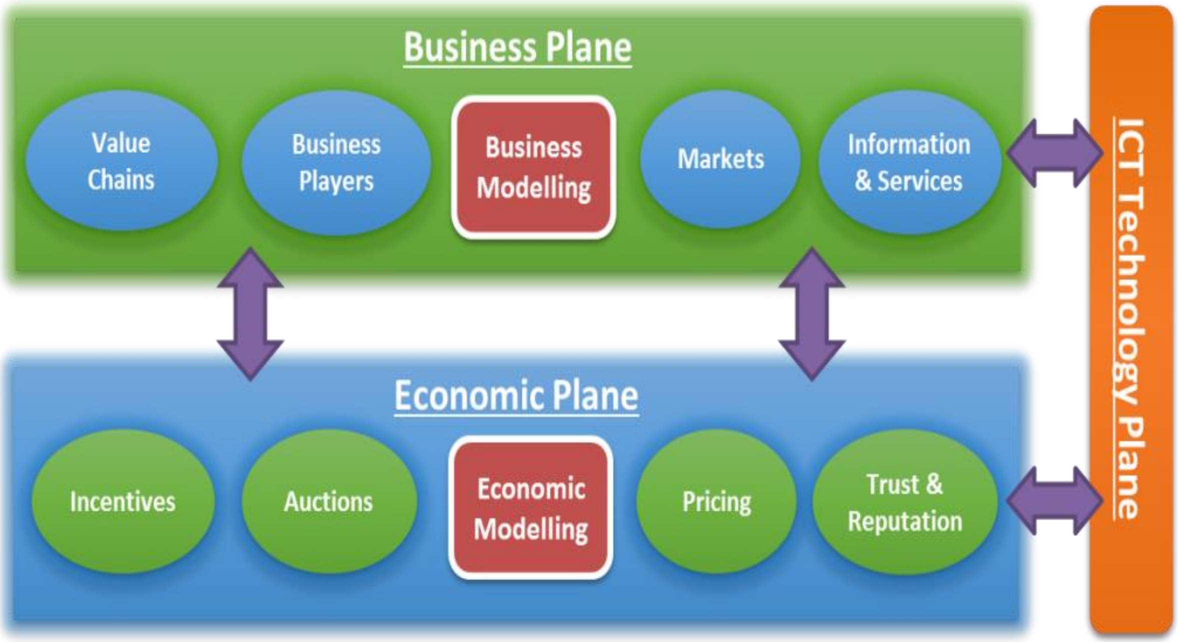
- Passive **consumers** turn into **proactive smart grid actors** being capable of providing **demand response** to the system.
- Consumers can **participate** either **directly** (e.g. in case of large scale consumers) or **through a third party Aggregator.**

Demand Response

"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"

What we do
@ Services, Technologies, and Economics group

- We investigate, develop and apply concepts, and mechanisms where ICT technology, economics, and information and “meet”:
  - *Future Internet and cloud computing*
  - *Energy and smart grids*
  - *Internet of Things*
  - *Wireless*
  - *Energy and Telecom Regulation*
  - *Software for ICT systems*
  - *E-markets*



Selected energy projects and STEcon-AUEB roles

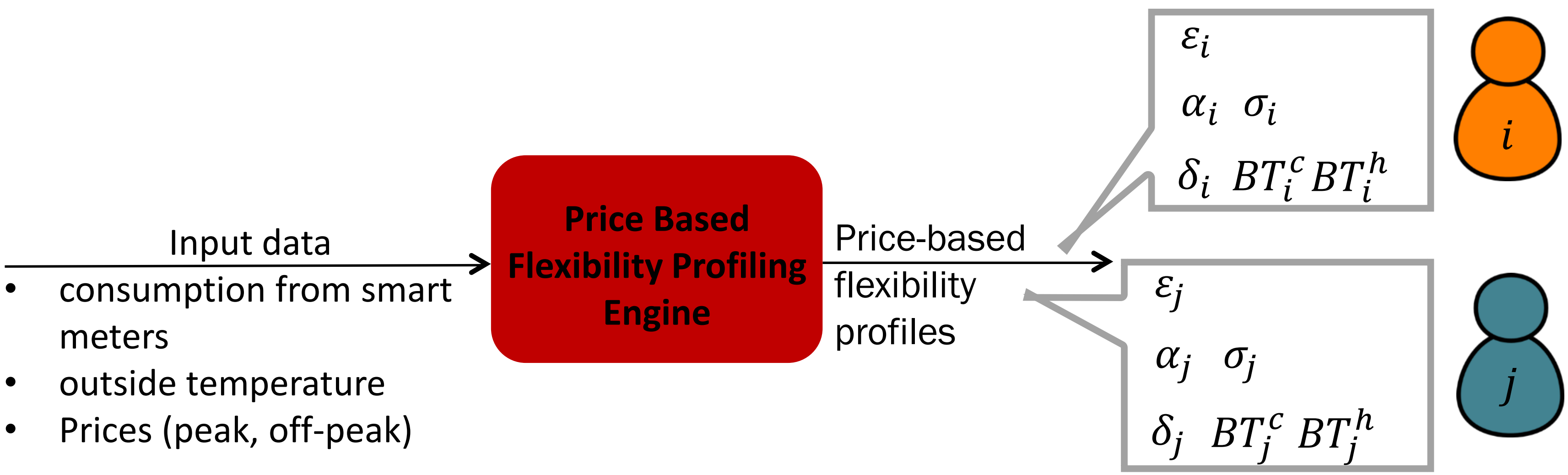
- WISEGRID: Wide scale demonstration of Integrated Solutions for European Smart Grid
  - *Socio-economic evaluation, business modelling, DR mechanisms and optimization, behavioural economics*
- NOBELGRID: New Cost Efficient Business Models for Flexible Smart Grids
  - *Economic and business modelling, CBA, KPIs, flexibility profiles, incentives schemes for DR in demonstration sites*
- OPTI: Optimization of District Heating Cooling systems
  - *Automated DR programs and contracts for DHC networks, economic optimization tools*
- ChargED: CleAnweb Gamified Energy Disaggregation
  - *Behavioural economics based incentive mechanisms and gamification*
  -
- WATTALYST: Modelling and Analysing DR Systems for Smart Grids
  - *Design, analysis and implementation of efficient DR programs*

Contribution

- Introduce a **flexibility profiling engine** that **profile for each end-user** that **reflects** end-user's **demand as function of retail prices and environmental conditions**.
- Describe how an entity acting as an **Aggregator** can **use the proposed engine** for **calculating** the **expected flexibility** that can be obtained by each end-user for a certain price, outside temperature and period (peak/off-peak).
- **Evaluate** the accuracy of the proposed engine using publicly available data set from a **dynamic pricing program** that was extensively applied in **London**.
- Provide guidelines about how these **profiles** can be **used by an Aggregator** in order to define key aspects of a **successful manual DR campaign**.
  - Price-based DR mechanism
  - Reward-based mechanism

The Price-based Flexibility Profiling component

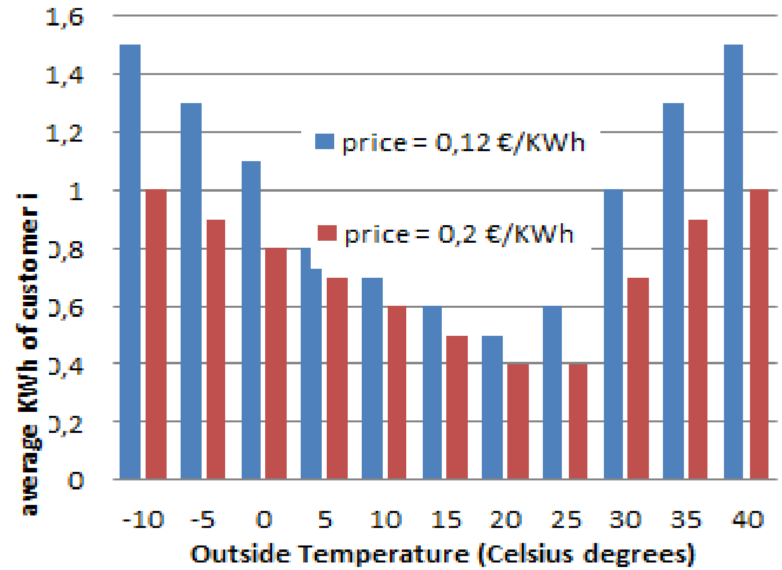
- The **Price Based Flexibility Profiling** component produces a **profile** for each customer for peak and off-peak periods, reflecting real-time demand flexibility as a function of:
  - *energy retail prices periods*
  - *environmental context/ conditions, and*
  - *customer preferences.*

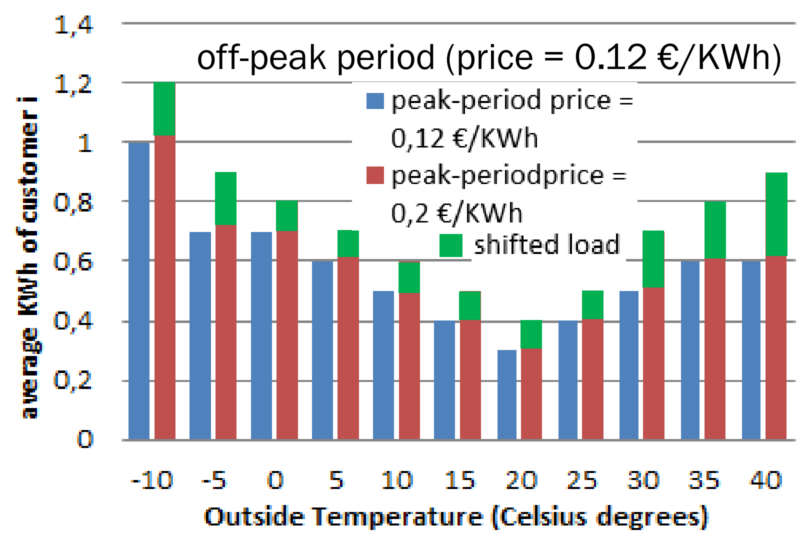


An example

- Setting:
  - *Customers pay according to a dynamic pricing scheme*
    - During peak periods the price is
      - *either 0.12 €/KWh*
      - *or 0.20 €/KWh*
    - During off-peak the price is 0.12 €/KWh
  - *Outside temperature ranges from -10°C to 40°C*

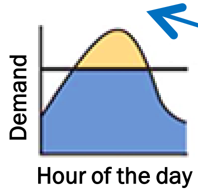
- Key observations:
  - *Customers' load is sensitive to both prices and extreme weather conditions*
  - Off-peak load can be assumed to stem from shifting



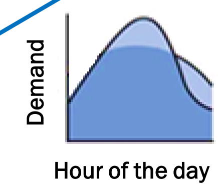


The User Profile

Average (own-price) elasticity of demand:
Measures the reduction of the customer's demand in a certain period due to the increase in the price of that period



Average elasticity of substitution:
Measures the load shifting that takes place after a change in price during the previous period(s)



Profile for i

ε_i

$\alpha_i \quad \sigma_i$

$\delta_i \quad BT_i^h \, BT_i^c$

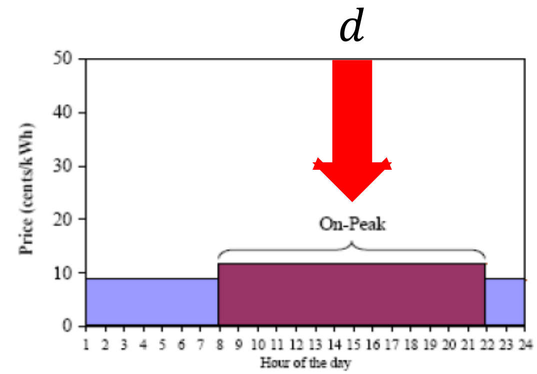
End-user's weather sensitivity

The maximum outside temperature
in C° for which cooling is not activated by a certain endpoint for a certain retail price of energy

Similarly with heating

Estimating the new consumption at peak period after a price increase

- The estimated consumption of endpoint i during peak period d and for a new price $\boldsymbol{p_d}$ is:



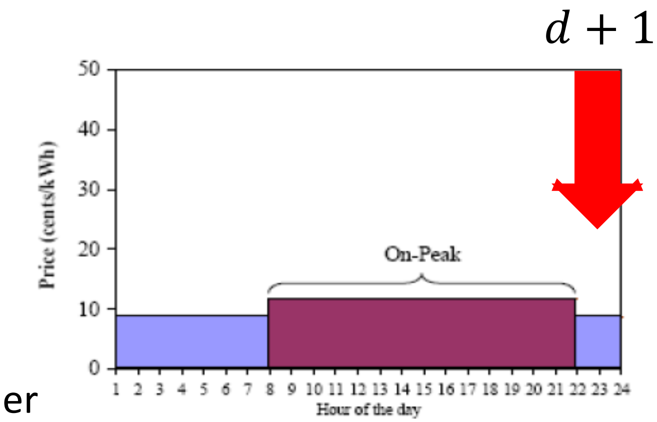
$$q_i^{p_d} = q_i^{p_0} \times e^{\varepsilon_i \times (\ln p_d - \ln p_0) + \delta_i (\mathrm{CDH}_i^{p_d} - \mathrm{CDH}_i^{p_0})}$$

- ε_i: Elasticity coefficient (from profile)
- δ_i: Sensitivity to Weather coefficient (from profile)
- $q_i^{p_d}$: **New consumption** at peak period d
- $q_i^{p_0}$: Initial consumption (known)
- p_d: New price (set by admin)
- p_0: Old price (known)
- $\mathrm{CDH}_i^{p_d}$: Cooling Degree Hours for new price (can be calculated from profile)
- $\mathrm{CDH}_i^{p_0}$: Cooling Degree Hours for old price (can be calculated from profile)

*Based on AUGMENTED CES MODEL of Ton et al. "Tool for determining price elasticity of electricity demand and designing dynamic price program." Innovative Smart Grid Technologies (ISGT), *IEEE PES,* 2013.

Estimating the new consumption at peak period after a price increase

- The consumption of endpoint i in the next period is:



Elasticity of substitution constant coefficient (from profile)

Elasticity of substitution variable coefficient (from profile)

Sensitivity to weather coefficient (from profile)

$$\overline{q_i^{p_d}} = q_i^{p_0} \times e^{\alpha_i + \sigma_i(\ln p_0 - \ln p_d) + \delta_i\left(\mathrm{CDH}_i^{p_d} - \mathrm{CDH}_i^{p_0}\right)}$$

Consumption at period $d+1$, because of increased price p_k at period d

Initial consumption at period $d+1$ (known)

Old price (known)

New price (set by admin)

Cooling Degree Hours for new price (can be calculated from profile)

Cooling Degree Hours for old price (can be calculated from profile)

Dataset

- From a **dynamic pricing program** that was **applied** in a large (1100) number of **households in London**, (01/01/2013 – 31/12/2013)

- Included **half hourly consumption data** each for household (no sub-metering data were available) for each of the three different price bands:
  - $p_0 = 0.1176£/kWh$, **baseline price**
  - $p_1 = 0.0399£/kWh$, **low price**
  - $p_1 = 0.672£/kWh$, **high price**

- After preprocessing, for each **day ,** for each **household** and for both **peak** (17:00 – 23:00) and **off-peak** (23:00 – 17:00) period we obtain:
  - *the time stamped **aggregated energy consumption***
  - *the **average value** of the **applied dynamic price***
  - *the **average outside temperature***

Accuracy

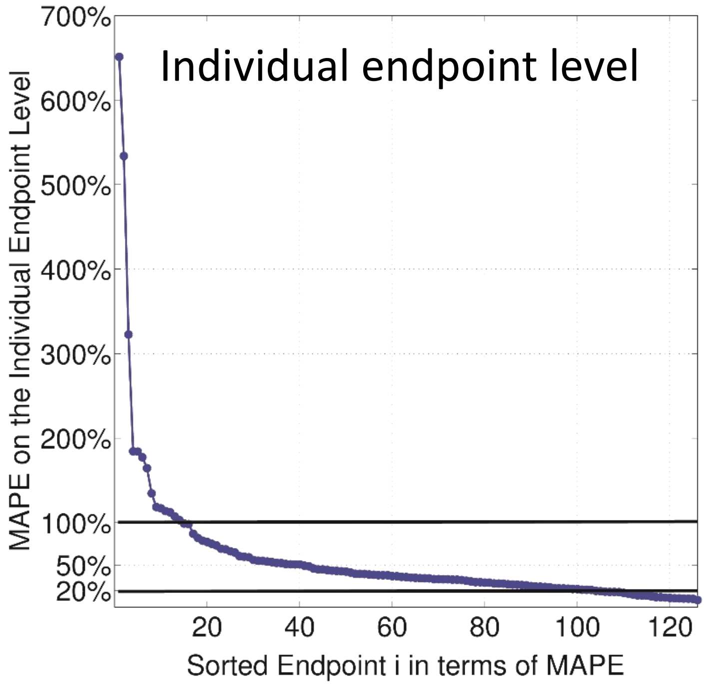
- **Training Period:** we consider a training period that lasted two months, **from 01/02/2013 until 31/03/2013**.
  - *Based on this dataset we calculated the **elasticity values** and other **endpoint specific parameters** for each endpoint.*

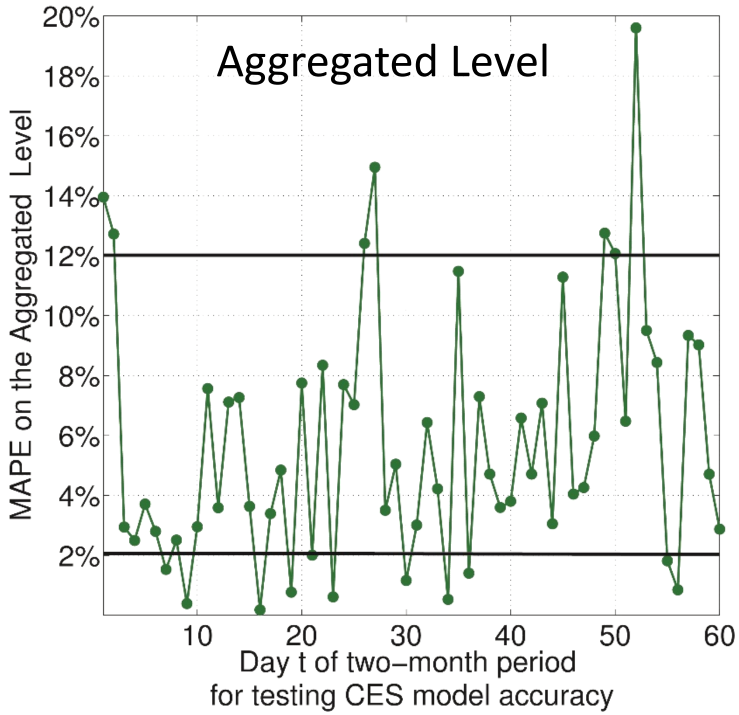
- Based on training period's outputs we tested PBFP component's accuracy.

- A subset of our initial dataset that includes data **from 01/11/2013 until 31/12/2013** for the 54 endpoints was used.
  - *Due to **similar weather conditions** with the **months considered** in the **testing period**.*

- Bibliography: **load forecasting on the individual household level** is a **challenging task** due to **the extreme system volatility**. Errors range from 20% to 100% (and even higher) and depend on dwelling lifestyle and regularity of appliance usage, such as:
  - *Operational characteristics of devices*
  - *The behaviours of the users, economic factors*
  - *Time of the day*
  - *Day of the week*
  - Holidays
  - Weather conditions
  - Geographic patterns
  - Other random effects

Forecasting Accuracy During Peak Periods in terms of Mean Absolute Percentage Error (MAPE)





- **Load forecasting on the individual household level** is a **challenging task** due to **the extreme system volatility**. Errors range from 20% to 100% (and higher) and depend on dwelling lifestyle and regularity of appliance usage

- **Aggregation considerably improves MAPE**.

Further usage of price-based profiles

- These **profiles** can be further processed by a DSO/Retailer (directly or through a third party Aggregator) in order to:

  - *come up with the details of a manual DR campaigns for obtaining the desired flexibility level.*

    - Calculate the **new retail price** in order to achieve the desired demand reduction, in case of dynamic pricing schemes

    - Decide which **consumers** to **target ,** the **quantity** that should be curtailed by each one of them together with the **personalized reward** for motivating them to adjust their consumption during a certain period.

  - *calculate the minimum **remuneration** that an Aggregator would be willing to accept from a DSO/Retailer to perform the DR campaign.*

Future Work

- Evaluate the accuracy of the proposed profiling engine in **real world demonstration activities** performed in three pilot sites of the **Nobel Grid research project**, namely:
  - *Manchester (U.K)*
  - *Flanders (Belgium)*
  - *Terni (Italy)*

- Evaluate the effectiveness and accuracy of the rewards obtained from the proposed reward-based mechanism

Thank you

Backup slides

Mechanism for implicit (price-based) DR

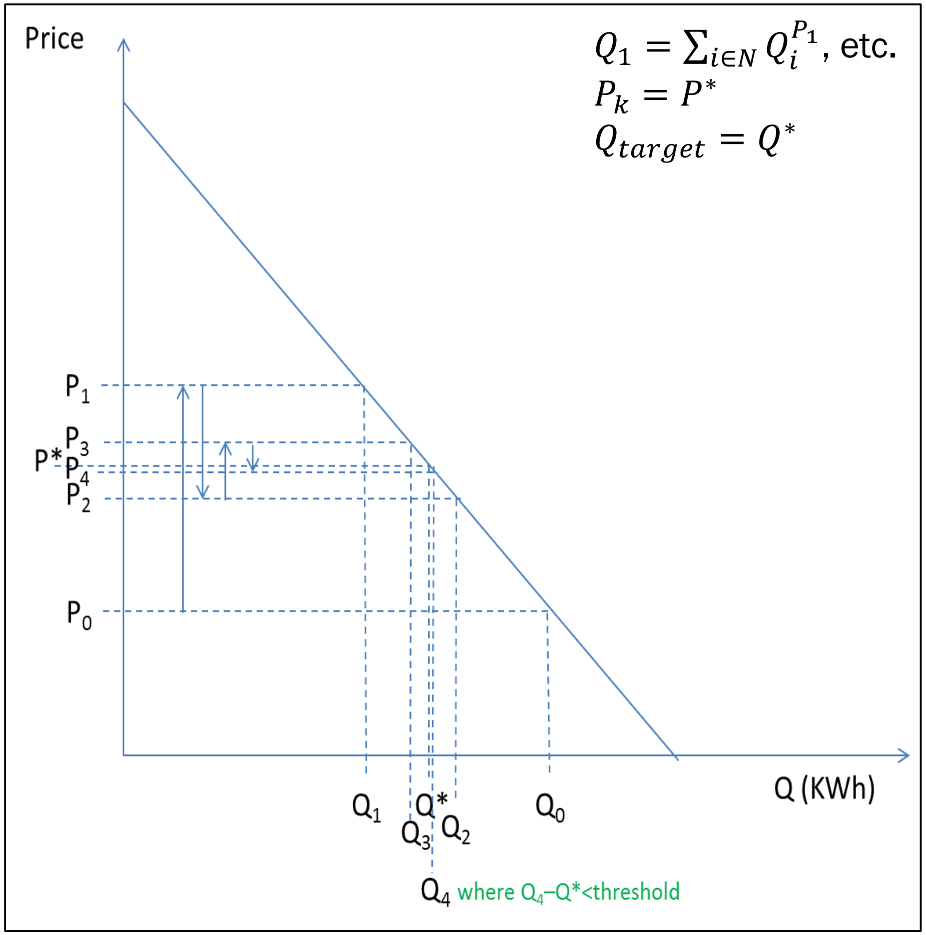
- A **Retailer** has to **reduce demand** to $\boldsymbol{Q_{target}}$ $\boldsymbol{kWh}$ during the next peak period, k.

- To achieve that he has to **employ** a **new price** $\boldsymbol{P_k > P_0}$ to a set of N consumers.

- He uses the **flexibility profiling engine**, for **characterizing the demand function** $\boldsymbol{Q_i}$, for each consumer i.

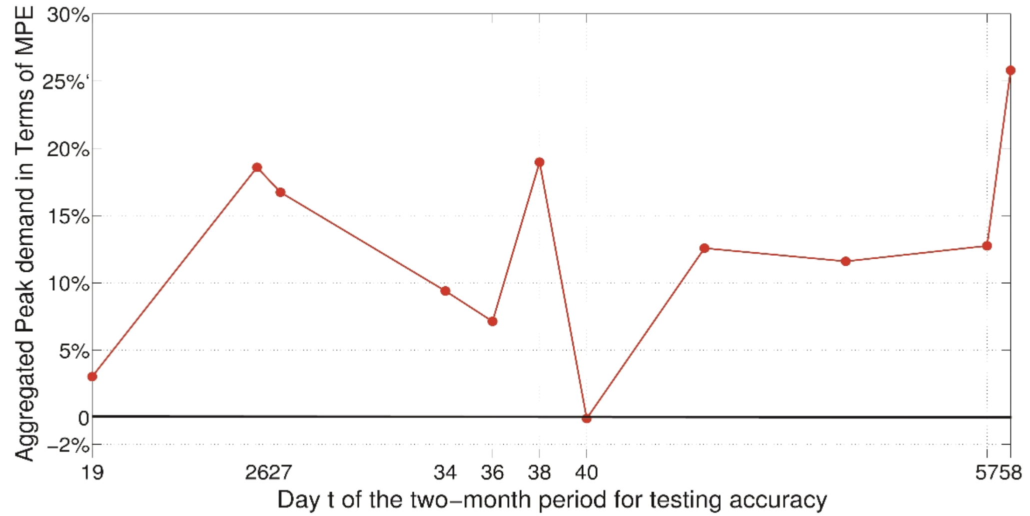
- By performing the proposed mechanism he **can find the new price** $\boldsymbol{P_k}$ that would **lead to** $\boldsymbol{Q_{target}}$ (in kWh).

Sketch of mechanism for implicit DR

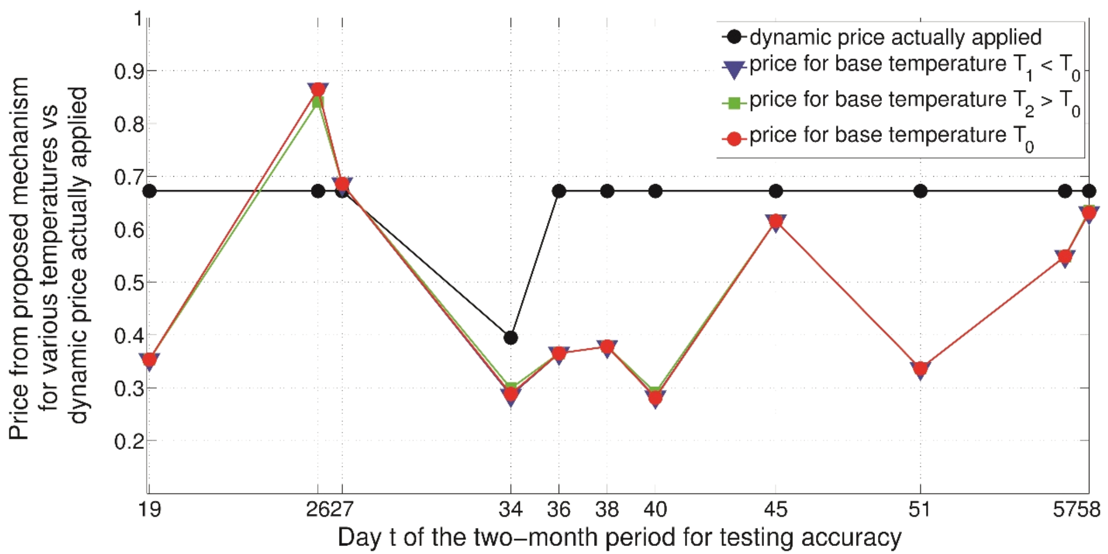


Evaluation of price-based mechanism

- Forecasting accuracy on the Aggregated Level during peak period in terms of MPE.



- Dynamic prices as outcome of the proposed price-based mechanism vs actual dynamic prices applied during testing period.



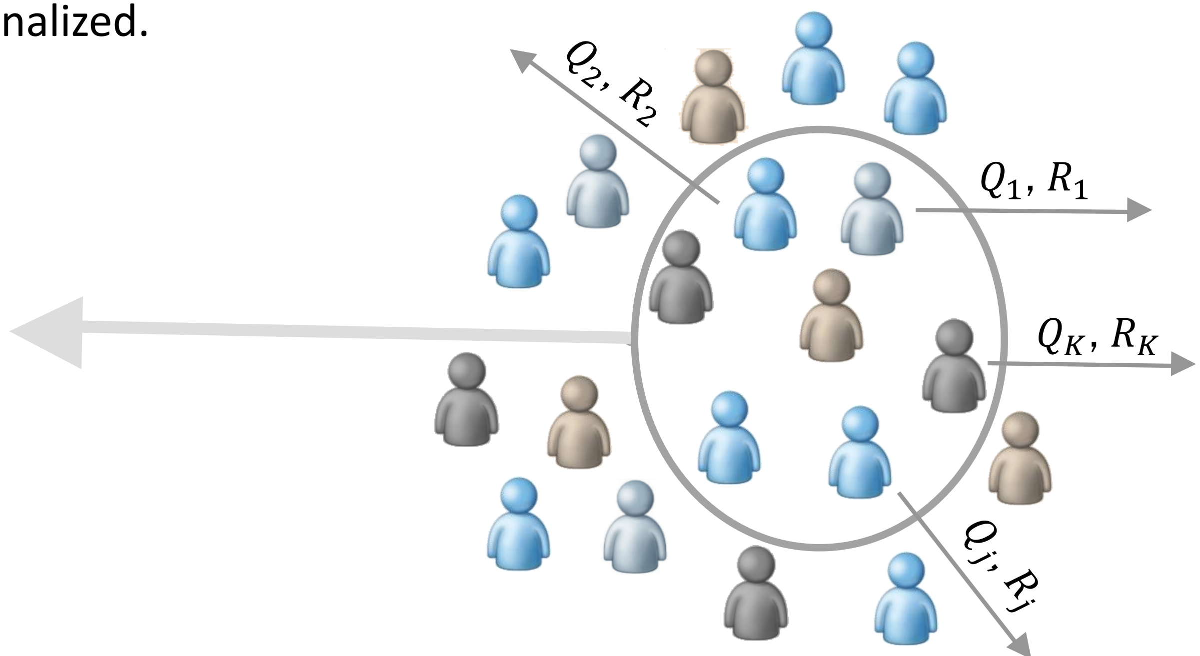
Mechanism for explicit (reward-based) DR

A DSO/Retailer has to reduce demand to $\boldsymbol{Q_{target}} \boldsymbol{kWh}$ during the next peak period. The proposed mechanism:

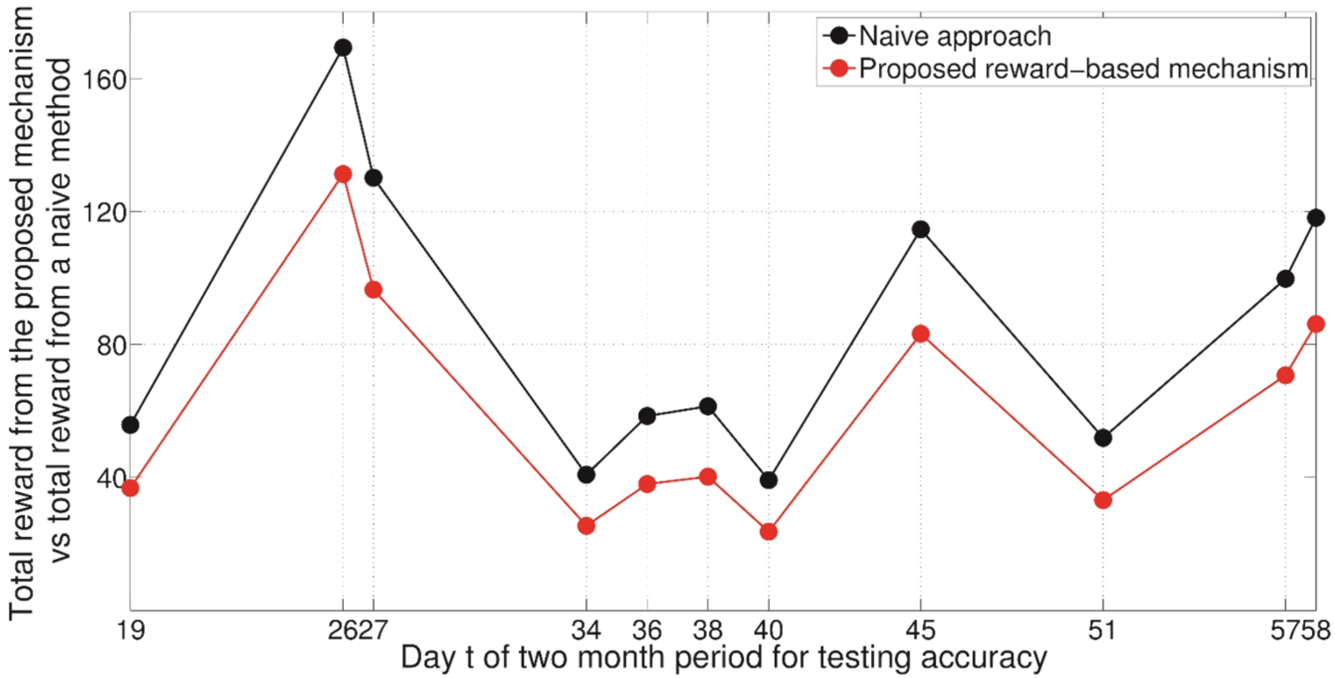
- Selects which consumers will be targeted for load curtailment.
- Estimates the amount of flexibility that should be requested by each one of them to achieve a certain amount of demand reduction $\boldsymbol{Q_{target}} = \sum_{j \in K} Q_j$ (with K we denote the set of selected consumers)
- Calculates the DR compensation R_i that should be offered to each selected consumer if she ultimately achieves the demand reduction.
- Both Q_i and R_i are personalized.

$$\underset{j}{\text{Min}} \sum_{j \in K} R_j$$

$$\boldsymbol{Q_{target}} = \sum_{j \in K} Q_j$$



Evaluation of reward-based mechanism



Comparison of the total rewards as outcome of the proposed mechanism vs the total rewards calculated by a naive approach.