A TECHNO-ECONOMIC ASSESSMENT OF **COMBINED HEATING AND COOLING PRODUCTION PLANT** FOR DISTRICT THERMAL NETWORK

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DISTRICT HEATING AND COOLING DEVELOPMENT IN FRANCE

Domestic Hot Water and Space Heating in France:
→ 35% of total energy consumed (665 sur 1900TWh)

[1] Paardekooper, S., Lund, R. S., Mathiesen, B. V., Chang, M., Petersen, U. R., Grundahl, L., ... Persson, U. (2018). Heat Roadmap France: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps.

French Energy Planning (PPE 2016):
→ DHS must deliver 5 times more R&W Energy in 2030 (40TWh)

[2] « Programmation pluriannuelle de l'Energie », République Française, 2016.

Biomass will have a major role:
→ 50% of the energetic mix of DHS by 2030

[2] « Programmation pluriannuelle de l'Energie », République Française, 2016.

BUT Biomass should be considered as a limited resource:
→ Other significant R&W resources must be found

[3] Ericsson K, Nilsson LJ. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass Bioenergy 2006;30:1-15.

Moreover, increasing amount of renewables on electric grid:
→ Surplus leading to over Voltage

[4] Blarke MB, Jenkins BM. SuperGrid or SmartGrid: Competing strategies for large-scale integration of intermittent renewables? Energy Policy 2013;58:381–90

[5] Nielsen MG, Morales JM, Zugno M, Pedersen TE, Madsen H. Economic valuation of heat pumps and electric boilers in the Danish energy system. Appl Energy 2016;167:189-200

FOCUS OF RECENT STUDIES

- **Combining**
  - Biomass
  - Power-to-heat / cold
  - Storage

- **Under various constraints**
  - Cost
  - Maximum CO2 content
  - Minimum renewable share (REnR)
  - Maximum biomass available

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Storage influence in a combined biomass and power-to-heat district heating production plant

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ABSTRACT

The increasing penetration of wind and solar electricity becomes challenging for grid operators. Interconnecting electrical and thermal networks through the Power-to-Heat concept brings flexibility to the electrical grid while supplying a significant renewable source to District Heating (DH). In the present paper, we study a DH production plant composed of a biomass generator, a heat-pump and a heat storage in the French energetic context. We assess the techno-economic performances of this system using Mixed Integer Linear Programming (MILP). A multi-objective parametric optimization method is applied to size the system using the available quantity of biomass, the maximum CO_2 content and minimum renewable energy ratio (REnR) of the heat production as ε-constraints. Our analysis shows that without strong constraints, heat pump and daily storage are used. For a limited amount of biomass available, we also show that investing in an inter-seasonal storage is necessary to reach high REnR. For comparisons, this energy system is also assessed with the Danish and German electric mix. We then verify the sizing stage results on the operational performances of a non-linear numerical simulator. With that methodology, it is possible to evaluate the impact of the MILP modelling level of detail on the obtained results. An error of 5.1% on the production trajectories is here obtained for a given system.

1. Introduction

In France, similarly to other European countries, 35% of the final energy consumption is devoted to space heating and domestic hot water preparation (DHW), which amounts to 665 TWh per year [1]. The French energy planning of 2016 [2] has identified District Heating Networks (DHN) as a solution to reduce the use of fossil energy to supply heat demands. Indeed, due to their ability to massively distribute renewable and recovery energies (R&R), DHN are expected to deliver 5 times more R&R in 2030, to reach about 40 TWh. Similarly, the Heat Roadmap France [3] recommends that DHN should cover up to 25% of the heat demand by 2050 while its current share is only 6%.

In parallel, the concept of 4th Generation District Heating [4,5] emphasizes the need to interconnect DHNs to the power grid, as a way to provide the flexibility required for a broader integration of intermittent renewable energies [6]. In France, while combined Heat and Power (CHP) is limited by the rather low price of nuclear-based electricity, this integration will then be first driven by Power-to-Heat (PtoH) [7]. Indeed, combining PtoH with thermal storage provides a cheap and efficient form of storing excess renewable power [8].

At the same time, and contrarily to other EU countries, biomass is expected to play a major role and reach 50% in the French DHN mix by 2030 [9]. It is worth mentioning that the number of biomass-based DHN in France has significantly grown over the last 10 years, mainly because of financial incentives. It is now estimated that about 500 DHN [10] are using biomass in their energy mix. However, biomass must always be considered as a limited resource, unevenly distributed and affected by transportation constraints [11]. Moreover, its renewable nature depends on its usage rate.

In this paper, we study the optimal sizing of a DHN production plant combining PtoH, biomass and storage in the French context. In particular, we consider the influence of several parameters on the need for different thermal energy storage sizes, from small water tanks to large inter-seasonal storages. We consider only water-based storage at the production side, although other technologies as well as storing heat at building level or in the network itself could be considered at later stages [12].

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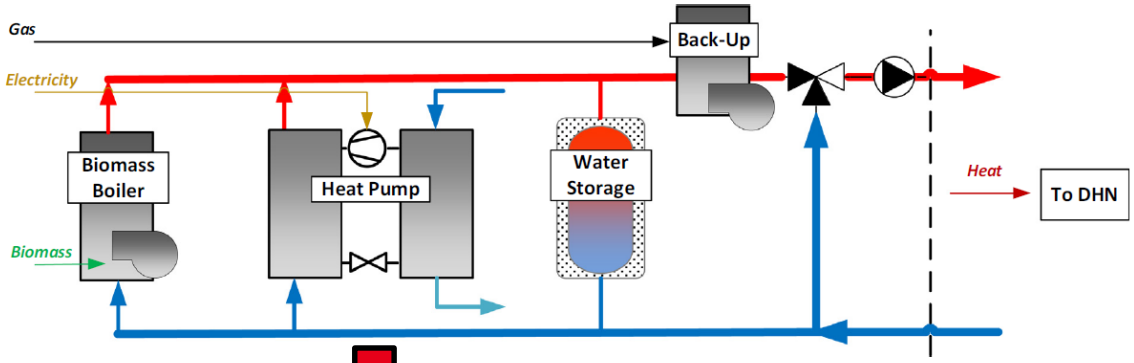
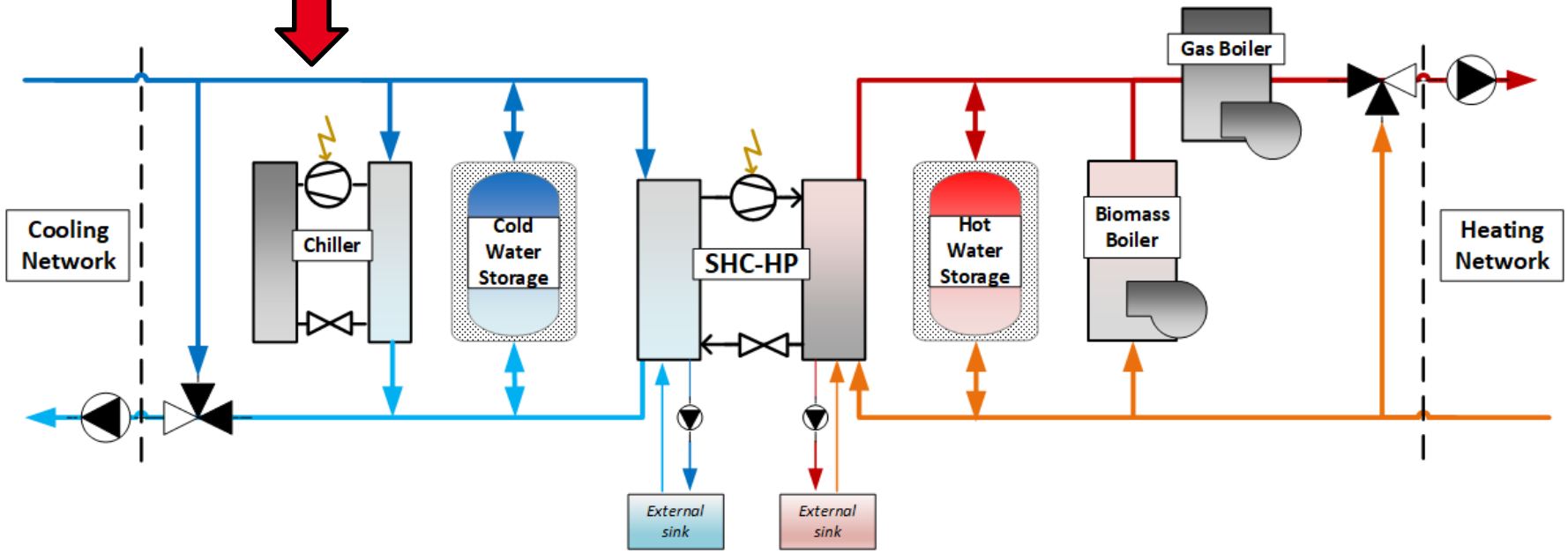
0360-5442/

IN THIS STUDY : **SIMULTANEOUS HEATING AND COOLING**





Outline:

1. Methodology
2. Electric variability
3. Some results

SHC-HP: Simultaneous Heating and Cooling Heat Pump

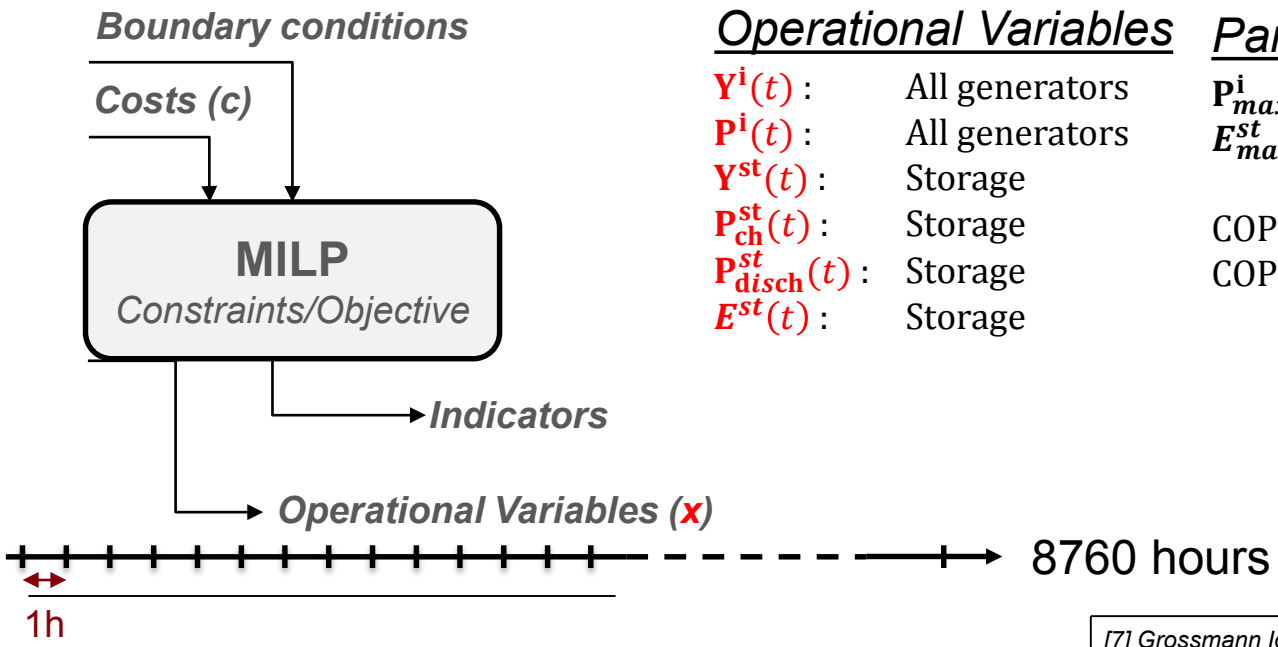
1- METHODOLOGY: **OPTIMIZATION** USING **MIXED-INTEGER LINEAR PROGRAMMING**

MILP formulation

$$\min_x c^T . x$$

$$\begin{cases} A.x = b \\ D.x \geq e \end{cases}$$

MILP and Energy Systems [7,8]



Hypothesis

- No effect of temperature accounted for (fixed COP)
- Operation does not affect electricity costs
- Only operational optimisation (for this study)

Operational Variables

$\mathbf{Y^i}(t)$: All generators
$\mathbf{P^i}(t)$: All generators
$\mathbf{Y^{st}}(t)$: Storage
$\mathbf{P^{st}_{ch}}(t)$: Storage
$\mathbf{P^{st}_{disch}}(t)$: Storage
$\boldsymbol{E^{st}}(t)$: Storage

Parameters

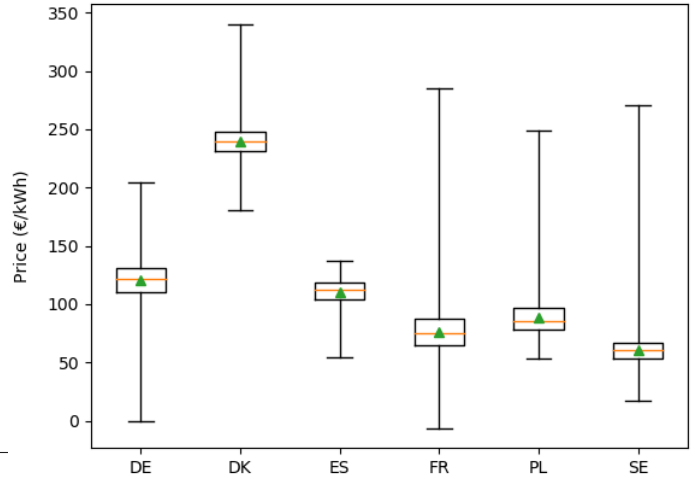
$\mathbf{P^i_{max}}$: All generators = 8 MW
$\boldsymbol{E^{st}_{max}}$: Storage = 4000 MWh

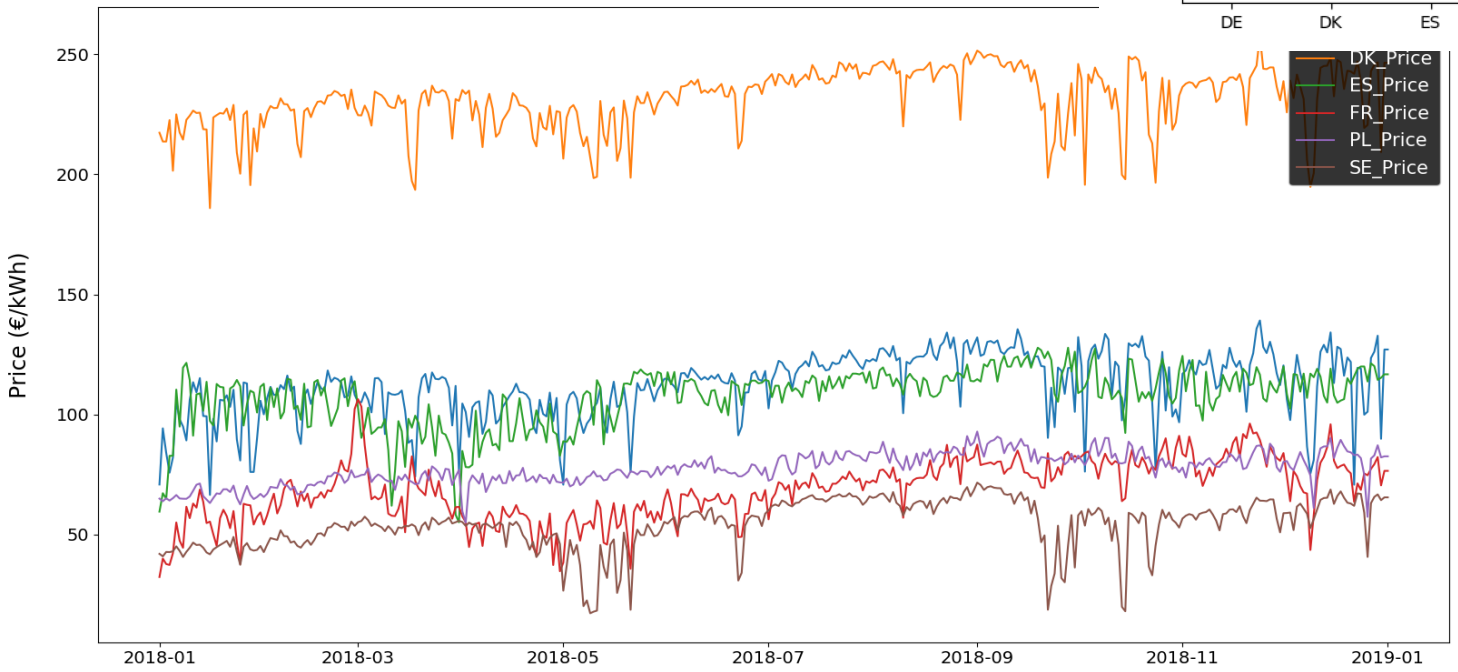
COP SHC-HP = 3
COP Chiller = 5

[7] Grossmann Ignacio E. 'Mixed Integer programming for the synthesis of integrated process flowsheets", Comp. Chem. Eng., 1985, 9(5) 463-82.
[8] M. Dahl et al., 'Cost sensitivity of optimal sector-coupled district heating production Systems', Energy, 2019

INDICATORS AND ELECTRIC VARIABILITY: **OPERATION COSTS**

- **Variable electricity price is considered**
  - Fixed base price + day-ahead market price
  - Data from European Network of Transmission System Operators



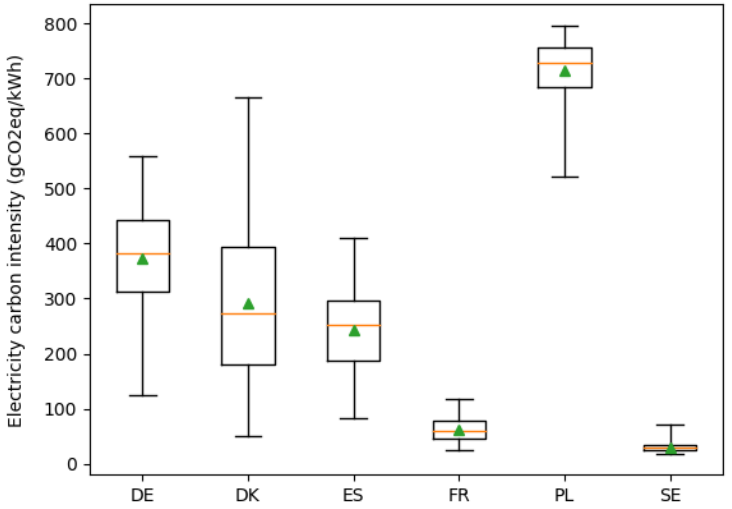


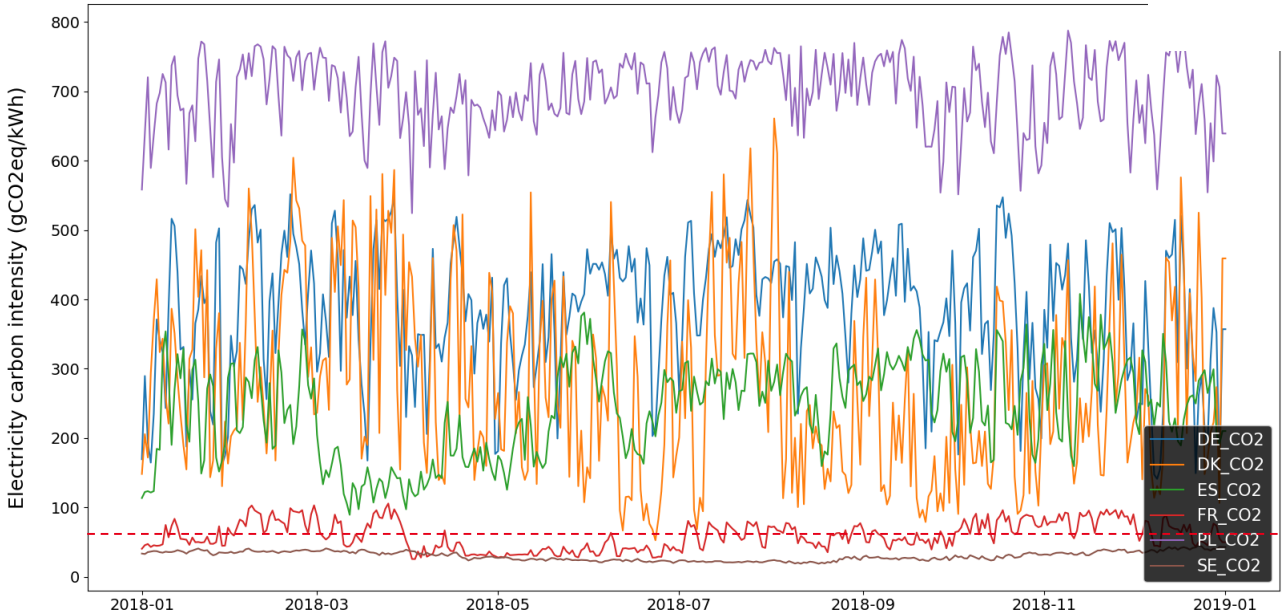
2- INDICATORS AND INFLUENCE OF ELECTRIC VARIABILITY: **CO2 CONTENT**

- **A maximum CO_2 content can be imposed**

$$CO_2^{tot} = \frac{\sum_{t=1}^{N_{steps}} \sum_{i=1}^{N_{gen}} \mathbf{CO_2^i(t)} \cdot \mathbf{P^i(t)} / \eta_i(t) \cdot \Delta t}{\sum_{t=1}^{N_{steps}} P_{heat}(t) + P_{cold}(t)}$$

$$\leq CO_{2_{max}}$$





Source: ENTSOE (averaged to daily values)

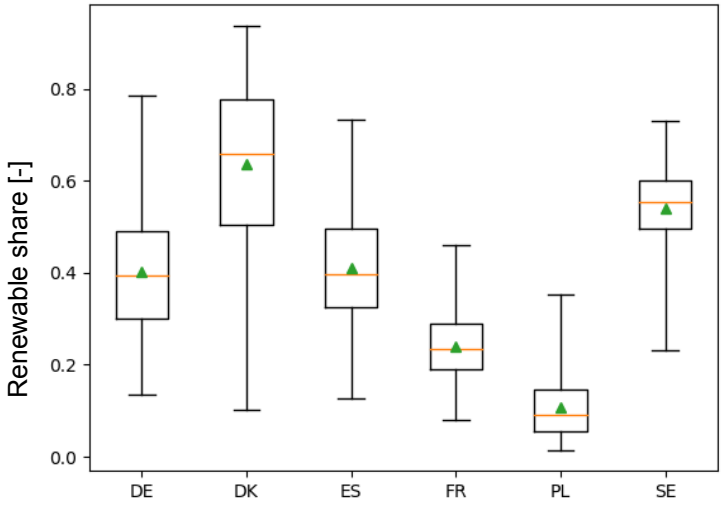
Biomass equivalent = 72
(considering COP = 3)

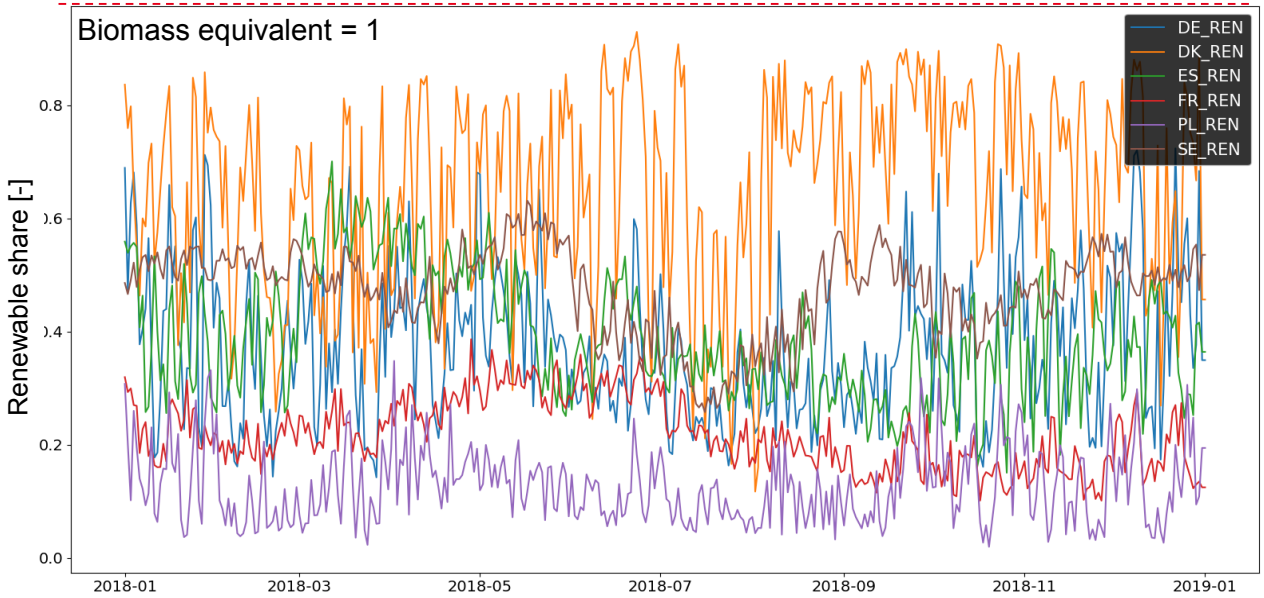
2- INDICATORS AND INFLUENCE OF ELECTRIC VARIABILITY: **RENEWABLE ENERGY RATIO**

- **A minimum renewable energy share (REnR) can be imposed**

$$REnR_{th}^{tot} = \frac{\sum_{t=1}^{N_{steps}} \sum_{i=1}^{N_{gen}} \boldsymbol{REnR_{th}^{i}(t)} \cdot \boldsymbol{P^{i}(t)} / \eta_i(t) \cdot \Delta t}{\sum_{t=1}^{N_{steps}} P_{heat}(t) + P_{cold}(t)}$$

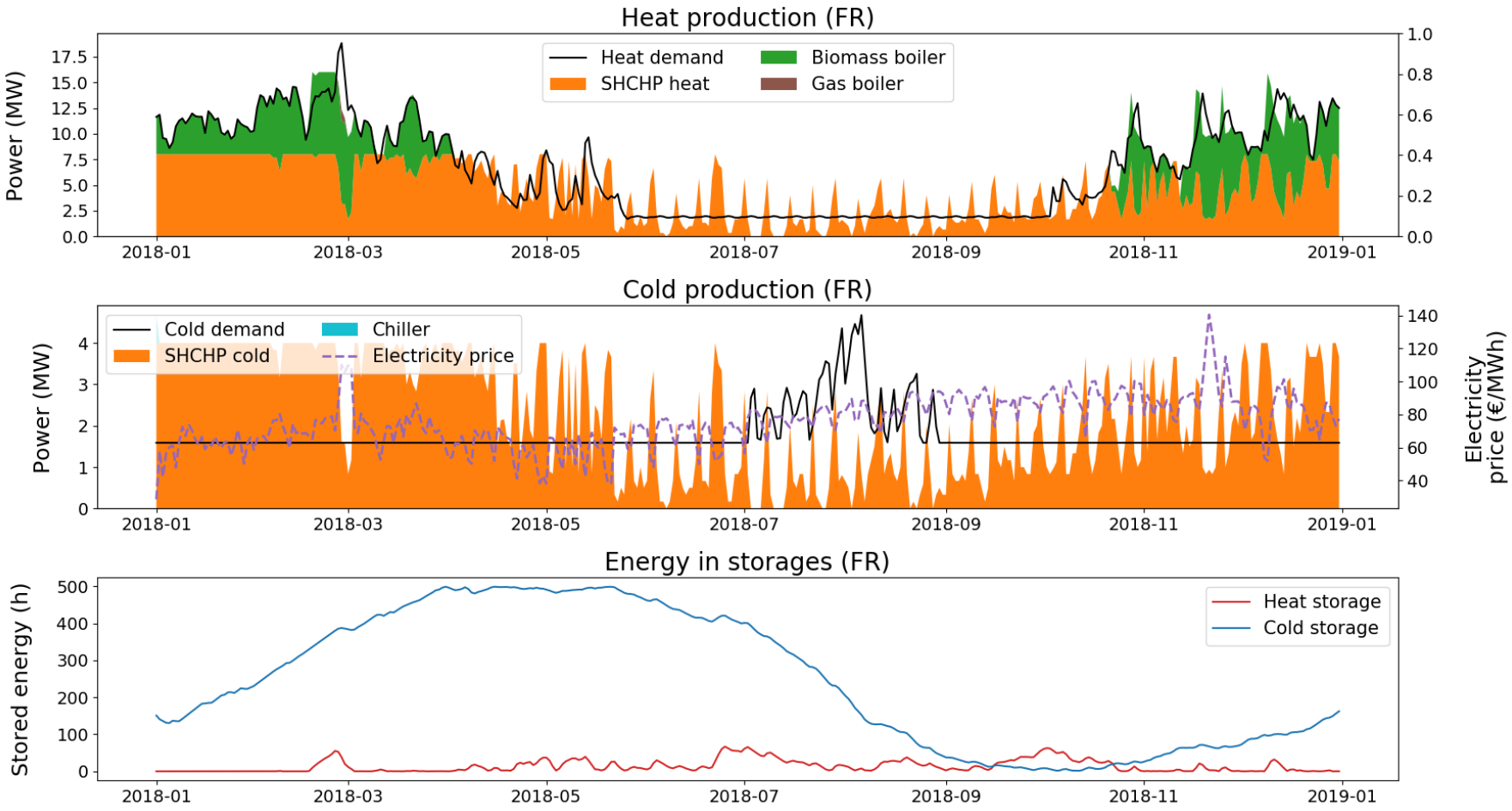
$$\geq REnR_{min}$$





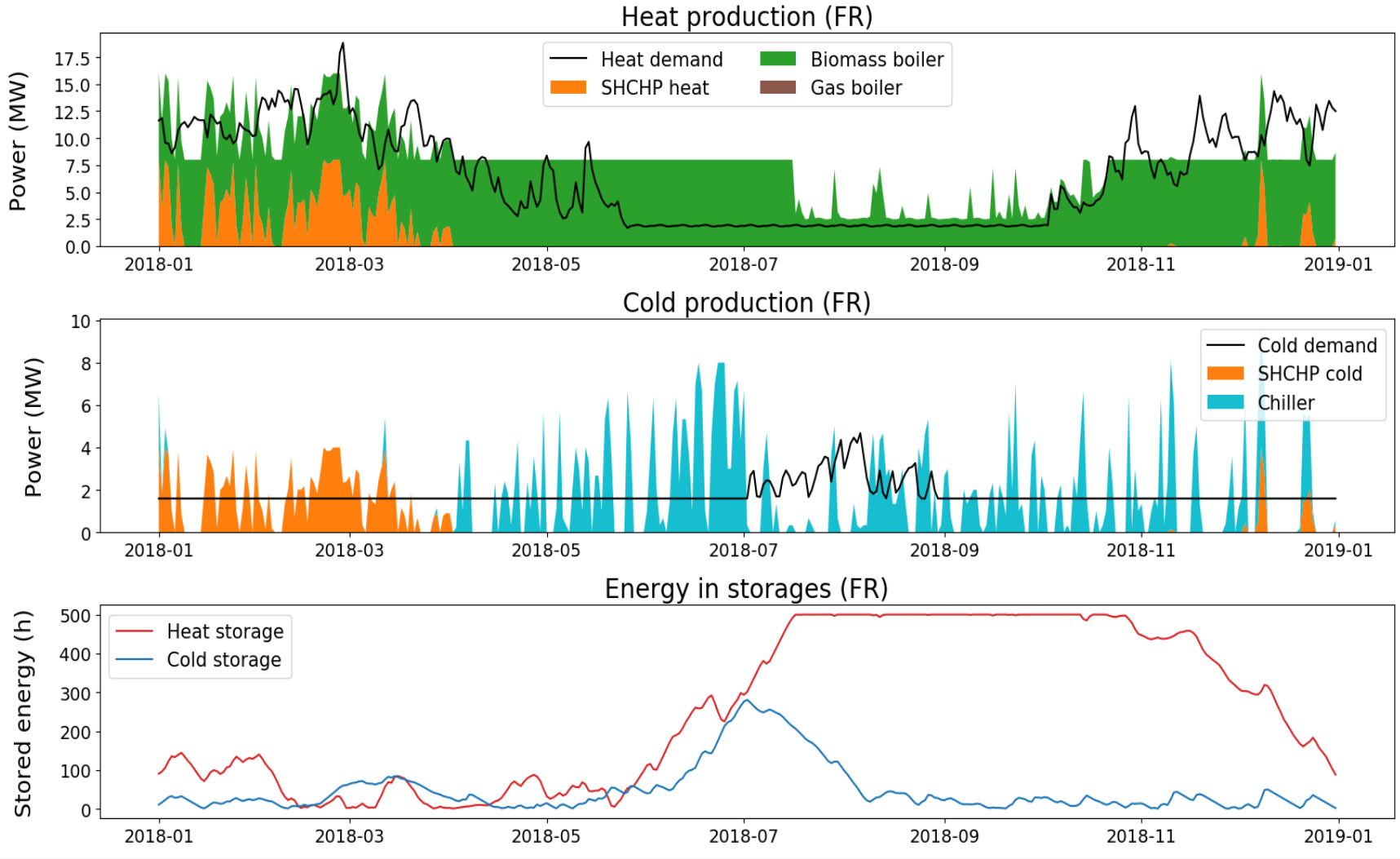
Source: ENTSOE (averaged to daily values)

3- SAMPLE RESULT FOR HEATING AND COOLING IN FRANCE: **BASE CASE**



Seasonal cold storage is interesting even without other constraints

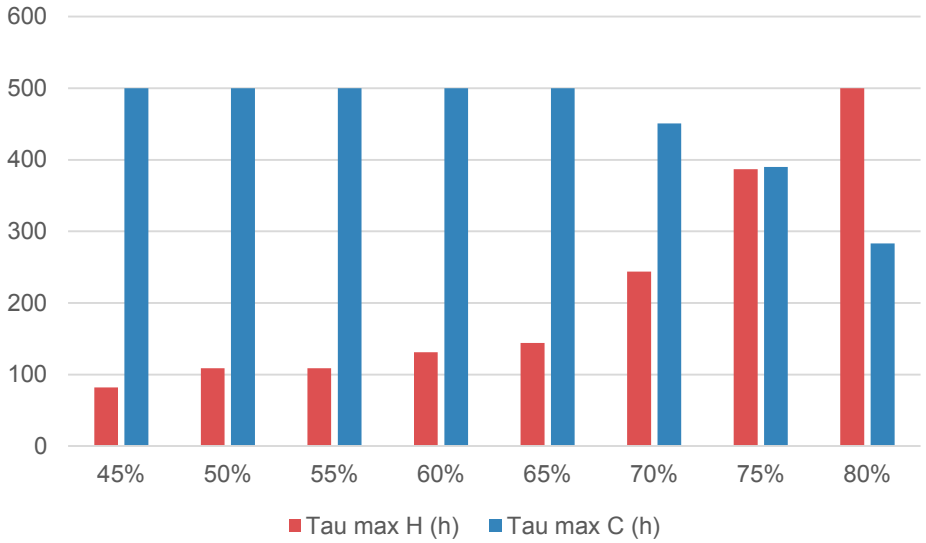
3- SAMPLE RESULT FOR HEATING AND COOLING IN FRANCE: **IMPOSING 80% RENEWABLES**



Seasonal hot storage is required when renewable targets are high

CURRENT CONCLUSIONS (FOR FRENCH CONTEXT)

- **CO2 emissions are very low in a combined biomass/HP system**
- **Simultaneous heating and cooling is beneficial mostly when the electricity price is low**
- **Need for heat and cold storage vary depending on imposed renewable energy share**



- **Many cases become infeasible**
  - Imposing biomass limits together with high renewable shares

MERCI DE VOTRE ATTENTION !

You are kindly invited to the upcoming

4th workshop on **Hybrid Energy Networks**
International Energy Agency – DHC TCP – Annex TS3
Le Bourget-du-Lac, France, October 16-17 2019

Looking forward to see you there !

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