European Commission

Coupling a power system model to a building model to evaluate the flexibility potential of DSM at country level

Elodie Ciciriello, Emeline Georges, Sylvain Quoilin

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Joint Research Center (JRC)
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Introduction

Objective of the work:

- develop an integrated model of the heat demand coupled to the power system
- assess the potential of the heat demand as a flexibility provider

Optimisation model minimizing the total operational system cost with

- supply side: unit commitment and dispatch model
- heat demand: space heating and domestic hot water
- electric heating: heat pumps and water heaters

Dispa-SET in a nutshell

- *Unit commitment and dispatch model* of the European power system
- Optimises *short-term scheduling* of power stations in large-scale power systems
- Assess *system adequacy and flexibility needs* of power systems, with growing share of renewable energy generation
- Assess feasibility of power sector solutions generated by the JRC-EU-TIMES model

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Dispa-SET 2.1: unit commitment and dispatch model

Wind, PV Generation (MWh/h)

Power Demand (MWh/h)

Commodity Prices (EUR/t)

Plant data (MW, eff,...)

Objective

- Minimise variable system costs

Constraints

- Hourly demand balances (power and reserve)
- Ramping constraints, minimum up and down times
- Storage balances (PHS,CAES)
- NTC based market coupling
- Curtailment of wind, PV and load shedding (optional)

Plant output (MWh/h)

Plant on/off status (binary)

Variable costs/prices (EUR/MWh)

Emissions (t CO2)

Formulated as a tight and compact mixed integer program (MILP)

Implemented in Python and *GAMS*, solved with *CPLEX*

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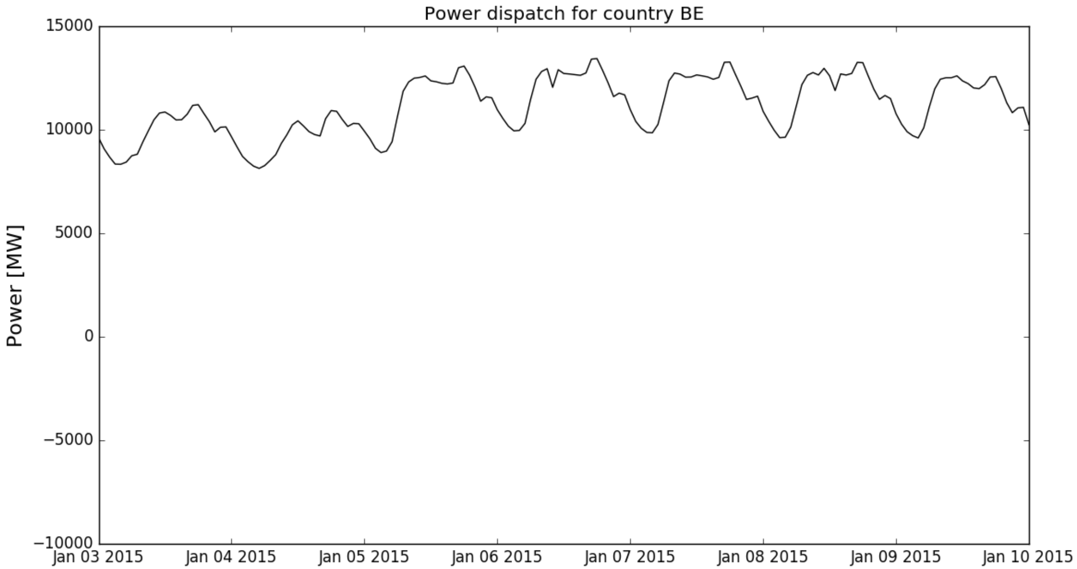
Dispa-SET 2.1

$$\min \sum_{i} SystemCost_i$$

$$\sum_{u} (P_{u,i} \cdot Location_{u,n}) + \sum_{l} (Flow_{l,i} \cdot LineNode_{l,n})$$
$$= Demand_{DA,n,h} + \sum_{r} (StorageInput_{s,h} \cdot Location_{s,n}) - ShedLoad_{n,i}$$
$$- LostLoadMaxPower_{n,i} + LostLoadMinPower_{n,i} \qquad (2)$$



Dispa-SET 2.1

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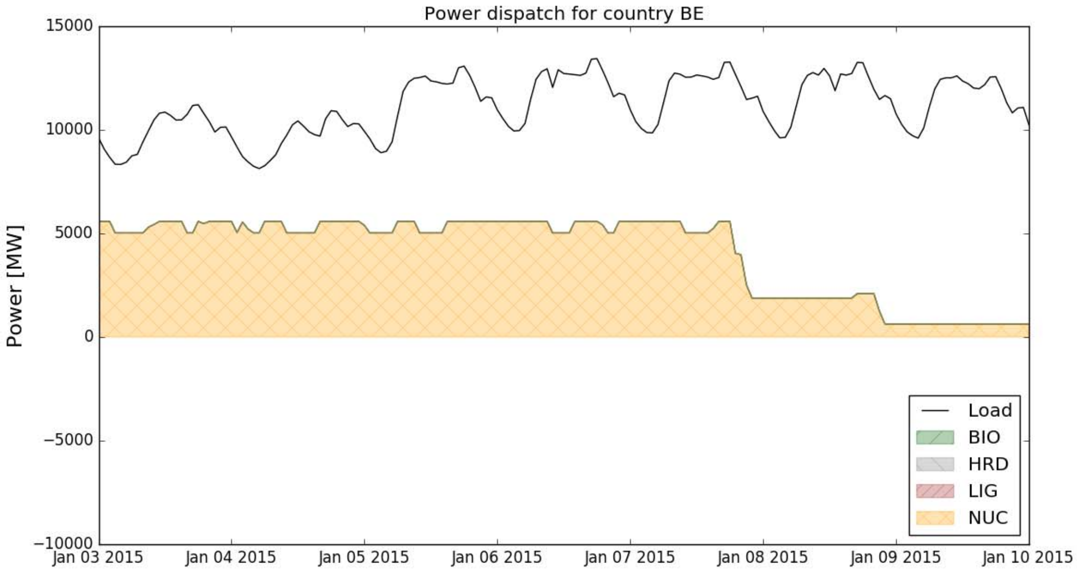

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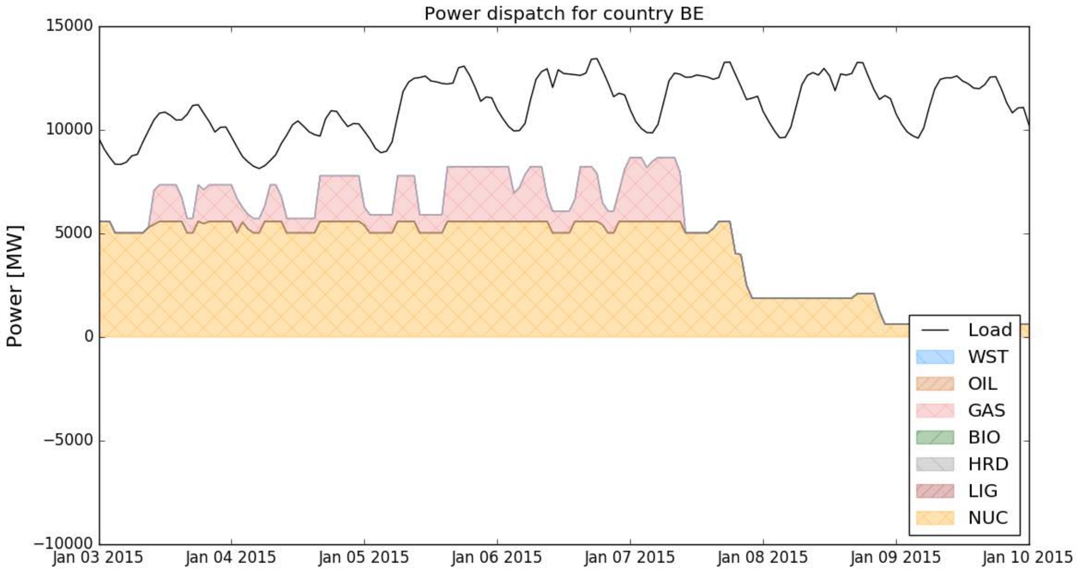

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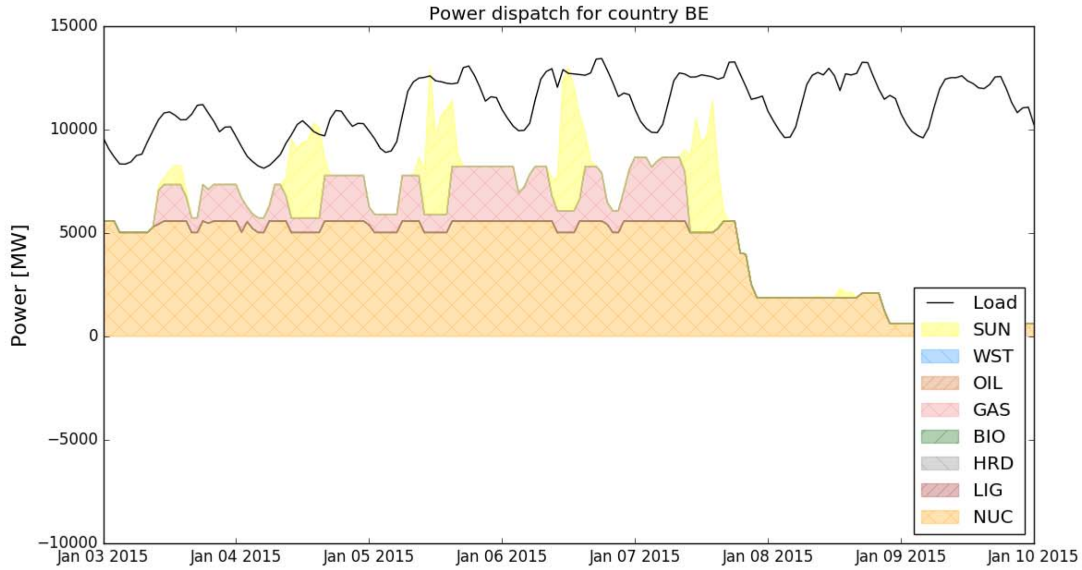

Dispa-SET 2.1

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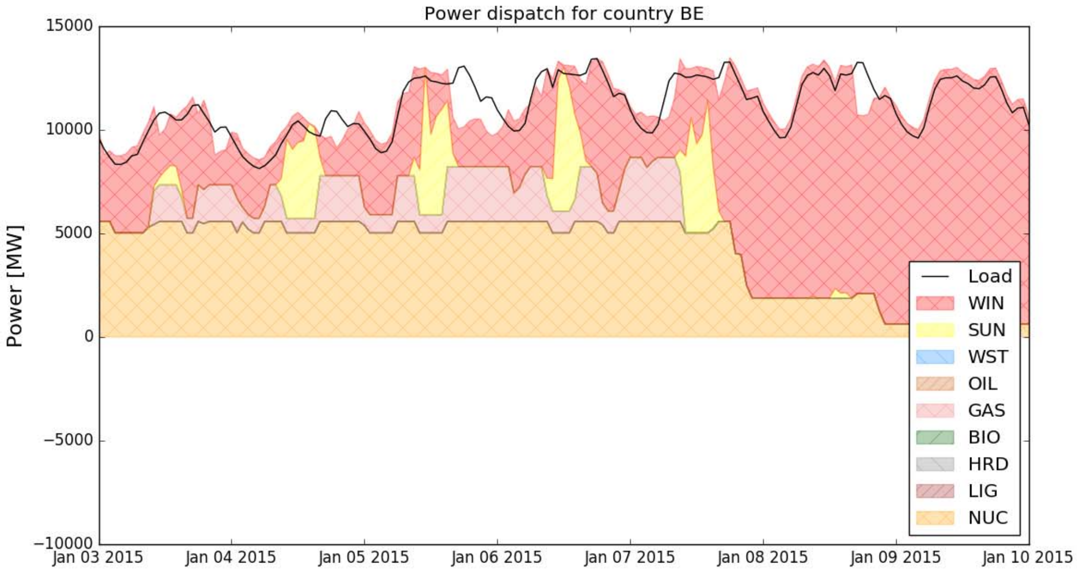
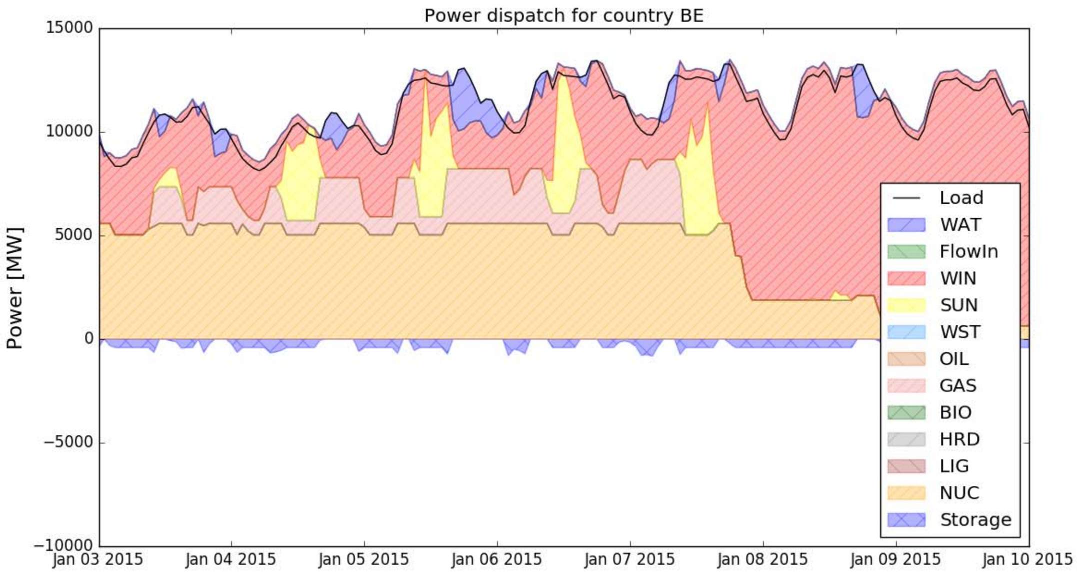


Dispa-SET 2.1

$$\min \sum_i SystemCost_i$$

$$\begin{aligned}
&\sum_u (P_{u,i} \cdot Location_{u,n}) + \sum_l (Flow_{l,i} \cdot LineNode_{l,n}) \\
&= Demand_{DA,n,h} + \sum_r (StorageInput_{s,h} \cdot Location_{s,n}) - ShedLoad_{n,i} \\
&\quad - LostLoadMaxPower_{n,i} + LostLoadMinPower_{n,i} \qquad (2)
\end{aligned}$$



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Dispa-SET 2.1

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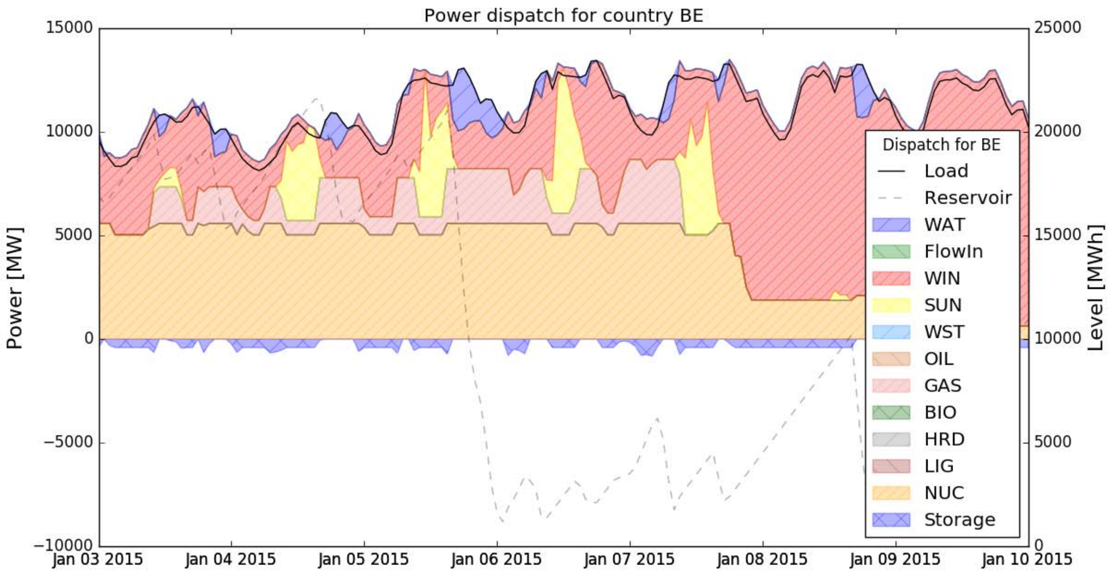

European Commission

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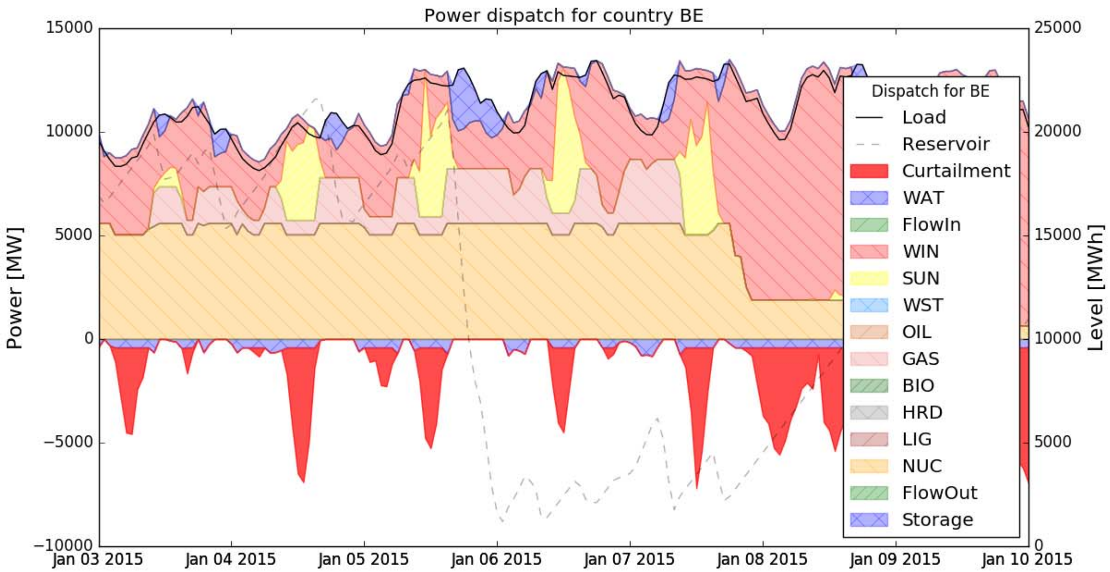
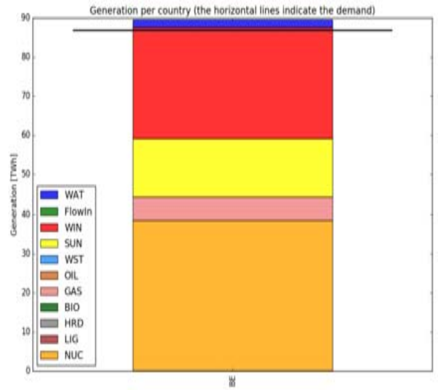
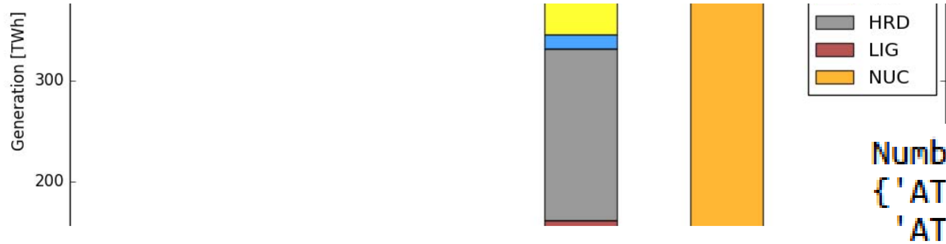


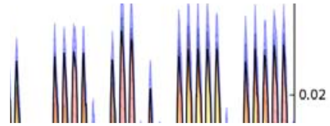


Dispa-SET 2.1: typical outputs

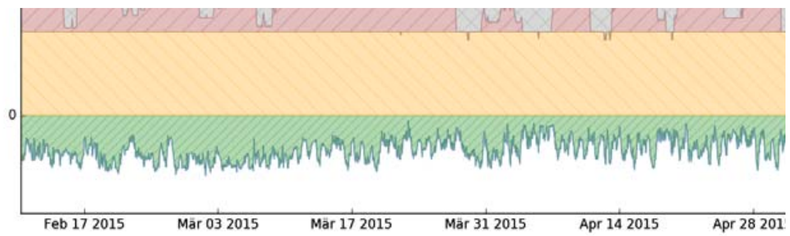
Country-Specific values (in TWh or in MW):

	Demand	PeakLoad	NetImports	LoadShedding	Curtailment
AT	59.375448	10144.000000	5.144132	NaN	NaN
BE	86.971154	13632.250000	8.911190	NaN	NaN
CH	44.694098	7794.262468	7.199527	NaN	NaN
DE	478.030824	76212.250000	-17.260122	NaN	NaN
FR	470.075612	90588.000000	-51.878128	NaN	NaN
NL	87.925973	16285.500000	5.682672	NaN	NaN





Aggregated statistics for the considered area:
Total consumption:1227.07310992 TWh
Peak load:203182.461067 MW
Net importations:-42.20072928 TWh



Number of hours of congestion on each line:

```
{'AT -> CH': 5917,
 'AT -> DE': 430,
 'BE -> FR': 62,
 'BE -> NL': 344,
 'CH -> AT': 720,
 'CH -> DE': 15,
 'CH -> FR': 56,
 'DE -> AT': 1522,
 'DE -> CH': 4378,
 'DE -> NL': 2803,
 'FR -> BE': 2689,
 'FR -> CH': 7665,
 'NL -> BE': 1403,
 'NL -> DE': 60}
```

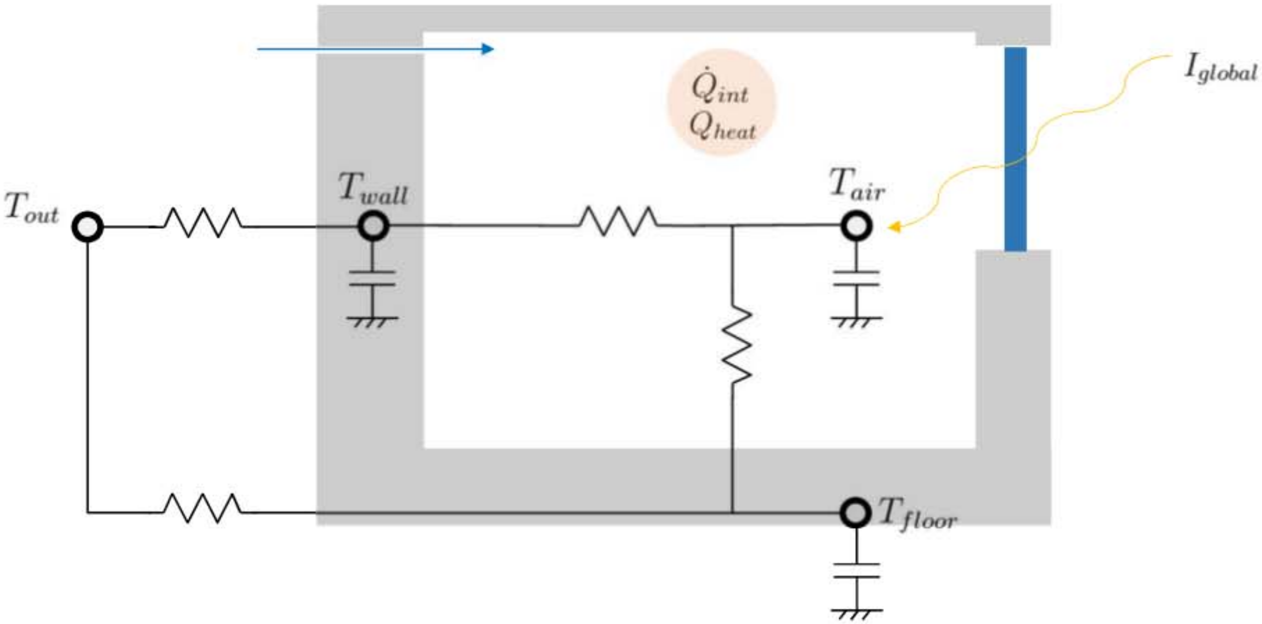
Heat model

$$T_t = \mathbf{A} T_{t-1} + \mathbf{B} U_t \qquad (4)$$

Space heating

$$T_t = \begin{pmatrix} T_{air} \\ T_{wall} \\ T_{floor} \end{pmatrix}_t$$

$$U_t = \begin{pmatrix} T_{out} \\ I_{glob} \\ \dot{Q}_{int} \\ \dot{Q}_{heat} \end{pmatrix}_t$$



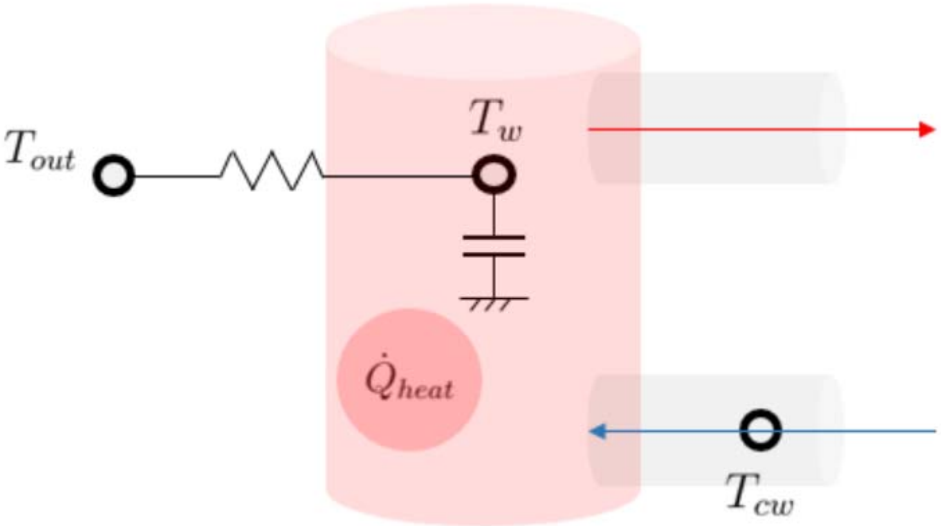
Heat model

$$T_t = \mathbf{A} T_{t-1} + \mathbf{B} U_t \qquad (4)$$

<u>**Domestic hot water**</u>

$$T_t = \left(T_w\right)_t$$

$$U_t = \begin{pmatrix} T_{out} \\ T_{cw} \\ \dot{Q}_{heat} \end{pmatrix}_t$$

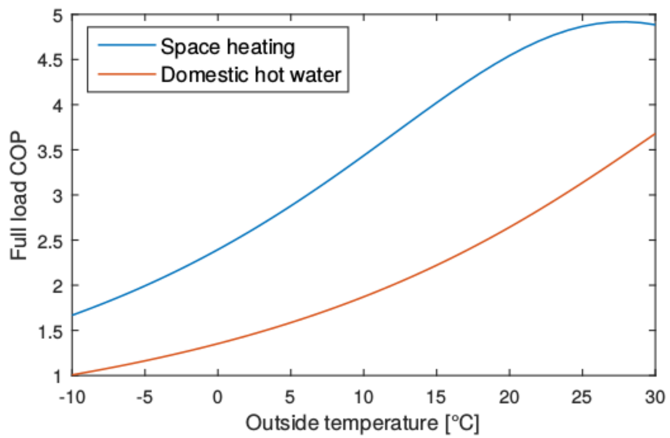


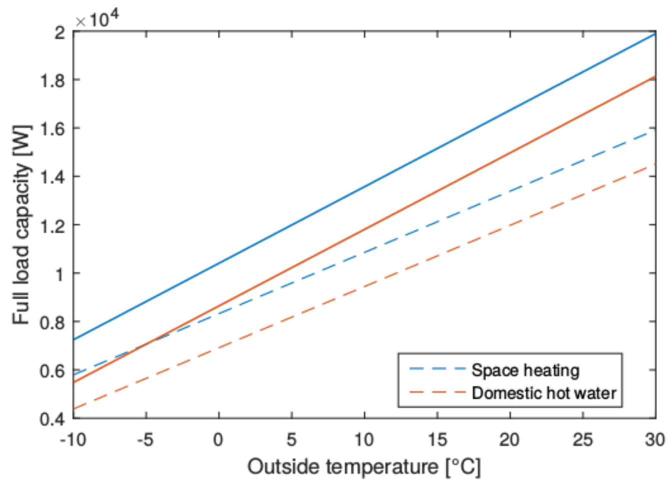
Heat model

Heat pumps: variable speed air-to-water

- $T_{out,n} = 7°C,\ T_{su,n} = 35°C$
- $\dot{Q}_n = 11,2\ kW\ /\ 14\ kW$
- $COP_n = 3,95$

- Full load characteristics: f(T_{su}, T_{out})





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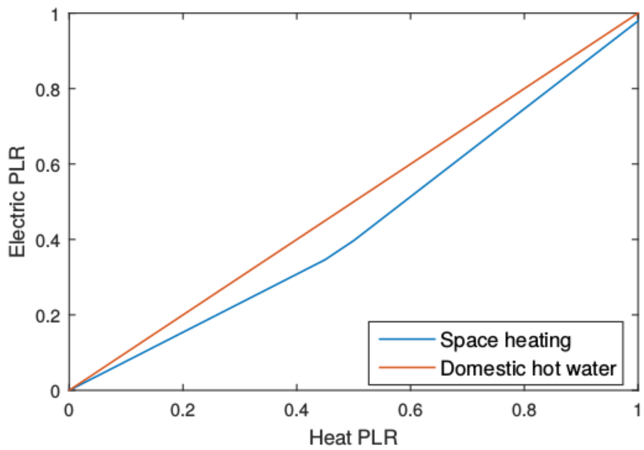
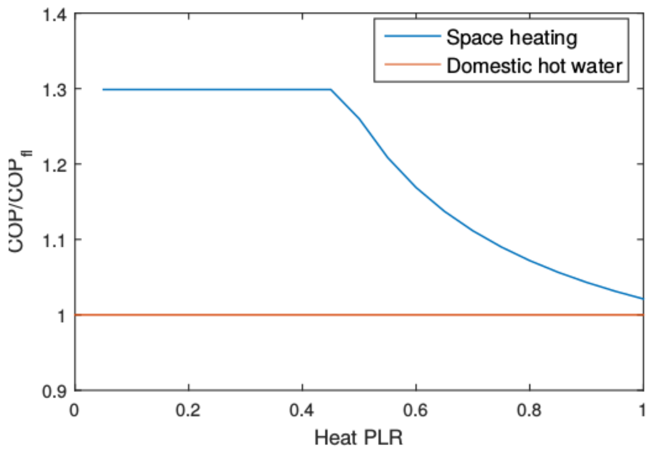
- Full load characteristics: f(T_{su}, T_{out})
- Partial load performance





Heat model

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- $T_{out,n} = 7^\circ C, \ T_{su,n} = 35^\circ C$
- $\dot{Q}_n = 11,2 \ kW \ / \ 14 \ kW$
- $COP_n = 3,95$

- Full load characteristics: f(T_{su}, T_{out})
- Partial load performance

Water heaters:

- $\dot{Q}_n = f(\dot{m}_w)$
- $COP = 1$

Model coupling

$$min \sum_i SystemCost_i$$

$$\sum_u (P_{u,i} \cdot Location_{u,n}) + \sum_l (Flow_{l,i} \cdot LineNode_{l,n})$$
$$= Demand_{DA,n,h} + \sum_r \left(StorageInput_{s,h} \cdot Location_{s,n}\right) - ShedLoad_{n,i}$$
$$-LostLoadMaxPower_{n,i} + LostLoadMinPower_{n,i} \quad (2)$$
$$\boxed{+10^{-6} \cdot \Delta P_i}$$

$$\Delta P = P_{flexible} - P_{base}$$

Difference between the actual building consumption and the baseline consumption

Modeling of the Belgian building stock

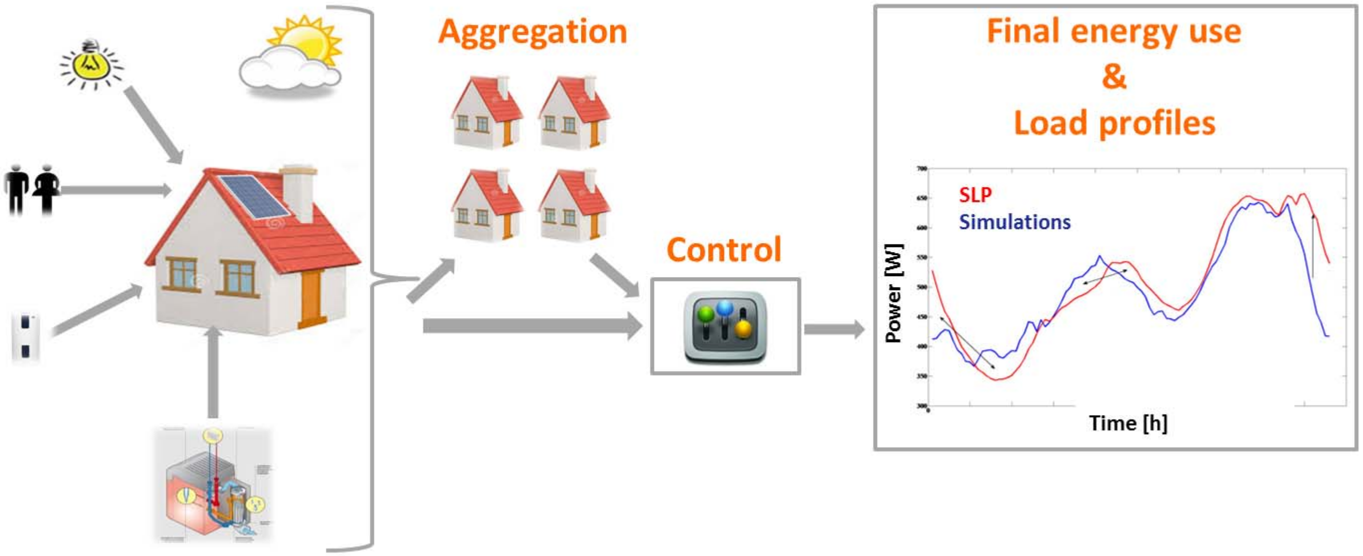
Database of building typologies validated with historical data.

Subset considered here: one building geometry and two insulation levels

- $U = 0.458$ [W/m²K] (75%)
- $U = 0.305$ [W/m²K] (25%)

Heat demand aggregation:

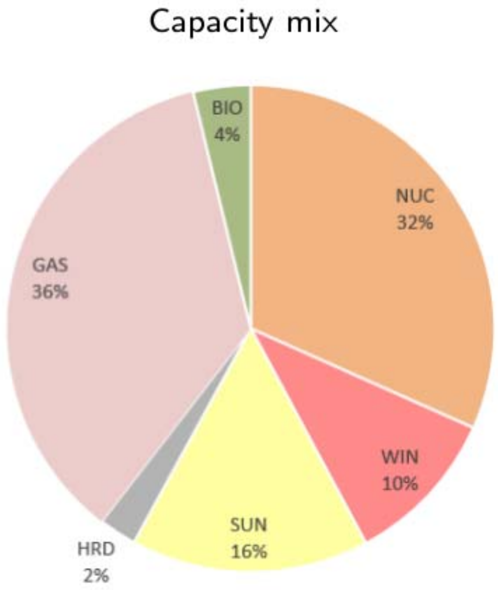
- 4 space heating comfort profiles
- 5 domestic hot water consumptions profiles



Simulations

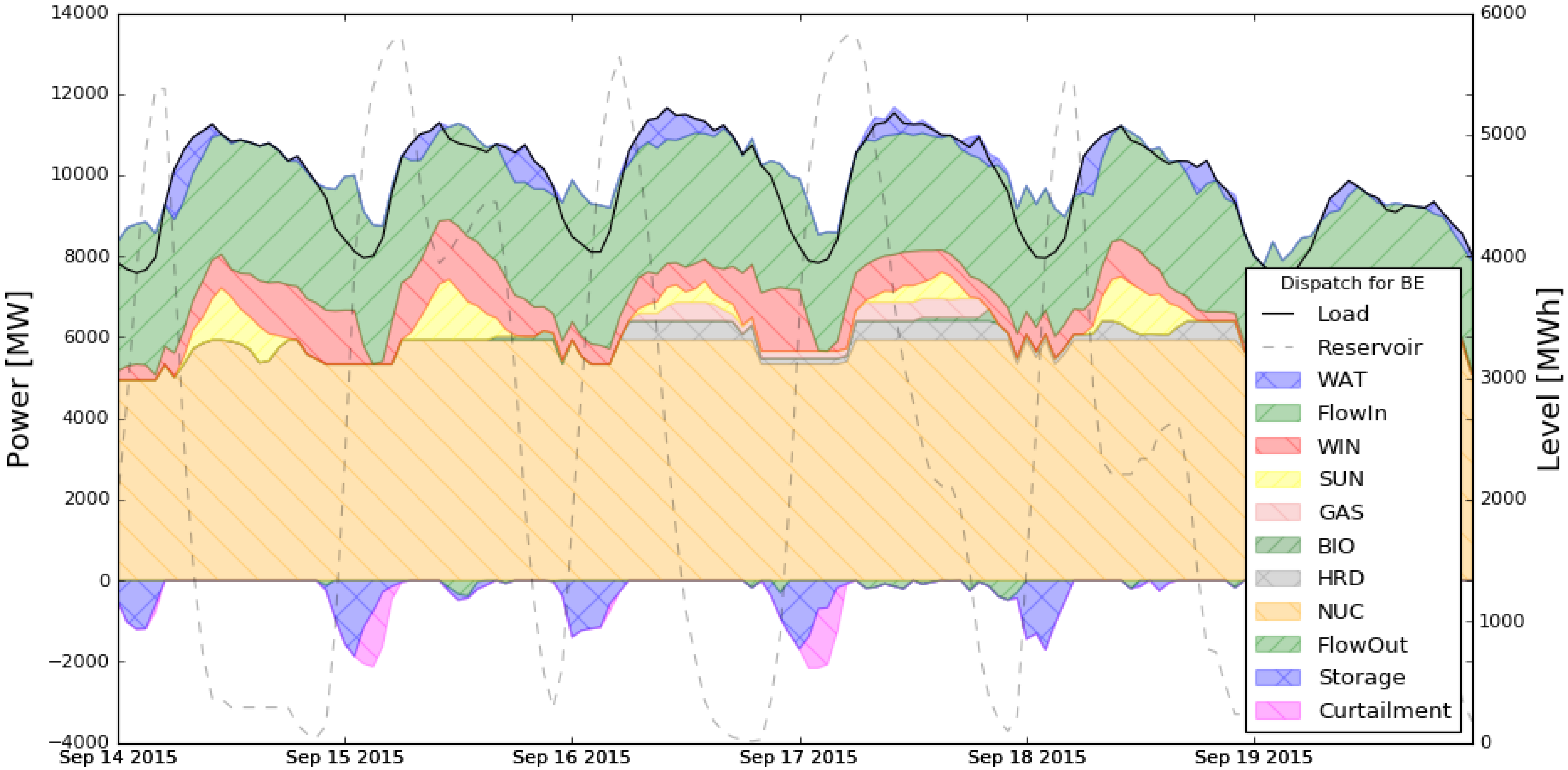
Base case study: Belgium in 2015

- 40 000 heat pumps
- 1 600 000 water heaters

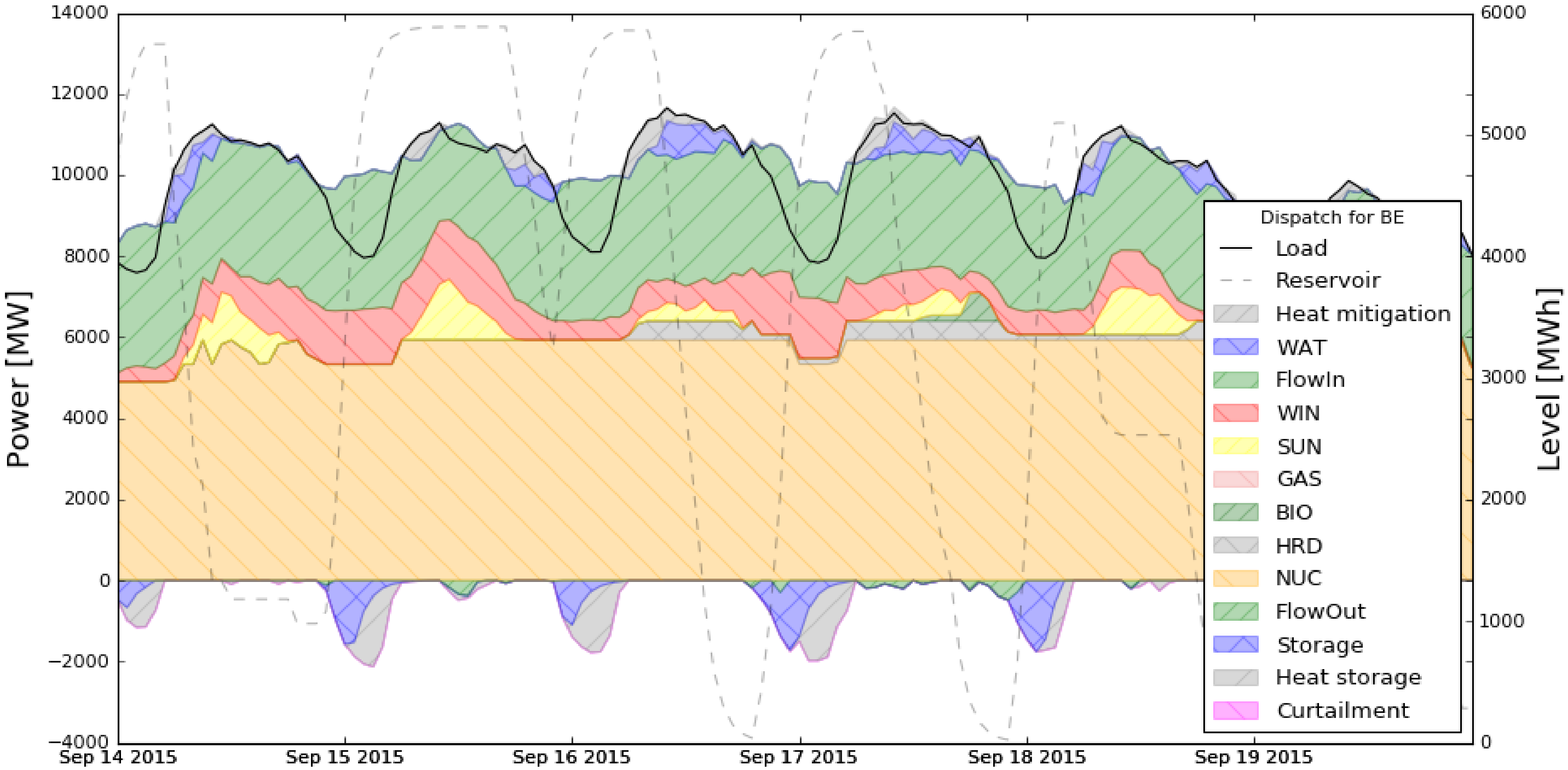


Parametric analysis:

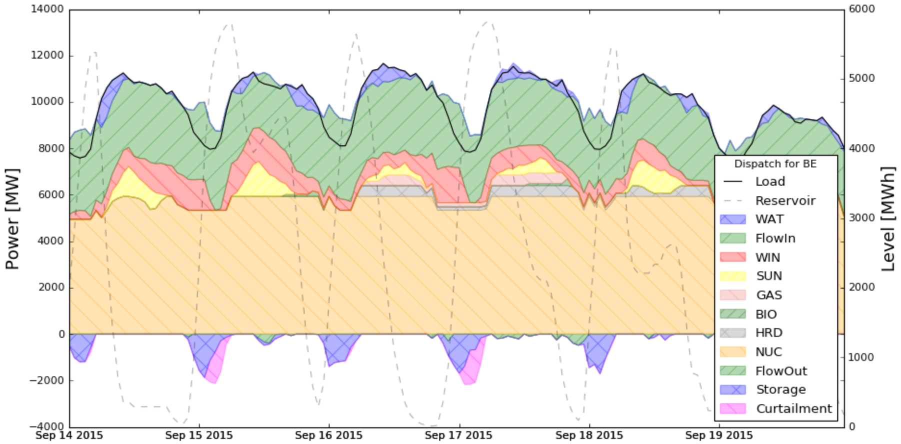
Heating system	Number of flexible units	Renewable capacity	Flexibility of the system
HP - WH	0 - 0.2 - 0.4 - 0.6 - 0.8 - 1M	R1 - R2 - R3	Non-flexible - Flexible

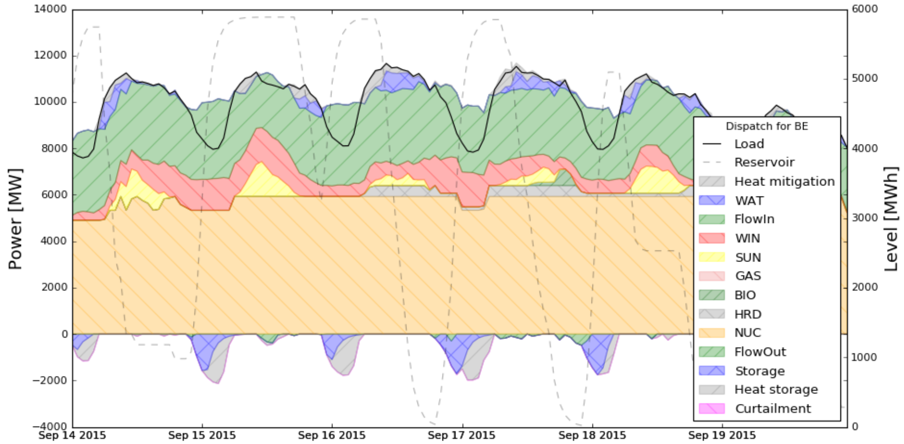


Power [MW]
Level [MWh]
14000
12000
10000
8000
6000
4000
2000
0
−2000
−4000
6000
5000
4000
3000
2000
1000
0
Sep 14 2015
Sep 15 2015
Sep 16 2015
Sep 17 2015
Sep 18 2015
Sep 19 2015
Dispatch for BE
Load
Reservoir
WAT
FlowIn
WIN
SUN
GAS
BIO
HRD
NUC
FlowOut
Storage
Curtailment


Dispatch for BE
Load
Reservoir
Heat mitigation
WAT
FlowIn
WIN
SUN
GAS
BIO
HRD
NUC
FlowOut
Storage
Heat storage
Curtailment
Power [MW]
Level [MWh]
14000
12000
10000
8000
6000
4000
2000
0
−2000
−4000
6000
5000
4000
3000
2000
1000
0
Sep 14 2015
Sep 15 2015
Sep 16 2015
Sep 17 2015
Sep 18 2015
Sep 19 2015

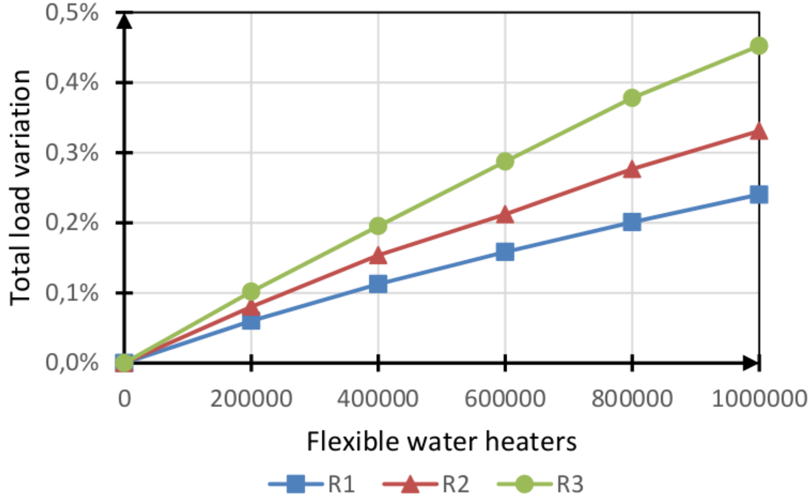
Simulation results: base case

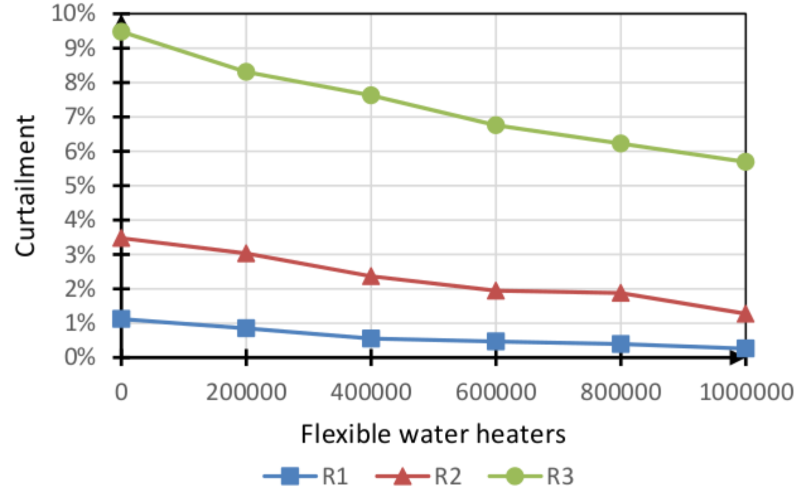


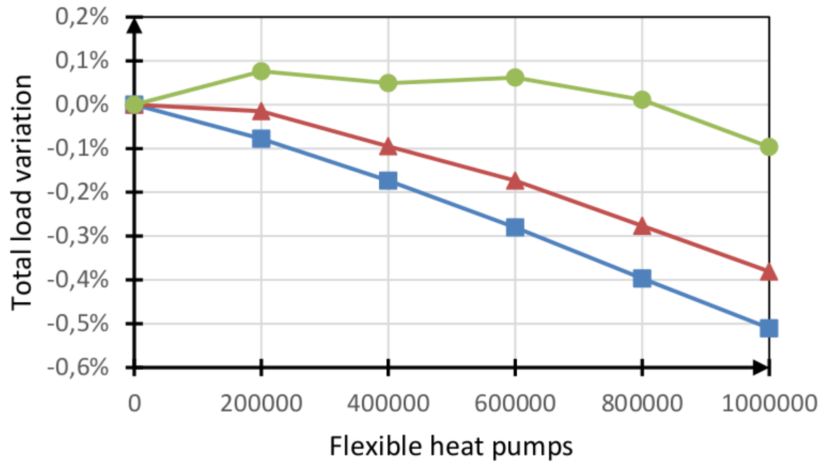


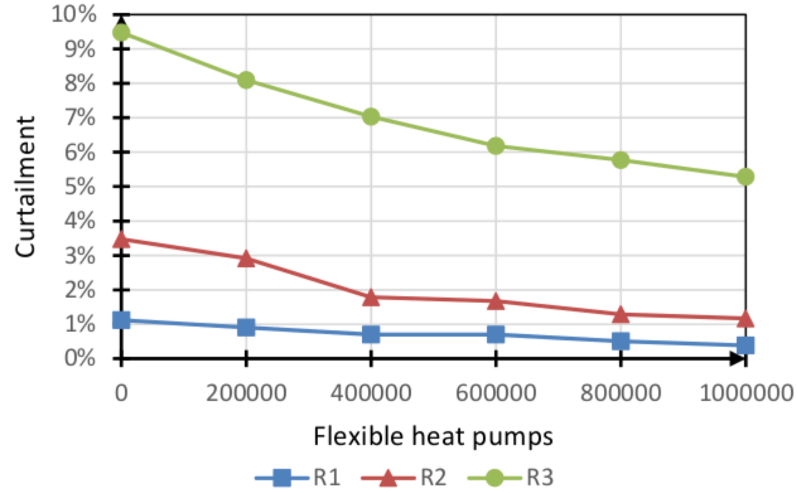
	OC [M€]	Load [TWh]	C [GWh]	RGS [%]	ε_{gl} [%]	HCF [%]
Base	712	87.0	95.5 (1.2%)	11.9		10,6
Heat pumps	710	87.0	85.7 (1.0%)	12.0	119	10,4
Water heaters	703	87.3	8.9 (0.1%)	12.1	75.1	6,7

More simulation results









Conclusions

- With 1M flexible devices:
  - Up to 35M€ of operational cost reduction
  - Up to 1TWh of curtailed power reduction (1MWh/device)
  - Benefits are higher when the flexibility need is high (more renewable)
  - Benefits are reduced when the system is more flexible
  - Heat pumps and water heaters provide the same heat storage
  - capacity
- Future improvements:
  - Adding cooling and/or more zones to the model
  - Include investments
  - Include uncertainty
  - EU-wide analysis
- All methods and models are released as open-source (Dispa-SET side): https://joinup.ec.europa.eu/software/dispaset/

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Dispa-SET 2.1 Inputs

Dispa-SET Configuration File

This is the standard configuration file for Dispa-SET. It defines the data sources for all the parameters and provides some indications regarding the structure of the data. This excel file must be provided when running the main dispa-set running script

Description	Standard simulation for 6 countries, with the MILP formulation

Simulation directo	Relative Path	Simulations/simulation_test	This section defines the output of the pre-processing (which is the input of the DispaSet solver)
Write excel	True/False	FALSE	The simulation environment is defined as a directory that contains all thre reuquired data and GAMS files
Write GDX	True/False	TRUE	It is recommended to write the data in the 3 different formats (excel, gdx, pickle), but if one is not needed,
Write Pickle	True/False	TRUE	it can be skipped.
GAMS path	Path		

Start date	Date	1/1/2015	Date and time parameters of the simulation
Stop date	Date	12/31/2015	Start and stop dates need to be within the provided data
Horizon length	Number of days	3	Hour 0 of the day is defined as midnight in timezone UTC+1
Look ahead	Number of days	1	

Clustering	True/False	TRUE	This sections defines parameters that influence the formulation of the problem
Simulation type	List	MILP	These parameters influence both the pre-processing (e.g. in LP clustering, all units are aggregated by type)
Reserve calculatio	List	Generic	and the solver (some constraints are removed when solving in LP)
Allow Curtailment	True/False	TRUE	

Demand	Relative Path	Database/Load_RealTime/##			
Outages	Relative Path				This section provides the paths to the raw data used to generate the Dispa-SET simulation template.
Power plant data	Relative Path	Database/PowerPlants/##/2			The path is a relative path, the current directory being the one where DispaSET.py is executed.
Renewables AF	Relative Path	Database/AvailabilityFactors			
Load Shedding	Relative Path		Default value	0.05	For datasets which have one file per country, replace the country code (2 characters) in the path by ##.
NTC	Relative Path	Database/DayAheadNTC/1h/			for example:
Historical flows	Relative Path	Database/CrossBorderFlows			../data/Demand/##/2014/load.csv
Scaled inflows	Relative Path	Database/HydroData/ScaledI			will fetch one load.csv file per country, by replacing ## with FR, DE, NL, etc.
Price of Nuclear	Relative Path		Default value	3	
Price of Black coa	Relative Path	Database/FuelPrices/Coal/2	Default value	11	
Price of Gas	Relative Path	Database/FuelPrices/Gas/20	Default value	20	All fuel prices are in EUR/MWh of primary energy (lower heating value)
Price of Fuel-Oil	Relative Path	Database/FuelPrices/Oil/2015	Default value	35	
Price of Biomass	Relative Path	Database/FuelPrices/Biomas	Default value	37	
Price of CO2	Relative Path		Default value	7	
Reservoir Levels	Relative Path	Database/HydroData/Reserv			

Countries to consider

	AT	TRUE	IE	FALSE
	BE	TRUE	IT	FALSE
	BG	FALSE	LT	FALSE
	CH	TRUE	LU	FALSE
	CY	FALSE	LV	FALSE
NUTS1 codes (ISO	CZ	FALSE	MT	FALSE
3166-1 standard) of the	DE	TRUE	NL	TRUE
simulated countries.	DK	FALSE	NO	FALSE
NB: all the selected	EE	FALSE	PL	FALSE
countries must be	FI	FALSE	PT	FALSE

Input database:

- RES generation profiles
- Power plants
- Demand curves
- Outages
- Fuel prices
- Lines capacities
- Minimum reservoir levels

From the same database different levels of model complexity are available:

- *MILP*
- *LP with all power plants*
- *LP one cluster per technology*
- *LP presolve + MILP*