# linear

## Intelligent Networks

Johan Driesen, EnergyVille & KU Leuven
ESI – KIC PhD School, Leuven, 19-5-2015

# Evolutions in the grid

- Increased share of intermittent renewables
- Stabilization/decrease controllable production
- Electrification of transport and heating

# Linear situated

⇒ Energy excesses and shortages
⇒ Grid capacity issues

Classical control paradigm
"production follows consumption"
no longer holds

⇒ storage
⇒ "consumption follows production" (i.e., demand response)

Linear focuses on
**Residential Demand Response**

How much flexibility is when available at residential premises?
For what and when can we best use this flexibility?

linear
Intelligent Networks

# Partners

## Research Partners

imec

Energy Ville

iMinds

vito
vision on technology

KU LEUVEN

Linear acknowledges the Flemish Government for its suppor

IWT

SMART GRIDS FLANDERS

## Industrial Partners

EDF luminus

eandis

infrax

LABORELEC GDF SUEZ

fifthplay

Miele

SIEMENS

proximus

telenet

VIESSMANN
climate of innovation

## Additional Members

AGORIA

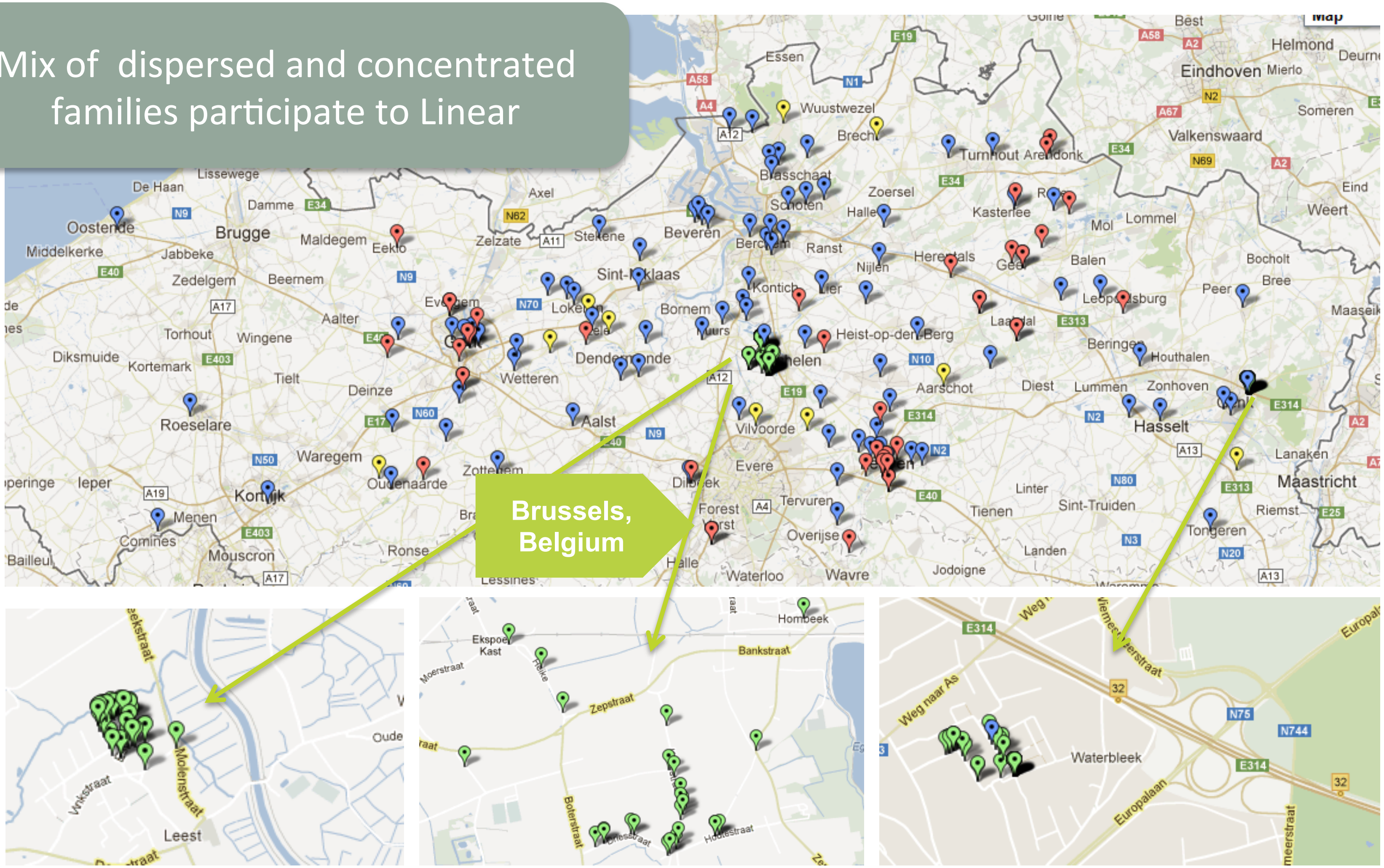
voka
Vlaams netwerk van ondernemingen

EWI

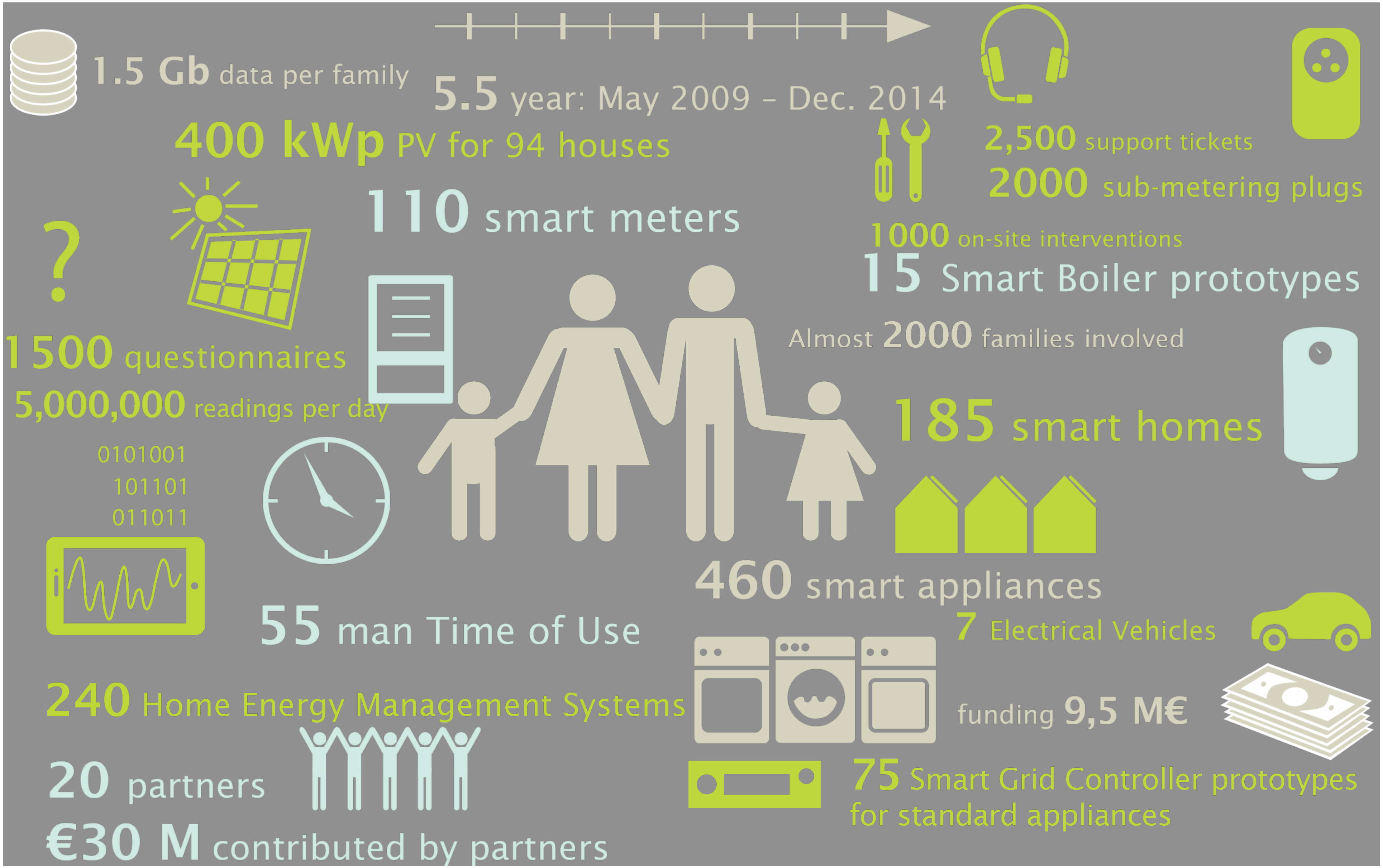
vreg

# 240 Families

Mix of dispersed and concentrated families participate to Linear

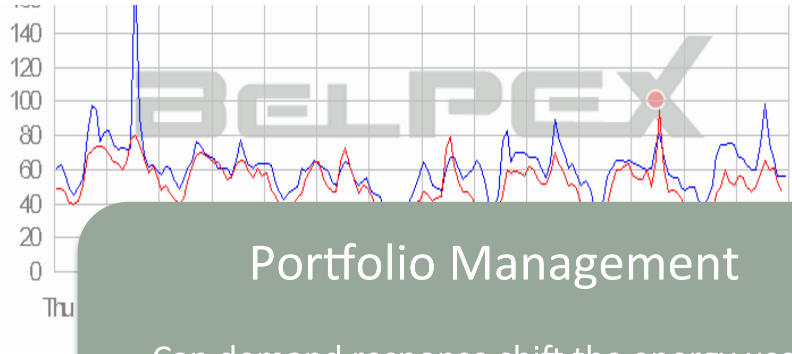


# In Figures


1.5 Gb data per family
5.5 year: May 2009 - Dec. 2014
2,500 support tickets
2000 sub-metering plugs
400 kWp PV for 94 houses
110 smart meters
1000 on-site interventions
15 Smart Boiler prototypes
?
Almost 2000 families involved
1500 questionnaires
5,000,000 readings per day
185 smart homes
0101001
101101
011011
460 smart appliances
55 man Time of Use
7 Electrical Vehicles
240 Home Energy Management Systems
funding 9,5 M€
20 partners
75 Smart Grid Controller prototypes
for standard appliances
€30 M contributed by partners

# Smart Appliances

# Business Cases




## Portfolio Management

Can demand response shift the energy use of families according to the day-ahead markets?

## Intraday (Wind) Balancing

Can the energy supplier use demand response to correct intraday imbalances in its portfolio, caused by differences between predicted and actually generated wind energy?

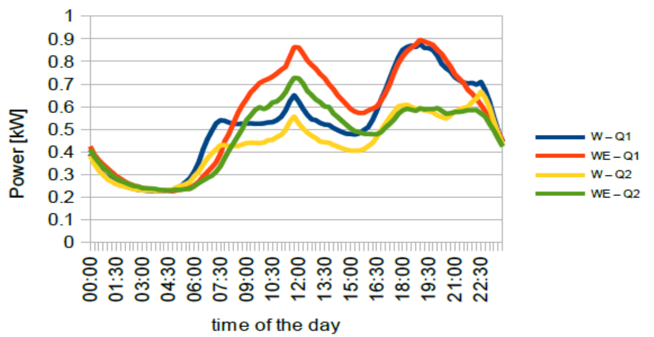
## Line Voltage Control

Can demand response help to reduce overvoltages and undervoltages in the distribution grid?

## Transformer Ageing

Can we lengthen the lifespan of the distribution grid transformers with demand response? Can we postpone investments in bigger transformers?

# Load profiles




**Cluster 3**

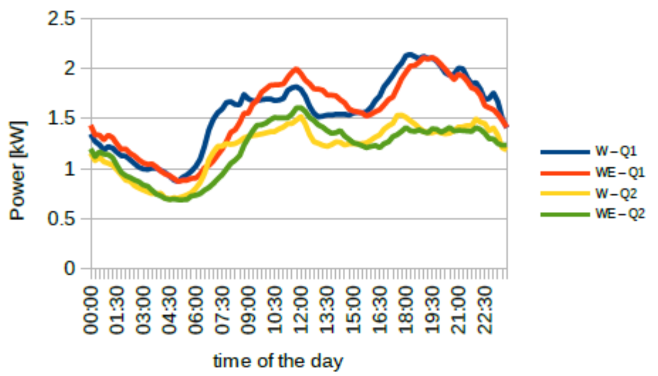
% of customers:
27.8 %

Average power:
487 W

Est. yearly consumption:
4266 kWh

Relates to (VREG):
average

Name:
average day-consumer




**Cluster 5**

% of customers:
7.7 %

Average power:
1326 W

Est. yearly consumption:
11616 kWh

Relates to (VREG):
relatively large and large

Name:
large day-consumer

**10 different clusters, e.g.:**

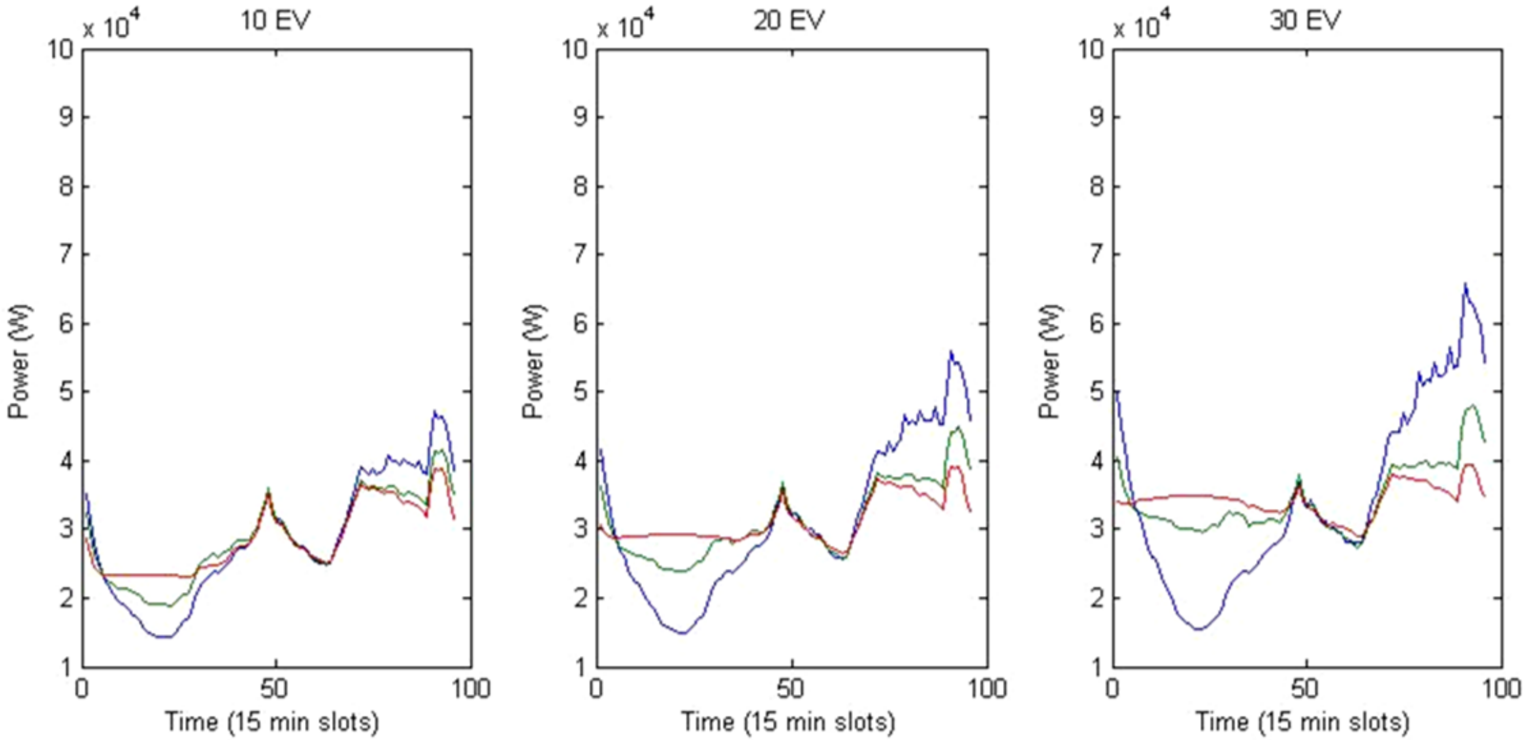
Average day consumer

Large day-consumer

- Statistical clustering based on questionnaire + measurement campaign
- Load profile generator

*W. Labeeuw et al.,* ***Residential Electrical Load Model based on Model Clustering and Markov Models***

# Load profiles

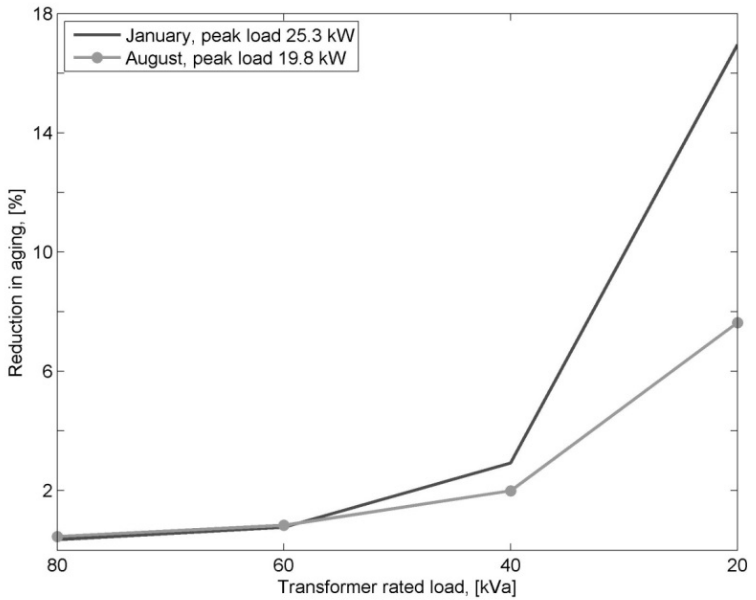



- Increasing stress on grid infrastructure
- Coordination strategies can be used to spread the peak in time

N. Leemput et al. : **A Case Study of Coordinated Electric Vehicle Charging for Peak Shaving on a Low Voltage Grid**

# Transformer aging

Can we lengthen the lifespan of the distribution grid transformers with demand response? Can we postpone investments in bigger transformers?

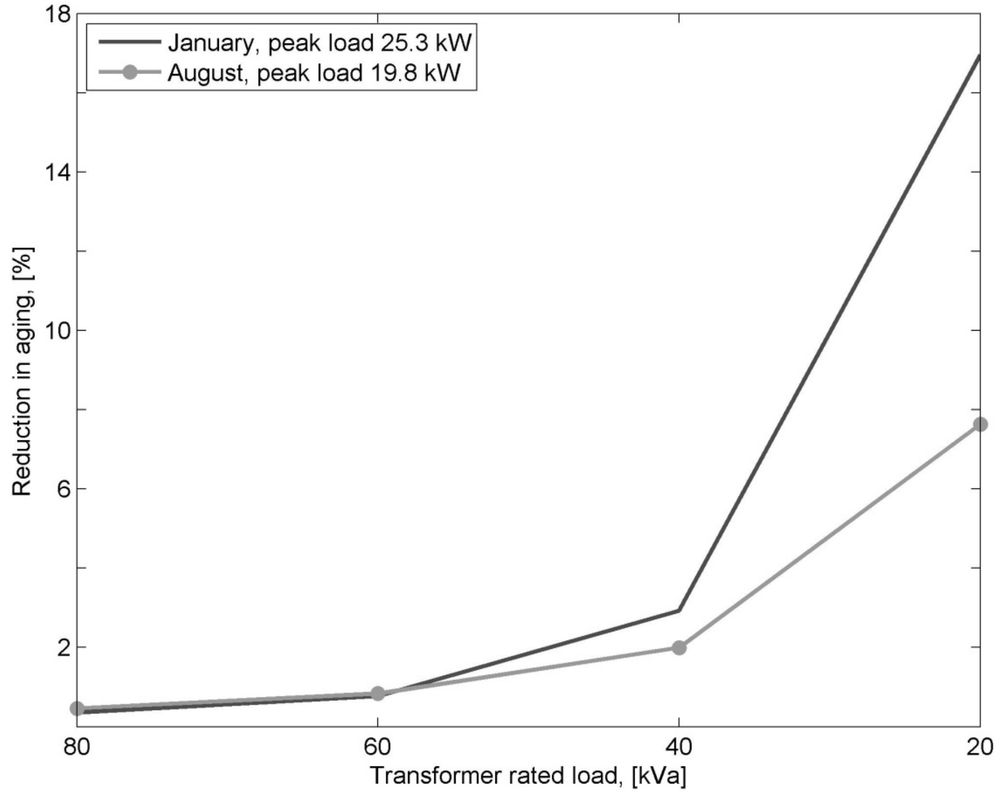



DSO focused

Control parameter: $T_{oil}$ & I

J. Jargstorf *et al*, **Effect of Demand Response on Transformer Lifetime Expectation**

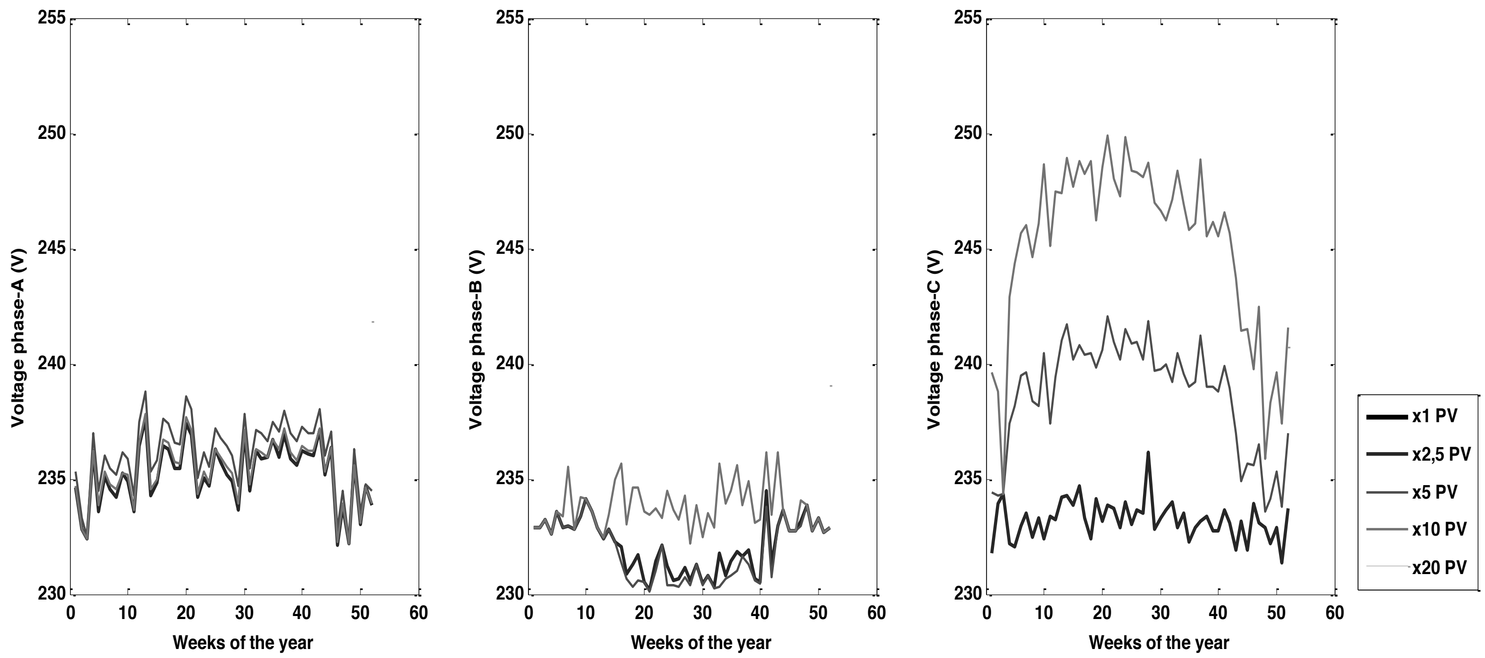
# Transformer lifetime




- Gain in effective lifetime only significant when peak load ~ 150% of transformer rating
- Business case behind transformer lifetime improvement appears to be limited

J. Jargstorf *et al*, **Effect of Demand Response on Transformer Lifetime Expectation**

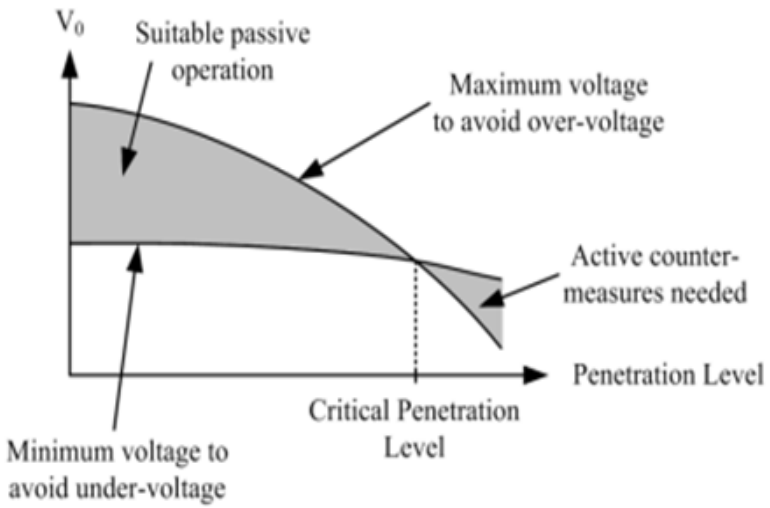
# Simulations to study voltage problems

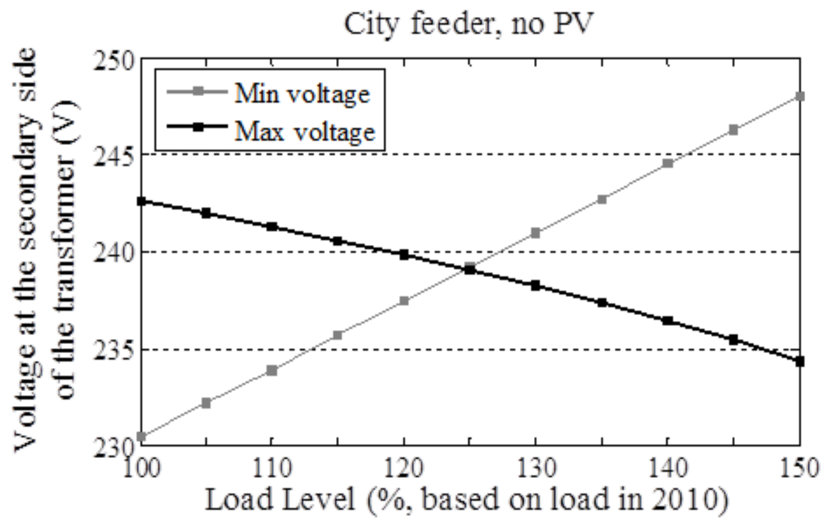



- Increasing load and PV penetration can cause voltage problems
- Results are extremely dependent on exact feeder configuration and load profile

C. Gonzalez *et al*, **LV Distribution Network Feeders in Belgium and Power Quality Issues due to Increasing PV Penetration Levels**

# Simulations to study voltage problems

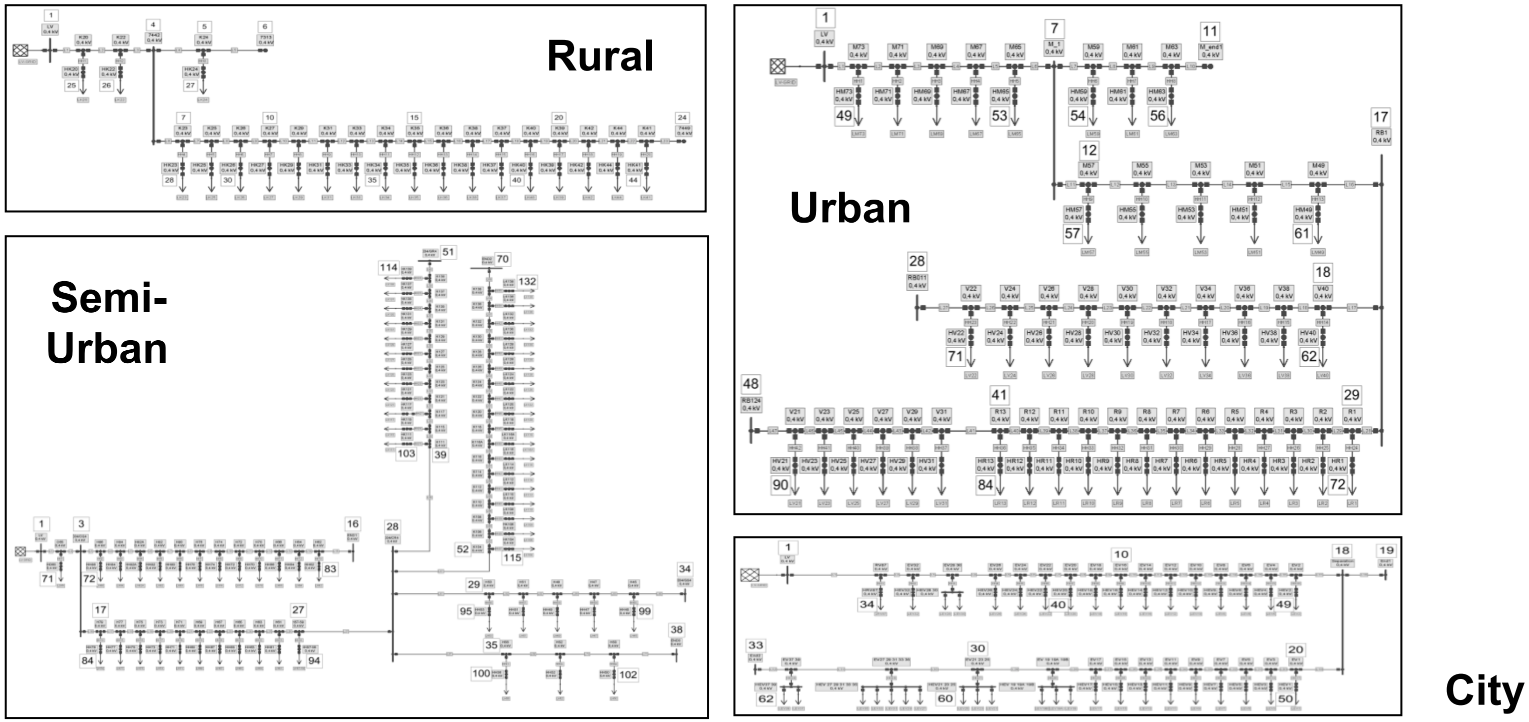



- Results are extremely dependent on exact feeder configuration and load profile

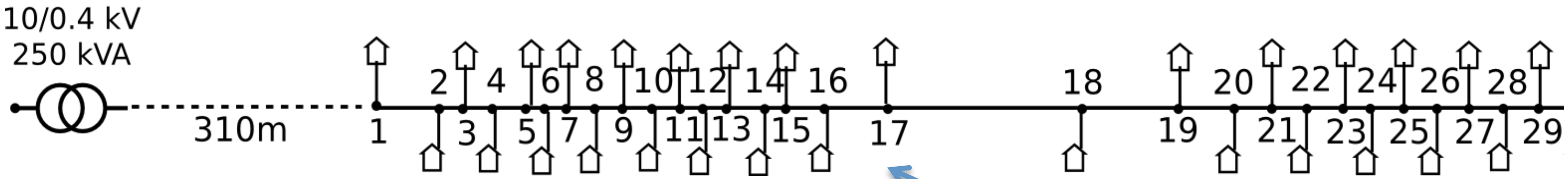
C. Gonzalez *et al*, **LV Distribution Network Feeders in Belgium and Power Quality Issues due to Increasing PV Penetration Levels**

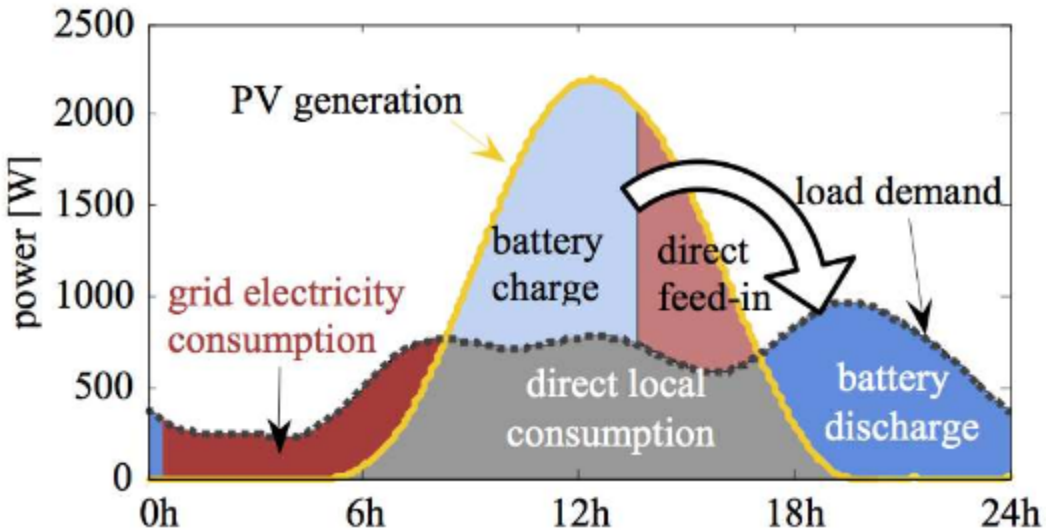
# The grids




Representative feeders from Infrax and Eandis

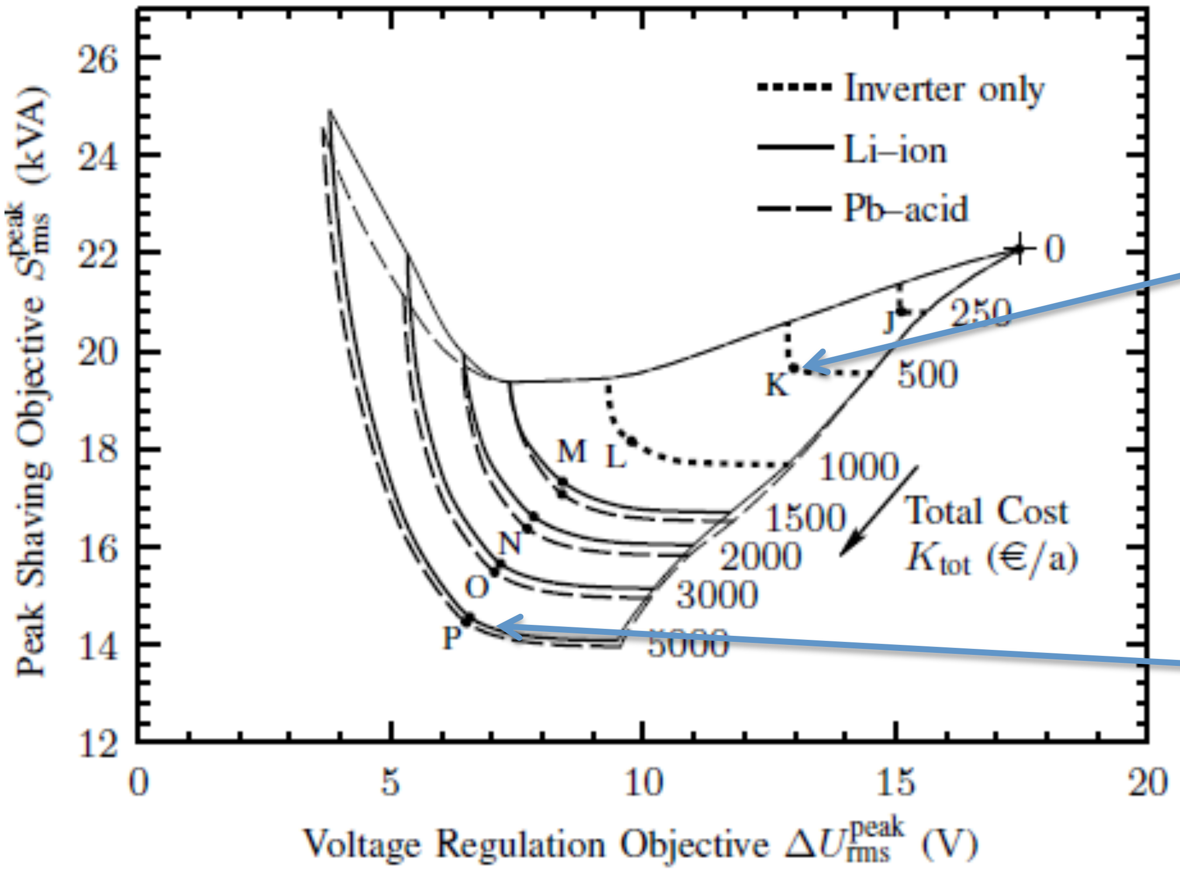
# Battery storage




Battery Energy Storage System

# Battery Storage




- Voltage improvement of 5V
- Peak reduction of 2kVA
- 500€/y

- Voltage improvement of 11V
- Peak reduction of 7kVA
- 5000€/y

Potential of battery storage: Techno-economic analysis

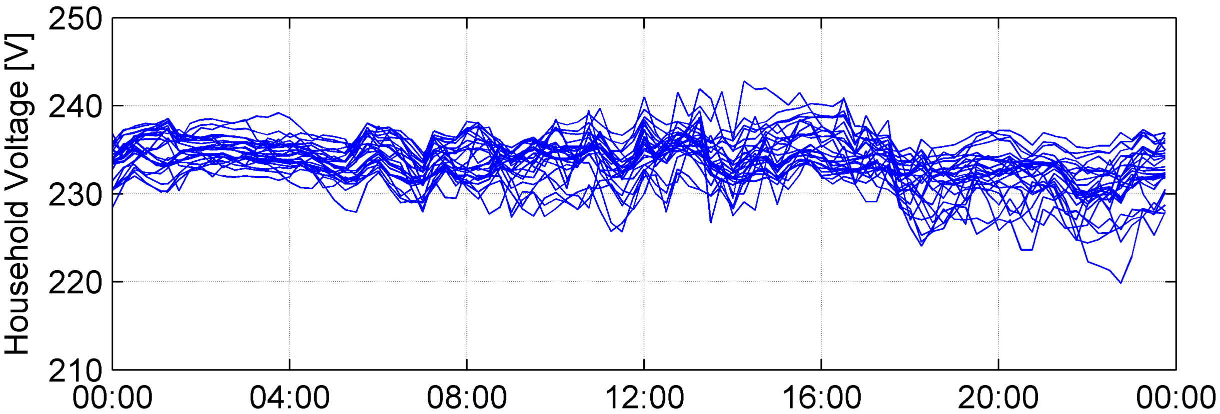
J. Tant *et al*, **Multi-Objective Battery Storage to Improve PV Integration in Residential Distribution Grids**

# Line Voltage Control

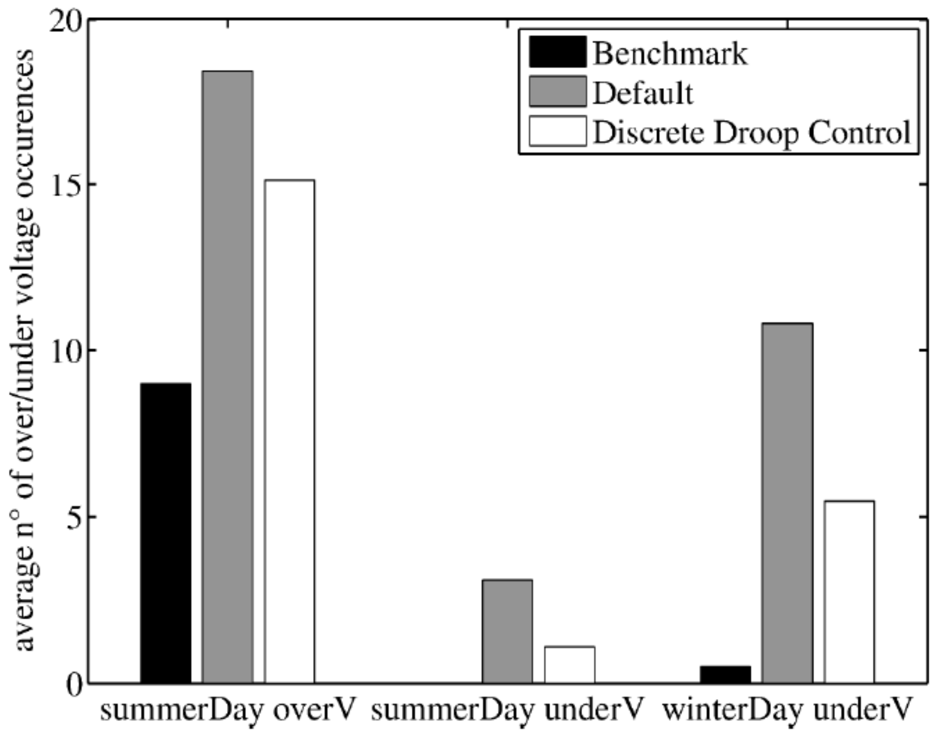
Can demand response help to reduce overvoltages and undervoltages in the distribution grid?

DSO focussed

Control parameter: V



# Voltage control: simulations

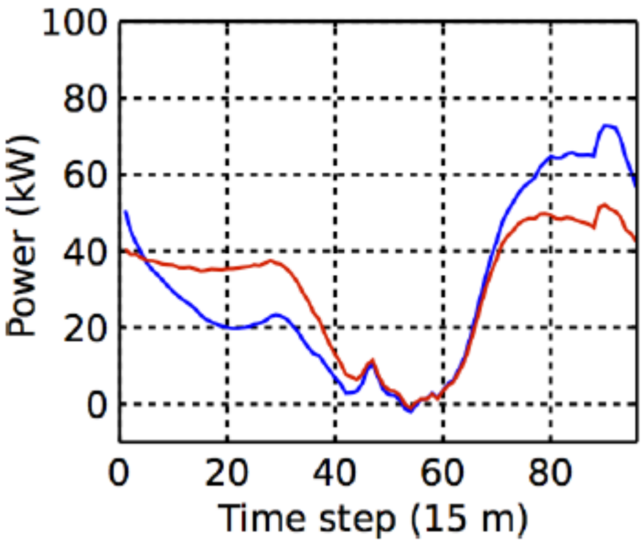


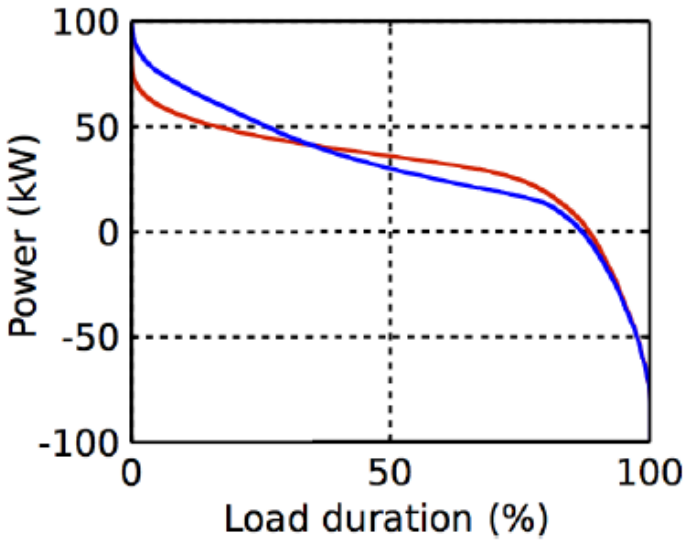

- ✓ **Field test feeder**
- ✓ **Field test scenario**
- ✓ **Whitegood**
- ✓ **6 boilers**

- ✓ Results extremely dependent on feeder topology, load profiles and amount of flexibility
- ✓ Reduction of typically 20-30% of voltage problems

S. Iacovella, R. D'Hulst *et al*, **Standalone LV distribution network control mechanism**

# Electric vehicles



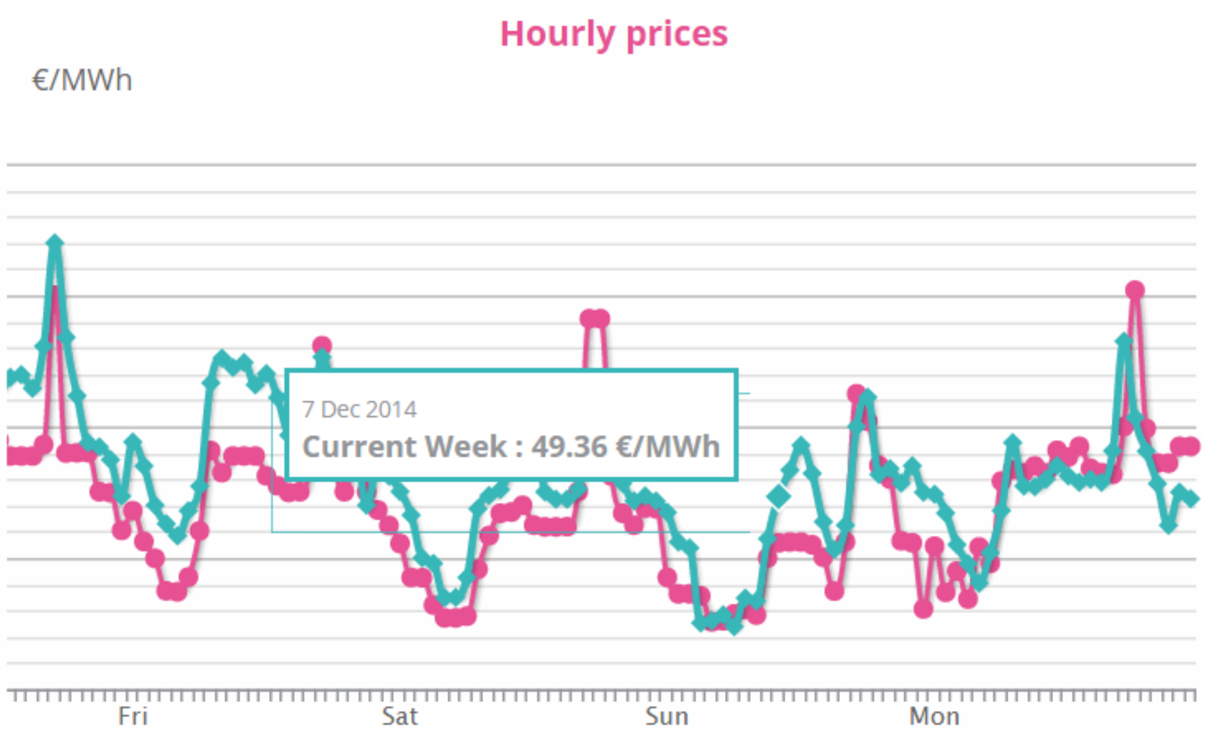




- ✓ Case study using coordinated charging
- ✓ 100% integration of Electric Vehicles obtained!

# Portfolio management

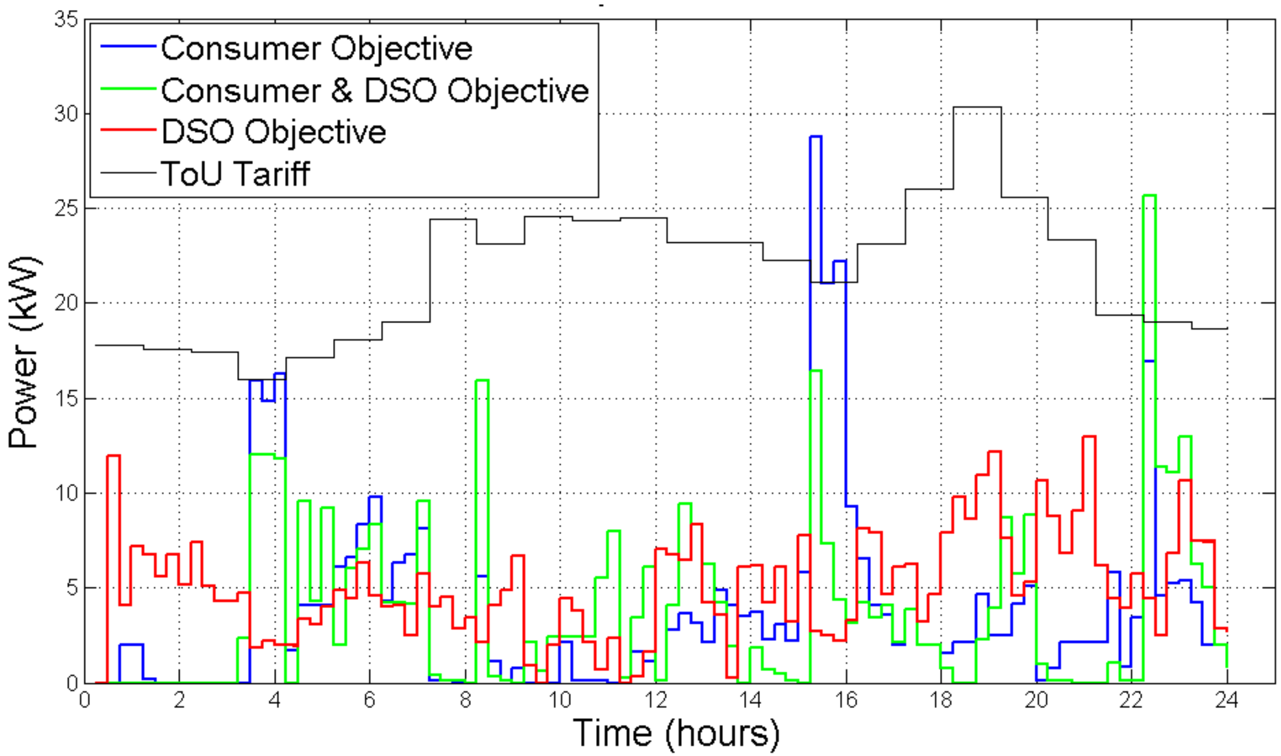
Can demand response shift the energy use of families according to the day-ahead markets?

Control parameter: €



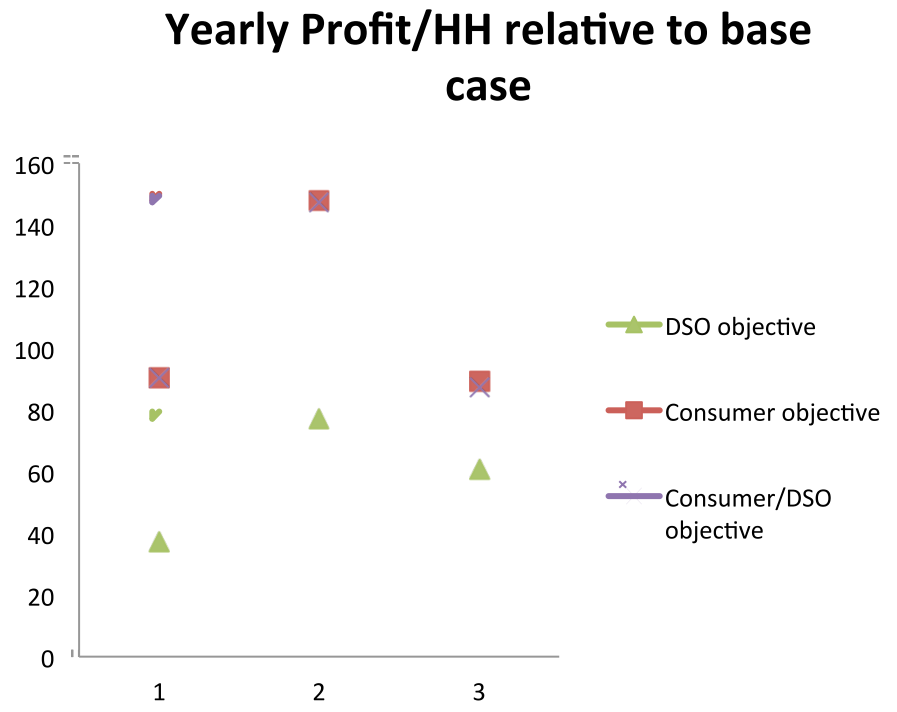

BRP focussed

# Portfolio management: Simulations



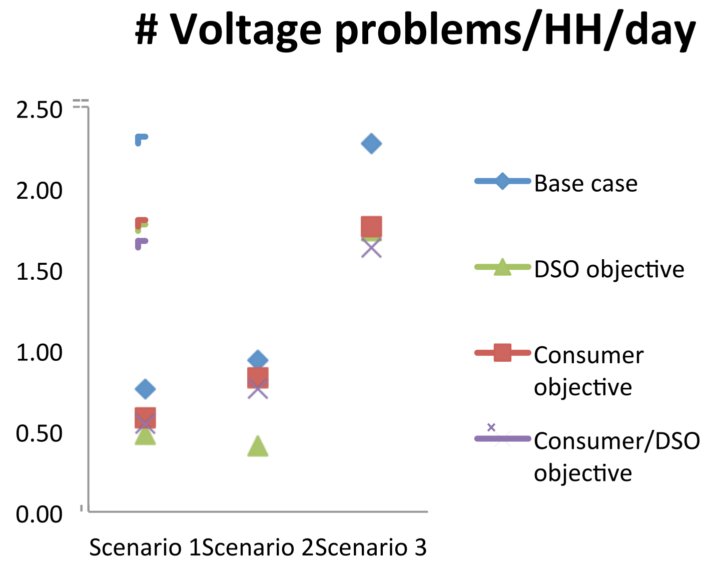

S. Iacovella et al.: **Double-Layered Control Methodology Combining Price Objective and Grid Constraints**

# Time of Use: Simulations




Scenario 1: 25% EV
Scenario 2: 50% EV
Scenario 3: 50% EV +50% boiler

- ✓ Genk LS07 feeder
- ✓ 38/38 smart Households
- ✓ 9 days
- ✓ All WG
- ✓ Deterministic



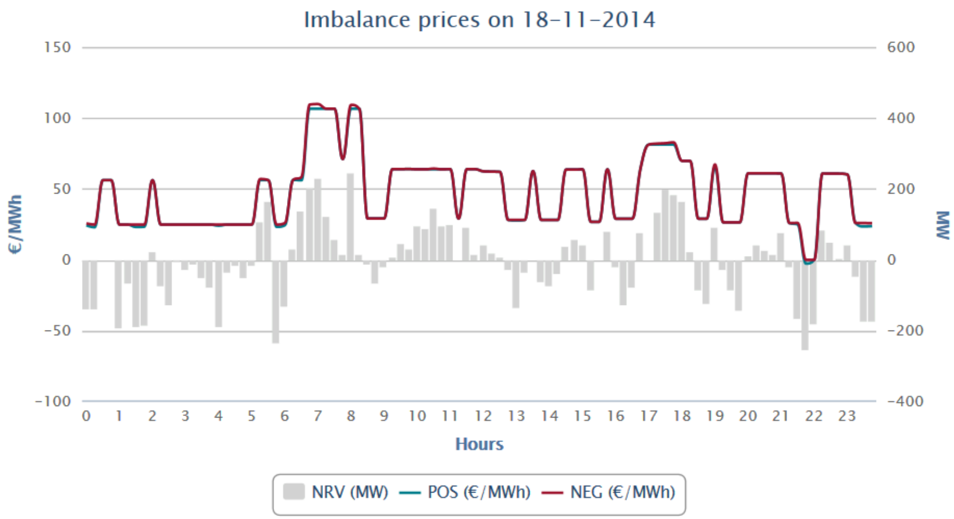

- Significant potential benefits for the consumer that is shifting consumption in time
- It is theoretically possible to combine Portfolio management and voltage control

# Intraday (wind) balancing

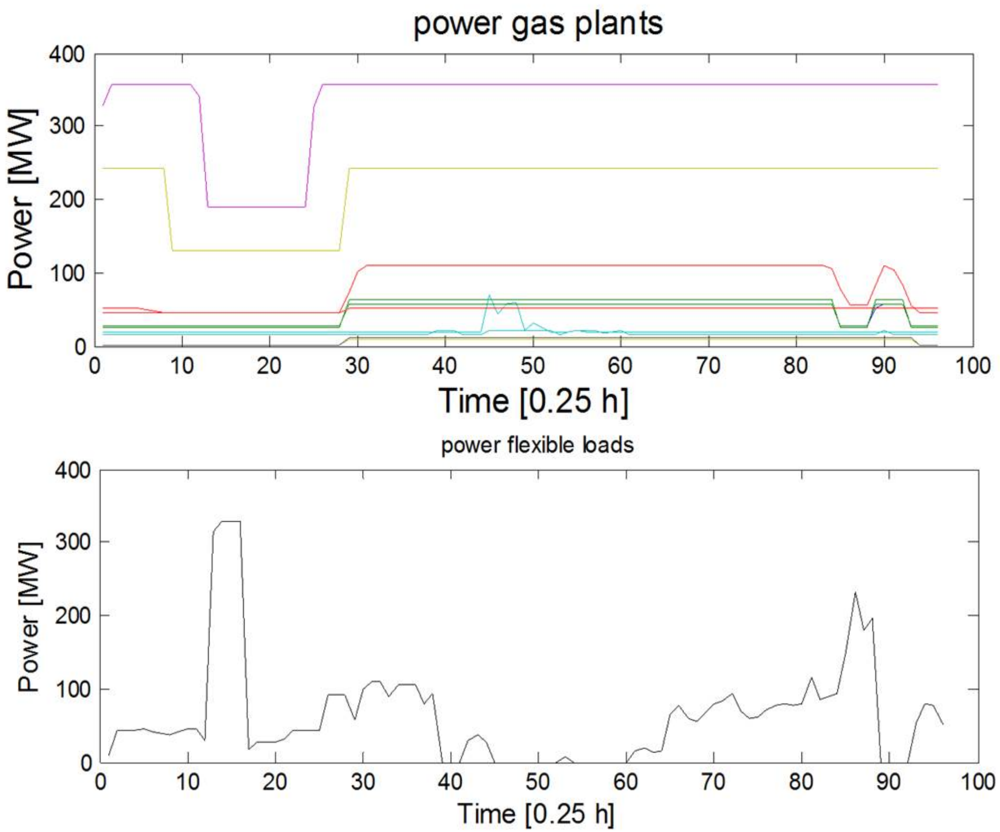
Can the energy supplier use demand response to correct intraday imbalances in its portfolio, caused by differences between predicted and actually generated wind energy?

BRP focussed

Control parameter: $\Delta P$



# Wind balancing




- Flexibility can be used by the BRP as an alternative for gas power plants
- The exact economic benefit is dependent on the amount of flexible consumption

K. Kessels *et al.*: **Feasibility of employing Domestic Active Demand For Balancing Wind Power Generation**

# Other research results

- Battery storage systems as an alternative to demand response

J. Tant *et al*, **Multi-Objective Battery Storage to Improve PV Integration in Residential Distribution Grids**

F. Geth et al. : **Voltage Droop Charging of Electric Vehicles in a Residential Distribution Feeder**

- Electric Vehicle charging coordination schemes

N. Leemput et al. : **A Case Study of Coordinated Electric Vehicle Charging for Peak Shaving on a Low Voltage Grid**

F. Ruelens et al. : **Stochastic Portfolio Management of an Electric Vehicles Aggregator Under Price Uncertainty**

- Combined Heat and Power as a bridge between electricity and gas grids

J. Vandewalle et al. : **The Role of Thermal Storage and Natural Gas in a Smart Energy System**

# Conclusions

- A realistic simulation environment was created to test the  potential of different smart grid solutions

- Transformer ageing can only be improved  by demand response if the peak load is sufficiently high compared to the rated load

- Improvement in the line voltage is possible with demand response and battery storage
- Results are highly feeder-dependent

- Significant benefits can be achieved for consumers who can shift their consumption in time, mainly for the large consumers such as EV and DHW
- Combination of portfolio management and voltage control does not significantly impact the business case

- Significant benefits can be achieved for the BRP when using demand response for balancing its portfolio

# The flexibility challenge

How to harvest flexibility at residences without comfort impact?

Linear focused on smart appliances

# The Linear Smart Appliances







Smart Start 16 02
Starten uiterlijk om: 19:23
Uiterlijk klaar om: 20:30
OK
Start/Stop
PC
Belading/
Dosering
Charge/
Dosage
Vlekken
Taches
Overige functies
Autres fonctions
Kreukvrij
stomen
Défroissage
vapeur
Kort/Court
Extra stil
Extra silencieux
Katoen
Coton
Kreukherstellend
Synthétique
Fijne was
Délicat
Wol
Laine
Hygiëne
Hygiène
Express 20
Opfrissen/Rafraîchir
Stoppen
Arrêt

SIEMENS

vito
vision on technology

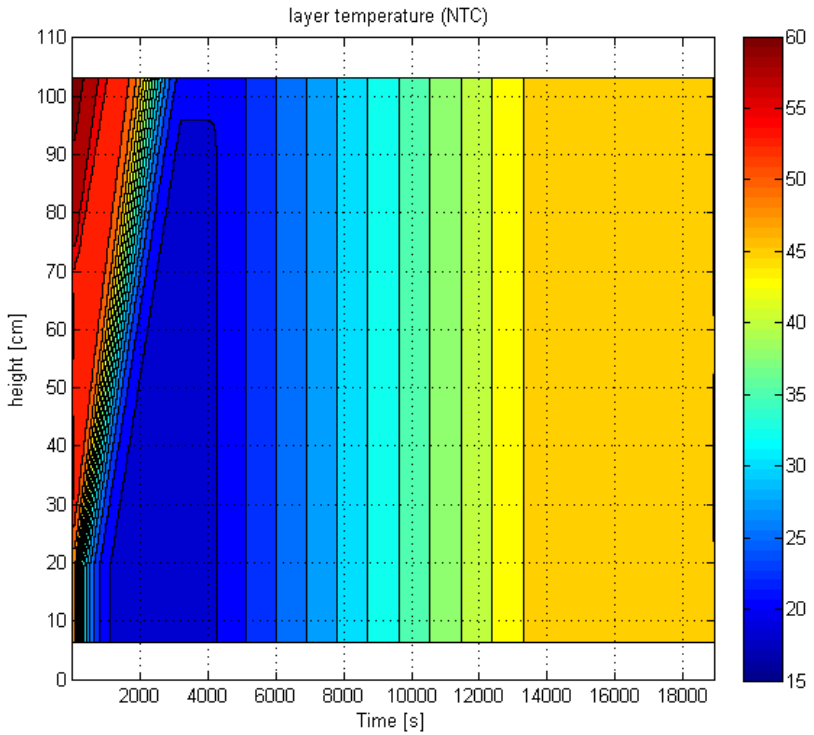
Energy Ville

# Domestic Hot Water Buffer

SIEMENS

vito
vision on technology

Energy Ville

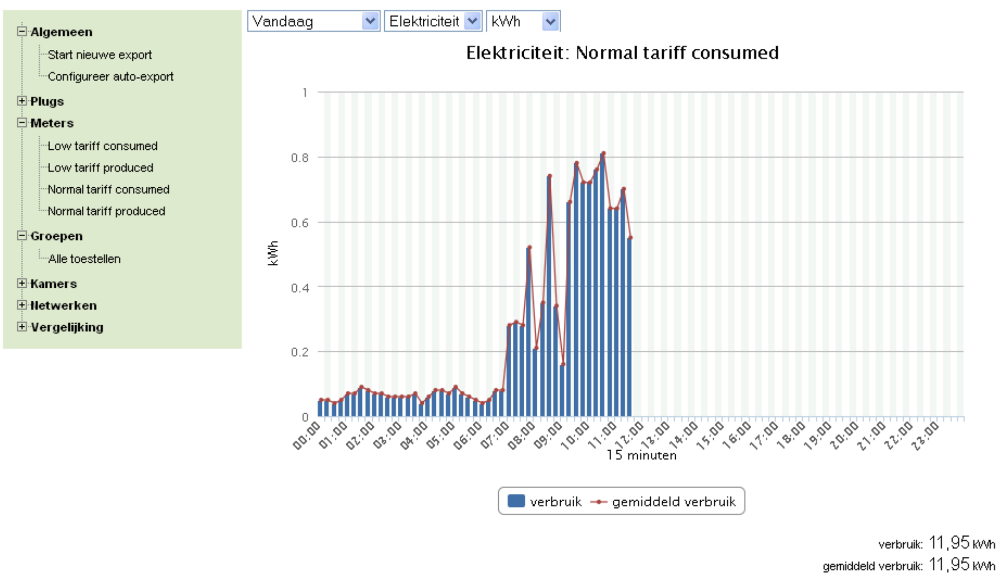



# Electric vehicles



# Home Energy Management

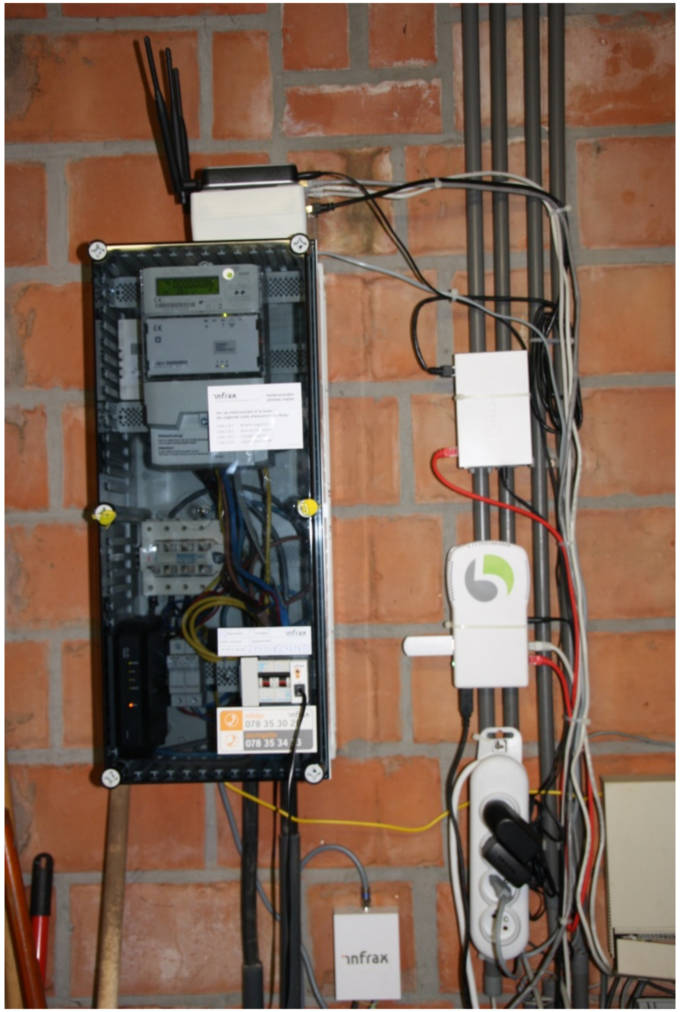
fifthplay




# Smart Meters

eandis


ınfrax



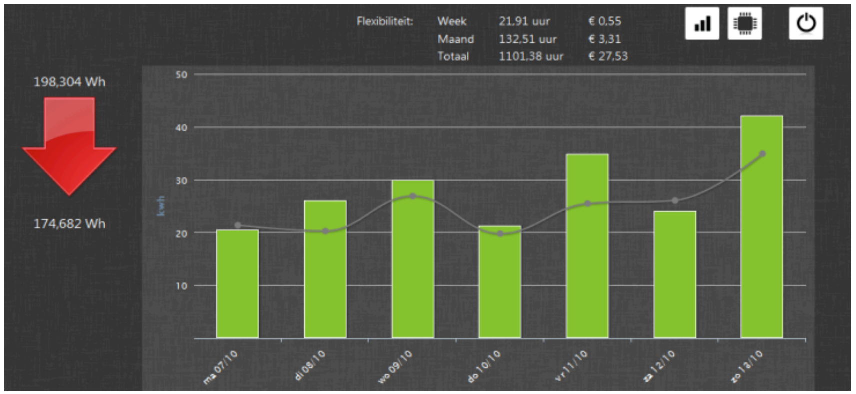
# 2 remuneration models

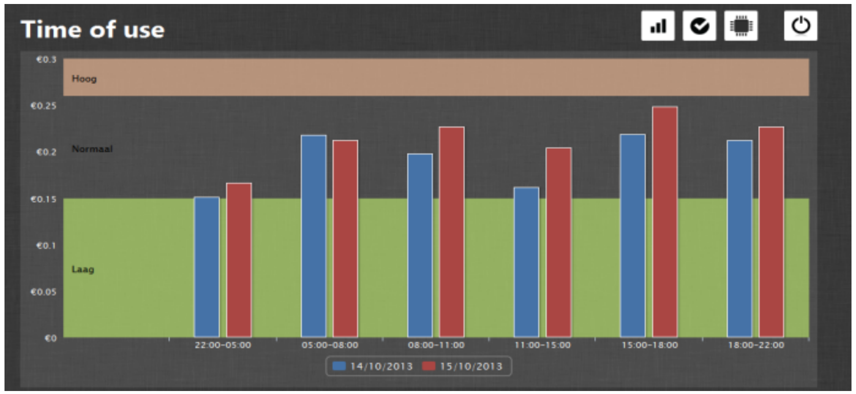
Capacity fee

185 families

Dynamic tariff

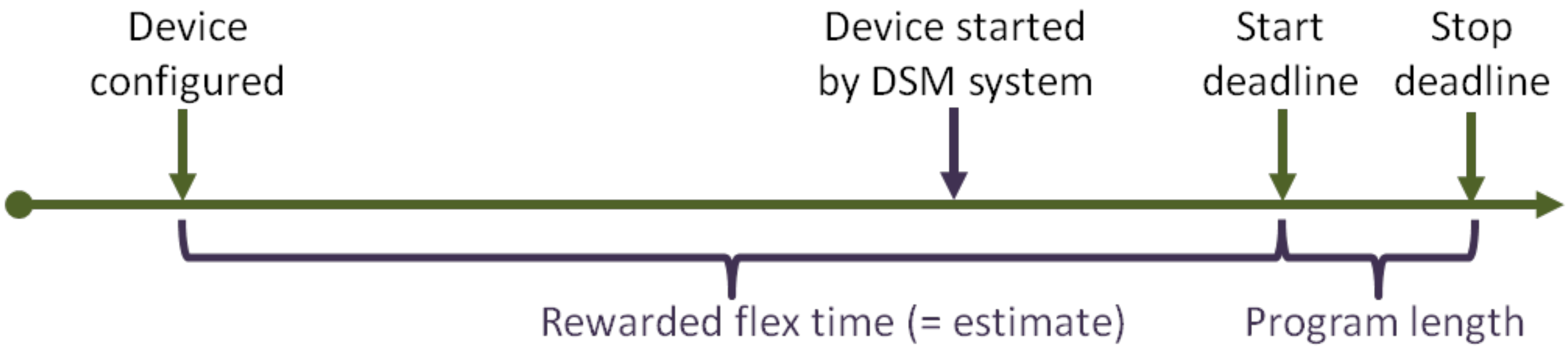
55 families



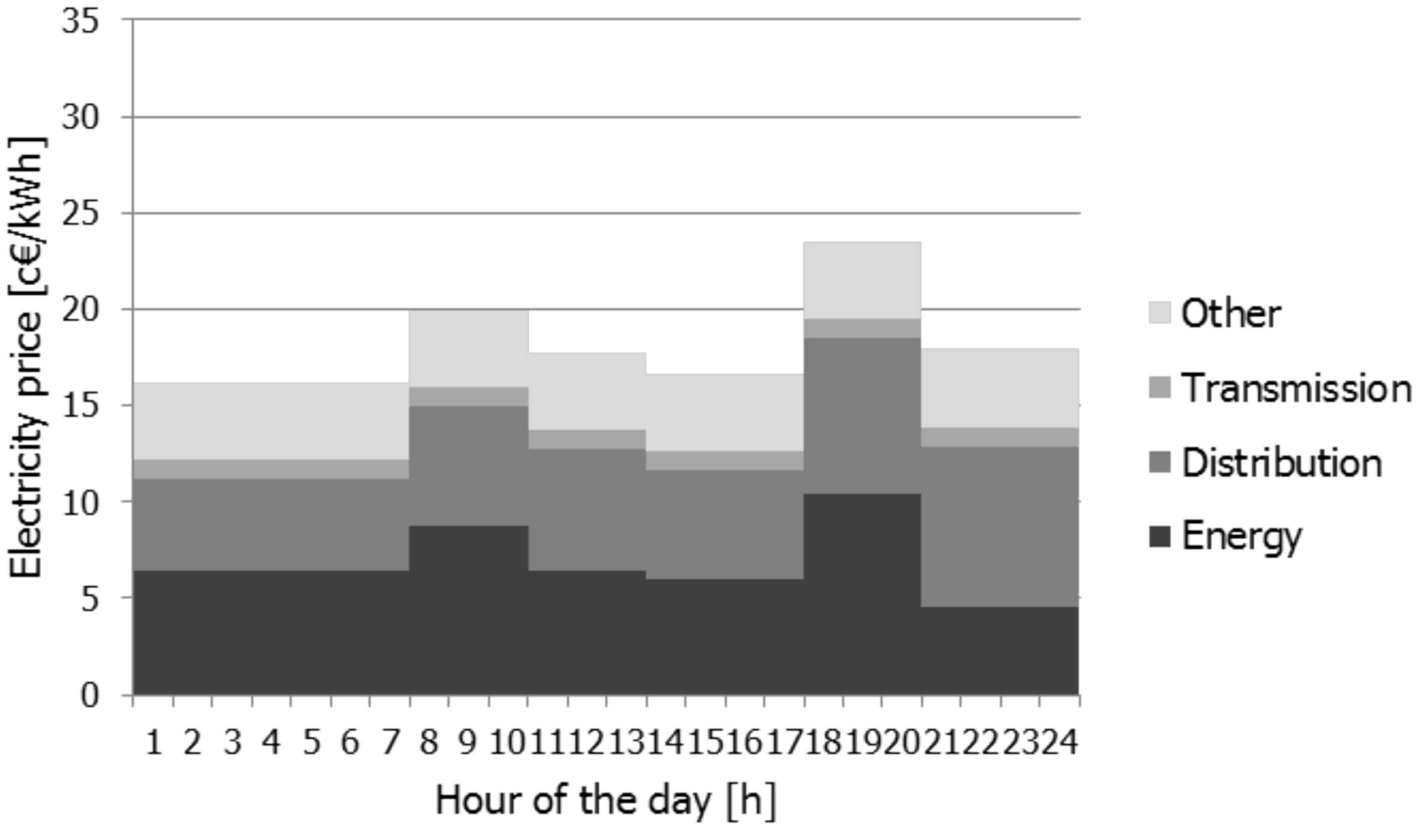
# Capacity fee

1€/40 hours

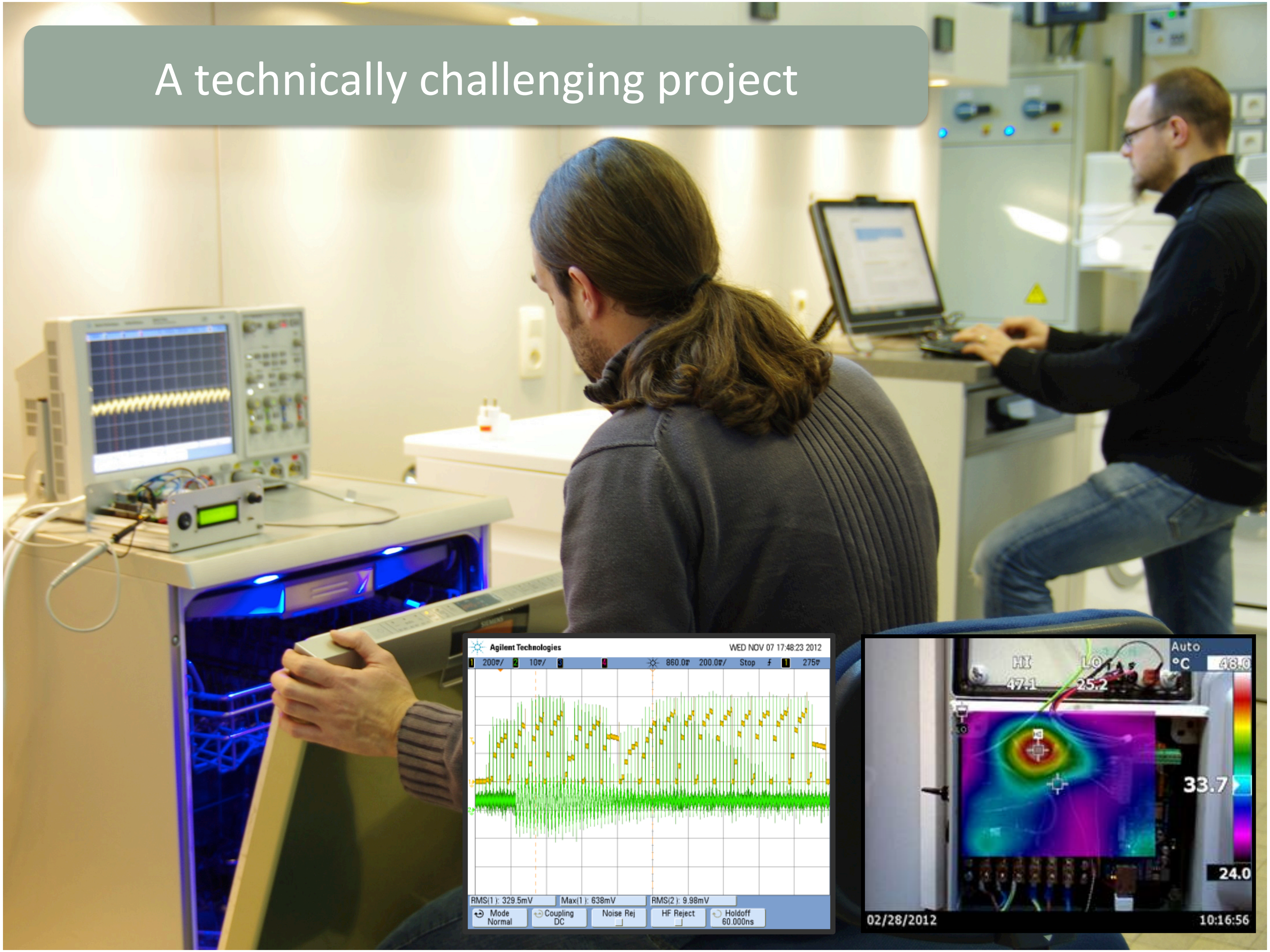



| | | | |
|---|---|---|---|
| Flexibiliteit: | Week | 23,32 uur | € 0,58 |
| | Maand | 139,52 uur | € 3,49 |
| | Totaal | 2564,63 uur | € 64,12 |

# Dynamic tariff




# A technically challenging project



# Integration crucial




***set_user_deadline***

- sets the time when the connected appliance must be started/finished at the latest (also see user deadline type)
- Method: "set_user_deadline"
- Attributes:
  - time [String] cfr section 3.2
- Possible errors:
  - **Command is not allowed in PAUSED mode** to avoid problems while waiting for device to start.
  - Incorrect time formatting

***set_deadline_type***

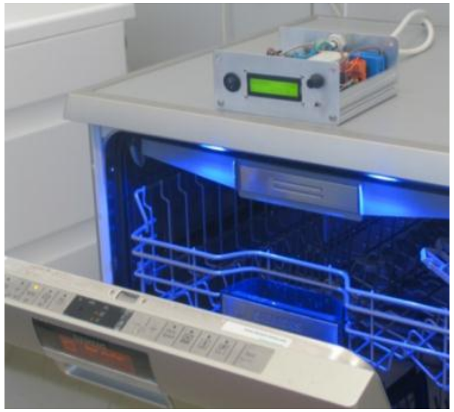
- sets the type of deadline for the connected appliance
- Method: "set_deadline_type"
- Attributes:
  - deadline_type [enum] START/END
- Possible errors:
  - **Command is not allowed in PAUSED mode** to avoid problems while waiting for device to start.
  - Incorrect formatting

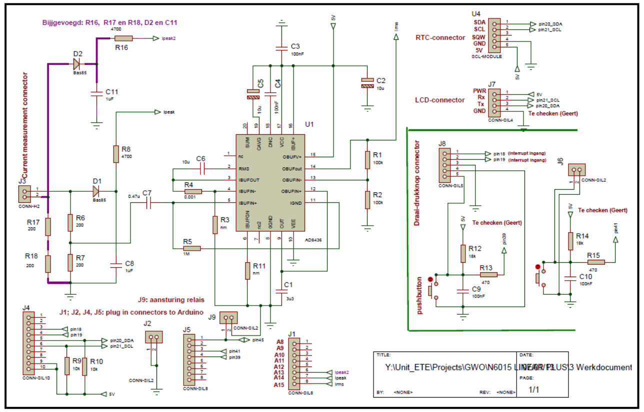
***set_appliance_name***

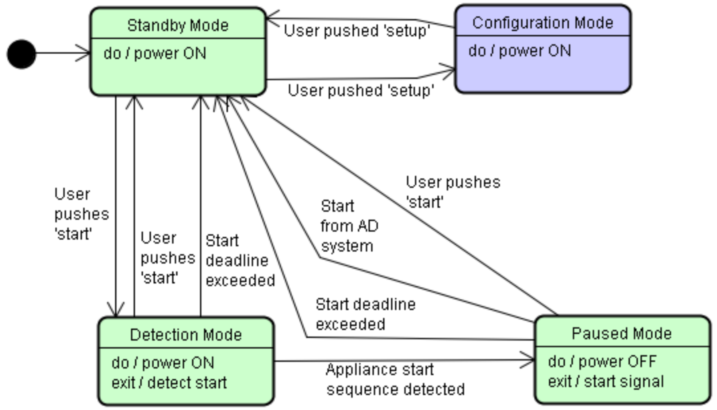
- selects the connected appliance
- Method: "set_appliance_name"
- Attributes:
  - appliance_name [enum] Siemens_WM16Y740FG/Siemens_SN26U893EU
- Possible errors:
  - **Command is not allowed in PAUSED mode** to avoid problems while waiting for device to start.

***start_appliance***

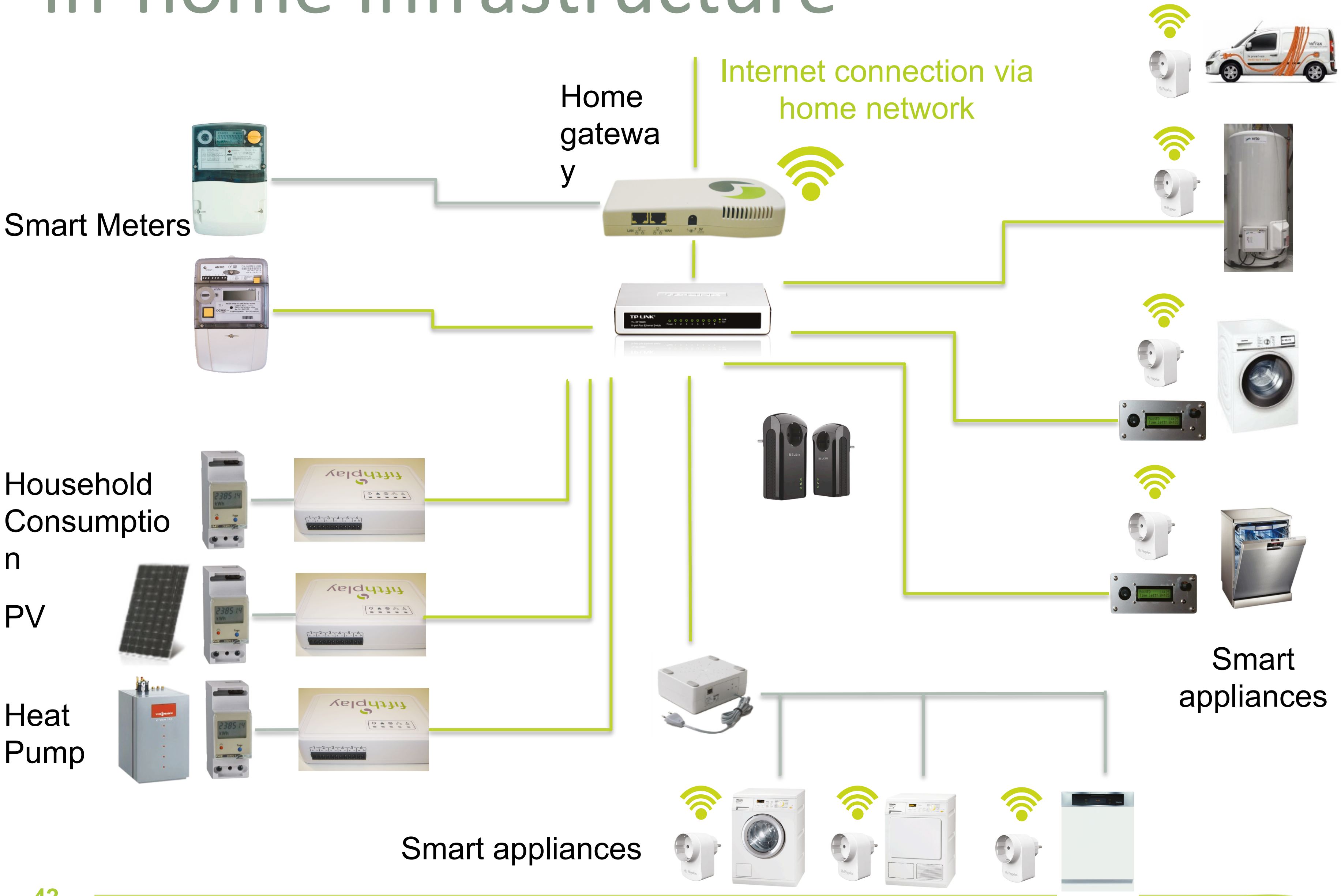
- command to remotely start the appliance when it is in waiting mode
- Method: "start_appliance"
- No attributes
- Possible errors:
  - State is not PAUSED







# In-home Infrastructure



# Example home setup

Garage

Total consumption measurement

# Laundry Room

Home Gateway

TD gateway

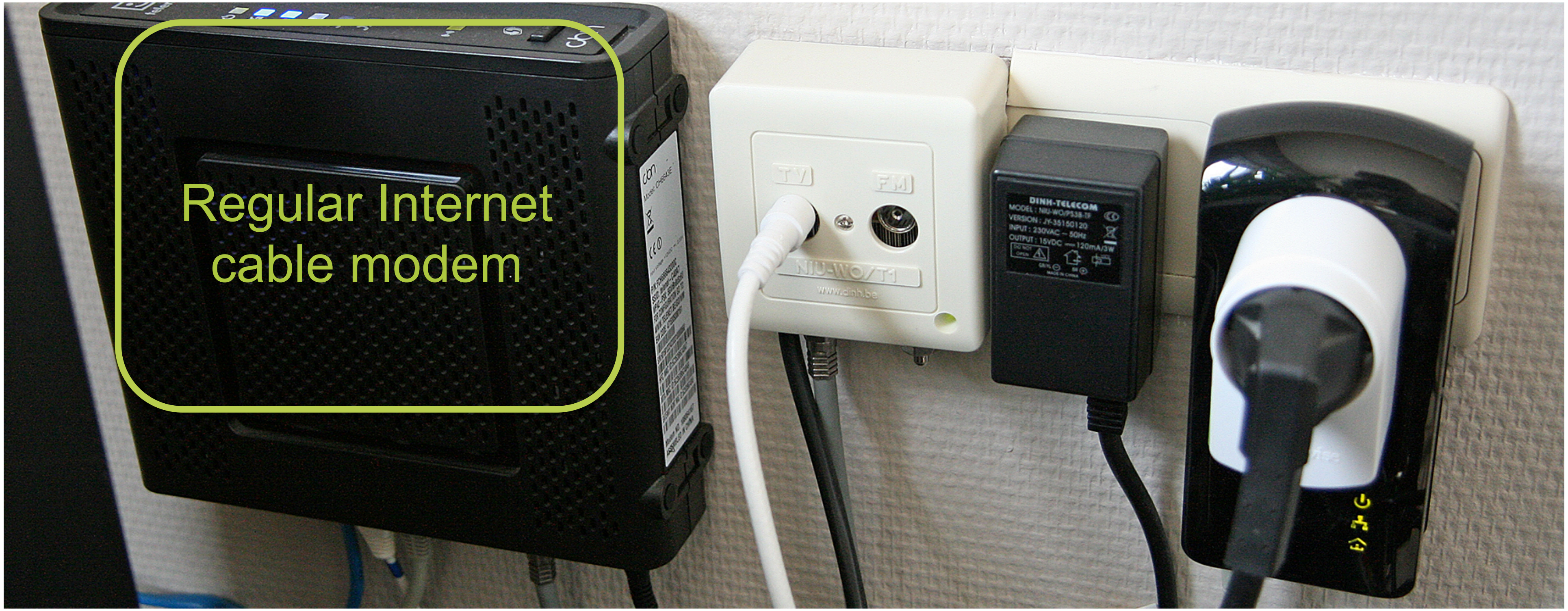
Submeters
WM & TD


External
controller
for WM

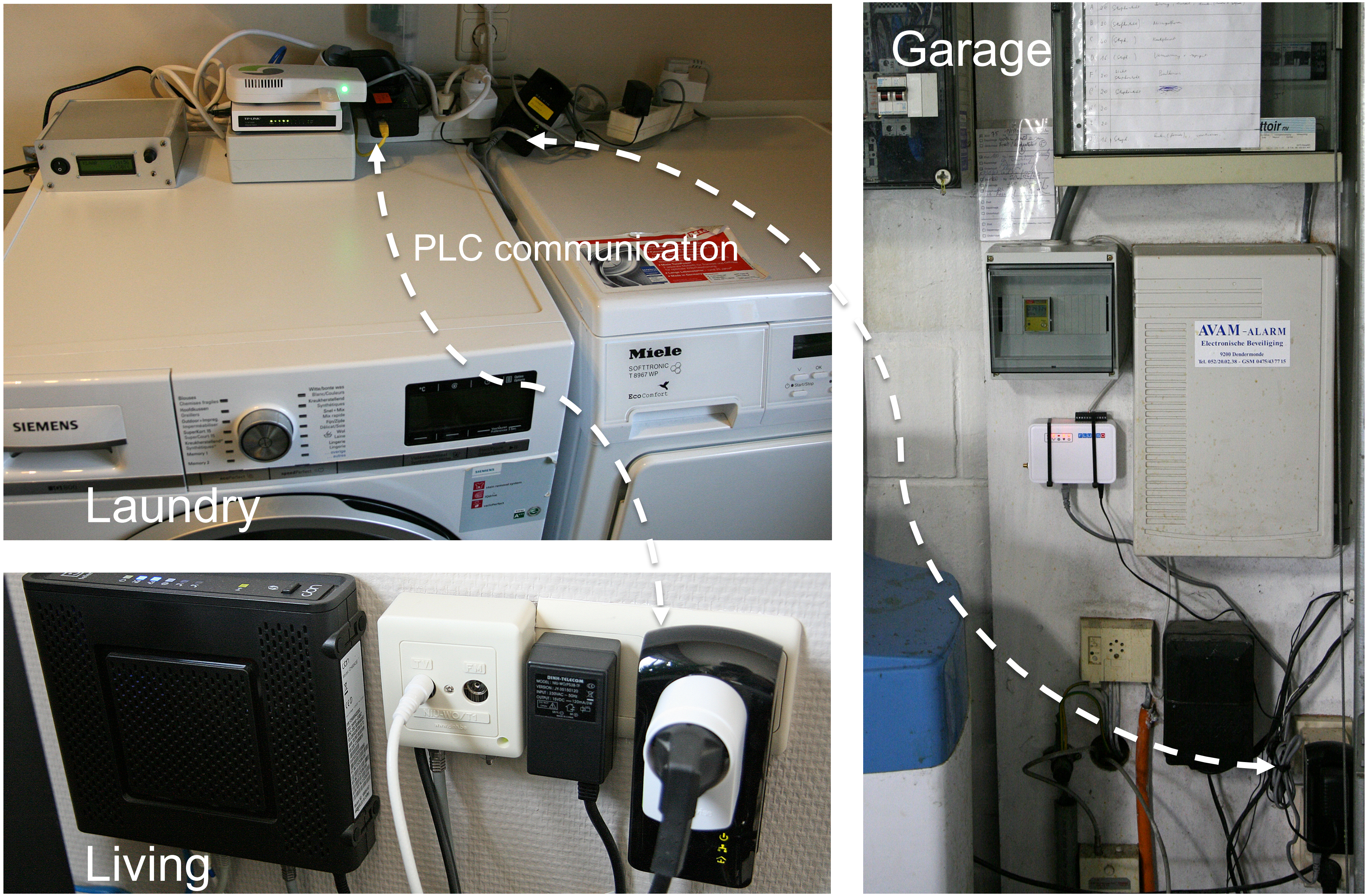
Non-smart
washing machine

Smart grid ready
tumble dryer

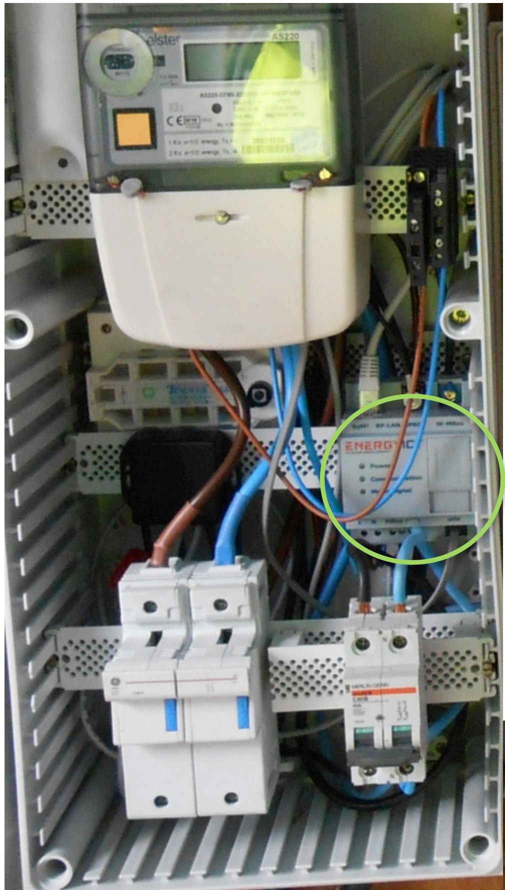
# Living Room

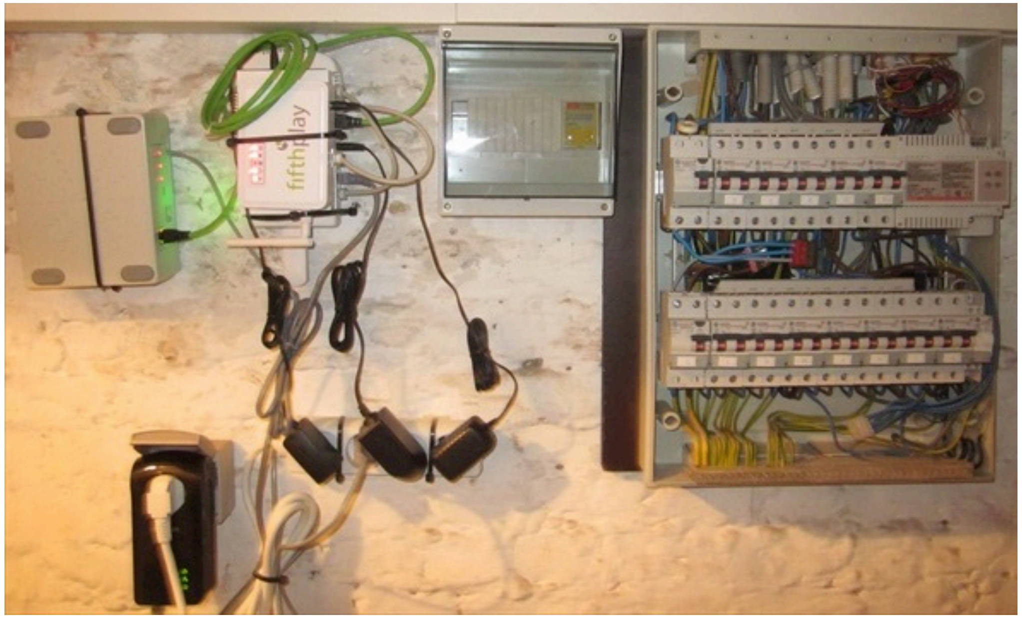


# Example home setup



# Installation examples

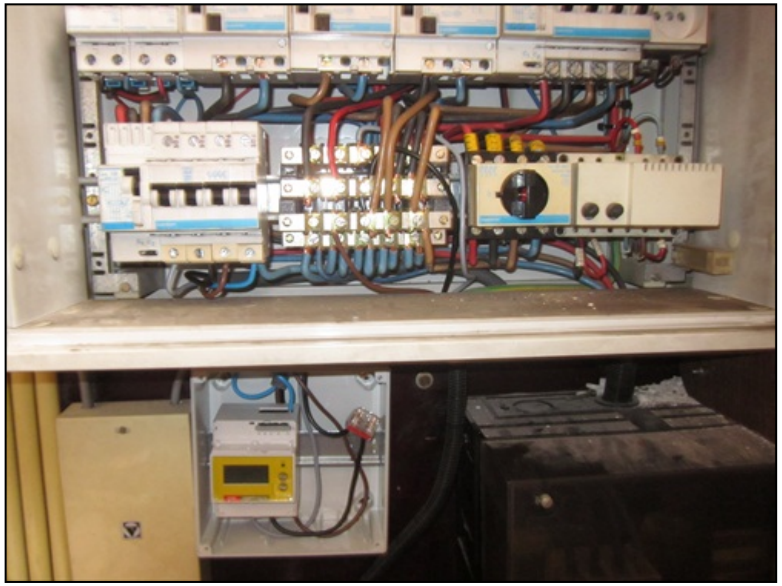





No smart meter available

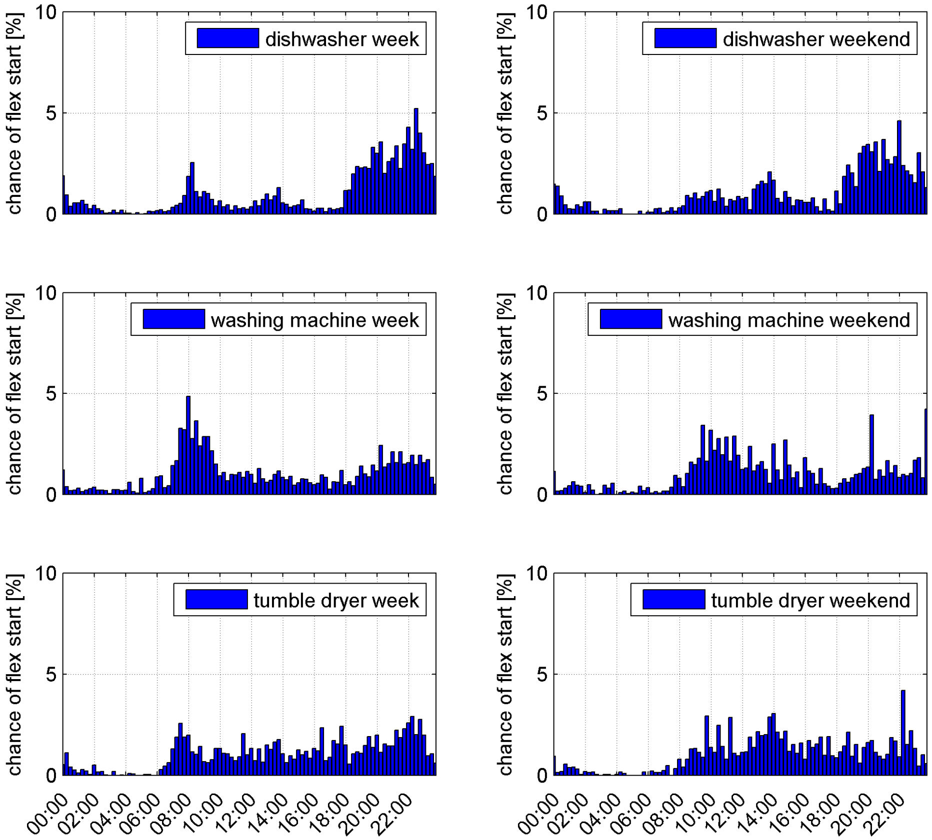
Smart meter integration

# Some are more complex

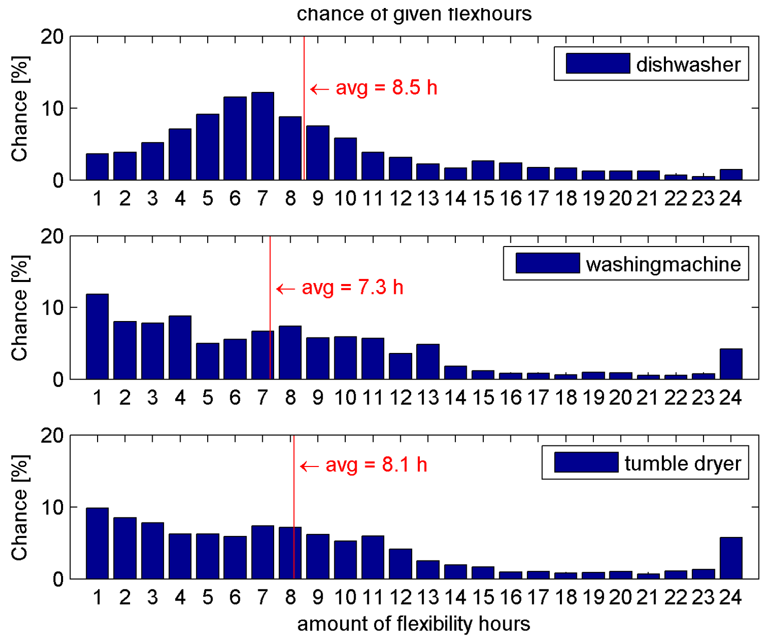



Every house
is a lab on its own

# Whitegoods: configurations



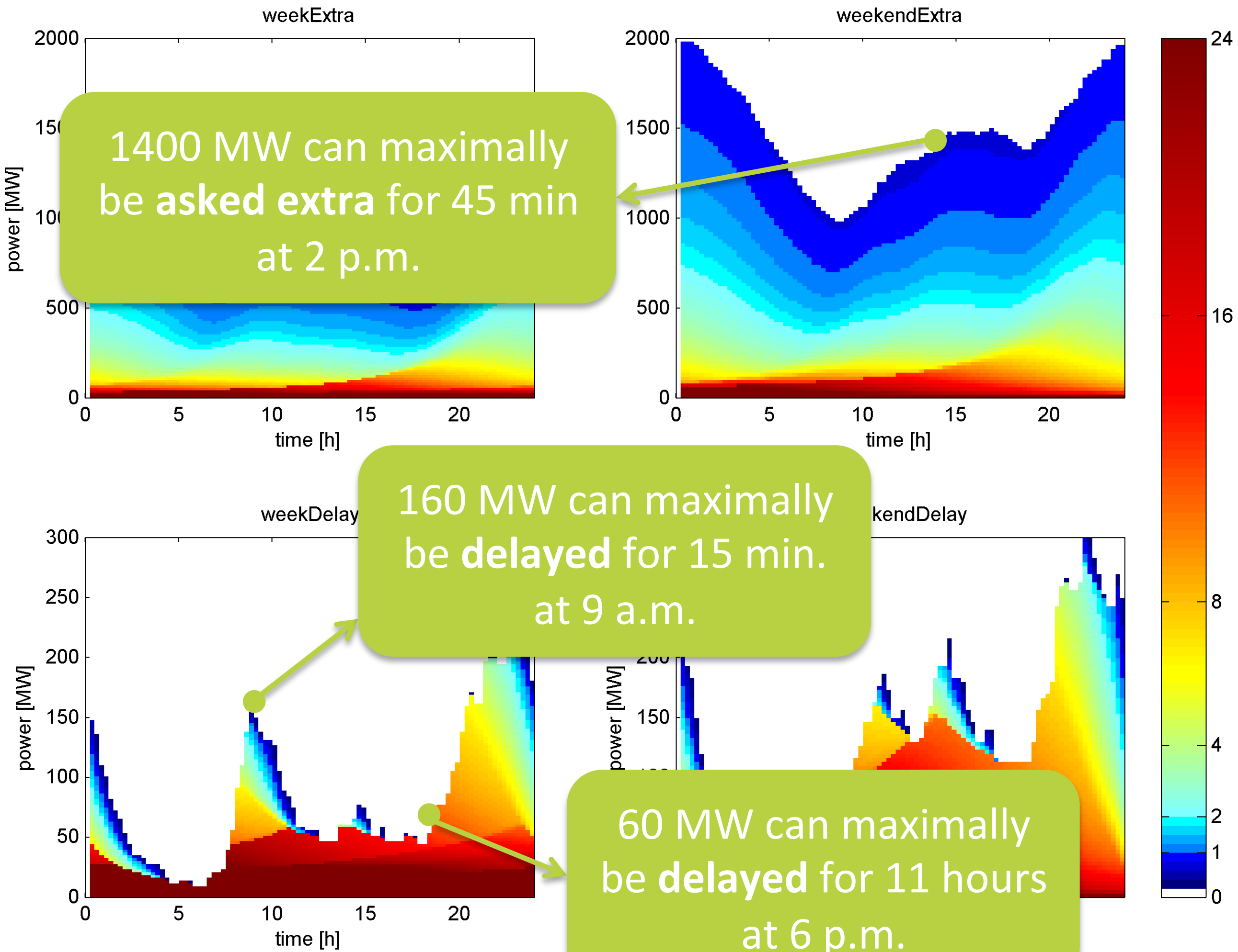

Dishwashers perform best
➔ Confirmed in questionnaire




Flex is concentrated in the evening, esp. for dishwashers

Underestimate, due to missed flex because of technical issues

# Whitegoods: flexibility potential of Belgium (extrapolation)




1400 MW can maximally be **asked extra** for 45 min at 2 p.m.

160 MW can maximally be **delayed** for 15 min. at 9 a.m.

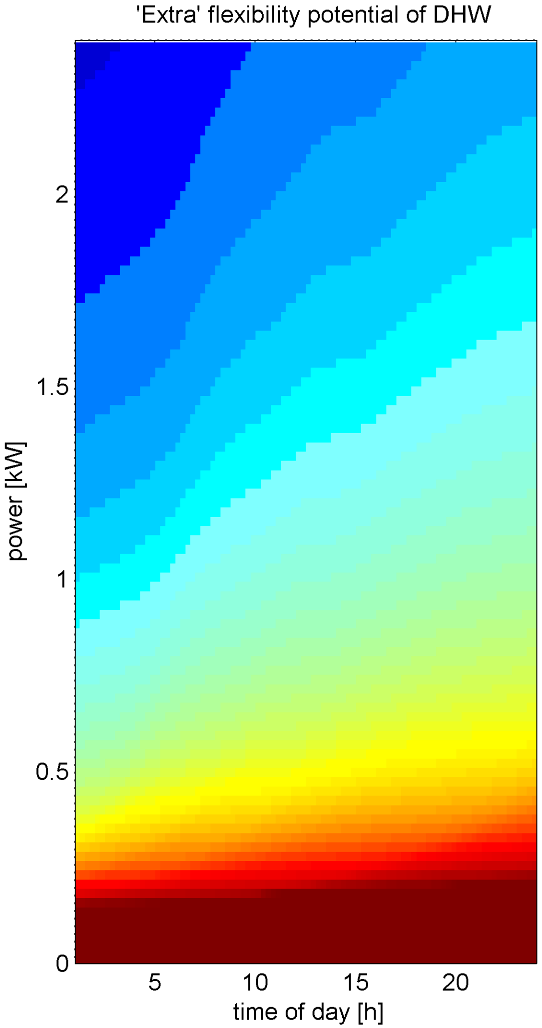
60 MW can maximally be **delayed** for 11 hours at 6 p.m.

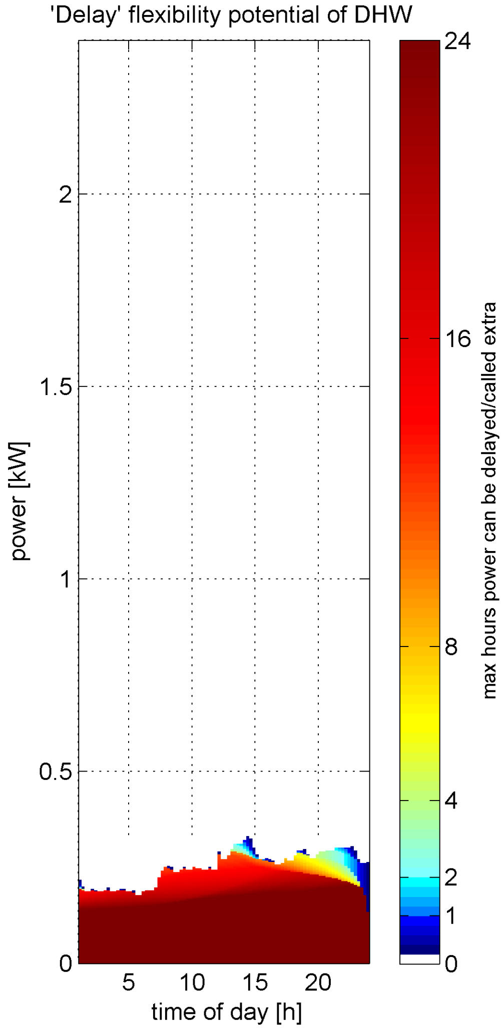
More flex in weekend, situated in the afternoon and esp. the evening

Flexibility is **asymmetric**

Assumption: all Belgians participate

# DHW buffer: flexibility potential





No week/ weekend differences

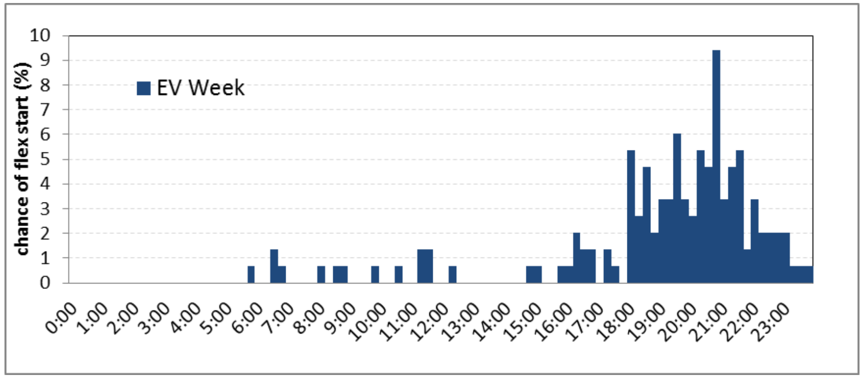
Potential per household factor 10 larger than whitegoods

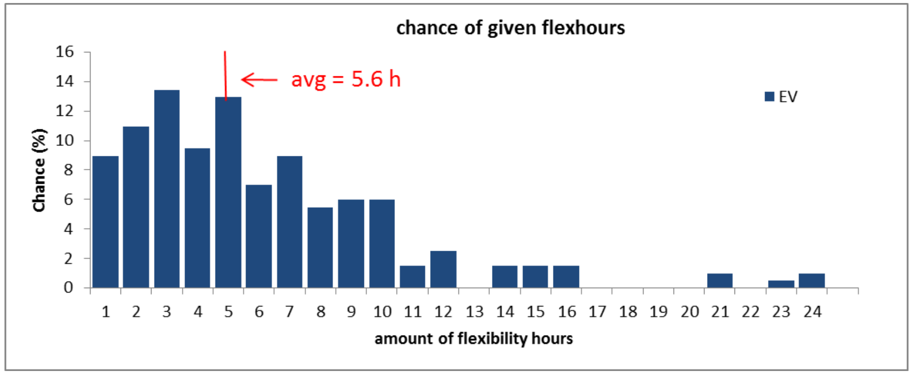
Flexibility is asymmetric

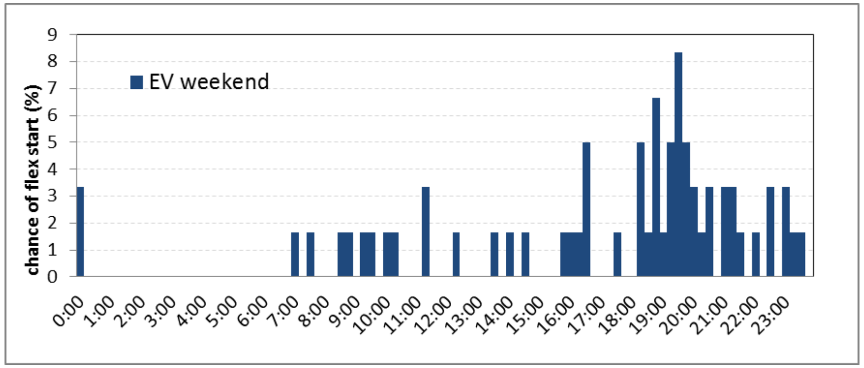
More positive flex, which increases through the day

Much less negative flex, which decreases through the day

# EVs: configurations



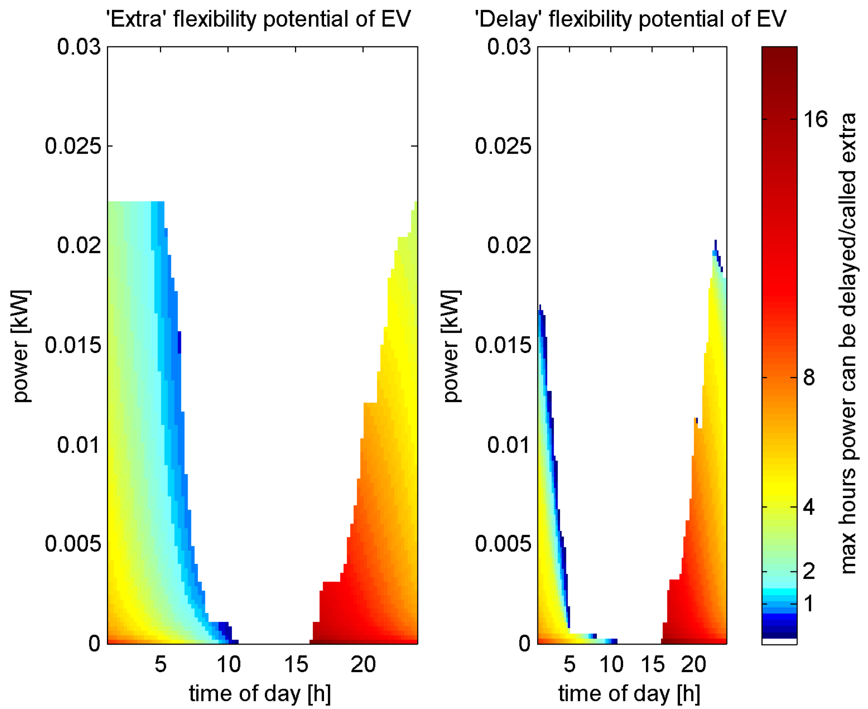





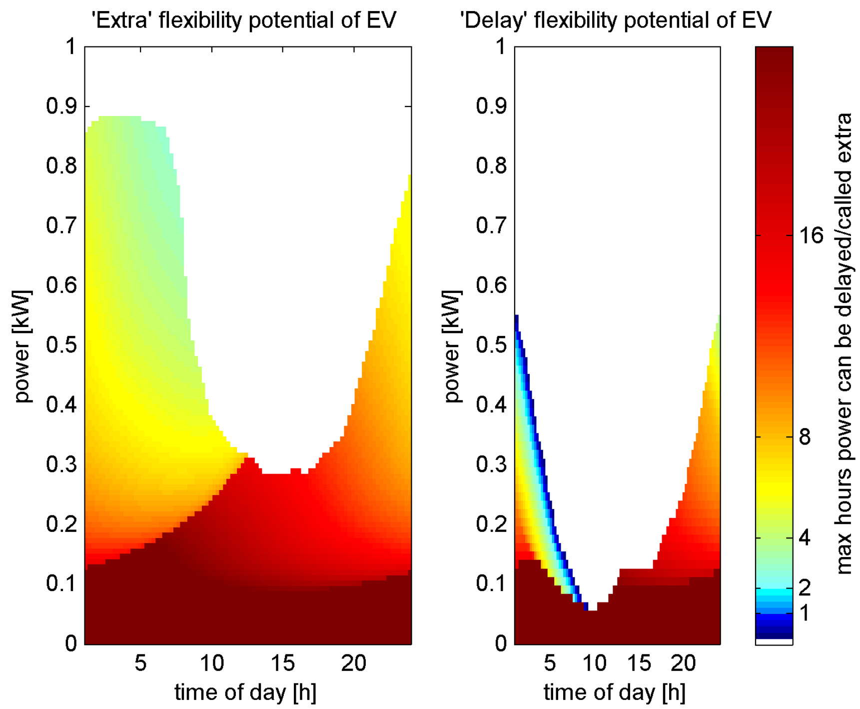
Flex is concentrated in the evening
➔ work-home traffic

# EVs: flexibility potential

User Configured




Theoretic maximum, based on arrival and departure times



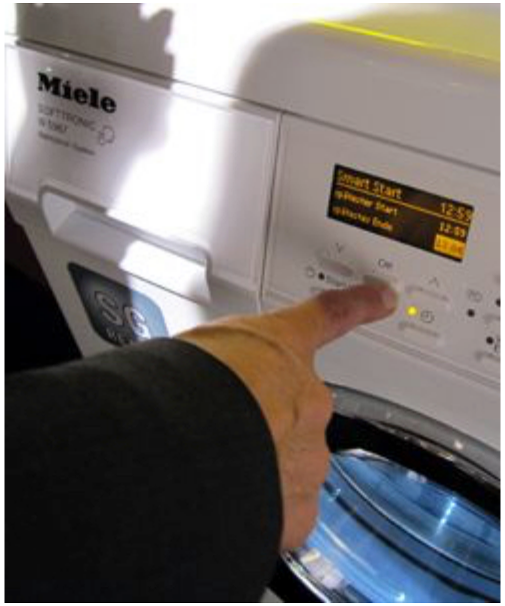

Asymmetric,
but much less pronounced

Very pronounced day gap

# Belgian Winter peak potential

- Based on Linear behavior
  - Measured before supply crisis
  - Focus on comfort
  - Continuous control, not (rare) emergency cases
- Uses statistical model that includes:
  - Probability presence appliance in household
  - Appliance usage frequency
  - Probability smart configurations
- Estimation for today's situation

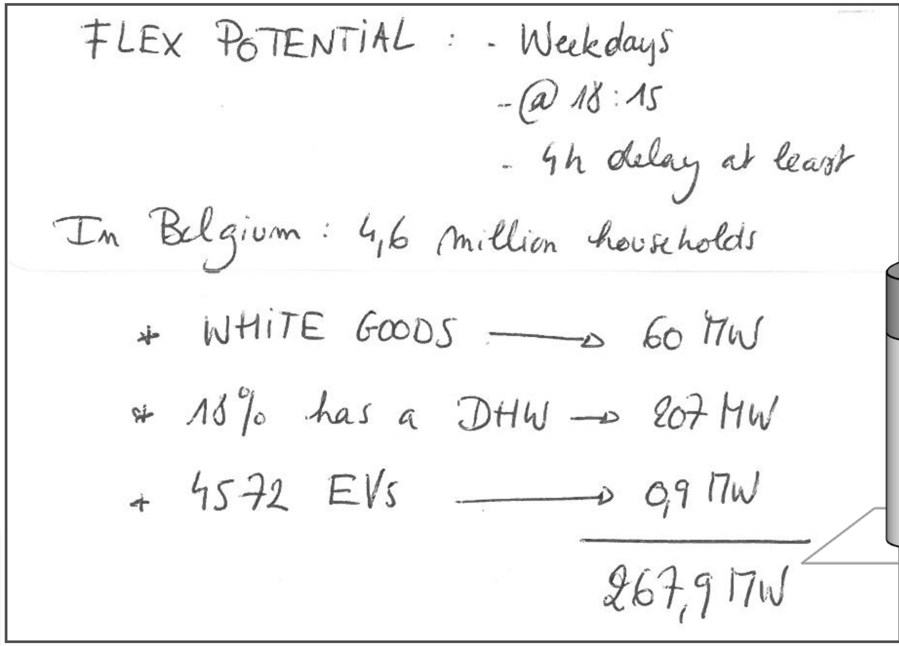
➔ Underestimate!



# Belgian Winter peak potential

- Back of the Envelope
- Most potential: buffered thermal appliances
- More EVs/heat pumps = more potential, but also higher peak

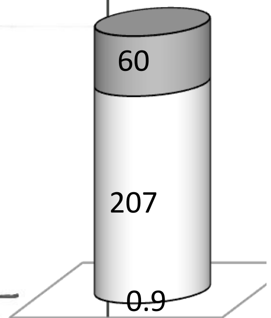
**Very rough (under)estimate, Orders of magnitude count**


FLEX POTENTIAL : - Weekdays
- @ 18:15
- 4h delay at least

In Belgium : 4,6 million households

+ WHITE GOODS → 60 MW
+ 18% has a DHW → 207 MW
+ 4572 EVs → 0,9 MW

267,9 MW




**Assumptions**

- White goods: all households participate, degree of participation varies
- 18% of the households heat water electrically, all have a Linear smart DHW buffer
- EVs: 4572 per 30 June 2014, 10A charging current
- No heat pumps included