

PSCC 2022      27<sup>th</sup> June to 1<sup>st</sup> July 2022  
XXII Power Systems Computation Conference

# Identification and Quantification of the Flexibility Potential of a Complex Industrial Process for Ancillary Services Provision

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# Content

Context, Motivation and Objectives

Use-case and Model

Results

Conclusions



Large energy and power density

Hedge with storage to increase flexibility

Production schedule to be satisfied

Process constraints limit the flexibility



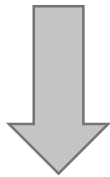
**Need to identify and quantify the flexibility available**

# INDUSTRIAL FLEXIBILITY QUANTIFICATION

**Feasible Region of a Process:** All operating points satisfying every constraints of the industrial process

**Industrial flexibility quantification:**

- Representing the outer or the whole envelope of the feasibility region
- Test for feasibility of operation under a set of uncertainty



**Industry is becoming more active on the electricity market mechanisms:**

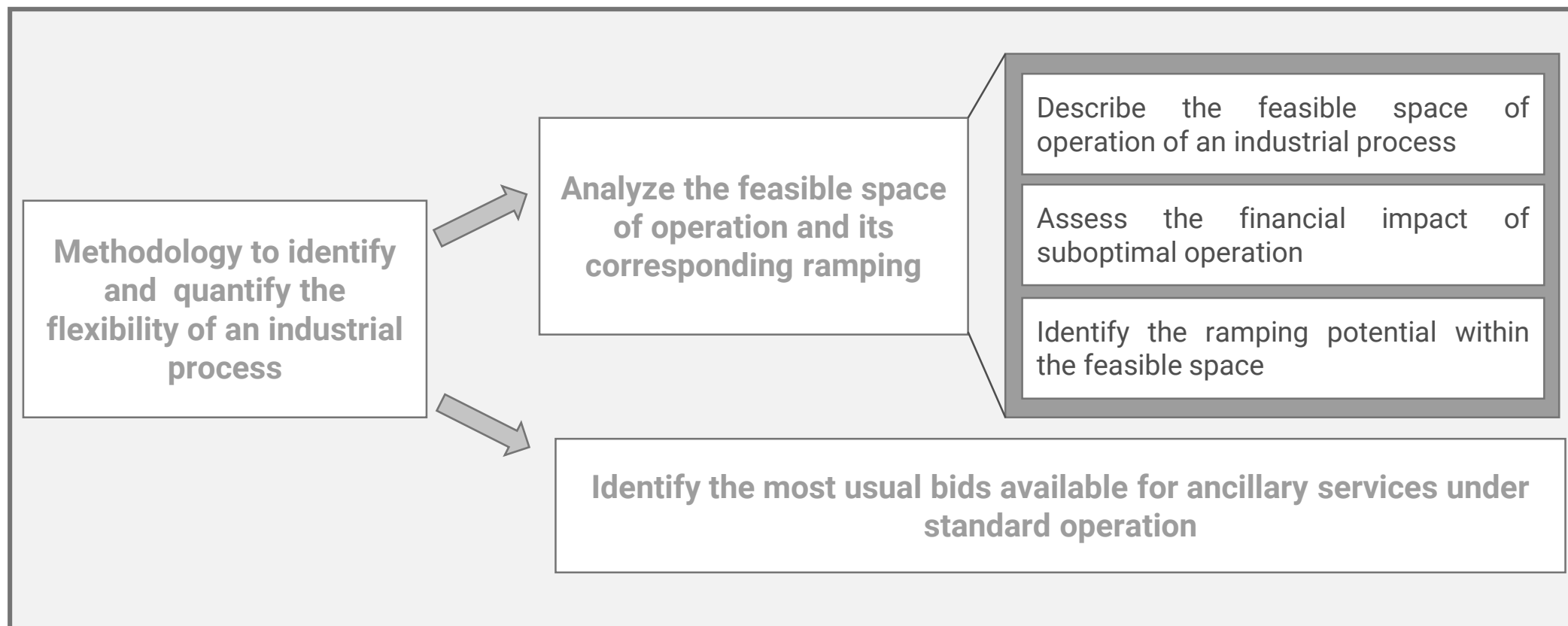
- Need to quantify the benefits of moving voluntarily within the feasible space

## Research Questions

How can we represent this feasible space of operation and its corresponding flexibility ?

What bids could a given plant send during operation ?

# OBJECTIVES



# USE CASE

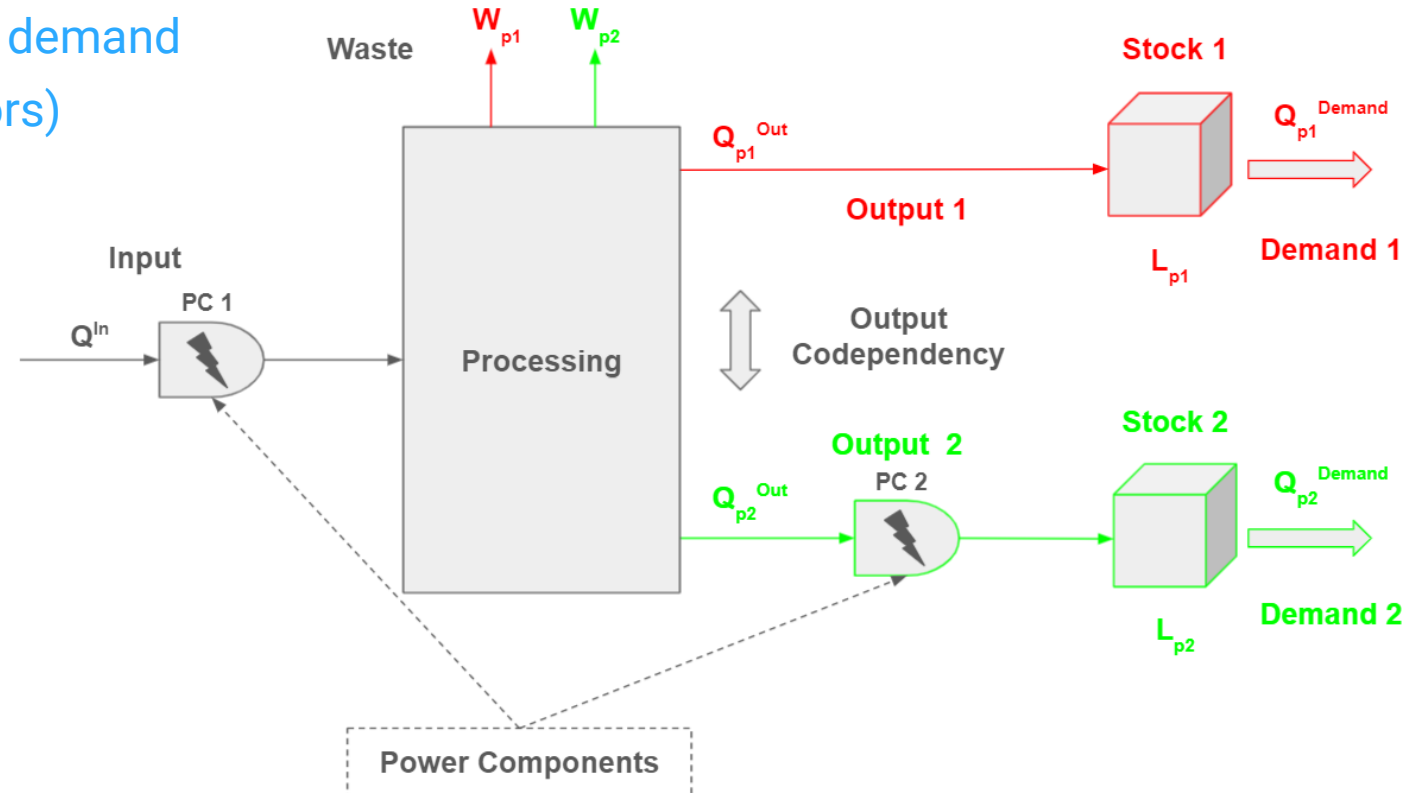
## Characteristics:

- Operating range: **11.5 MW to 15 MW**
- **Two storable products** with hourly demand
- **2 Power Components** (Compressors)
- Product Value:

Product 1:       **1 €/U**  
Product 2:       **3 €/U**

## Specific process constraints:

- Multiple interconnected outputs
- Variable amount of product waste with a minimum necessary value



# LP OPTIMIZATION MODEL

Linearised Constraints

Product Waste

Input and Output Flows

Day-ahead price

Product Value

$$\text{minimize } \sum_t^T E_t^{DA} \cdot \delta_t^{DA} - \sum_p (L_{T,p} - L_{0,p}) V_p$$

$$E_t, \{PC_1, PC_2\},$$

$$Q_t^{In}, Q_t^{Out}, \{P_1, P_2\},$$

$$L_{t,p}, W_t, \{P_1, P_2\}$$

s.t.:

Mass Conservation Constraints:

$$Q_t^{In} = f(Q_t^{Out}, W_t, \{P_1, P_2\}, \text{Parameters}), \quad \forall t$$

Product Storage and Demand:

$$L_{t,p} = L_{t-1,p} + Q_{t,p}^{Out} - Q_{t,p}^{Demand}, \quad \forall t > 1, p$$

$$L_{T,p} \geq L_{0,p}, \quad \forall p$$

Power Components:

$$E_{t,c} = g(Q_{t,c}, \text{Parameters}), \quad \forall t, c$$

Energy Balance:

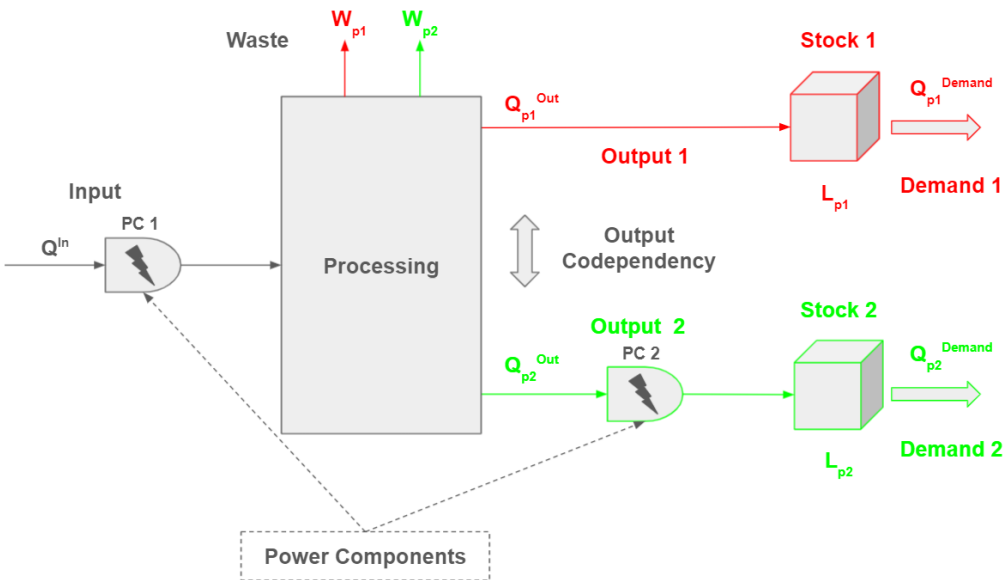
$$E_t^{DA} = \sum_c E_{t,c}, \quad \forall t$$

With:

$p \in \{p_1, p_2\}$  the two products,

$t \in \{0, \dots, T\}$  the time steps,

and  $c \in \{PC_1, PC_2\}$  the two power components



# FEASIBLE SPACE OF OPERATION AND RAMPING POTENTIAL

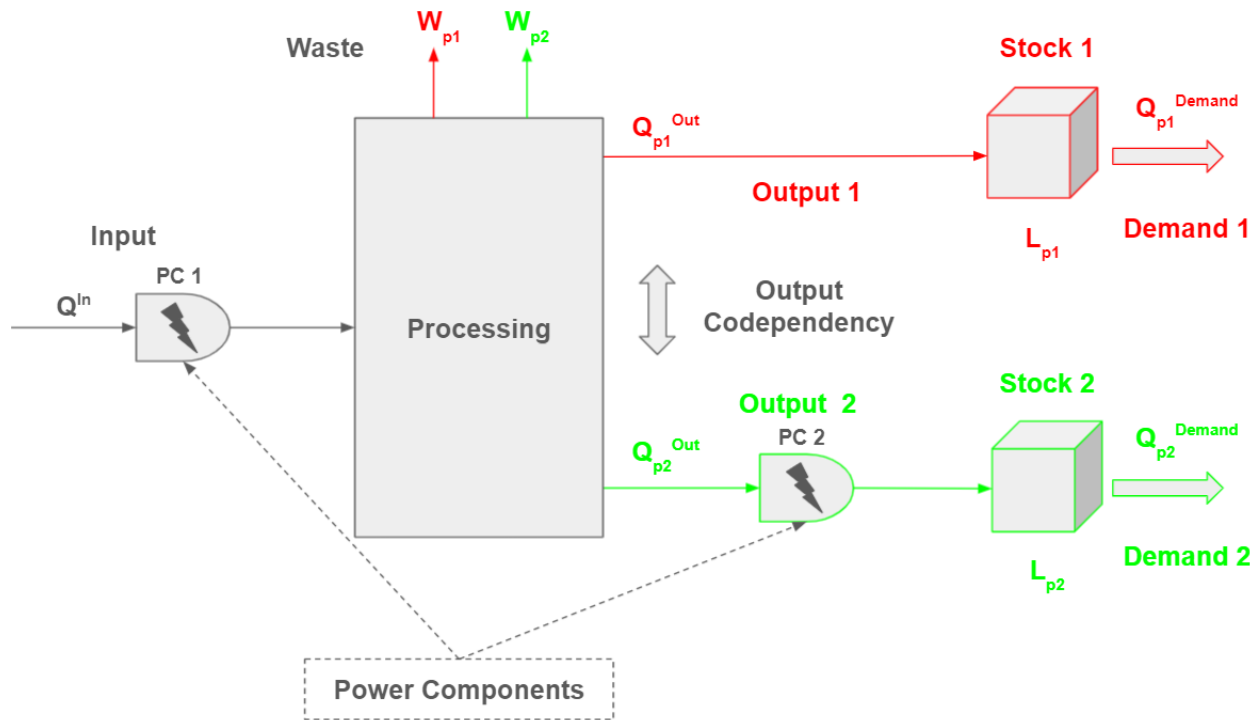
2 product outputs: The feasible space can be plotted in 2D

3 main steps:

- Creation of a grid of operating point based on maximal and minimal theoretical outputs  
=> New Constraint added to the problem:

$$Q_{t, \{p1, p2\}}^{OUT} = Q_{t, \{p1, p2\}}^{FIXED}$$

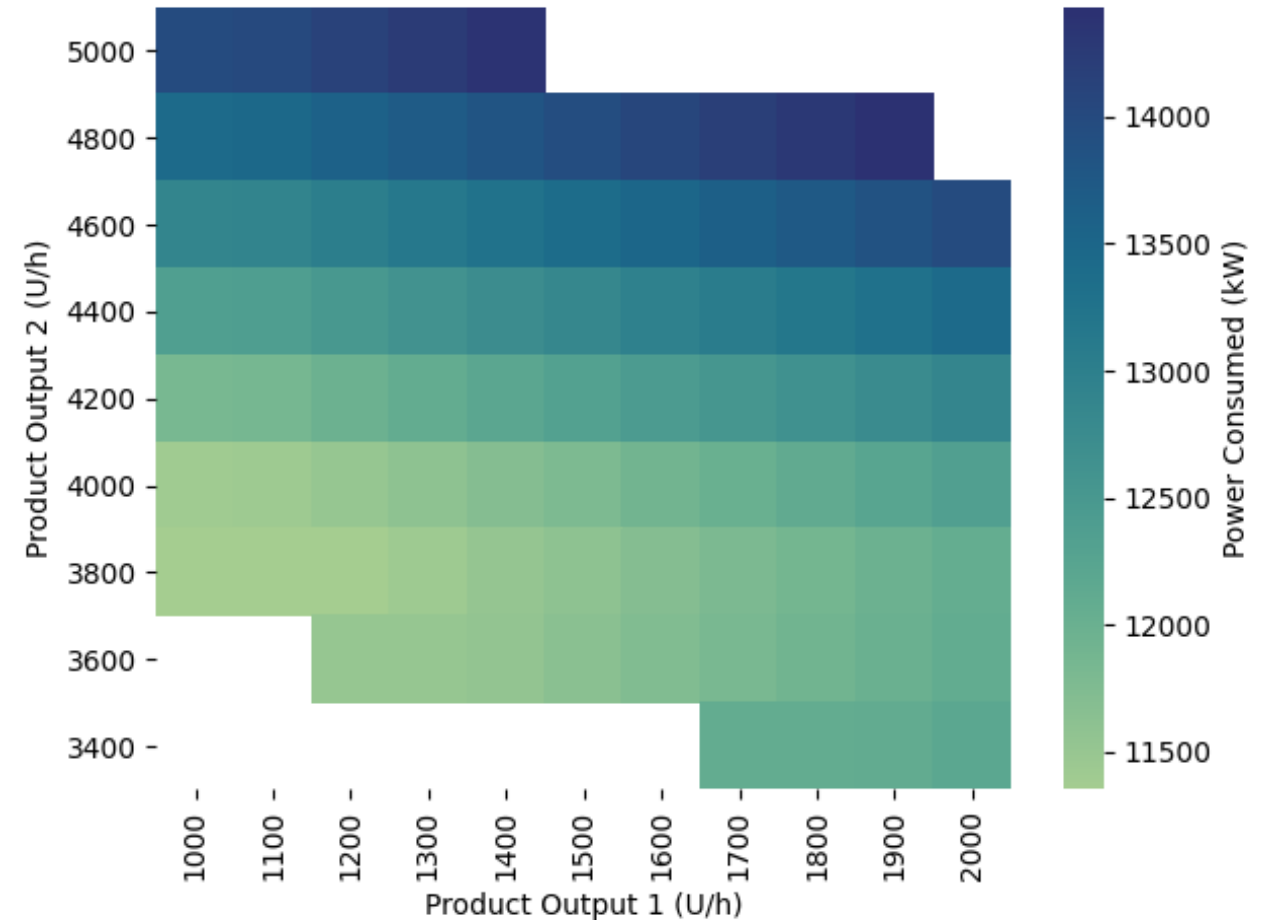
- Check for feasibility and extract optimal power consumption
- Heatmap representing the optimal power consumption for each feasible operating point





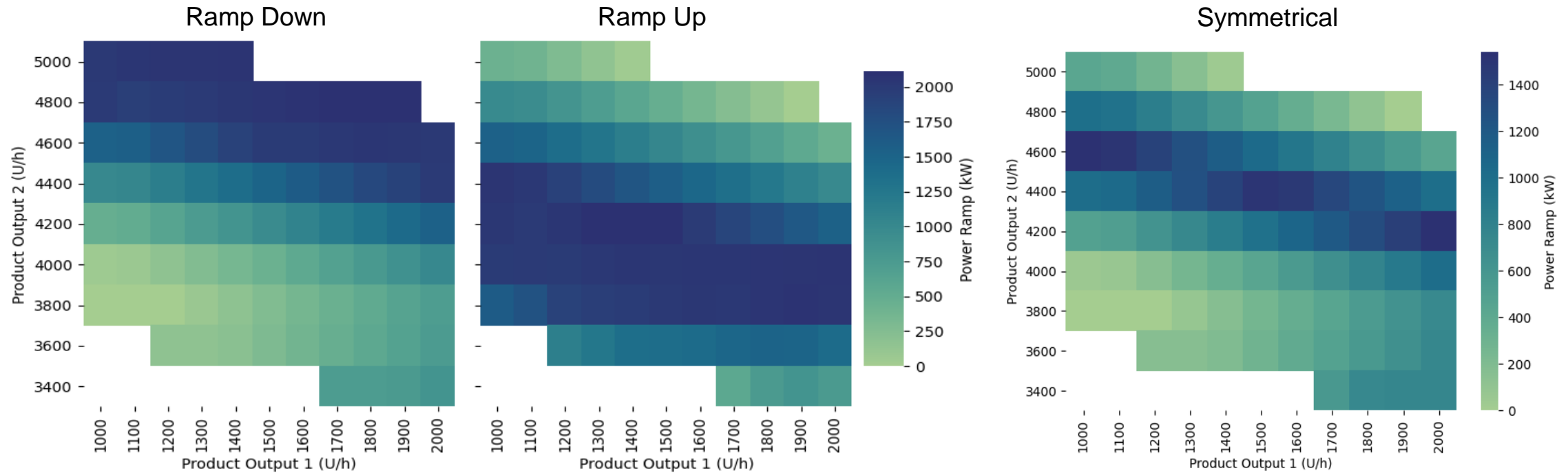
# FEASIBLE SPACE OF OPERATION

- Minimal and maximal outputs cannot be reached for both products at the same time
- Some operating points are more efficient than others



# RAMPING POTENTIAL

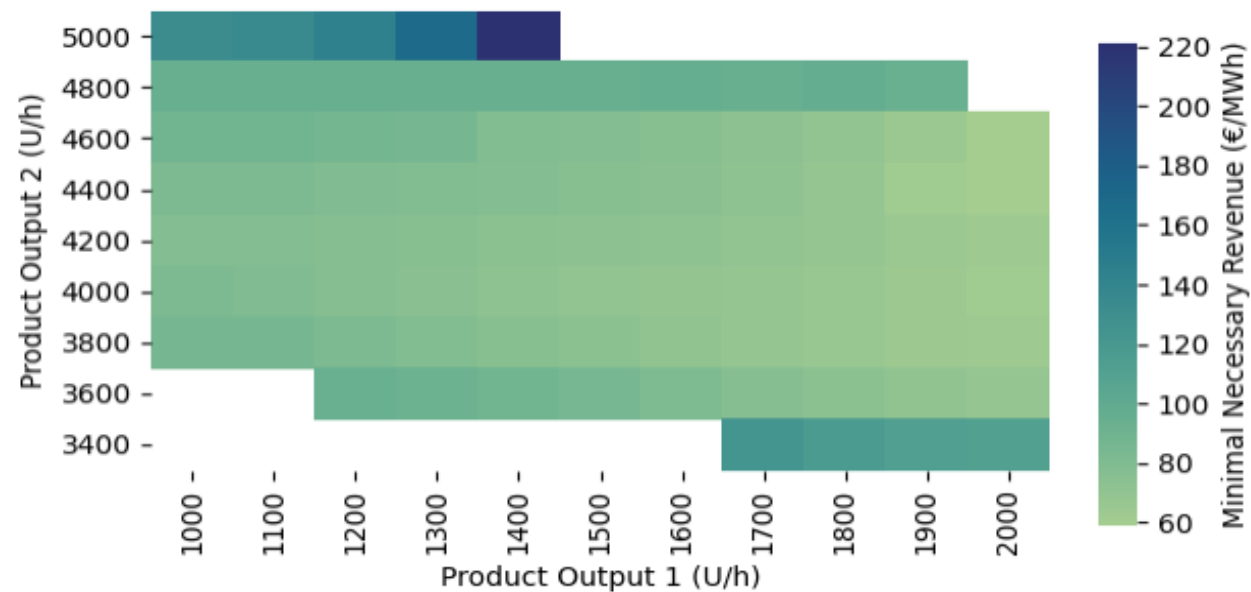
- For each feasible point of operation, assess the largest power shift available



- From 0 to 2 MW for unilateral ramping, and 0 to 1.5 MW for symmetrical ramping

# FINANCIAL IMPACT OF SUBOPTIMAL OPERATION

- Increase the power consumption without changing the product output
- Allow for downward regulation while under hard product output constraints
- Link the cost of lost product to unlocked ramping

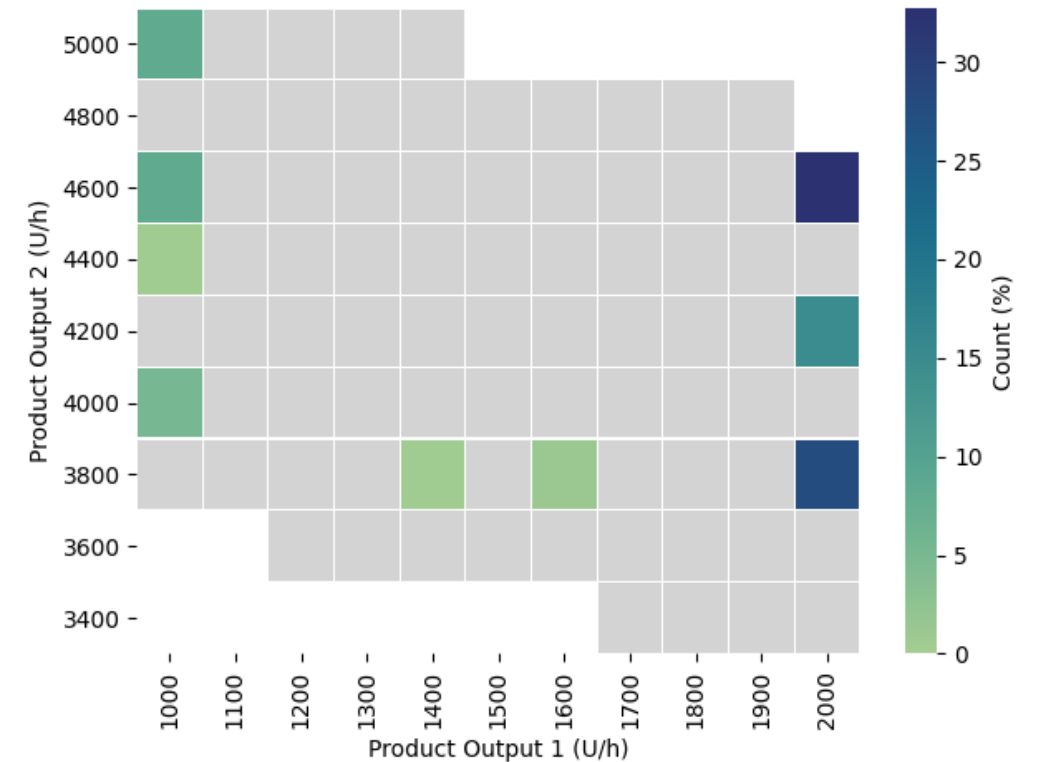
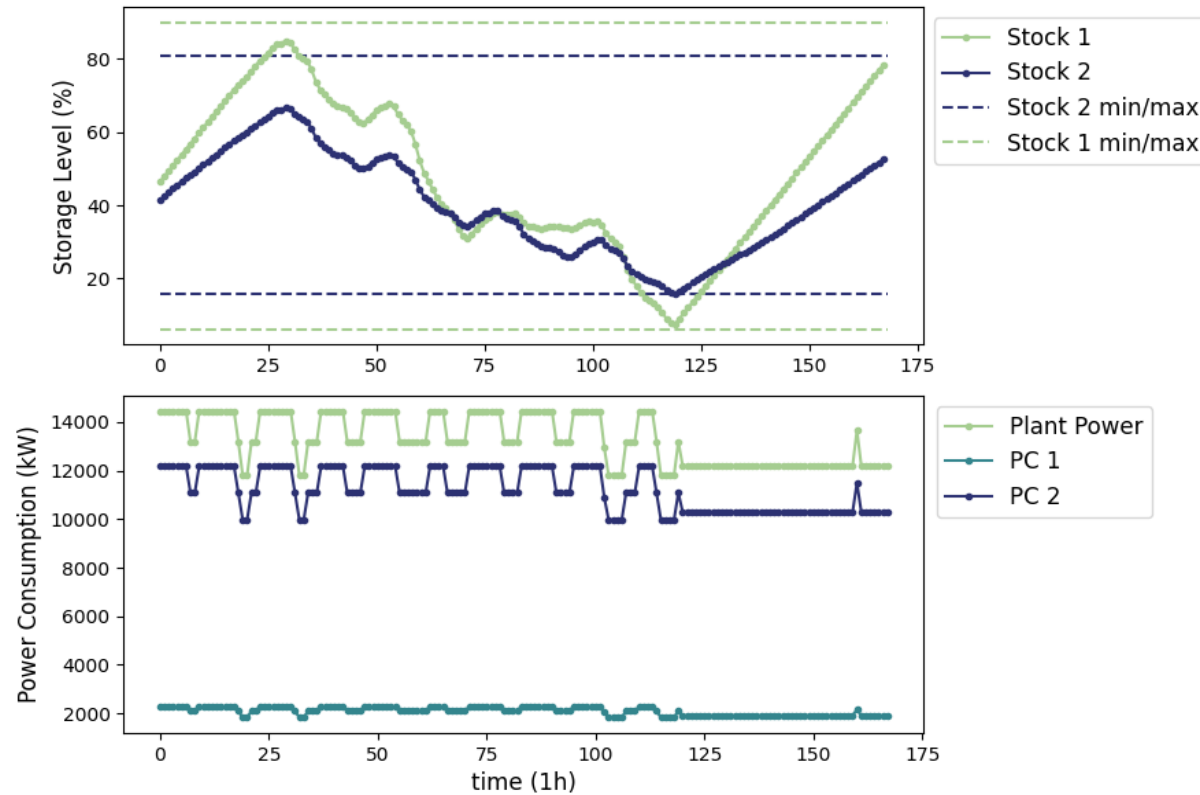


## Conclusions:

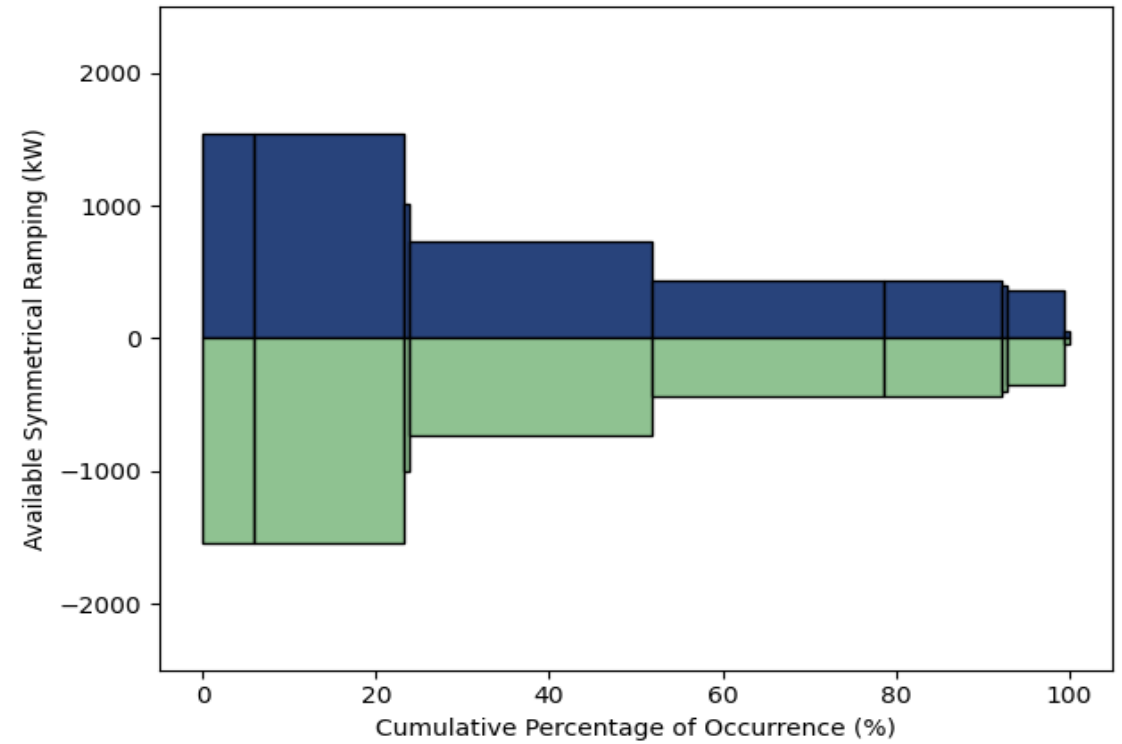
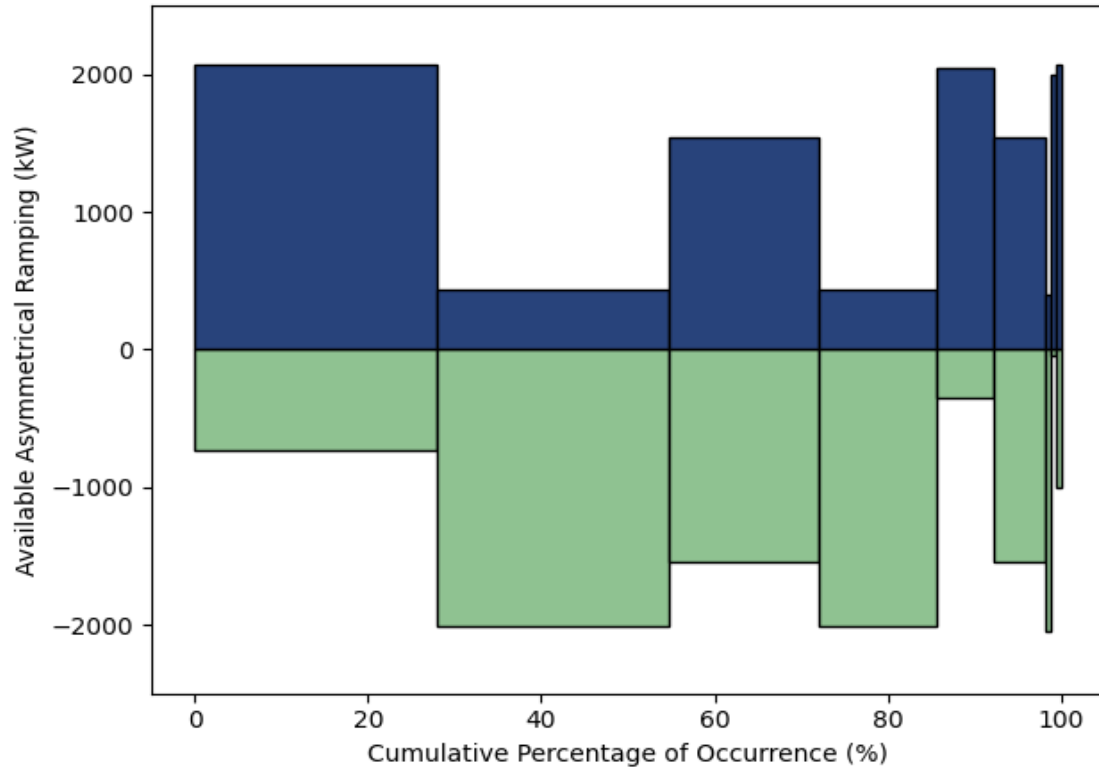
- Lost revenue ranges from 60 to 220 €/MWh
- A higher product 1 output reduces the necessary revenue
- Additional information needed to assess the cost of such operation

# USUAL OPERATING POINTS

- Observe the changes in consumption and storage levels
- Extract the usual operating points and assess their frequency of appearance



# AVAILABLE ANCILLARY SERVICE BIDS



## PERCENTAGE OF AVAILABLE RAMP

| Ramp     | Up  | Down | Symmetric |
|----------|-----|------|-----------|
| >500 kW  | 59% | 93%  | 52%       |
| >1000 kW | 59% | 65%  | 24%       |
| >1500 kW | 59% | 64%  | 23%       |
| >2000 kW | 35% | 41%  | 0%        |

# CONCLUSIONS

## Representation of the feasible space and the potential ramping

- Visual representation of the limits coming from the product interdependency
- Visual representation of the ramping available for each operating point within the feasible space

## Analysis of suboptimal operation

- Last resort option to provide reserve when no other way is possible
- Cash flow is likely to be negative for that kind of operation

## Usual operating points and available ramping

- Extract the usual operating points and their frequency of appearance
- Maximum of 2 MW of asymmetrical flexibility (35/40% frequency)
- Maximum of 1.5 MW of symmetrical flexibility ( 23% frequency)

# THANK YOU !

This work is performed in the frame of a PhD supported in part by ANRT through a Cifre Grant.

