Multi-Objectives, Multi-Period Optimization of district networks Using Evolutionary Algorithms and MILP:

Daily thermal storage

Samira Fazlollahi,

Supervisor:

François Maréchal

Industrial Energy Systems Laboratory, Ecole Polytechnique Fédérale de Lausanne (EPFL)

Veolia Environnement Recherche et Innovation (VERI)

Outline

- Motivation and objective
- District energy system optimization: Method
  - Structuring phase
  - Multi-objective nonlinear optimization phase
- Daily thermal storage: Model
- Illustrative example
- Conclusion

Objective and motivation (1)

- Design a district energy system:

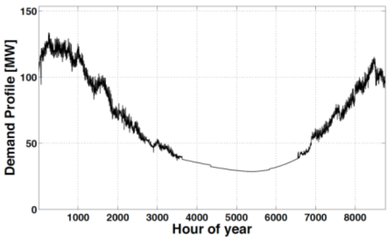
Goal: Size + Operation

Multi-Objective:

- ✓ Economic (total cost)
- ✓ Environment (CO2)

Multi-period

- Dynamics behavior of demand profile during several years
- Daily thermal Storage



Goal

✓To develop a computational framework for Multi-Period, Multi-objective optimization of district energy system

✓To integrate the daily thermal storage in the optimization model

✓To study the influence of a thermal storage on operating condition and capital investment

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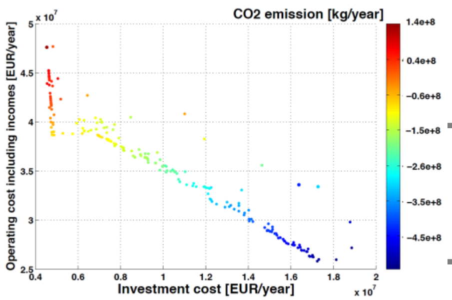
A computational framework for Multi-Period, Multi-objective optimization of district energy system:

Integration of a thermal storage

Main steps of methodology

Multi-objective nonlinear optimization phase



Post-processing phase

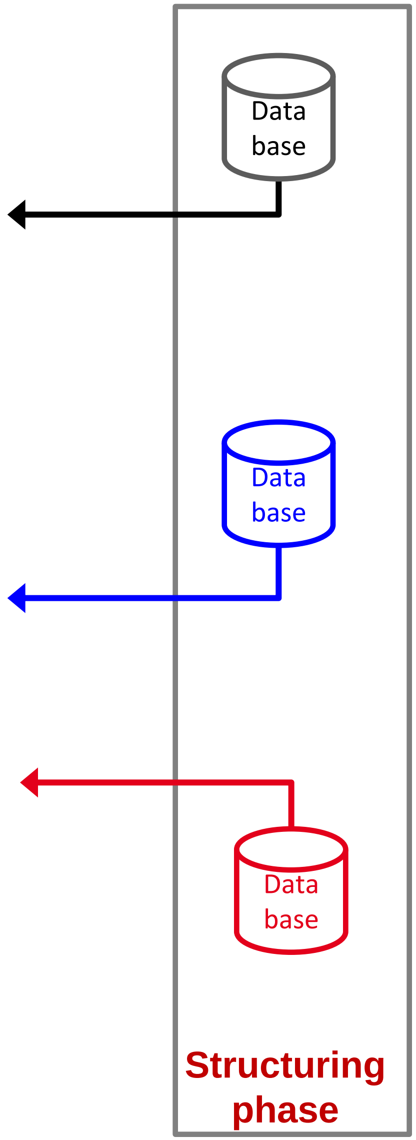
Structuring phase

Structuring phase

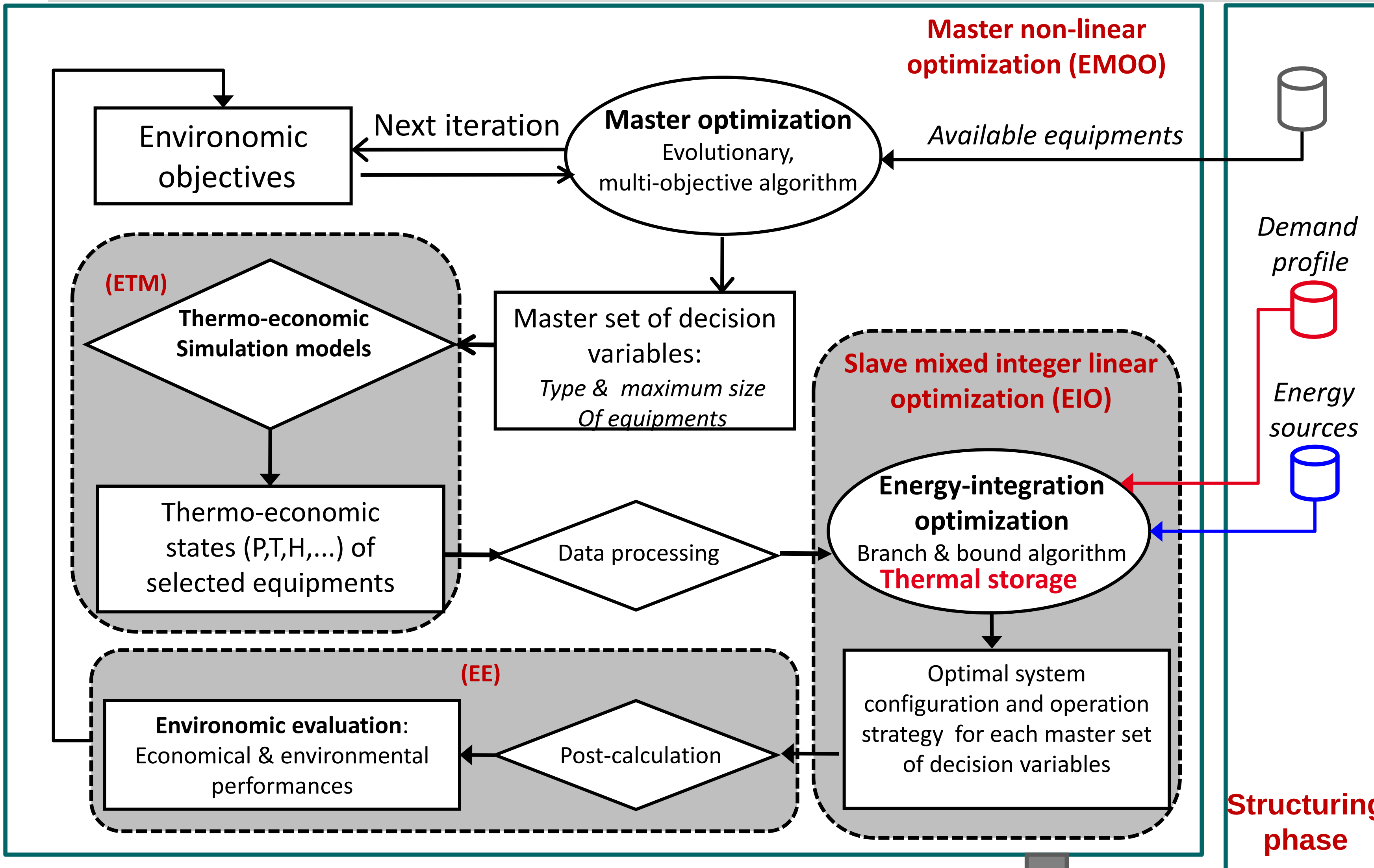
Goal: to collect and manipulate the required data:

✓ *Available equipments*
- *Conversion technologies*
- *Backup technologies*

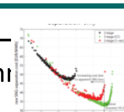
✓ *Supply and demand profiles:*
- *Energy sources*
- *Energy demand: Typical days*
  - *Heating*
  - *Hot water*
  - *Cooling*
  - *Electricity*



Multi-objective nonlinear optimization phase



Optimisation ↓ Structuring



S.Fazlollahi, F.Marechal , Multi-objective, multi-period optimization of biomass conversion techn… ing evolutionary algorithms and mixed integer linear programming (milp). Applied Thermal Engineering, 2011.

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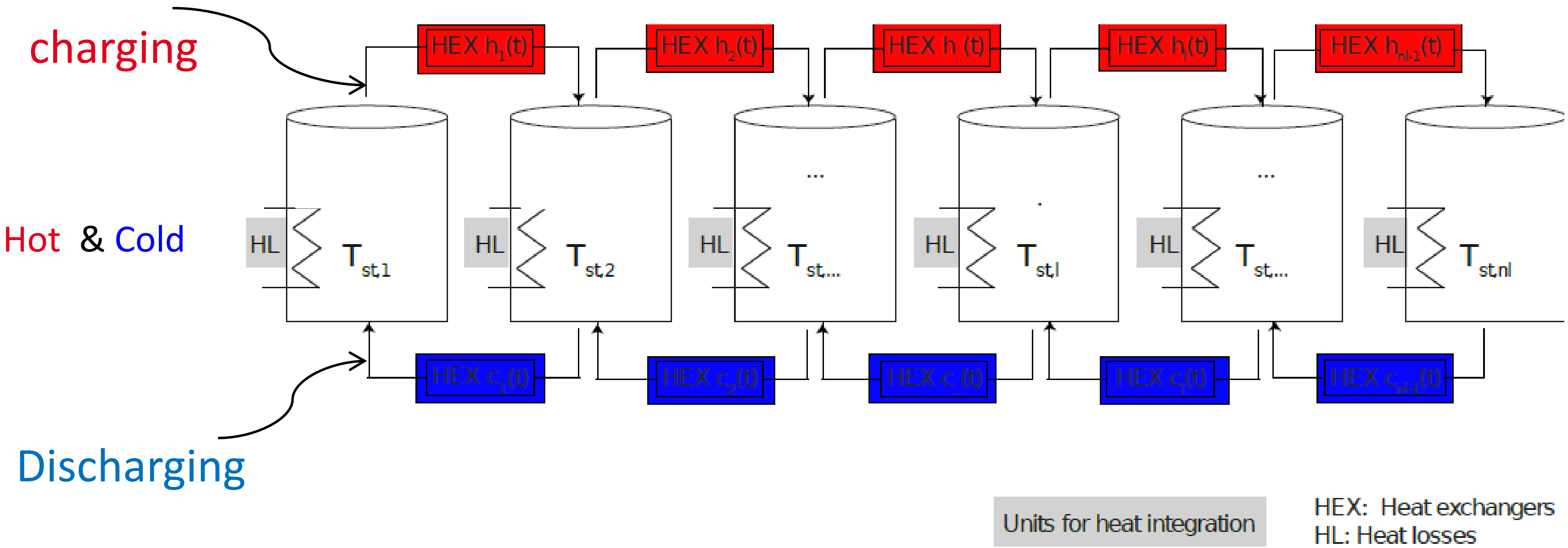
Daily thermal storage

Daily thermal storage: Model



Decision variables:

- ✓ Heat availability in each temperature interval
- ✓ Charging and discharging rate in each time step
- ✓ Temperatures of the storage tank
- ✓ The initial heat load of each temperature interval in **t0**

Parameters:

- ✓Maximum capacity of the storage system: Q^{max}
- ✓Number of temperature intervals
- ✓Investment cost

Daily thermal storage: Model

- Energy balance of the storage system

Q: **Reference heat load (parameter)** f : **Utilization rate (variable)**

1. Limits on charging and discharging rate

$$F_{\min_S} \times y_{S_p^c} \leq \max(f_{S_{T,p}^c}) \leq F_{\max_S} \times y_{S_p^c}, \forall p = 1, \ldots, N_p$$

$$F_{\min_S} \times y_{S_p^h} \leq \max(f_{S_{T,p}^h}) \leq F_{\max_S} \times y_{S_p^h}, \forall p = 1, \ldots, N_p$$

Utilization rate

T: temperature intervals p: time steps

2. Cyclic constraint

Reference heat charging

$$\sum_{p=1}^{N_p} \sum_{T=1}^{N_T} (f_{S_{T,p}^c} \times \dot{Q}^{-}_{S_{T,p}^c} - f_{S_{T,p}^h} \times \dot{Q}^{+}_{S_{T,p}^h}) \times \Delta p = 0$$

Total charging load

Daily thermal storage: Model

3. Initial heat load

Initial heat load (MWh)

$$\sum_{T=1}^{N_T} Q_T^0 \leq Q^{\max} \rightarrow V^{\max}$$

4. Heat load availability in each intervals

$$Q_T^0 + \sum_{p=1}^{N_p} \left(f_{S_{T,p}^c} \times \dot{Q}_{S_{T,p}^c}^{-} - f_{S_{T,p}^h} \times \dot{Q}_{S_{T,p}^h}^{+} \right) \times \Delta p \geq 0,$$

$$\forall T = 1, \ldots, N_T, \forall p = 1, \ldots, N_p$$

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Illustrative example

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Illustrative example: Structuring phase

Goal: Design the energy system in a district with 3000 inhabitants

- provide heat and hot water demand
- electricity as an opportunity

Table 3: CO_2 Intensity and Price of available resources

Resources	$\triangle CO_2$: $[kg/MJ]$	Price: [31] [€/MJ]:
Electricity	0.3071[32]	0.0198
Natural Gas	0.0641	0.0092
Biomass	0	0.0036
SNG	0	0.0099

Hourly heat demand profile of a typical year

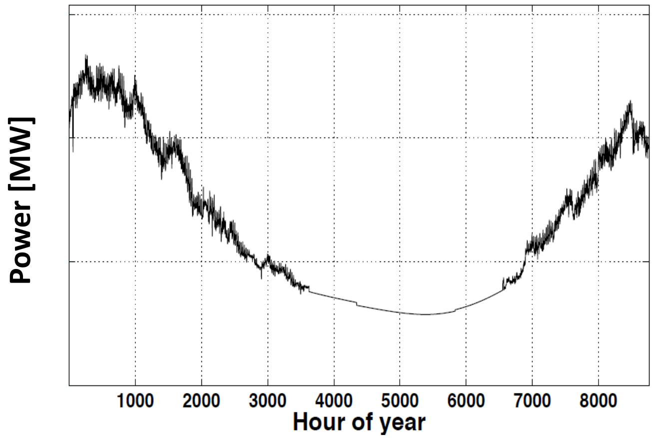


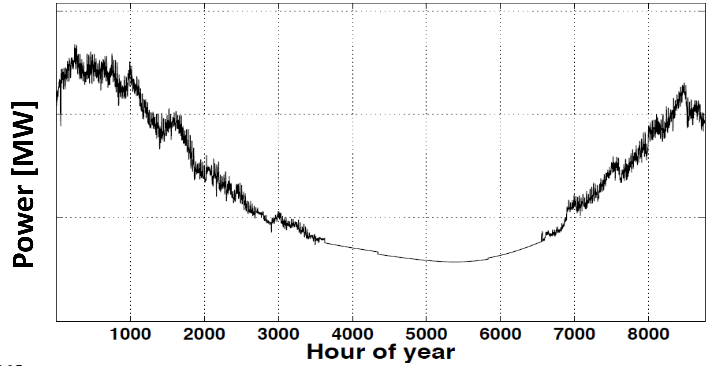
Table 5: Reference capacity of each equipments with the corresponding ranges

Equipment	Reference: $[MW_{th/el}]$	Ranges: $[MW_{th/el}]$	β_s [€/kW/an]	α_s [k€/an]	O&M [€/MWh]	
Boiler (NG)	42_{th}	[0 210]	14	84	3.5	[20]
Boiler (BM)	42_{th}	[0 210]	14	84	10.4	[20]
Engine (NG)	5_{el}	[0 100]	25	15	10	[15]
Engine (BM)	5_{el}	[0 50]	25	15	10	[15]
SNG*	20_{bm}	[0 200]	67	10^3	40	[36]
Gasifier*	20_{bm}	[0 200]	64	10^3	1	[36]
Gas turbine(NG)	20_{el}	[0 200]	73	14	50	[15]
Gas turbine(BM)	20_{el}	[0 200]	73	14	50	[15]
Steam turbine	30_{el}	[0 200]	32	272	10	[20]
BRC	2_{el}	[0 20]	38.5	96	30	[37]

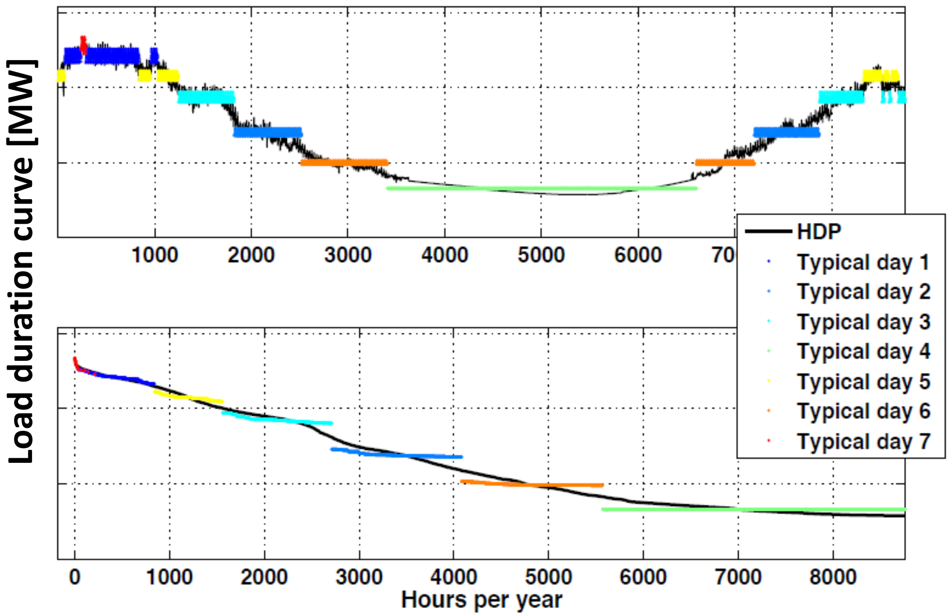
BM: Biomass, NG: Natural gas
*It is based on the fuel consumption

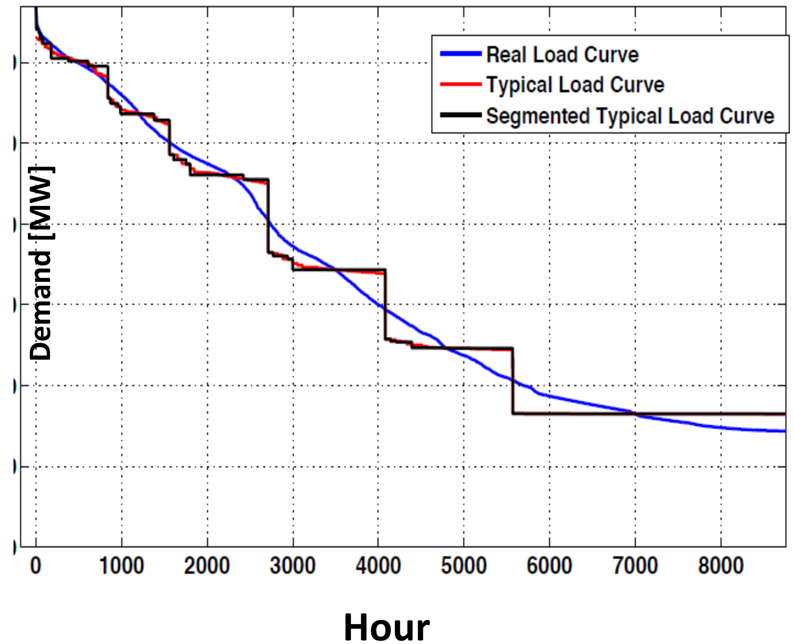
S.Fazlollahi, F.Marechal , Multi-objective, multi-period optimization of biomass conversion technologies using evolutionary algorithms and mixed integer linear programming (milp). Applied Thermal Engineering, 2011.

Structuring phase: Typical days



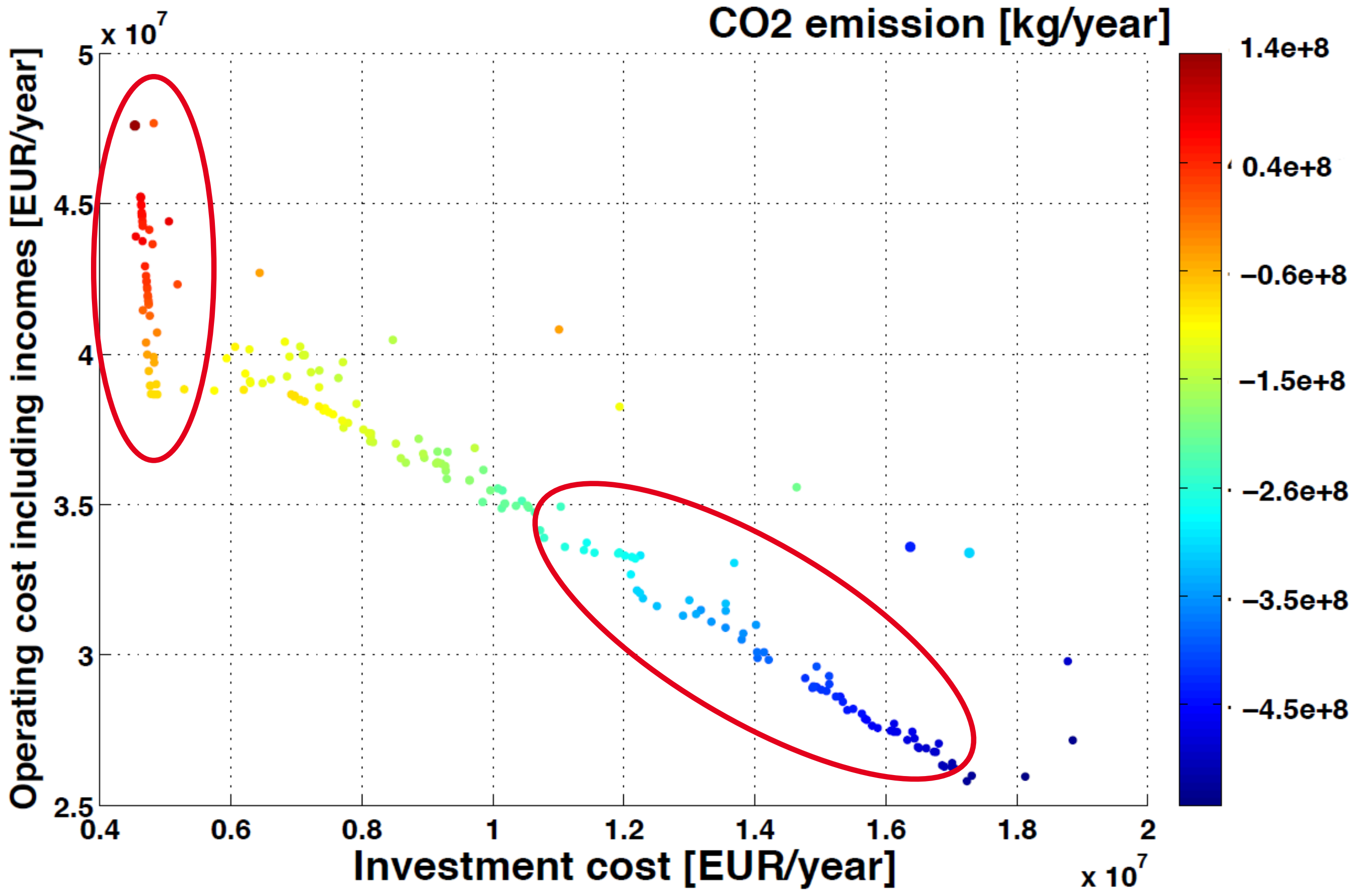
7 Typical days





S. Fazlollahi, S. L. Bungener and F. Maréchal. *Multi-Objectives, Multi-Period Optimization of district heating networks: Selection of typical days. The 22nd European Symposium on Computer Aided Process Engineering (ESCAPE), London, 2012.*

Illustrative example: Multi-objective optimization results



Objectives:

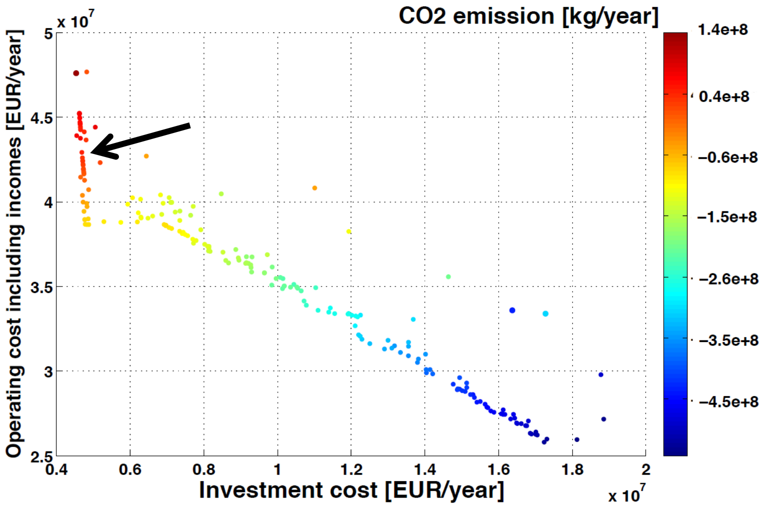
- Investment cost [Euro/year]
- Operating cost [Euro/year]
- CO2 emission [Kg/year]

Illustrative example: Post-processing phase

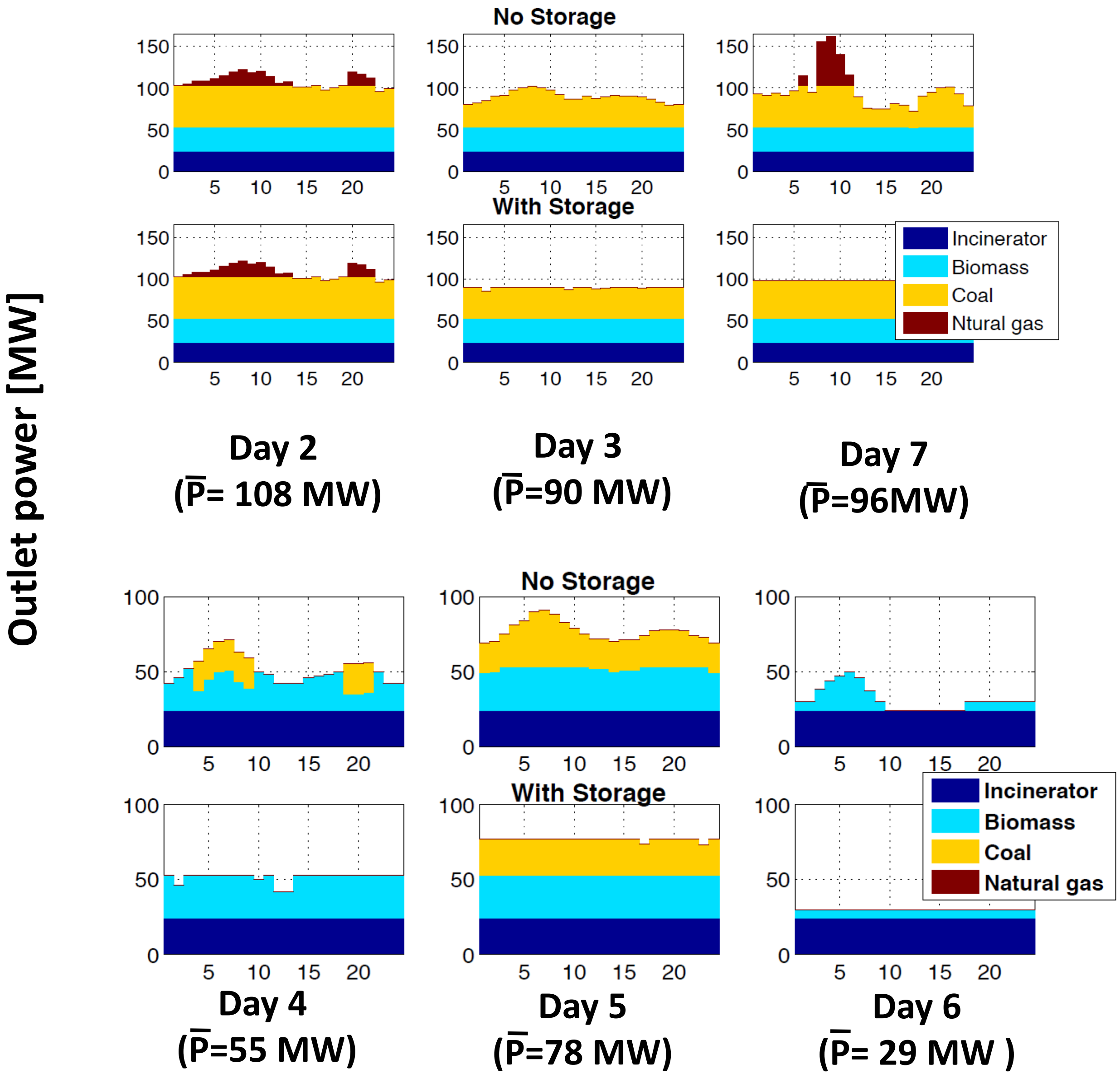
evaluate and **select** a solution(s)

Configuration of a selected solution :

- Incinerator integrated with steam turbine [26 MWth]
- Biomass boiler [23 MWth]
- Coal boiler [30 MWth]
- Backup natural gas boiler

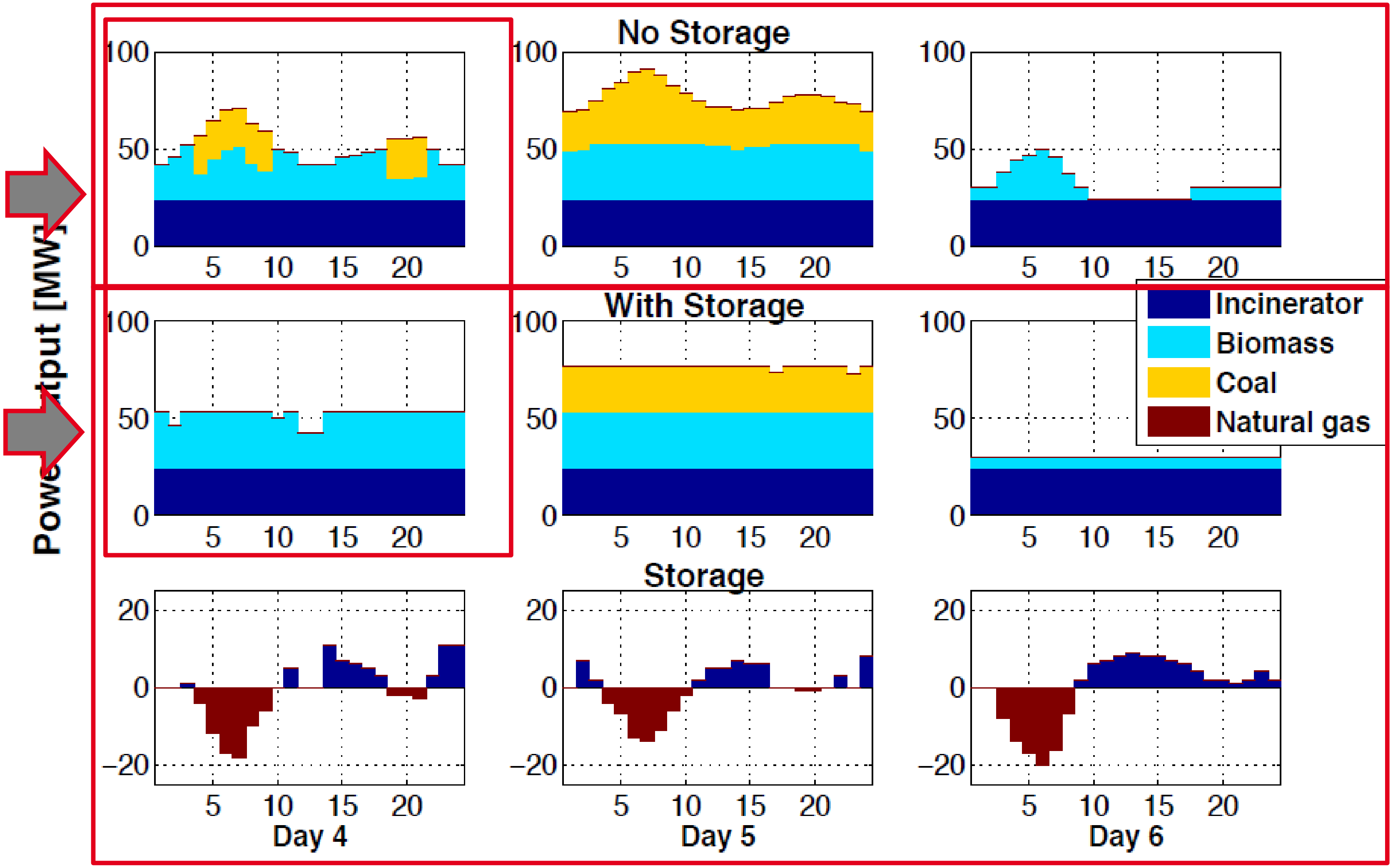


Illustrative example: Daily units operation



Post- processing → Optimisation → Structuring

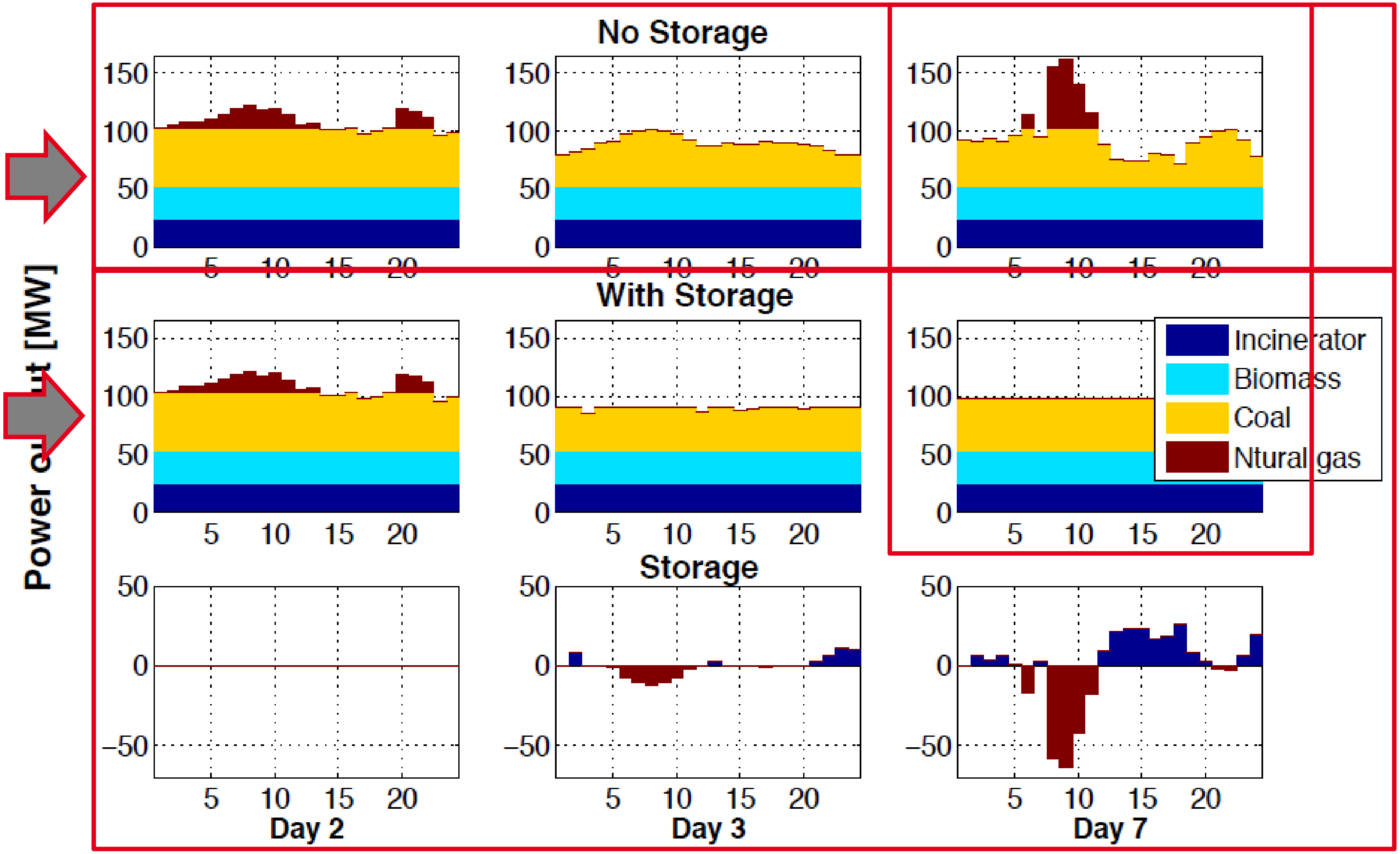
Illustrative example: Daily units operation



($\bar{P}$=55 MW) ($\bar{P}$=78 MW) ($\bar{P}$= 29 MW)

Structuring → Optimisation → Post- processing

Illustrative example: Daily units operation



($\bar{P}$= 108 MW) ($\bar{P}$=90 MW) ($\bar{P}$=96MW)

Structuring → Optimisation → Post- processing

Illustrative example: Results

- **7.5 % reduction in the total investment cost**

  Natural gas boiler 69 MW ⟶ 18 MW

- **19% reduction in the annual operating cost**

- **14 % reduction in the annual coal consumption**

- **15.8 % CO_2 emission reduction**

Illustrative example: Daily storage operation

- Optimizing the operation and investment strategy
  - →Operating strategy
  - →Storage tank volume
  - →Storage tank management strategy

Structuring ↓ Optimisation ↓ Post- processing

Conclusion

- Motivation
  - Integrating the daily thermal storage in the Multi-Period & Multi objective optimization model of district energy system:
    - →Design
    - →Operation
    - →Environomic objectives
- The illustrative example shows the influence of a thermal storage on sizing and operating condition of the system
  - Decrease the install capacity
  - Remove the fluctuation of operating condition

Thank you for your attention

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