3RD INTERNATIONAL CONFERENCE ON
SMART ENERGY SYSTEMS
AND 4TH GENERATION DISTRICT HEATING

# ITERATIVE SIMULATION AND OPTIMIZATION APPROACH FOR ENERGY PERFORMANCE EVALUATION OF GROUND SOURCE HEAT PUMP SYSTEMS

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# Aim : Modelling approaches

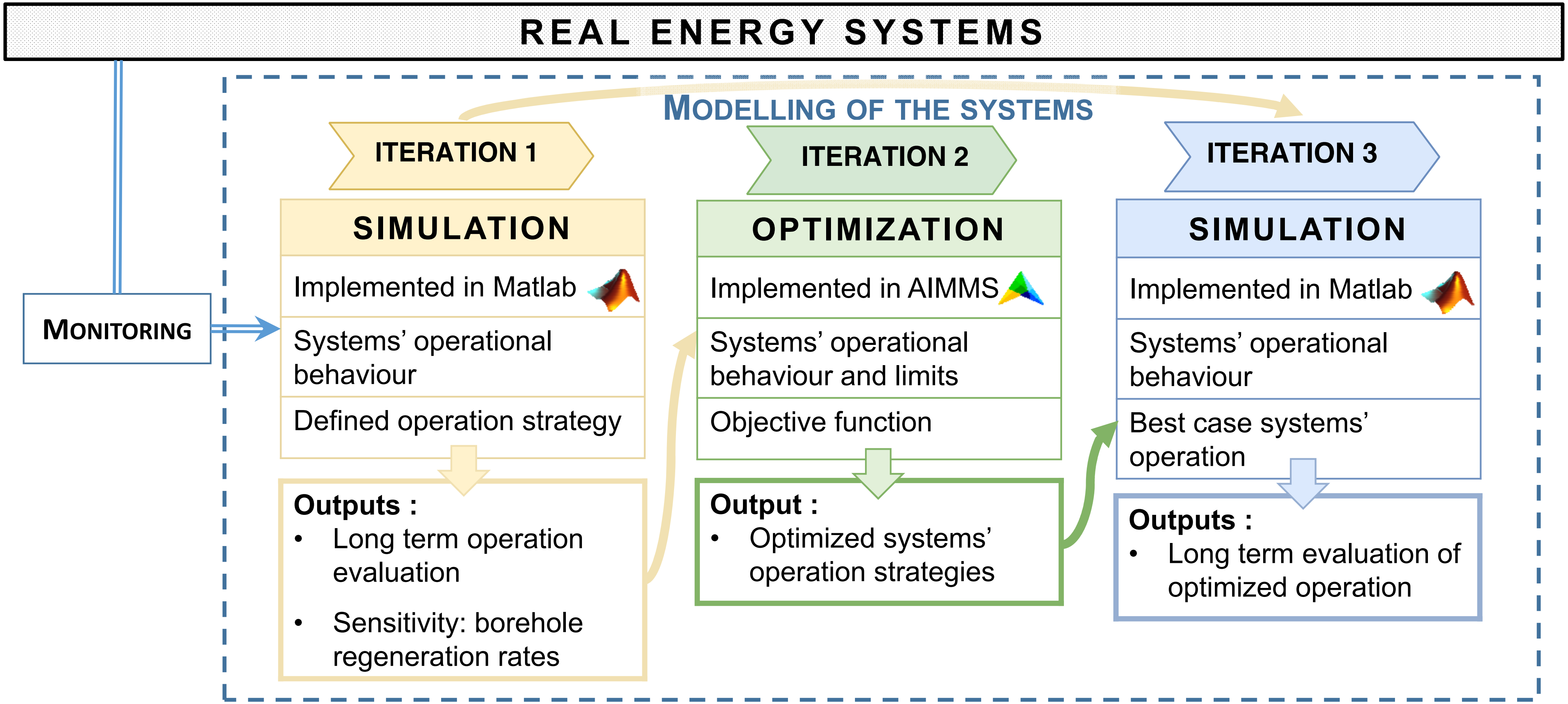


| SIMULATION | OPTIMIZATION |
|---|---|
| + **Accurate representation** of systems real behaviour<br>+ **Implementation flexibility**<br>+ Well adapted for **sensitivity analysis** | + **High quality** of the solutions<br>+ **Implementation simplicity** |
| - **Difficult to achieve high quality solutions** (operation strategy, design)<br>- **Time intensive modelling process**<br>- Requires **deep understanding** of the **systems' behaviour** | - **Limitation of the implementation** due to **linear formulation** constraints => risk of **oversimplification**<br>- **Difficulty to interpret the results**<br>- **Perfect foresight** assumption<br>- Limitation of the **formulation of the objective function** |

Lund, H., Arler, F., Østergaard, P. A., Hvelplund, F., Connolly, D., Mathiesen, B. V., & Karnøe, P. (2017). energies Simulation versus Optimisation : Theoretical Positions in Energy System Modelling, 1–17. https://doi.org/10.3390/en10070840

Nguyen, A., Reiter, S., & Rigo, P. (2014). A review on simulation-based optimization methods applied to building performance analysis. *APPLIED ENERGY*, *113*, 1043–1058. https://doi.org/10.1016/j.apenergy.2013.08.061

# Methodology



ITERATION 1

SIMULATION

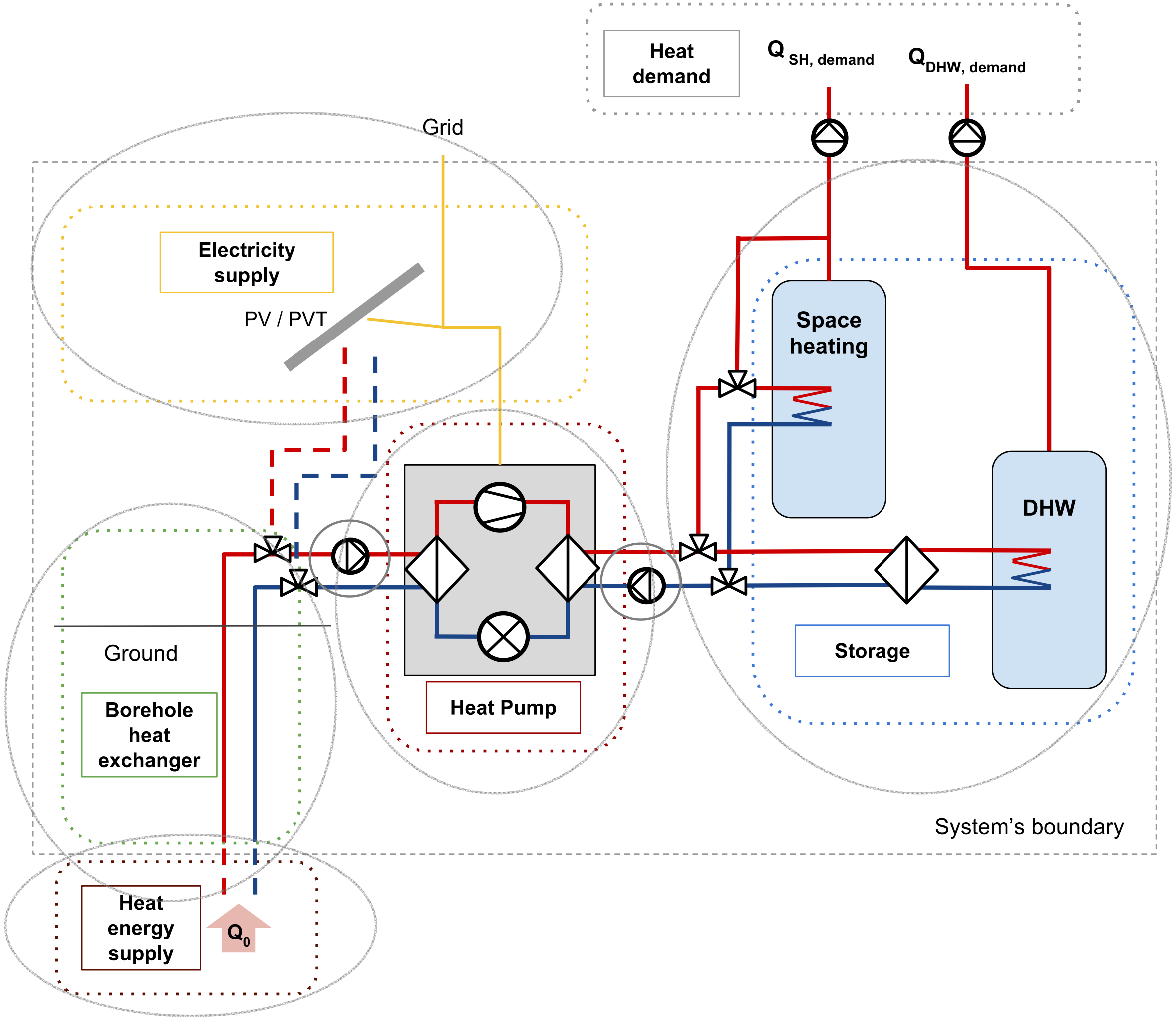
ITERATION 2

OPTIMIZATION

ITERATION 3

SIMULATION

# Iteration 1, simulation: Modelling




**Systems' components**:

- **Ground** surrounding the borehole
- **Borehole heat exchanger system**
- **Heat pump** (HP)
- **Storage tanks** : space heating (SH) and domestic hot water (DHW)
- **Pumps**
- **Photovoltaics panels** (PV) / **Hybrid panels** (PV/T)

**Simulation of the 1st year of operation**

**+ 30 years of operation**

**ITERATION 1** — **SIMULATION**

**ITERATION 2** — **OPTIMIZATION**

**ITERATION 3** — **SIMULATION**

**Outputs** :

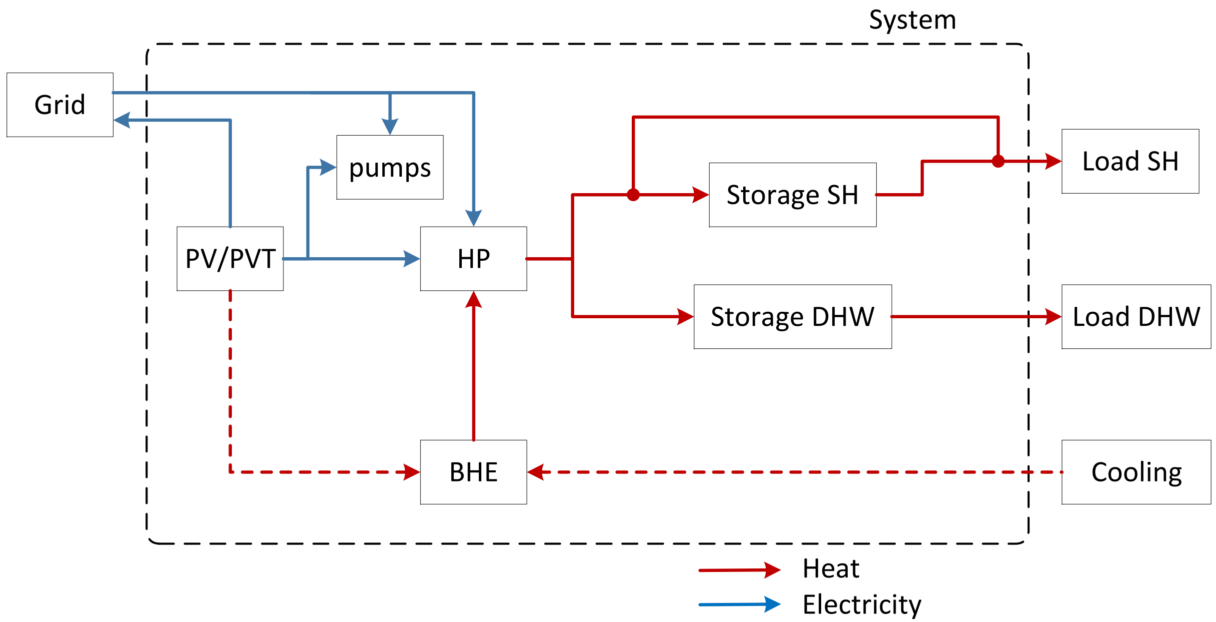
- Parameters calibration :
  - Storage tanks sizes
  - Storage tank standing losses
  - Heat pump production capacity
- Values of the coefficient of performance of the heat pump and PV efficiency

# **Iteration 2, optimization:** Modelling

**New optimization models :**

- Implemented as MILP problem in AIMMS
- Representing the **systems operational behaviour and limits**
- Based on **simulations' results**.

⇒ Define the **HP and storage tanks operation** that optimize the objective function.




The **objective function** is defined as the **operational carbon emissions minimization** :

$$Carbon_{total} = \sum_{t} (E_{HP}^{Grid}(t,i) \cdot CF_{grid} - E_{grid}^{PVT}(t,i) \cdot CF_{PV,prod})$$

Carbon factors for CH-mix and PV produced from **KBOB *Liste Ökobilanzdaten in Baubereich 2009-1-2016***

# **Iteration 2, optimization:** Parameters integration

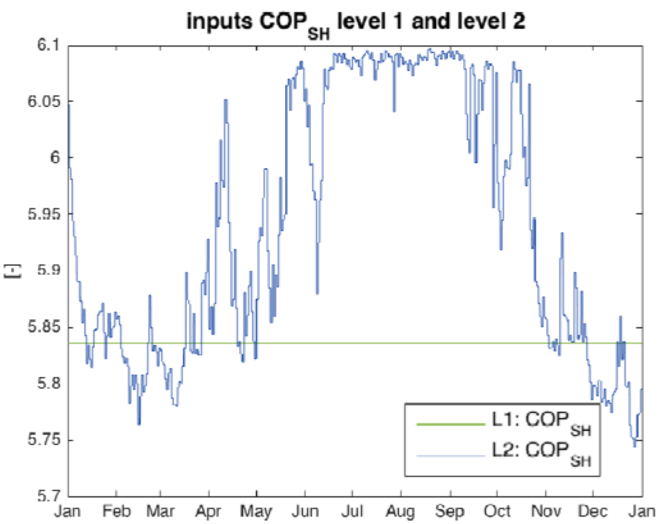
Linear constraints formulation ⇒ **COPs** of HP and **PV efficiency** are not dynamically calculated

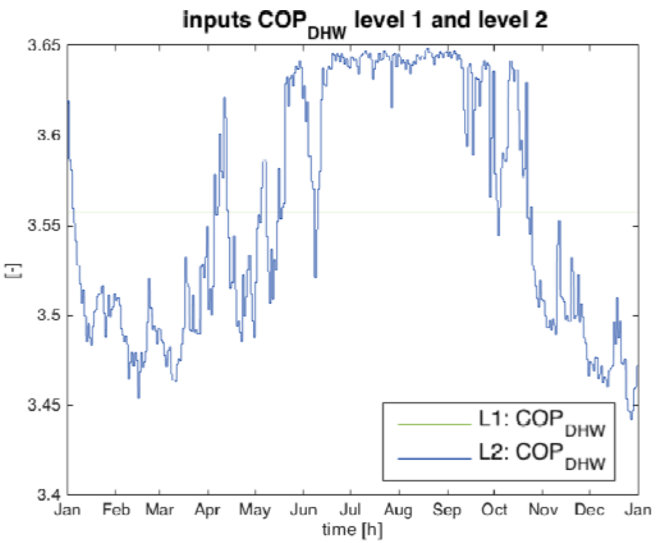
⇒ COPs of HP and PV efficiency are **extracted from simulation results**

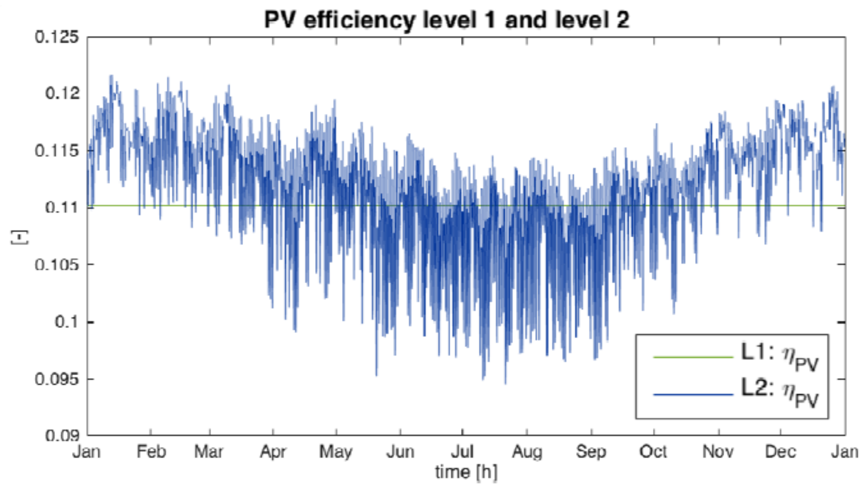
⇒ **Different levels of precision in the definition of the parameters integrated in the models:**

**Level 1** : **Constant** parameters over the year

**Level 2** : **Hourly defined** parameters

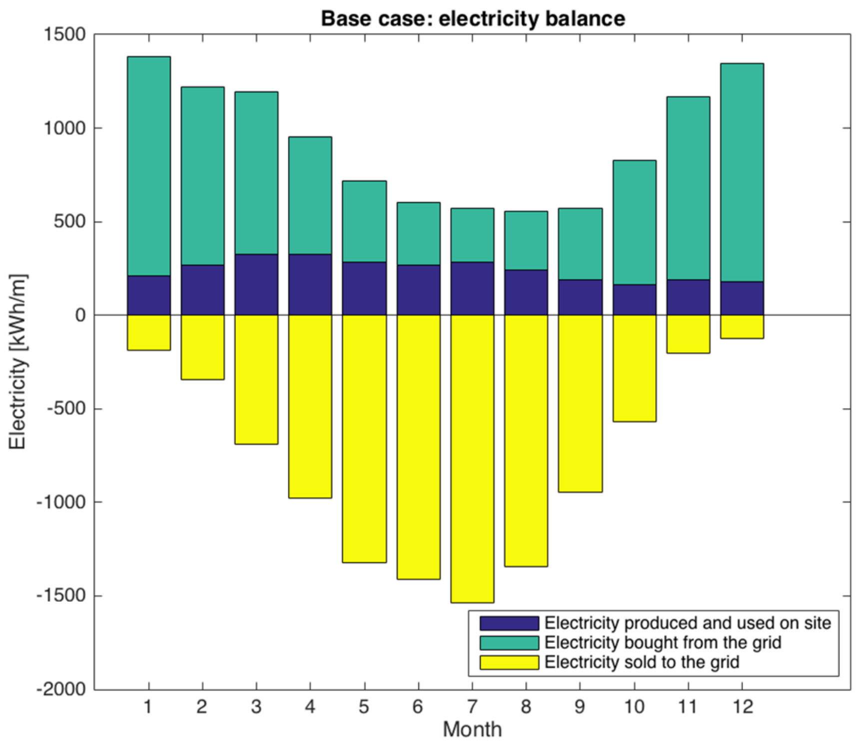


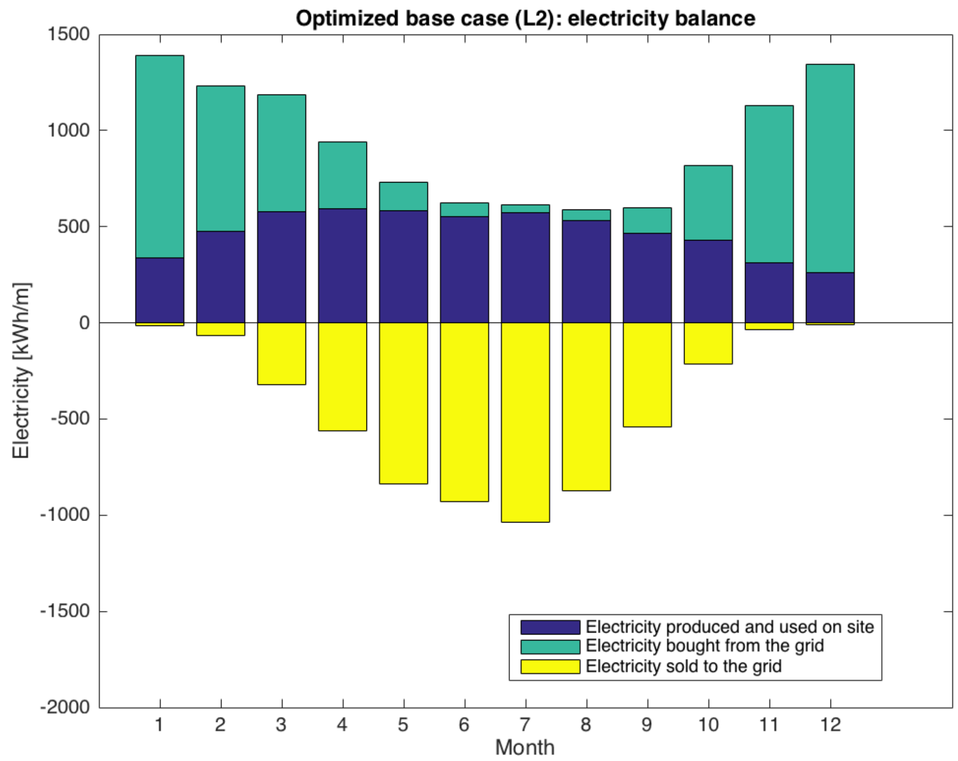



# **Iteration 2, optimization** : Electricity balance

## Simulation 1




## Optimization 2



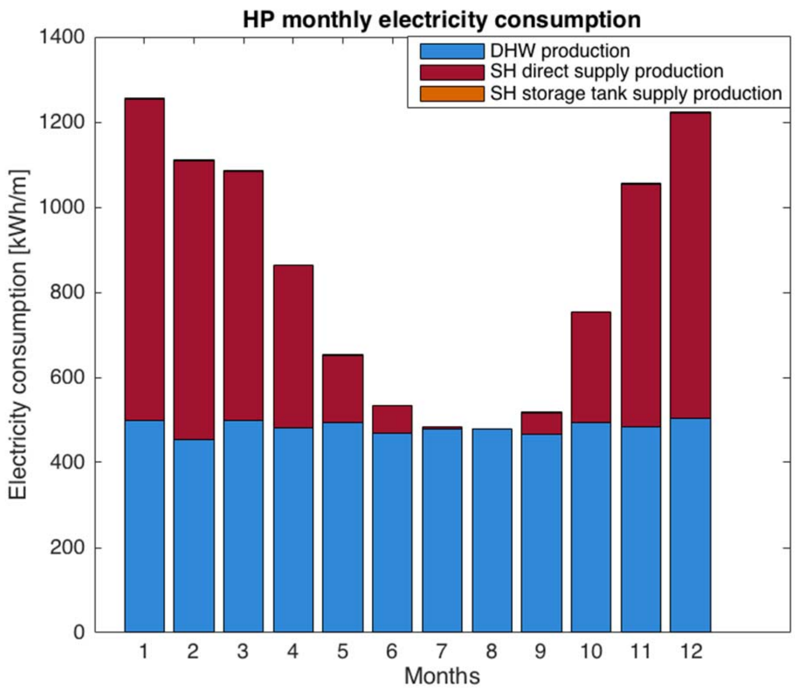

⇒ Significant increase of the PV produced electricity self-consumption

Load cover factor : (26%) **51%** (PV self used el. / tot el. consumption)

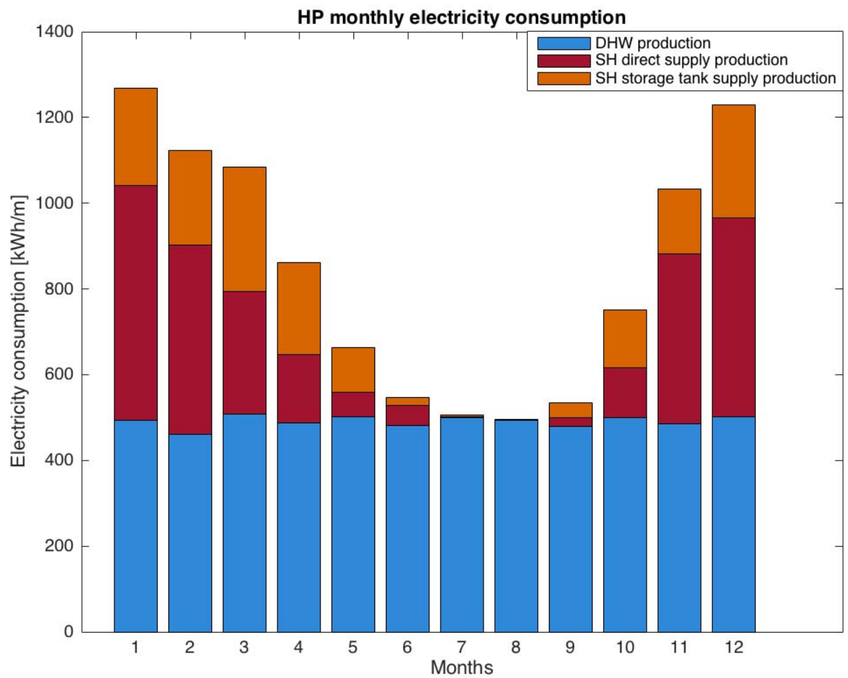
Supply cover factor : (23%) **49%** (PV self used el. / tot PV produced el.)

# **Iteration 2, optimization** : Heat pump operation

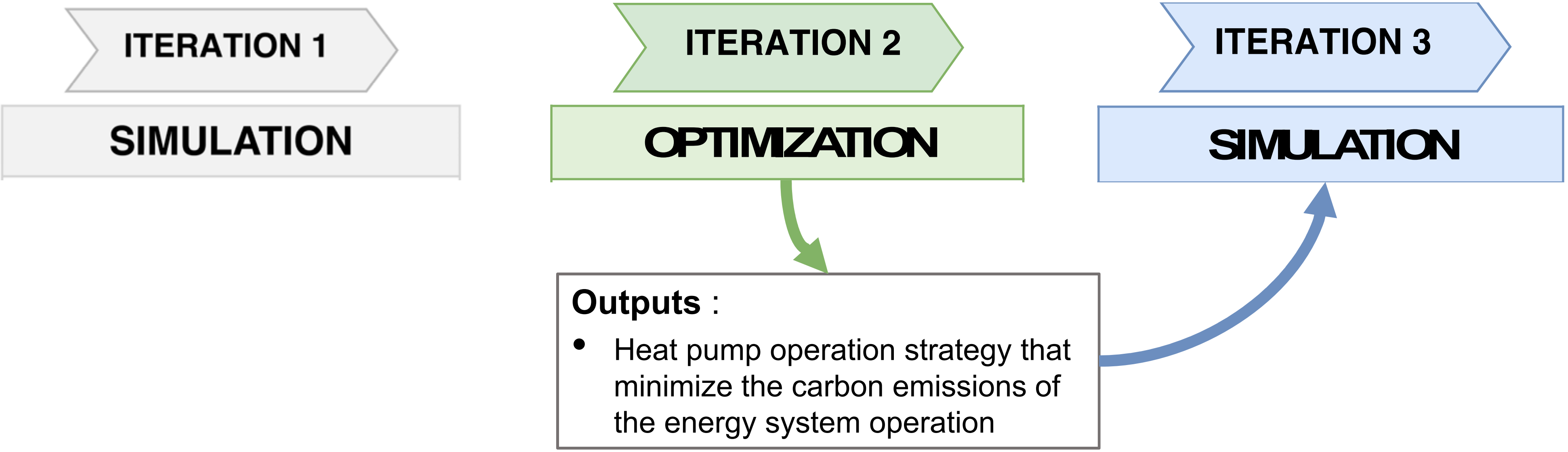
## Simulation 1




## Optimization 2




⇒ **SH storage tank** is more used (40% of the heat production for SH purposes)
Higher share of the SH heat production for **storage tank supply in the hot season**


ITERATION 1
SIMULATION
ITERATION 2
OPTIMIZATION
ITERATION 3
SIMULATION
**Outputs** :
• Heat pump operation strategy that minimize the carbon emissions of the energy system operation

# **Iteration 3, simulation** : Level of precision of parameter integration

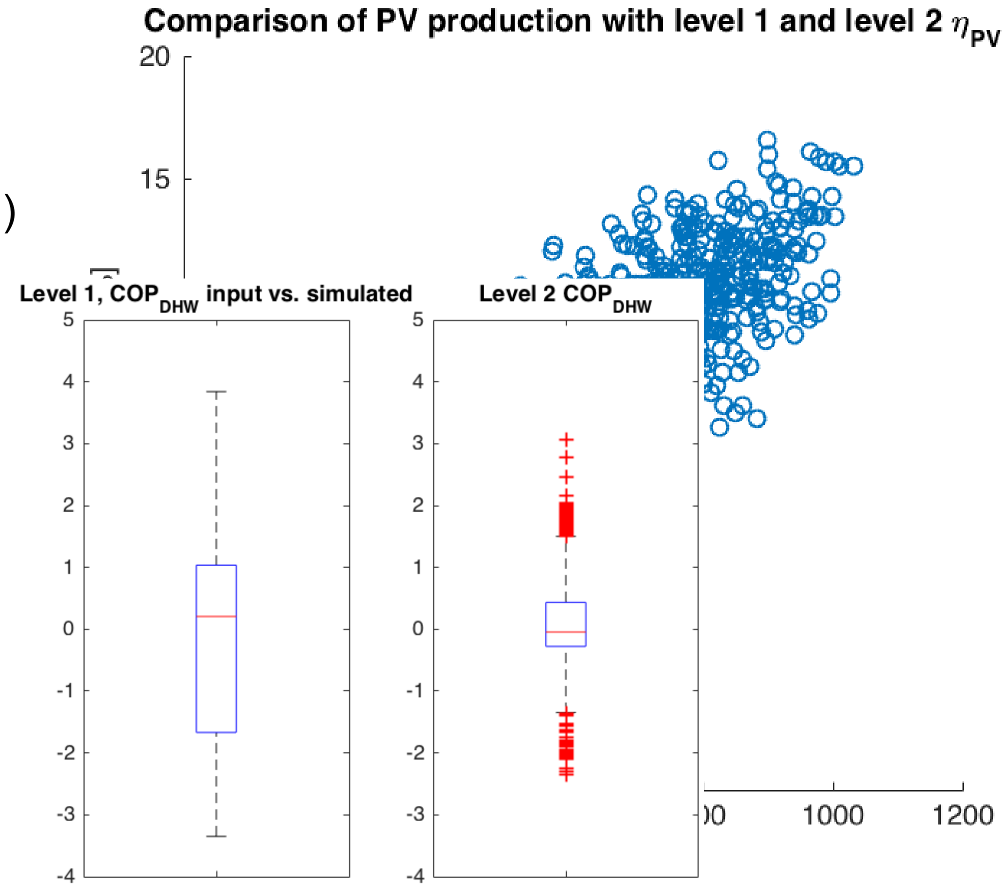
Comparing **optimization results (iteration 2)** and **simulated optimized HP operation (iteration 3)**

- **PV efficiency:**

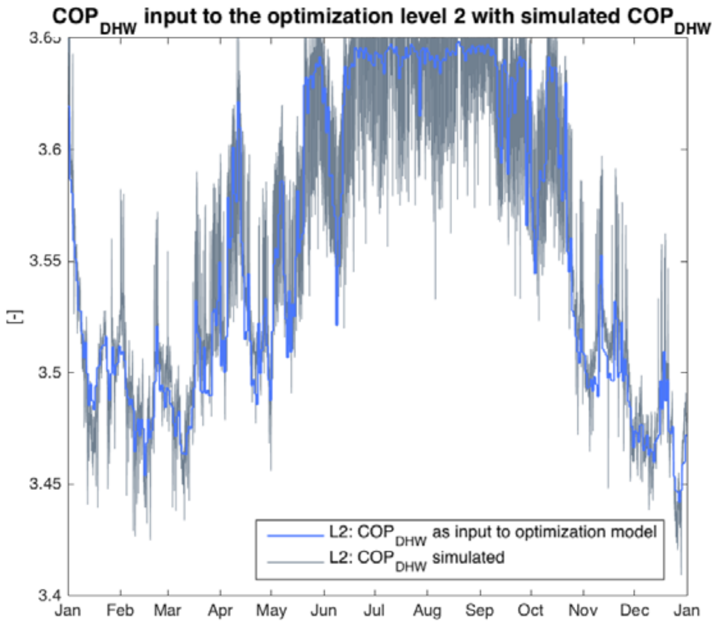
  Constant PV efficiency (level 1) :

  Hourly defined efficiency (level 2) :

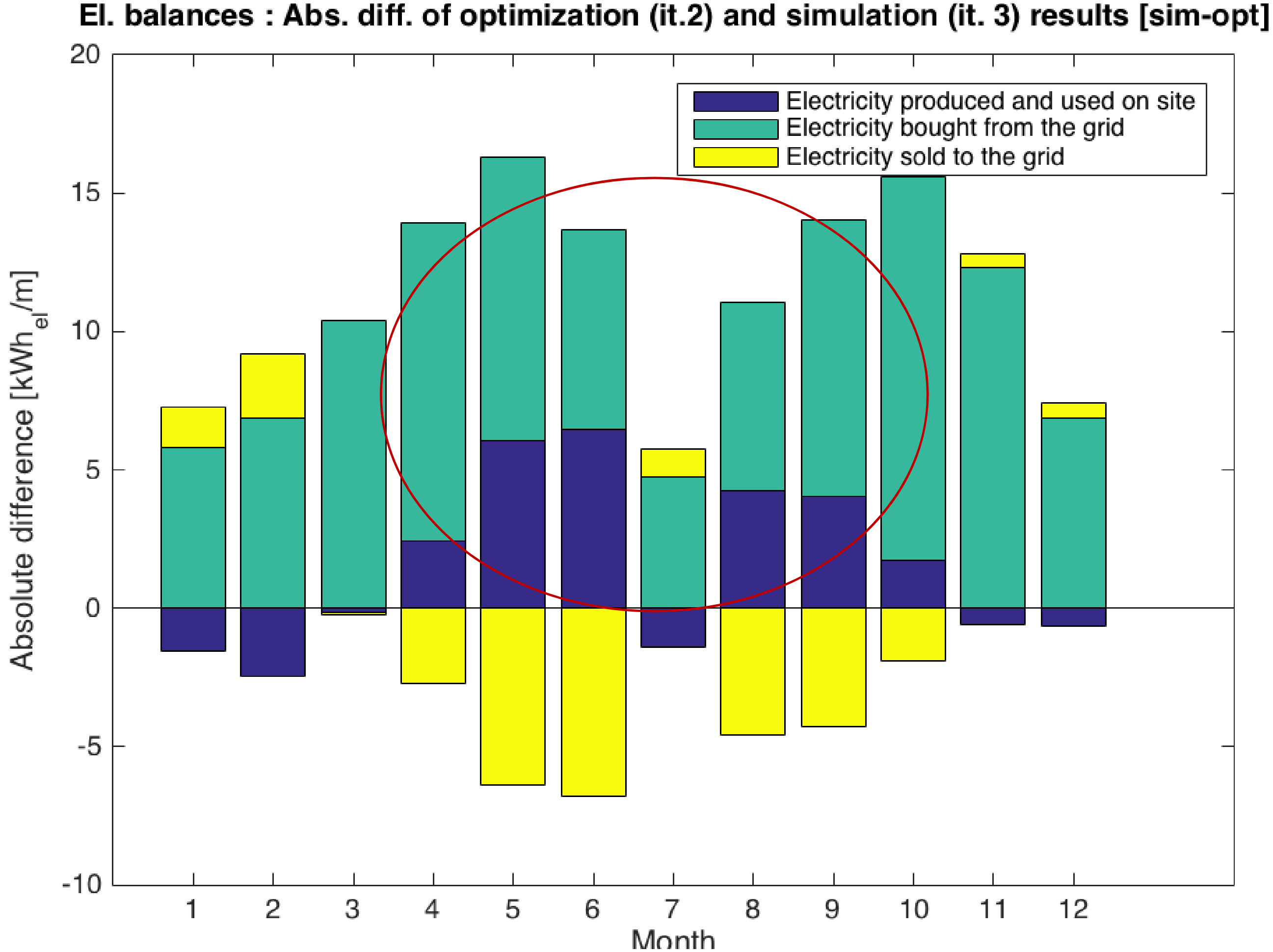
  negligible difference (0.0245 %)




- **COP :**



# **Iteration 3, simulation** : Comparison optimization it.2 and simulation it. 3



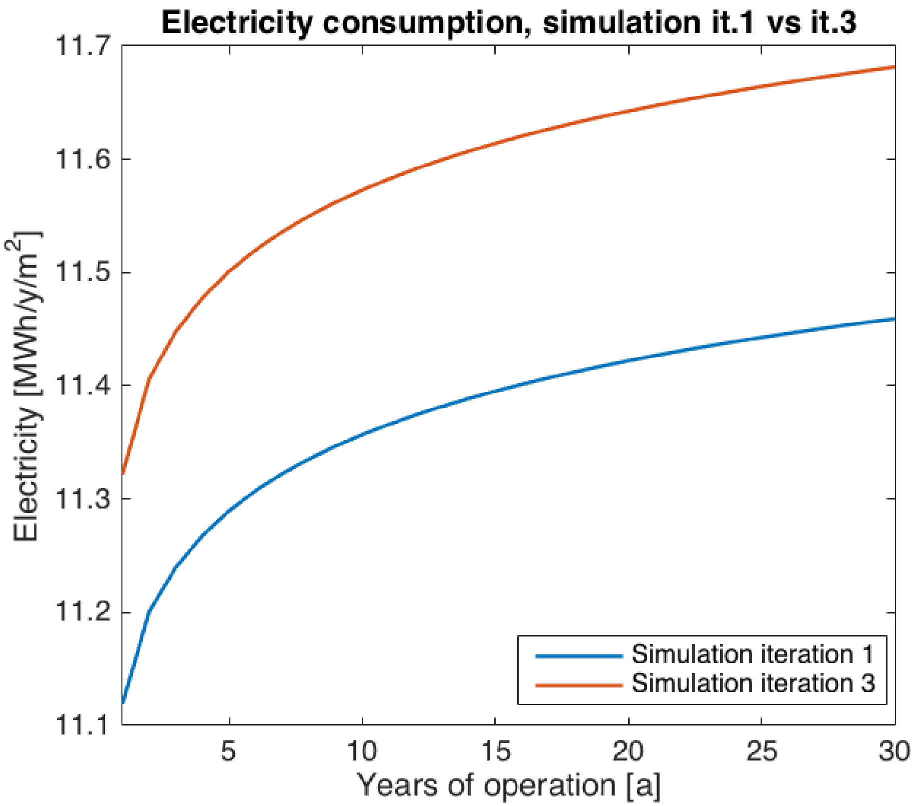

**Electricity balance:**

- **Electricity bought from the grid**: Underestimation in the optimization result for summer
- **Electricity sold to the grid** : Underestimation in the optimization result in the coldest months

⇒ **In absolute values:** low difference.

**⇒ From short time variations of the COP**

# **Iteration 3, simulation** : comparison of simulation it.1 and it.3




**Ground temperature:**
- slightly higher temperature decrease
  ⇒ more heat produced

**COP:**
- COP it. 3 slightly lower than it.1

**Electricity consumption:**
- It.3: Higher electricity consumption

# **Discussion** : Iterative process

ITERATION 1 — **SIMULATION** → ITERATION 2 — **OPTIMIZATION** → ITERATION 3 — **SIMULATION** → ?

**Contributions**:

+ More **accurate** parameters integrated
+ Information **on systems' operational behaviour and limits**

**Limitations**:

✗ COPs as daily mean; shorter variation needs to be dynamically defined

**Contributions**:

+ HP production **profile** that minimize the greenhouse gas emissions of the operation

**Limitations**:

✗ Difference in the **results** of optimization and simulation

✗ Different models, HP operation profile **not completely compatible** (storage tank temperatures)

# CONCLUSIONS



**On the iterative modelling approach:**

+ Iterative approach **combines benefits** from both modelling methods:
  - **Simulation** model provides an accurate virtual representation of the energy systems;
    - well adapted for sensitivity analysis
  - **Optimization** model provides a high quality operation strategy
+ Increasing level of precision of the parameters improves the accuracy of the results

− Time intensive approach due to the implementation in different software

*Future work:* Limitations in the interactions that need to be investigated

***Thank you for the attention !***