N-SIDE
OPTIMIZING YOUR DECISIONS

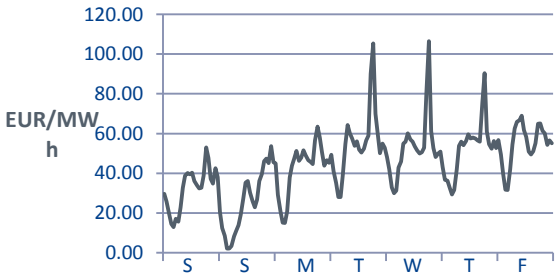
Advanced Analytics to Capture the Full Value of Demand Response and Energy Flexibility in Industrial Sites

Aurélien Crucifix, Consultant, N-SIDE

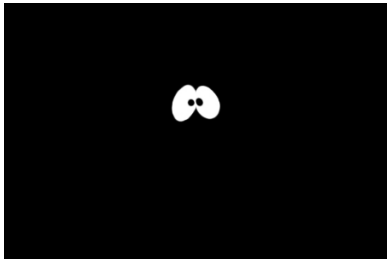
New problems in energy optimization: the industrial perspective
January 27, Edinburgh

Why and how to leverage flexibility from energy-intensive processes ?

Increasing electricity price volatility

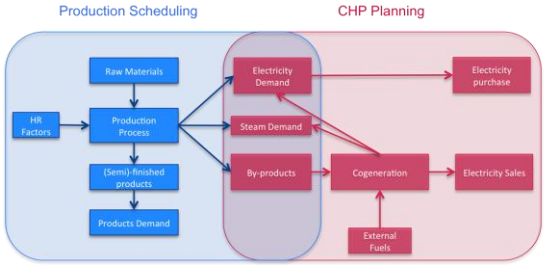


Increasing need for Demand Response services

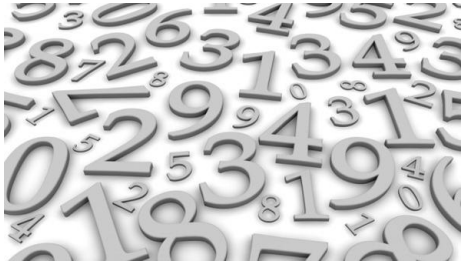


Advanced Analytics to transform this complexity into opportunities

Increasing complexity of the energy structure of the industries



Increasing amount of data to be leveraged



1. Demand Response: Opportunities and challenges for industrial sites
   A. The markets: Where to value my flexibility ?
   B. The processes: Where to find and how to manage my flexibility ?

2. Advanced Analytics to make the most out of energy flexibility

1. Demand Response: Opportunities and challenges for industrial sites
   A. The markets: Where to value my flexibility ?
   B. The processes: Where to find and how to manage my flexibility ?

2. Advanced Analytics to make the most out of energy flexibility

How to design an optimal energy flexibility strategy ?

Markets

Where to value my flexibility ?

Processes

Where to find and how to manage my flexibility ?

The market challenge: Where to value my flexibility ?

Direct Market Access
Indirect Market Access

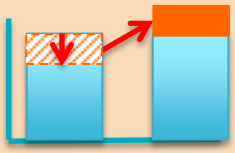
	Years / Months in advance	1 to 7 days in advance	Real-time
Price based	Forward contracts (OTC) Fixed contracts	Day-ahead market Spot-price based contracts	Intraday and balancing markets Deviation penalties
Reserve	Reserve participation (e.g. France, Belgium) Contract with an aggregator	Reserve participation (e.g. Germany, Austria)	Activation from TSO Activation from aggregator

The process challenge:
Where to find and how to manage my flexibilities ?

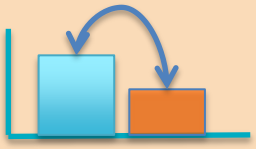
Electricity Consumption

Consume electricity at optimal moment

1. **Load Shifting**

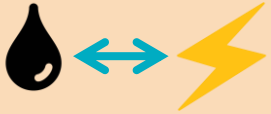


2. **Load Scheduling**



3. **Load Shedding**

4. **Fuel Switching**



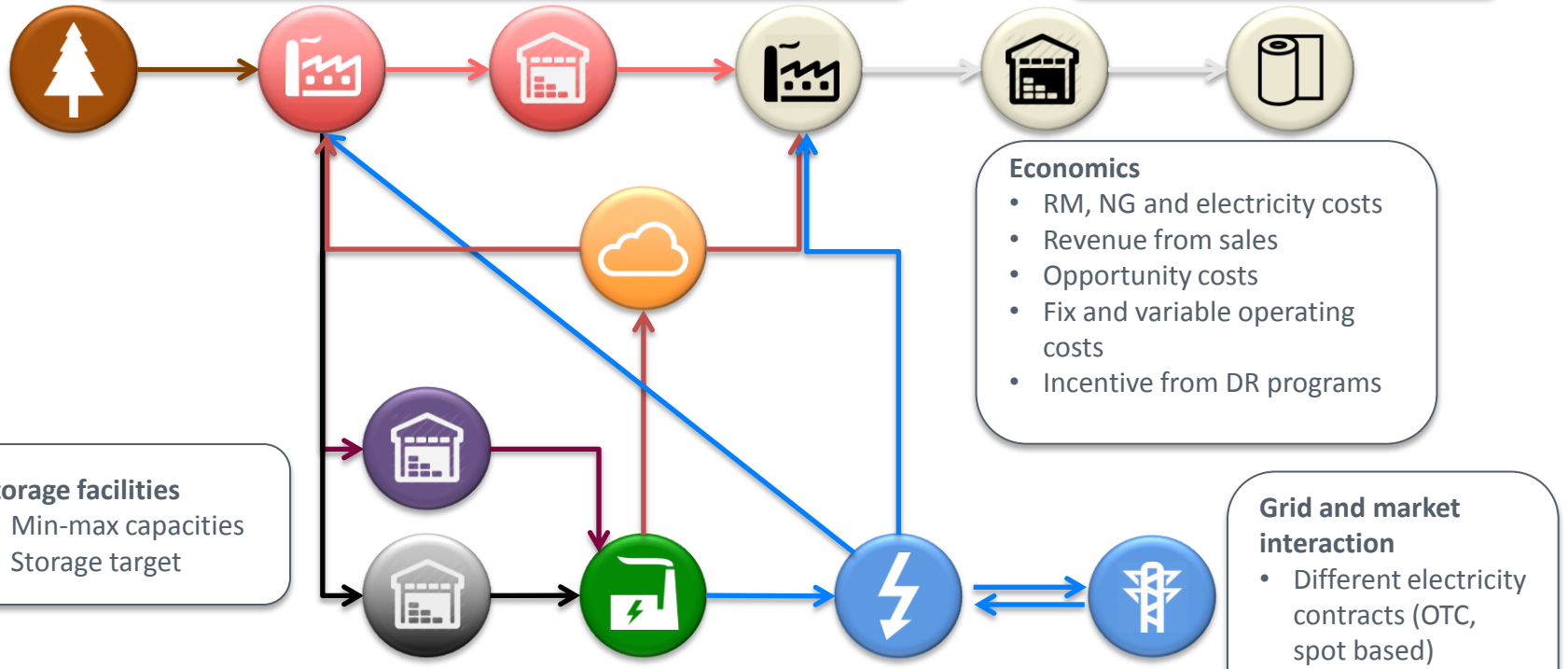
Electricity Generation

Produce electricity at optimal moment

5. **CHP Modulation**

6. **By-product Optimization**

A mathematical model is key for considering all the factors…



Industrial processes
- All input and output flows
- Ramping up and down
- Min-max capacities
- ON-Off procedure
- Operating rates

Product Demand
- Quantities and delivery dates
- Must / May serve

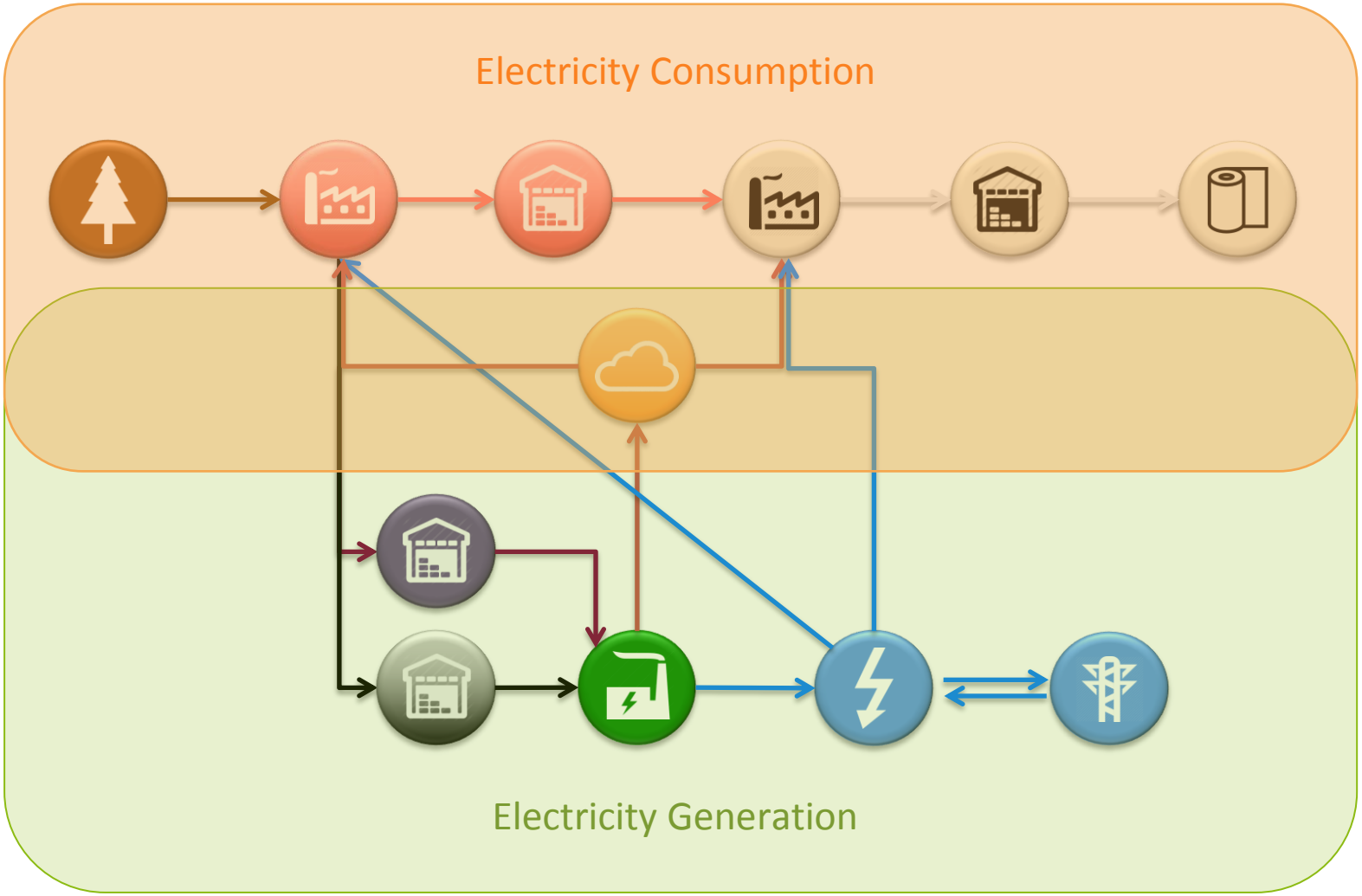
Economics
- RM, NG and electricity costs
- Revenue from sales
- Opportunity costs
- Fix and variable operating costs
- Incentive from DR programs

Storage facilities
- Min-max capacities
- Storage target

Grid and market interaction
- Different electricity contracts (OTC, spot based)
- Capacity constraints

CHP Unit (boilers, turbines, …)
- Min-max capacities
- Operating rates
- Ramping up and down
- ON-OFF procedure
- Different steam pressure levels
- Fuel mix constraints
- Maintenance planning

…in an integrated way…



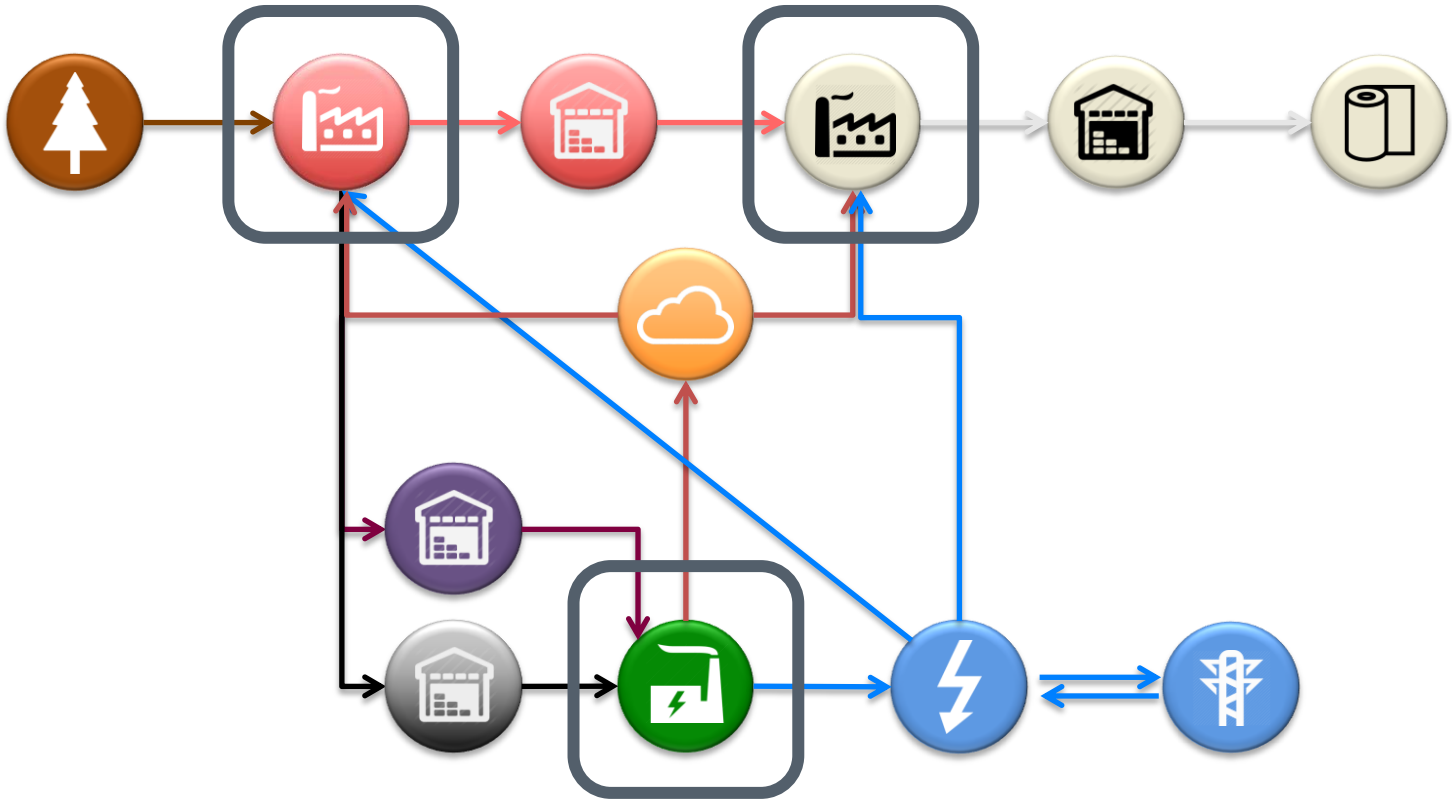
… on the different key timeframes

Strategic Optimization	Reserve Optimization	Scheduling Optimization	Real-time Optimization
			
• Optimal electricity contract • Optimal investment in flexibility assets	• Optimal choice of flexibility products and volumes • Optimal power and energy price	• Optimal scheduling of electricity load • Optimal planning of CHP unit	• Optimal imbalance minimization • Optimal activation management

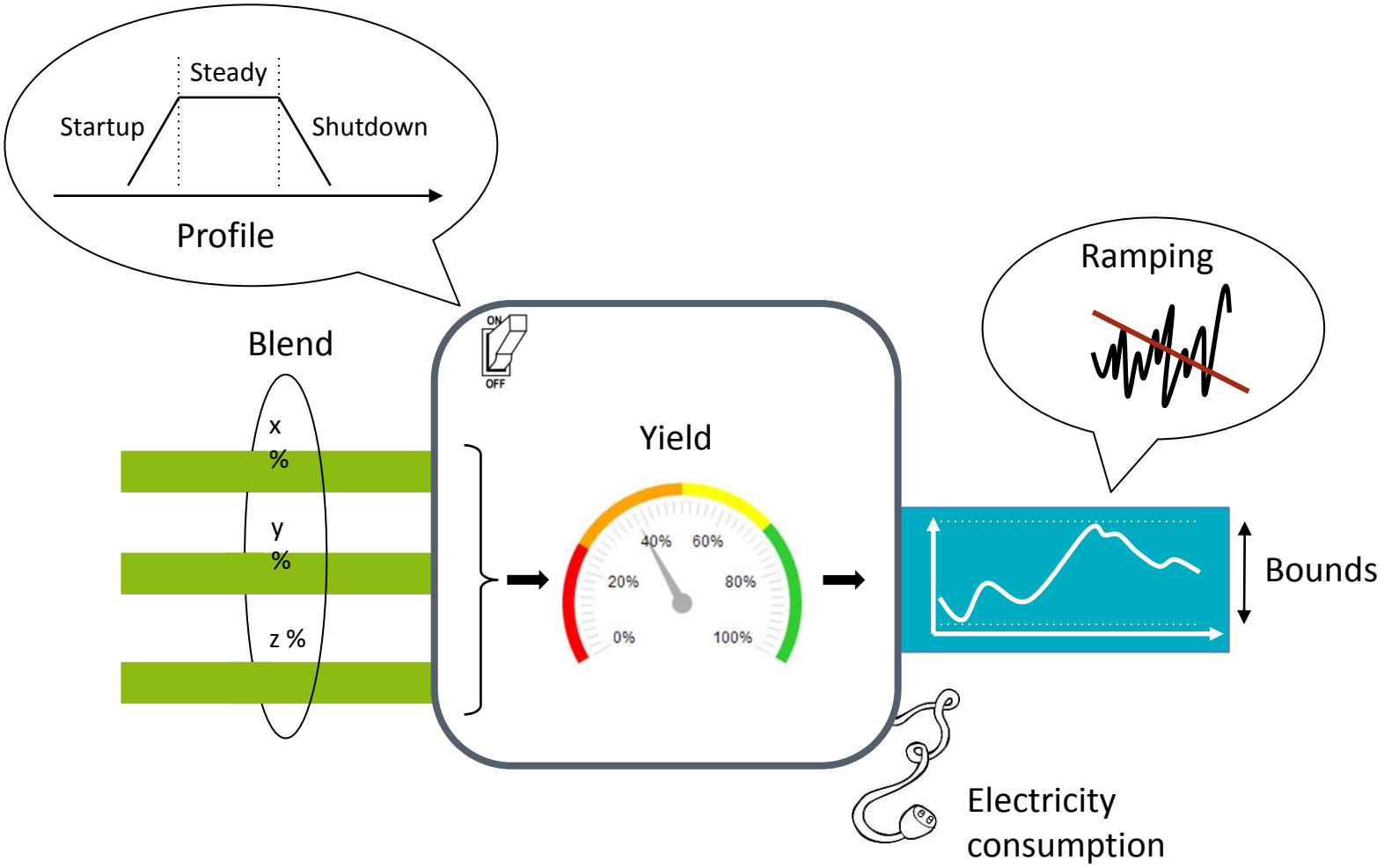
1. Demand Response: Opportunities and challenges for industrial sites
   A. The market aspect: Where to value my flexibility ?
   B. The process aspect: Where to find and how to manage my flexibility ?

2. Advanced Analytics to make the most out of energy flexibility

An complex **integrated optimization model** of the plant must be solved



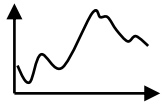
Modelling industrial processes

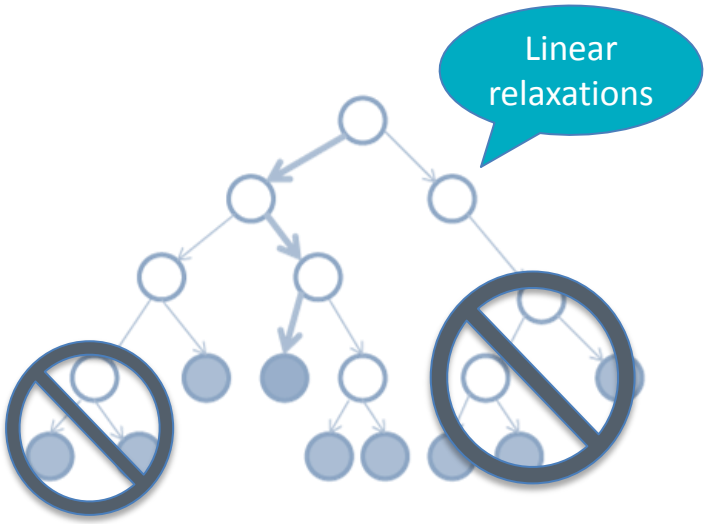


Mixed Integer Programming (MIP) for industrial processes

Modeling an industrial process

- Mostly continuous variables to model quantities (e.g. flows between processes)
- Some binary variables, to capture the discrete nature of some decisions (e.g. on-off status)
- Usually linear(isable) constraints (e.g. piecewise linear representation of the yield of the machines)





Finding the optimal set of decisions

- Difficult problems: non-convex, no polynomial-time algorithm
- In practice, with a good solver, **global optimum** is found within a few minutes
- Widely used branch-and-bound algorithm: recursive tree search of binary options

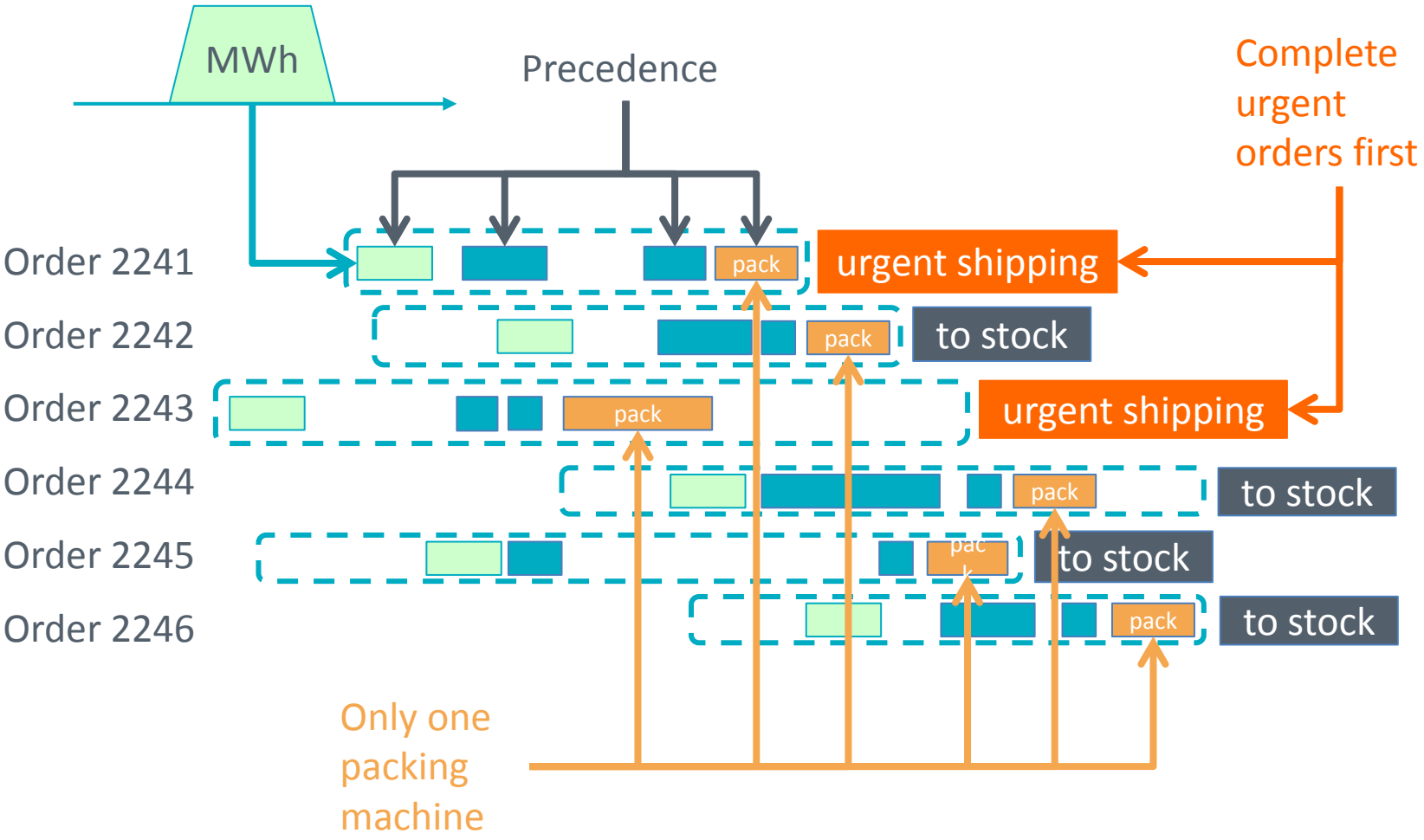
Some technical challenges arising from MIP

- **Solving time** may rise exponentially with the number of binary variables and the addition of coupling constraints

- Ill-conditioning and **numerical difficulties** are likely to arise with data of poor quality

- Some processes are better represented by **non-linear constraints and integer variables** (i.e. batch processes).

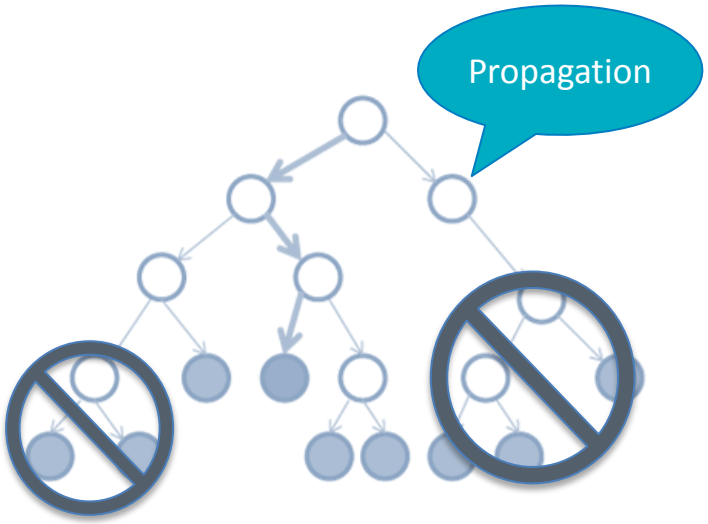
Modelling batch processes



Constraint Programming (CP) for batch production

Modeling a production unit of a batch process

- Only discrete variables, to model machines performing activities as well as start and end time of activities
- Need for disjunctive constraints: at most one activity scheduled on a given machine at any time, stock evolution, setup times,…
- Complex precedence and transition constraints



Finding the optimal set of decisions

- Difficult problems: highly non-linear, no known polynomial-time algorithm
- In practice, with a good solver, **very good solution** is found within a few minutes
- Widely used propagation algorithms: do not explore decisions leading to a dead-end

N-SIDE
OPTIMIZING YOUR DECISIONS

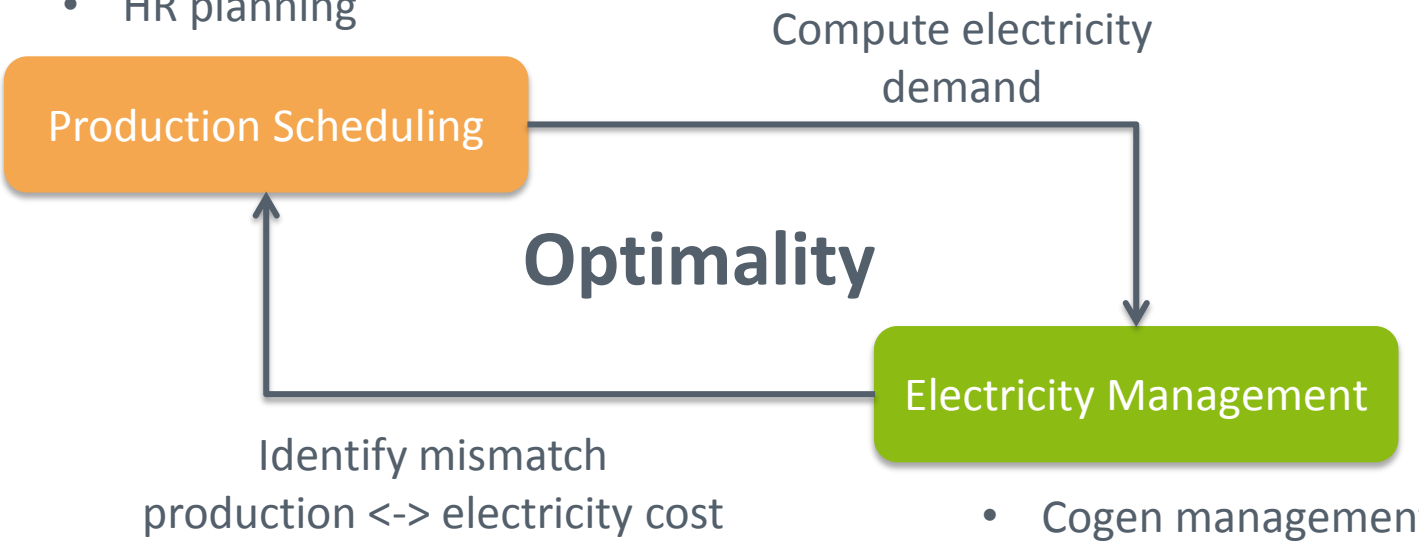
Some Technical challenges arising from CP

- Algorithmic efficiency strongly depends on how production has been modelled using CP constraints
  - Several models are possible
  - Good model may be millions of time faster than bad ones
  - Requires expertise

- Constraint programming enables to exploit knowledge humans have of the production process
  - Advantage: leads to more efficient algorithms
  - Disadvantage: no automatic configuration with no brain efforts
  - Advange by far worth the effort

The resulting integrated optimization problem is solved using decomposition techniques

- Start of batch production
- Machine usage
- HR planning



- Cogen management
  - When to turn on/off
  - Needs of by-products
- Total energy cost

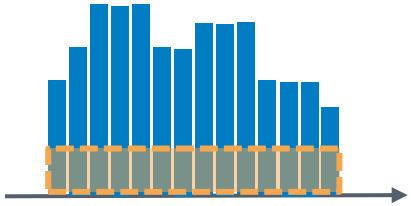
The model should take into account multiple markets and time frames

Scheduling Optimization

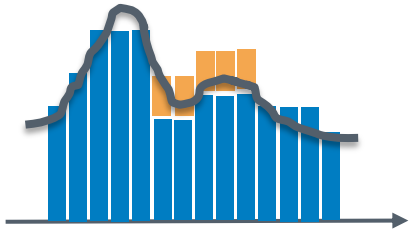
Real-time Optimization

Day-ahead Market

Nominations on DAM



Respect balance

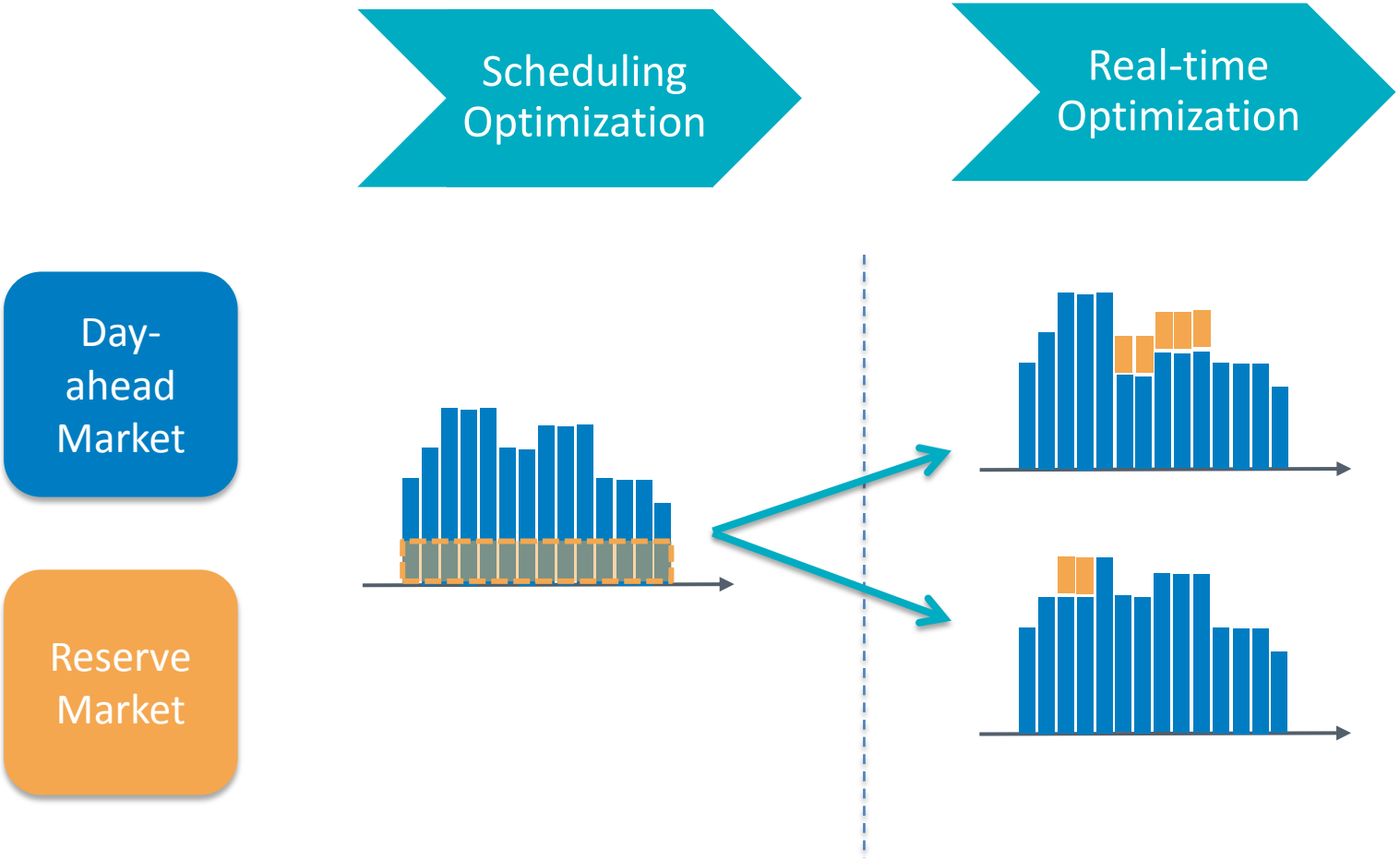


Reserve Market

Bid interruptible consumptions on the reserve market

Choose which processes to stop in response to an activation

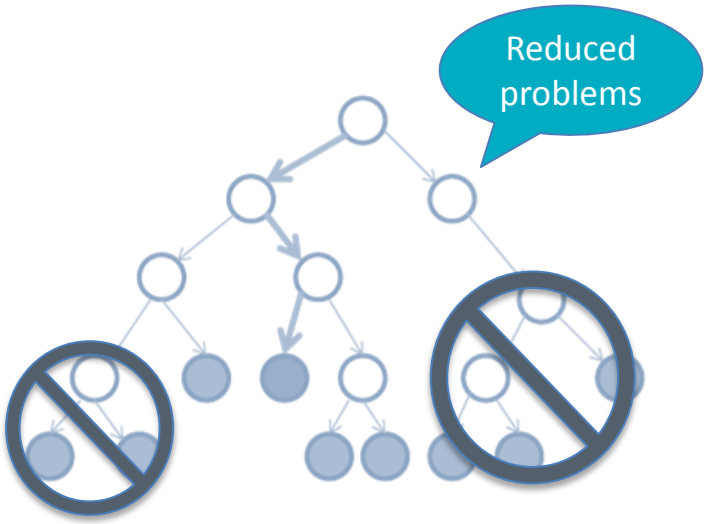
Real-time activation is **uncertain** when committing a schedule



Multi-Stage Stochastic Programming (MSSP) for multi-market optimization

Multi-market modelling

- Multiple real-time scenarios should be considered
- Non-anticipativity constraints: scheduling decisions should be taken commonly for all real-time scenarios



Finding the optimal set of decisions

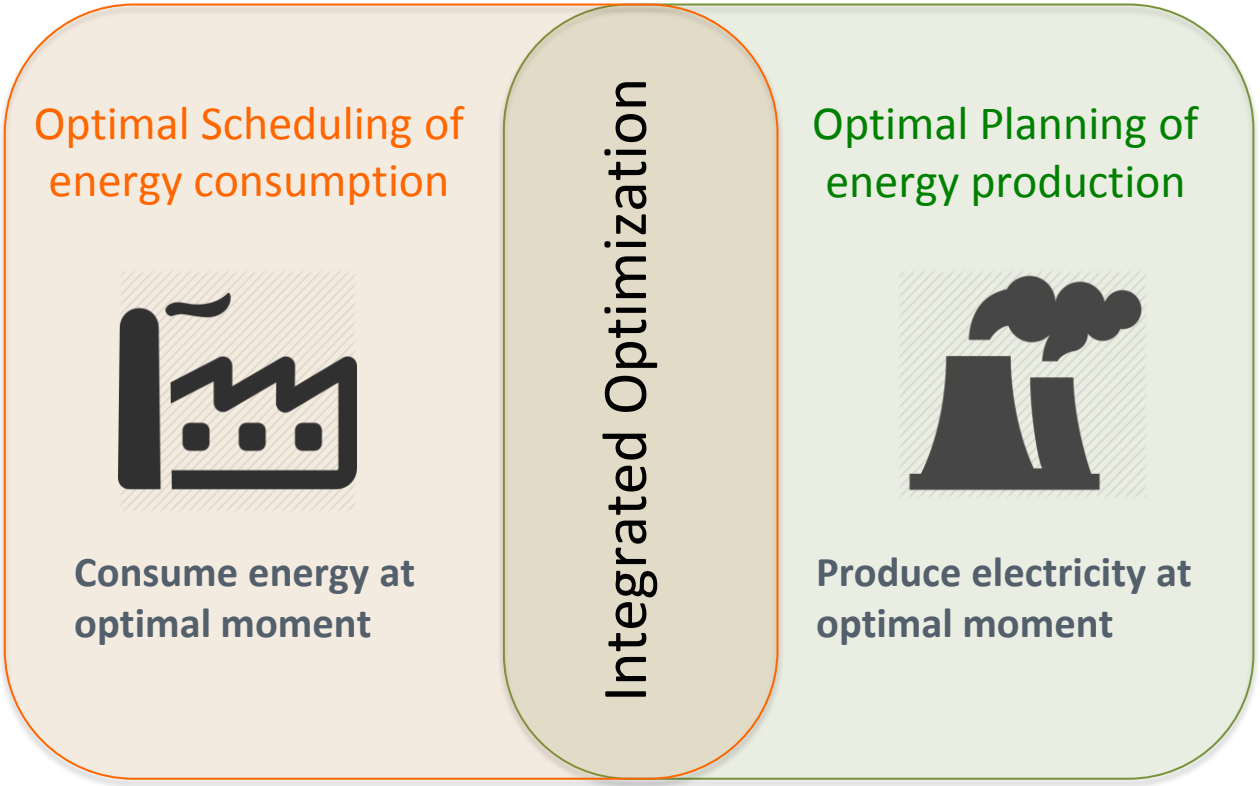
- Difficult problems: non-convex, no polynomial-time algorithm
- In practice, with a good solver, **global optimum** is found within a few minutes
- Widely used decomposition algorithm: solve a reduced problem and add only the violated constraints

Technical challenges arising from MSSP

- **Problem size** rises exponentially with the number of scenarios.

- Generating the minimal number of **relevant scenarios** is crucial

Helping industries get the full value of their energy flexibility thanks to advanced analytics



Thank you !

N-SIDE
Watson & Crick Hill Park – Bldg. H
Rue Granbonpré, 11
B- 1348 Louvain-la-Neuve

Aurélien Crucifix
Consultant
+32 476 31 35 95
acr@n-side.com

Sudheendra Gunthur
Business Development Manager
+32 477 99 45 02
sgu@n-side.com