Demand response in district heating systems: on operational and capital savings potential

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Outline

- DH grid as storage – the state of the art
- Methods: soft-coupling of models
- Case study: Zagreb, Croatia
- Results

Current state of the art

- Thermal mass of buildings and the thermal mass of water utilization:
  - [1] Storage capacity in water much smaller than the storage capacity in walls
  - [2] control strategy: loading phase: 2 AM and lasted for 3.5 hours - reducing the morning peak load
    - up to 15% of daily peak demand can be moved, increasing the distribution losses by about 0.3% [16].
  - No paper implemented dynamic utilization of flexibility

1 Vandermeulen A, Reynders G, van der Heijde B, Vanhoudt D, Salenbien R, Saelens D, et al. Sources of energy flexibility in district heating networks: building thermal inertia versus thermal energy storage in the network pipes. Submitt to USIM 2018 - Urban Energy Simul 2018.

2 Basciotti D, Judex F, Pol O, Schmidt R-R. Sensible heat storage in district heating networks: a novel control strategy using the network as storage. IRES - 6th Int Renew Energy Storage Conf Exhib 2011:4.

Our approach

- Dynamic demand-response implementation in a real-time
- Temperature oscillations for ± 3.5 ^oC
- Much more often utilization of district heating grid as storage
- Soft – linking of DH planning models and operational demand-response model (flexibility)
    - » shadow prices
- DH expansion / increase in capacity was not modelled

Methods

- DH planning model:
  - – Minimizing total socio-economic costs
  - – Constraints:
    - Meeting the heat demand
    - Storage operation
    - Enough capacity in the system

$$minimize \sum_{n\in N}\sum_{s\in S}\sum_{t\in T}\Big[\big(C^{VO\&M}_{n,t} + C^{fuel}_{n,t} + C^{CO2}_{t} K_n - R^{ele}_{n,t} L_n\big) q_{n,t} + \big(C^{VO\&M}_{s,t} + C^{fuel}_{s,t} + C^{CO2}_{t} K_s - R^{ele}_{n,t} L_s\big) q_{s,t}\Big] + \big(C^{cap}_{n} + C^{FO\&M}_{n}\big) q^{cap}_{n} + \big(C^{cap}_{s} + C^{FO\&M}_{s}\big) q^{cap}_{s} .$$

- Flexibility representation:
  - – Change in temperature:

Heat generation

Original heat demand

$$\frac{dX_t}{dt} = \frac{1}{C}(Y_t - B_t)$$

Parameters:

C – amount of energy that can be shifted

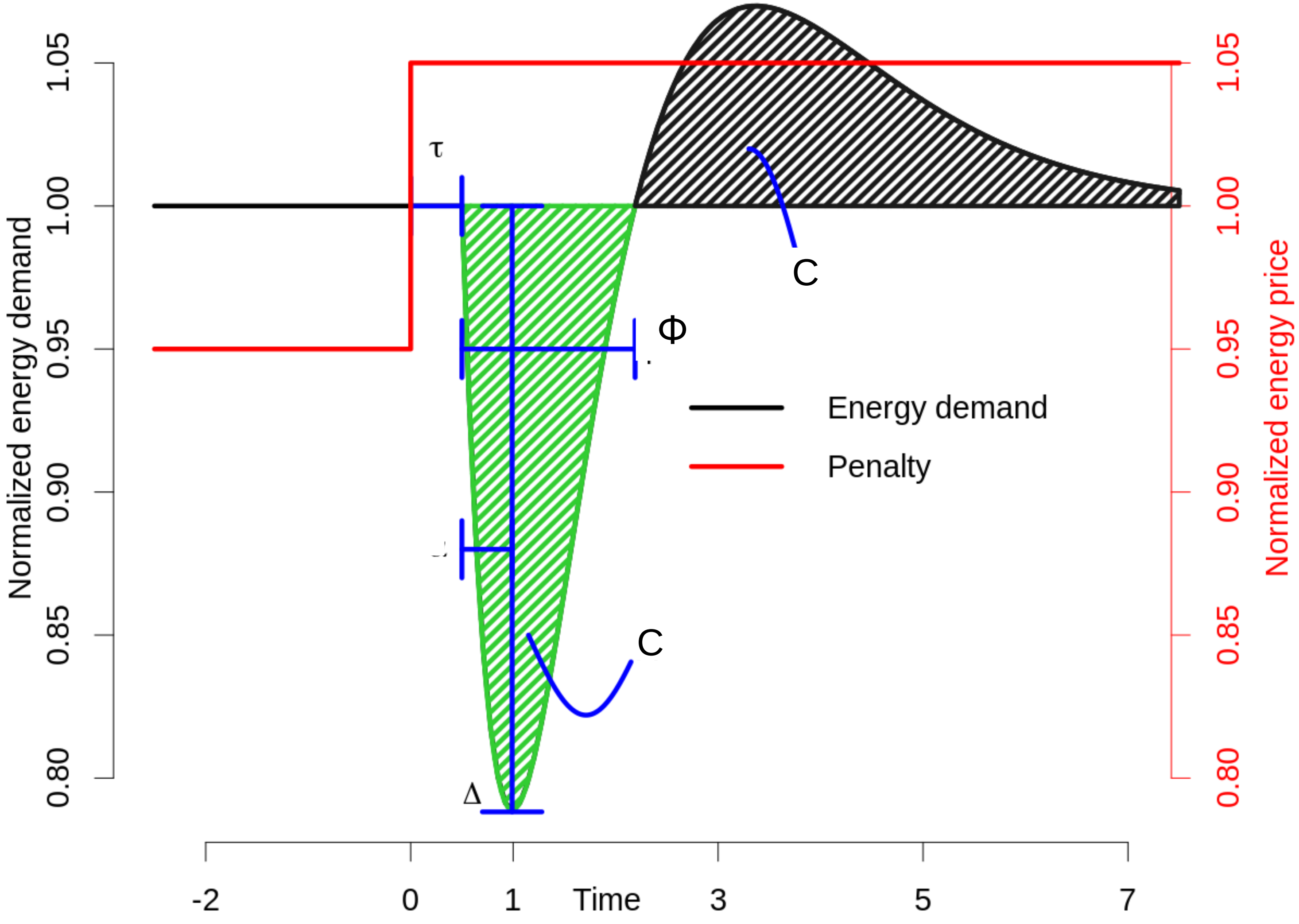
Φ – how quickly returning to the baseload

Δ – how much of consumption can be used flexibly

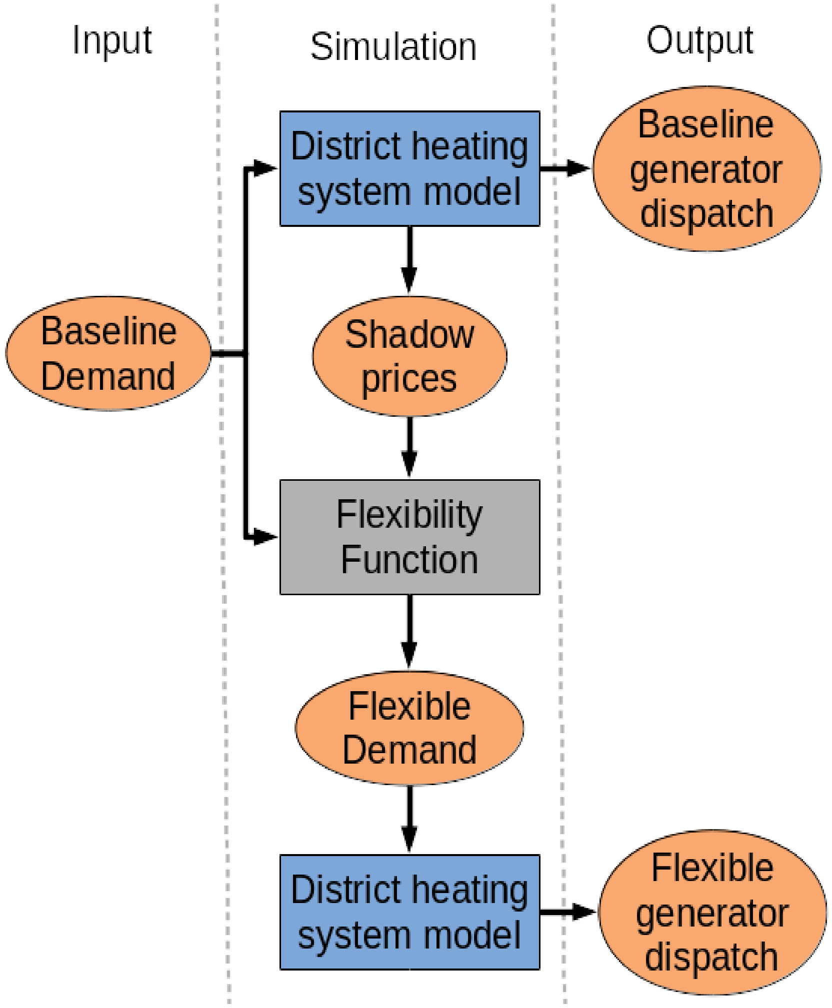
U – energy price (DH price)

  - – Change in consumption due to flexibility: $\delta_t = 2logit\,(\,\Phi(\,\mu - X_t) - k\,u_t(\mathbb{1}(u_t \le 0)g(1 - X_t) + \mathbb{1}(u_t > 0)g(X_t)) - 1$
  - – New heat demand: $Y_t = B_t + \Delta((1 - B_t)\mathbb{1}(\delta_t > 0)\delta_t + B_t\mathbb{1}(\delta_t \le 0)\delta_t,$

Methods


τ
Φ
C
C
Δ
Energy demand
Penalty
Normalized energy demand
Normalized energy price
Time
1.05
1.00
0.95
0.90
0.85
0.80
-2
0
1
3
5
7

Soft-linking of models



Input

Simulation

Output

Baseline Demand

District heating system model

Baseline generator dispatch

Shadow prices

Flexibility Function

Flexible Demand

District heating system model

Flexible generator dispatch

Case study – Zagreb DH

Type of the plant	Nº units	El. capacity MW	Heat capacity MW
District heating north			
Back pressure cogeneration plant*	2	0	71 + 162
Combined cycle cogeneration plant	2	2 x 25	2 x 10.25
Gas boiler	2	0	2 x 116
District heating south			
Back pressure cogeneration plant	1	120	200
Gas boiler	2	0	2 x 116; 2 x 58
Combined cycle cogeneration plant	2	202 + 110	2 x 80
Thermal storage	1	0	750 MWh
District heating north and district heating south			
electric boiler		0	116+135**
heat pump		0	116+135**

2 different systems!

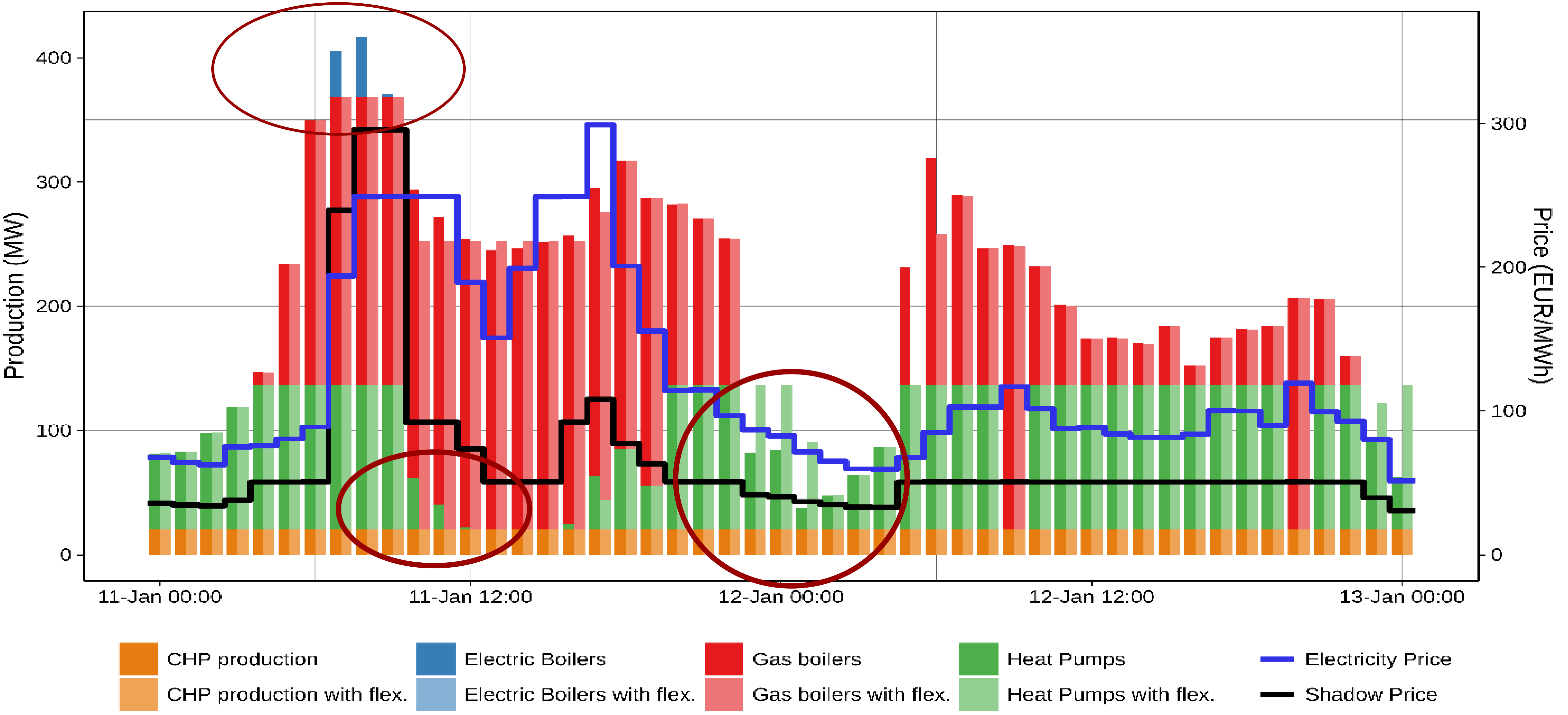
Case study – Zagreb DH

Basic	Electrified District Heating (Ele_DH)	Capacity extension (Cap_Ext)
- Currently operating plants	**DH north:** - NO back pressure units in the DH north - Heat pump and electric boiler <u>added</u>: 116 MW_h each **DH south:** - NO gas boilers - Heat pump and electric boiler <u>added</u>: 135 MW_h each	**DH north, installed:** - 2x gas CHP plants: 10.25 MW_h each - gas boiler with the capacity of 116 MW_h. **DH south, installed:** - 2x gas CHP plants: 80 MW_h each - heat accumulator: 750 MWh **Possible new investments:** electric boilers, heat pumps, gas boilers, CHP units, extension of the heat accumulator

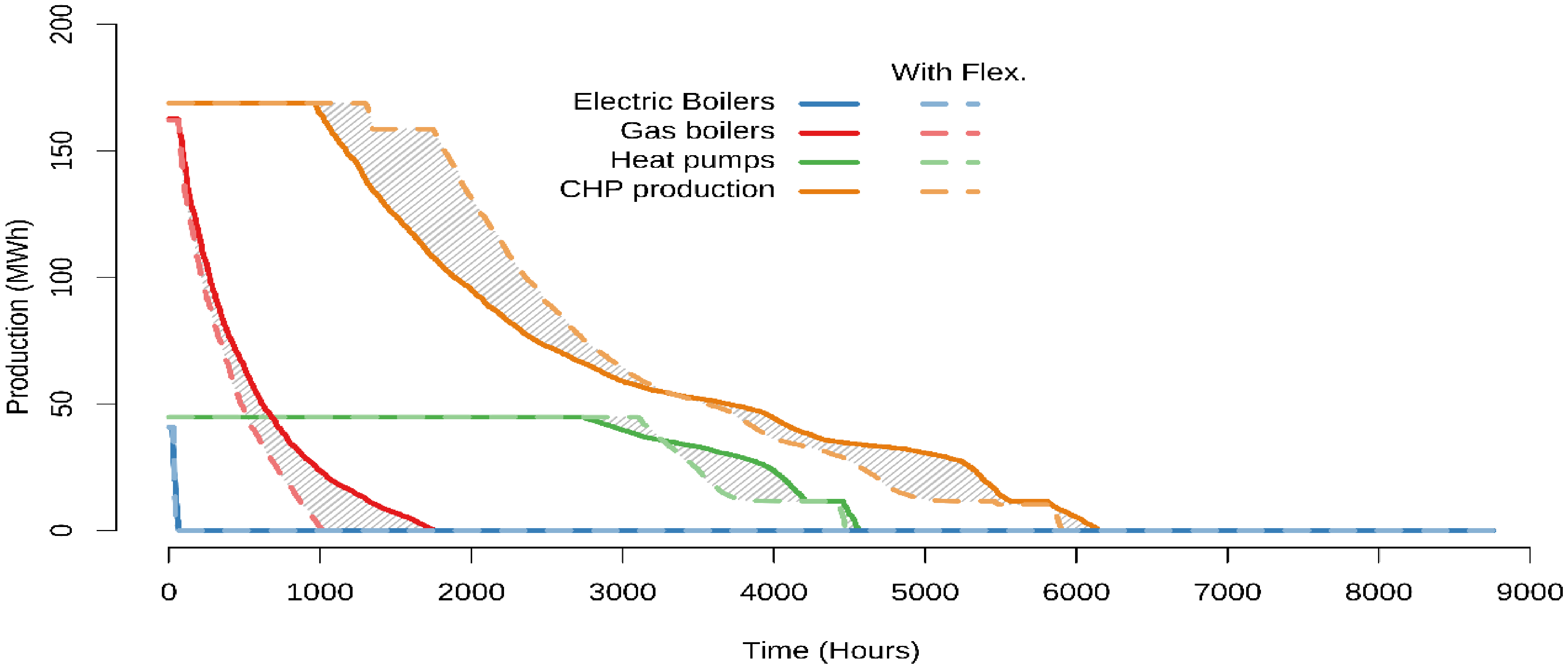
Energy generation

	Total CHP production (GWh)	Total gas boilers production (GWh)	Total electric boilers production (GWh)	Total heat pump production (GWh)
Basic	881	905	0	0
Basic with flexibility	893	893	0	0
Difference	1.3%	-1.3%		
Ele_DH	696	136	8.3	946
Ele_DH with flexibility	699	113	8.4	966
Difference	0.3%	-16.7%	1.2%	2.2%
Cap_Ext	963	236	3	584
Cap_Ext with flexibility	994	212	3	576
Difference	3.2%	-9.8%	-4.6%	-1.3%

DH north – impact of flexibility – Ele_DH scenario



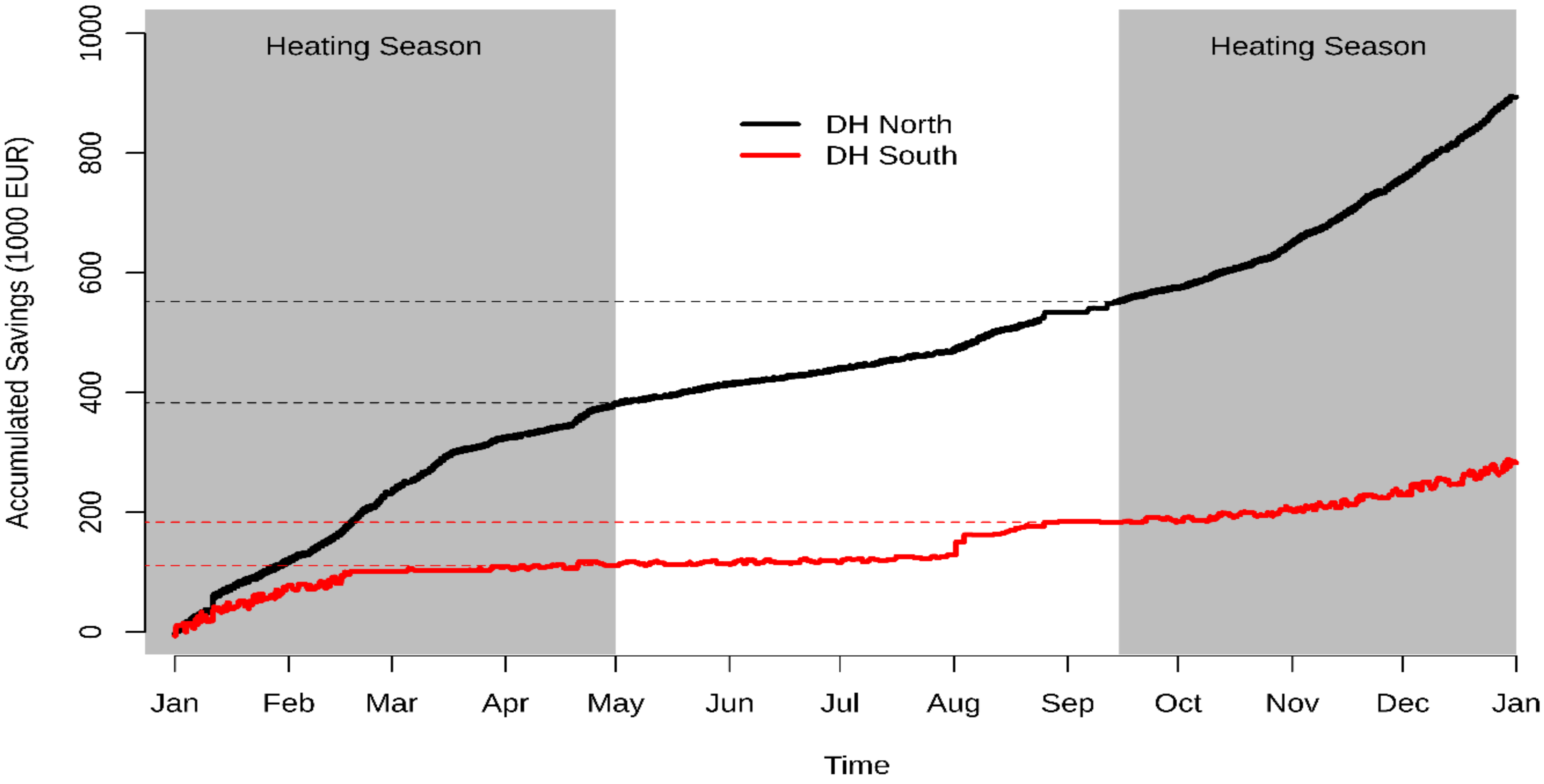
Generation duration curves – Ele_DH scenario



Total socio-economic costs – mil EUR

		DH North			DH South		
	Objective Value Total	Objective Value	Capital Costs	Operational costs	Objective Value	Capital Costs	Operational costs
Basic	96.9	48.1	18.6	49.1	48.9	32.7	109.6
Basic with flexibility	96.6	48.0	18.6	49.2	48.6	32.7	110.0
Difference	**-0.4%**	**-0.2%**	**0.0%**	**0.1%**	**-0.5%**	**0.0%**	**0.4%**
Ele_DH	78.5	31.9	12.0	36.4	46.6	38.9	88.5
Ele_DH with flexibility	77.4	31.0	12.0	35.6	46.3	38.9	88.6
Difference	**-1.5%**	**-2.8%**	**0.0%**	**-2.2%**	**-0.6%**	**0.0%**	**0.1%**
Cap_Ext	57.5	19.7	23.8	74.5	37.8	27.0	87.5
Cap_Ext with flexibility	54.4	16.7	23.8	77.4	37.8	27.0	87.5
Difference	**-5.4%**	**-15.5%**	**0.0%**	**3.9%**	**-0.2%**	**-0.1%**	**-0.1%**

Accumulated savings – Ele_DH scenario



Conclusions

- Utilization of DH grid as storage: ±3.5 K
- Socio – economic savings: from 0.36 MEUR to 3.1 MEUR (0.4% to 5.4%)
- heat accumulator extension capacity could be reduced by 6%
- Automated parametrization
- Centralized implementation by DH operators

Acknowledgements

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https://smart-cities-centre.org/

Methods

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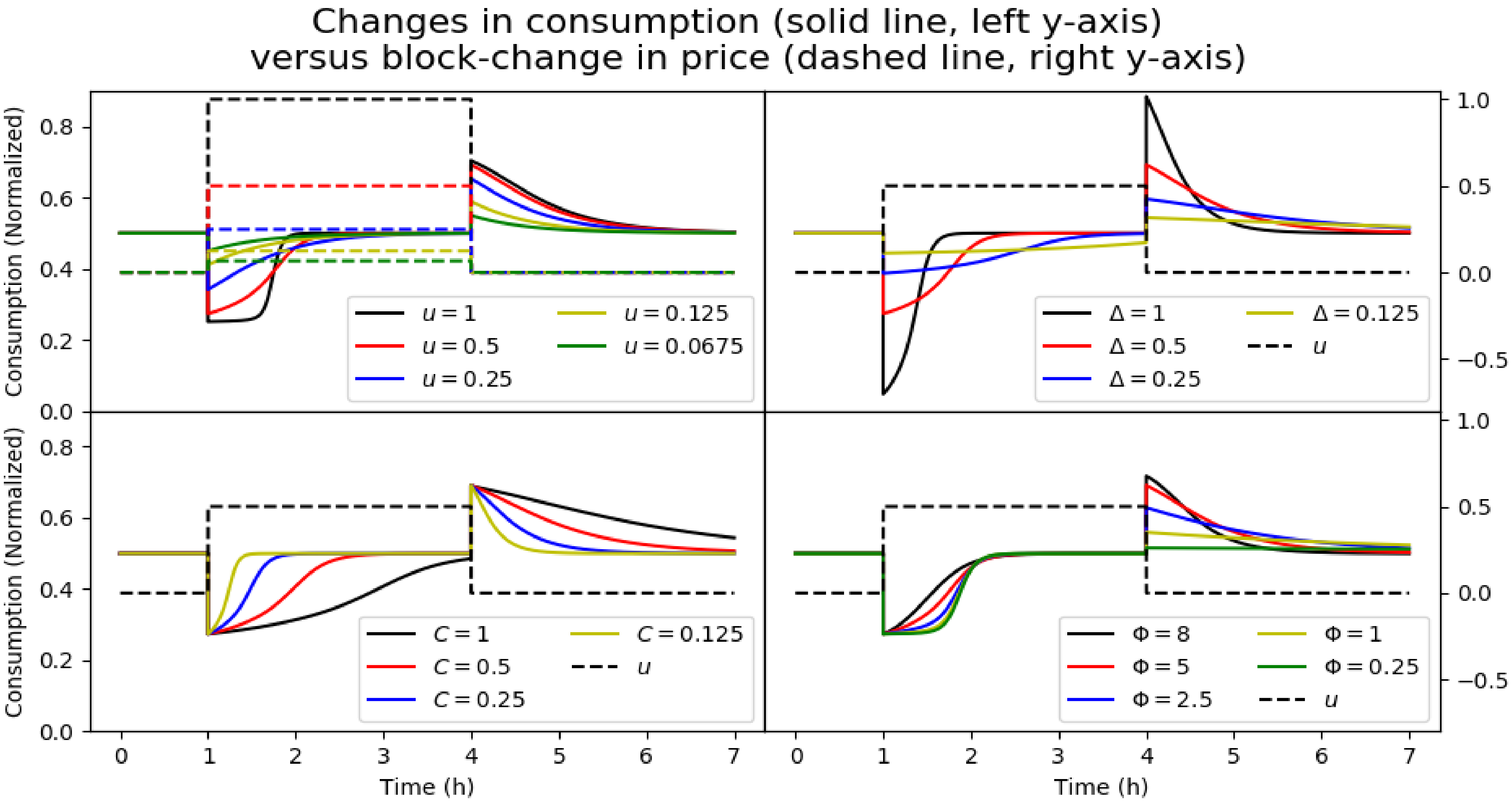

Changes in consumption (solid line, left y-axis)
versus block-change in price (dashed line, right y-axis)

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Results (III)

		DH North					DH South				
	Objective Value Total	Objective Value	Capital Costs	Operational costs	Revenue from electricity sales	Operational costs with electricity sales income*	Objective Value	Capital Costs	Operational costs	Revenues from electricity sales	Operational costs with electricity sales income*
Basic	96.9	48.1	18.6	49.1	19.7	29.5	48.9	32.7	109.6	93.4	16.2
Basic with flexibility	96.6	48.0	18.6	49.2	19.8	29.4	48.6	32.7	110.0	94.1	15.9
Difference	-0.4%	-0.2%	0.0%	0.1%	0.7%	-0.3%	-0.5%	0.0%	0.4%	0.7%	1.6%
Ele_DH	78.5	31.9	12.0	36.4	16.6	19.9	46.6	38.9	88.5	80.8	7.7
Ele_DH with flexibility	77.4	31.0	12.0	35.6	16.6	19.0	46.3	38.9	88.6	81.2	7.4
Difference	-1.5%	-2.8%	0.0%	-2.2%	0.6%	-4.5%	-0.6%	0.0%	0.1%	0.5%	3.7%
Cap_Ext	57.5	19.7	23.8	74.5	78.7	-4.1	37.8	27.0	87.5	76.7	10.8
Cap_Ext with flexibility	54.4	16.7	23.8	77.4	84.6	-7.2	37.8	27.0	87.5	76.7	10.8
Difference	-5.4%	-15.5%	0.0%	3.9%	7.5%	-73.4%	-0.2%	-0.1%	-0.1%	0.0%	0.5%