Multiobjective optimization of a food process based on expert knowledge Example of 0.1 μm skim milk microfiltration

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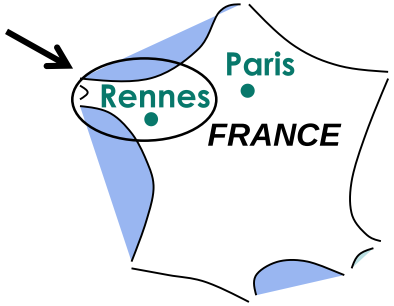
Maëllis Belna[1,2,3]*, Amadou Ndiaye[2], Franck Taillandier*[4], Christophe Fernandez[2], Louis Agabriel[3]

Geneviève Gésan-Guiziou[1]

[1]STLO, INRAE, Institut Agro, 35 Rennes, France
[2]I2M, INRAE, Université de Bordeaux, 33 Talence, France
[3]Boccard, Research and Development, 35 Montauban-de-Bretagne, France
[4]RECOVER, INRAE, 13 Aix-Marseille Université, France

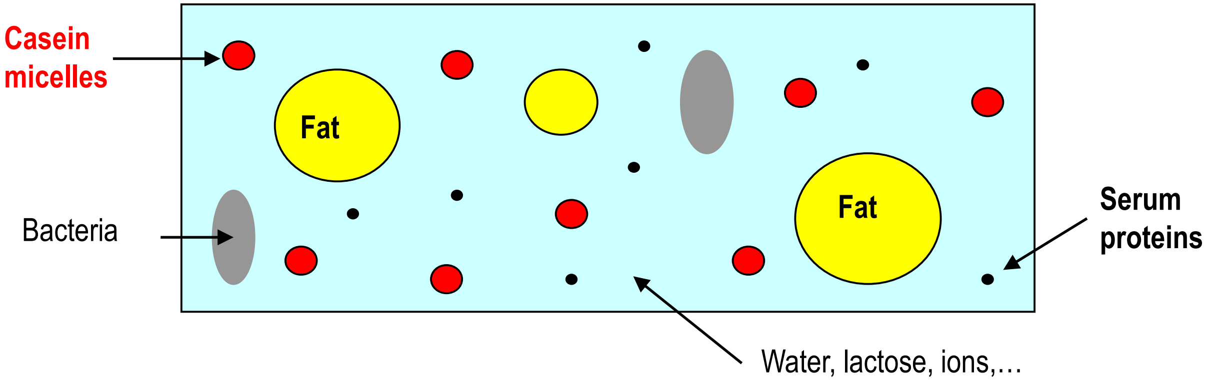


Optimal Project (2017-2020):
Optimized design of membrane processes for the production of dairy ingredients

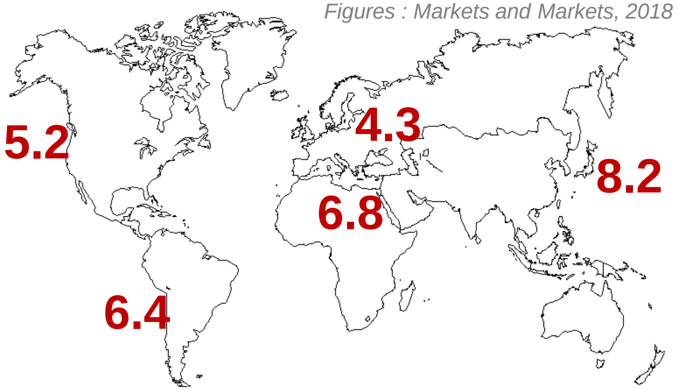
> Economic context

- Membrane processes

  Dairy sector : estimated market growth of 4-8 % between 2018 and 2023



Figures : Markets and Markets, 2018



%$ membrane market in dairy sector

> Economic context

- Membrane processes

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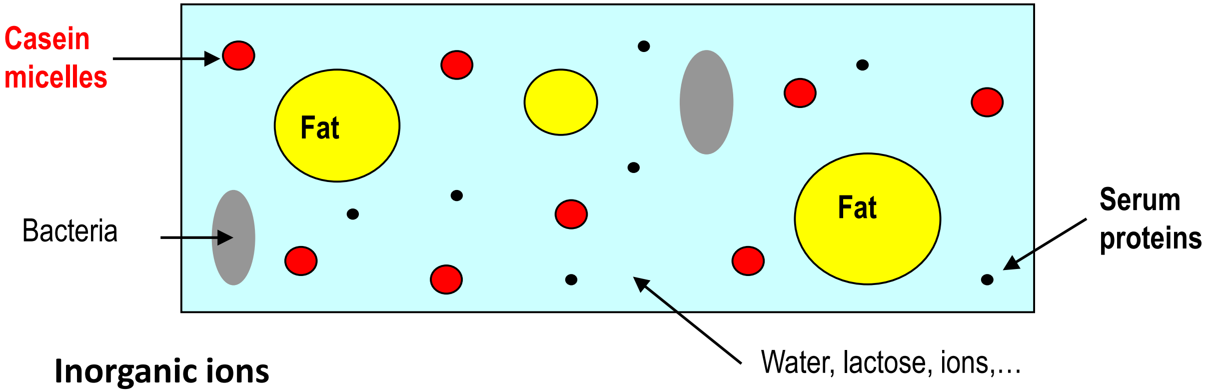

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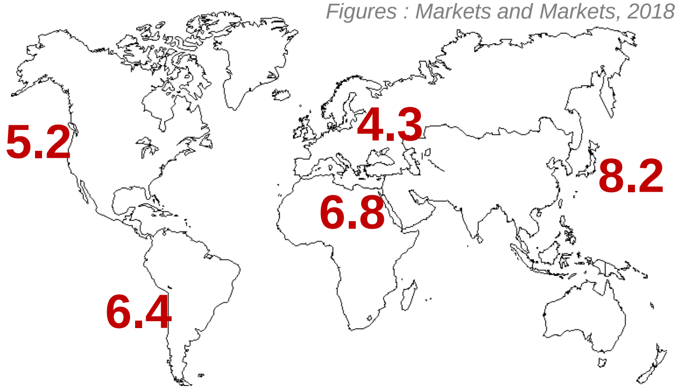

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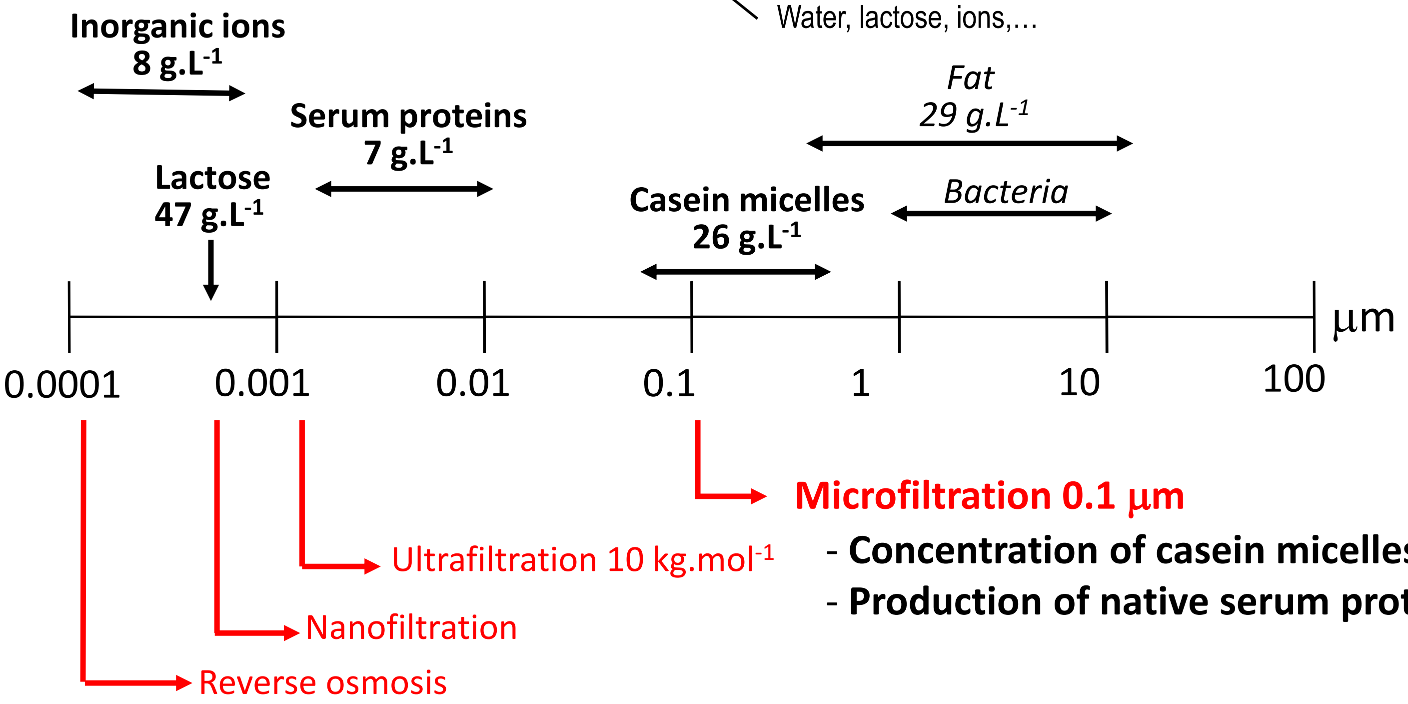


Microfiltration 0.1 µm

- **Concentration of casein micelles → Cheese making** 
- **Production of native serum protein concentrates → Ingredients**  

> 0.1 µm Skim milk MF technologies

Membranes

Ceramic

Polymeric

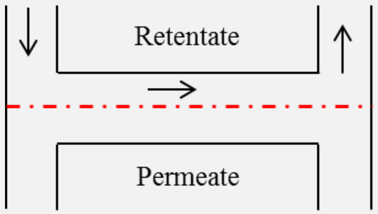
Various Operating Conditions

- **Temperature**
- **Volume Reduction Ratio, VRR**
- **Transmembrane pressure**
- **Crossflow velocity**
- **…**

Various Technologies

Conventionnal, SW

$P_{re} > P_{ro}$

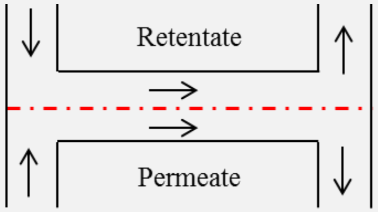


$P_{pe} = P_{po}$

UTP

Uniform transmembrane pressure

$P_{re} > P_{ro}$



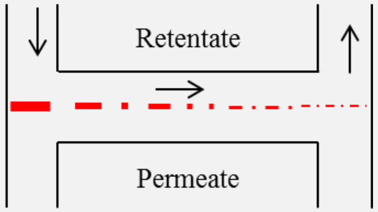
$P_{pe} > P_{po}$

Circulation of permeate

GP

Permeability gradient

$P_{re} > P_{ro}$



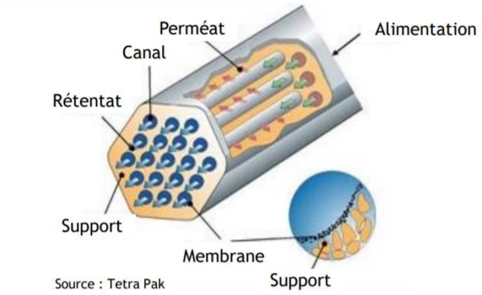
$P_{pe} = P_{po} \neq 0$ bar

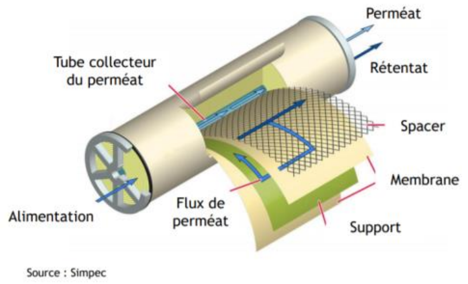
Permeate under pressure

> MF technologies : conflicting objectives

Multiple technologies

- ≠ Membrane configurations & materials
- ≠ Operating conditions
- ≠ Filtration performances





Performances for VRR = 3 VRR : Volume Reduction Ratio	**Ceramic**		**Polymeric**
	UTP	GP	SW
Filtration temperature	50°C	50°C	12°C
Permeation flux	75-100 $L.h^{-1}.m^{-2}$	75 $L.h^{-1}.m^{-2}$	10 $L.h^{-1}.m^{-2}$
Serum proteins transmission	65-70 %	60 %	20-50 %
Membrane lifetime	10 years	10 years	3 years
Membrane costs	+	++	- -
Example of production for 24h	At 50°C : 2 productions of 8h + 2 cleanings		At 12°C : 1 production of 20h + 1 cleaning

> Current approaches to guide the design of the milk MF plant

- ## In the scientific litterature

  - Single optimization objective: experiments that reveal the influence of one variable on a group of chosen variables/ojectives
  - Few studies on optimization of several objectives, but not achieved simultaneously
  - No comparison of the different MF technologies (Except : Zulewska et al, 2009: but comparison in one set of operating conditions)

- ## At the industrial level

  - Based on the know-how of operators and available expert knowledge,
    = f^n (history, experience equipment manufacturer)
  - Lack of data, knowledge to compare the three filtration technologies (in terms of fraction compositions, operating variables and design of the plant)

MF process has never been optimized to integrate conflicting stakeholder objectives

> Objective

Develop a **multiobjective optimization approach** to design 0.1 µm milk MF …

Product
Milk

Membrane type

Processing technology

Operating conditions

Multiple MF designs but no existing rules to guide the design of the milk MF plant

?

Technical objectives

Economic objectives

Environmental objectives

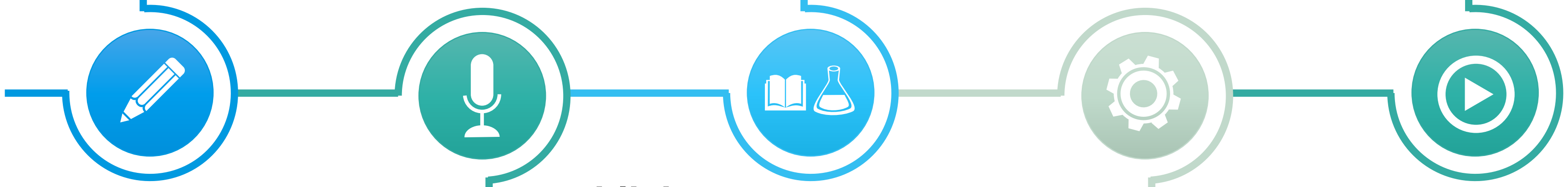
Conflicting objectives of MF

Lack of predictive MF performance models

… based on **expert knowledge integration**

Input of Artificial Intelligence

> Methodology
Multi-objective optimization using expert knowledge



01 **Define the MF optimization problem**

02 **Establish “influence relations”**

03 **Acquire data on the MF process**

04 **Model the optimization objective functions**

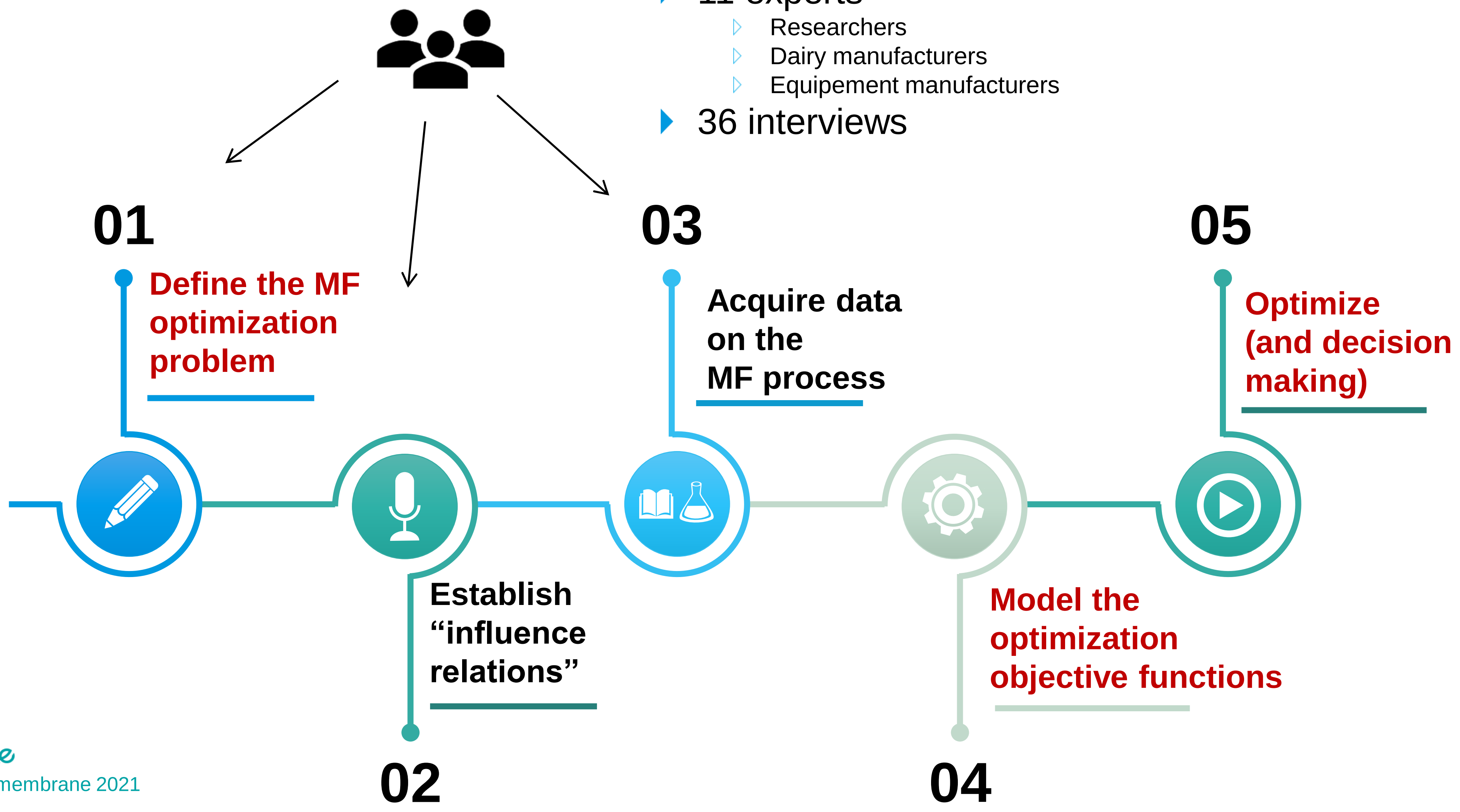
05 **Optimize (and decision making)**

> Methodology
Multi-objective optimization using expert knowledge

Gather knowledge from experts

- Semi-structured interview
- 11 experts
  - Researchers
  - Dairy manufacturers
  - Equipement manufacturers
- 36 interviews

Belna et al., 2020



> Define the optimization problem

01

- **Scope of the optimization :** MF optimization

skim milk 0.1 µm microfiltration	characteristics of milk = constant	TMP = constant	filtration temperature = 12°C polymeric 50°C ceramic	casein permeation = not considered	cleaning & desinfection = efficient and reproducible

- **Optimization objectives**

$\max CD_{CN,r}$ — *Casein concentration in retentate on dry basis*

$\max CD_{SP,p}$ — *Serum protein concentration in permeate on dry basis*

$\max \eta_p$ — *Serum protein protein recovery ratio*

$\min CI$ — *Investment cost*

$\min CPR$ — *Production cost*

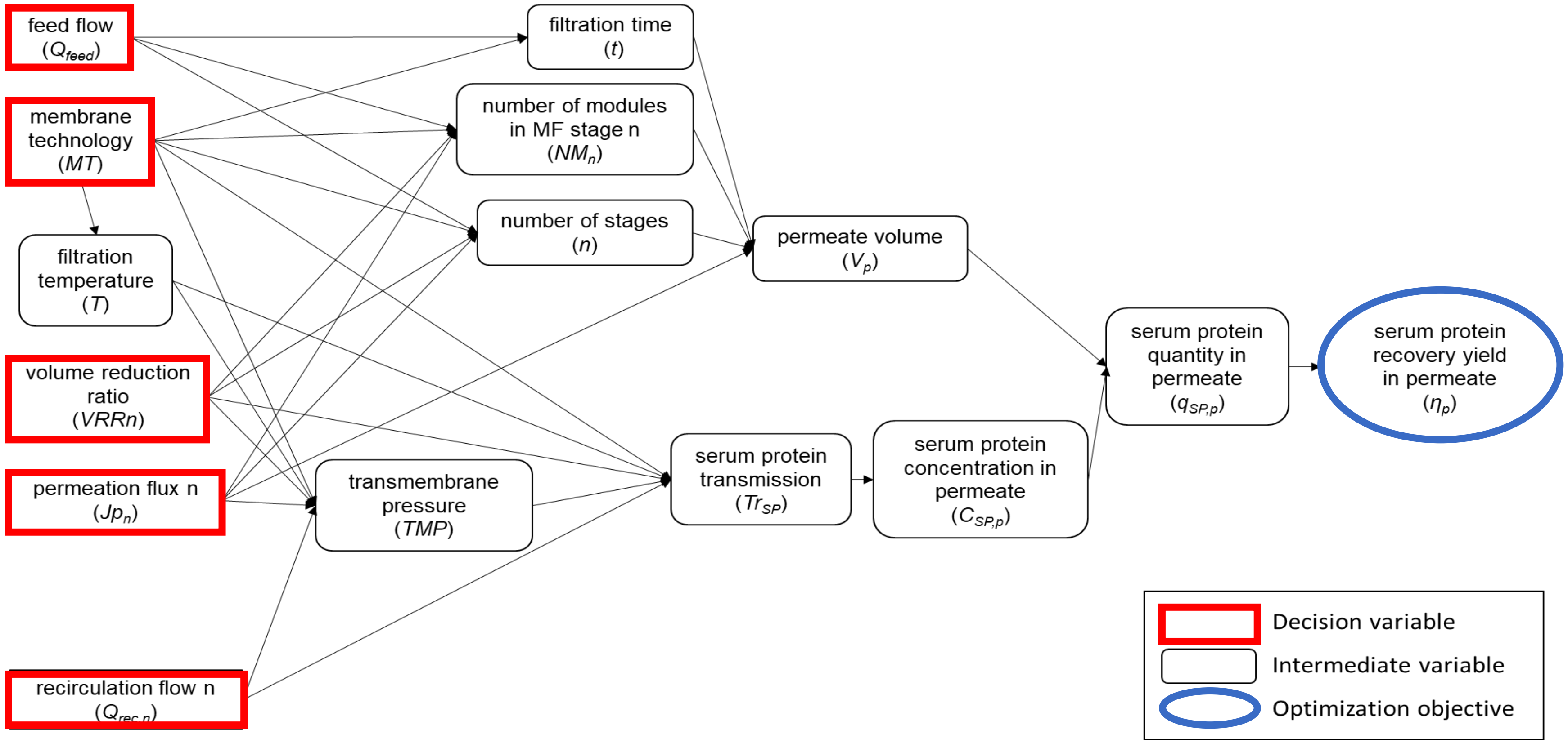
Casein micelles
Serum proteins

> Establish "Influence relations"

02

- 5 optimization objectives
- 6 decision variables
- 31 intermediate variables

Belna et al., 2020



Causal map of the serum protein recovery yield in permeate

$$max\ \eta_p = f(q_{SP,p}(C_{SP,p}(Tr_{SP}),\ V_p(t(Q_{feed}, MT), n, NM_n))$$

> Acquire data on MF process

03

literature

Industrial production datasets

Expert knowledge

Pilot-sacle laboratory data

assumptions

Pilote plateforme STLO
Tetra Alcross MFS-7, TetraPak Filtration System

> Modelling the optimization objective functions

Definition of the equations of the optimization objectives

Equations representative of the MF system

… over the ranges of variation of the existing data

04

Strongly constrained model

> Optimize MF process

05

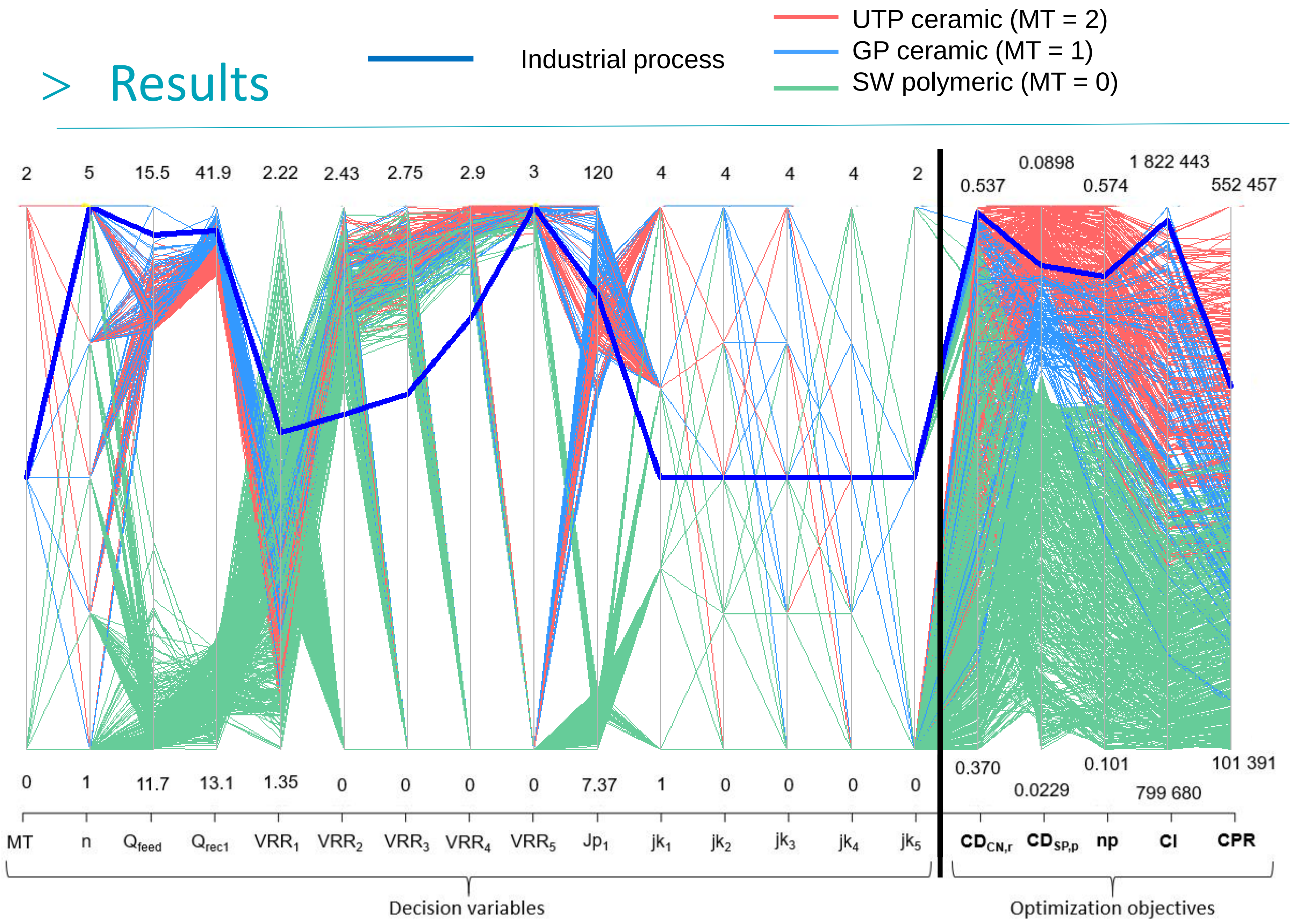
- Optimization → Determination of Pareto front = set of optimal compromises

  Metaheuristics NSGA-II

  Population size was set to 1000 and offspring to 2500
  Distribution parameter was set to 30
  Crossover and mutation operator probabilities set to resp. 0.9 and 0.5
  Tolerances on decision variables, objective functions and constraints set resp. to 0.1, 0.01, and 0.
  Termination criterion was the maximum number of evaluations, set to 5 000 000.

- Multi-stage MF plant
- Volume of milk treated per day : V_{feed} = 230 m^3 / day

> Results

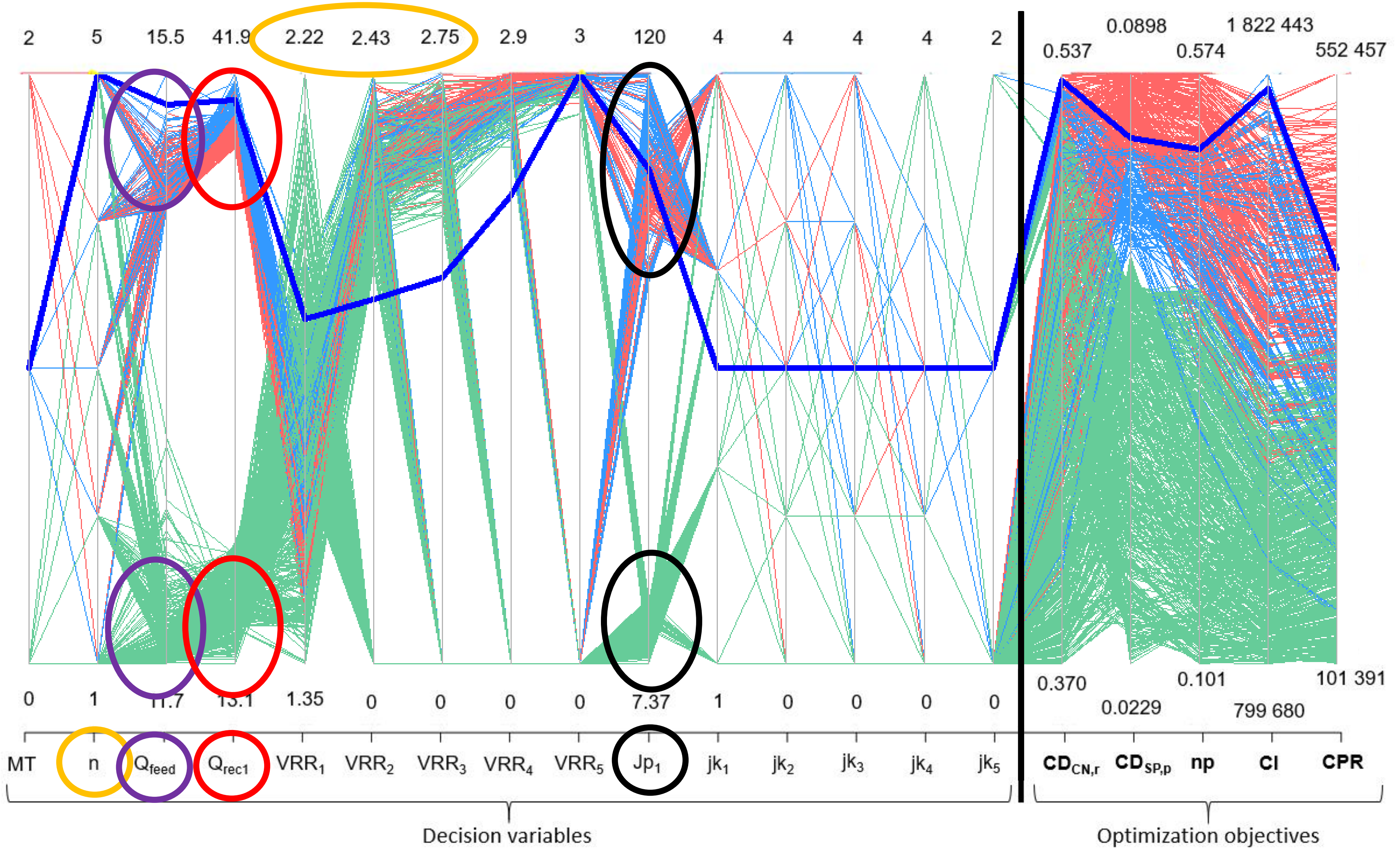


Q_{feed} ($m^3.h^{-1}$) ; Q_{rec1} ($m^3.h^{-1}$) ; Jp_1 ($L.h^{-1}.m^{-2}$) ; CD_{CNr} ($g.kg^{-1}$ DM) ; CD_{SPp} ($g.kg^{-1}$ DM) ; CI (€) ; CPR (€)

05

- Over 1000 Pareto-optimal solutions

> Results



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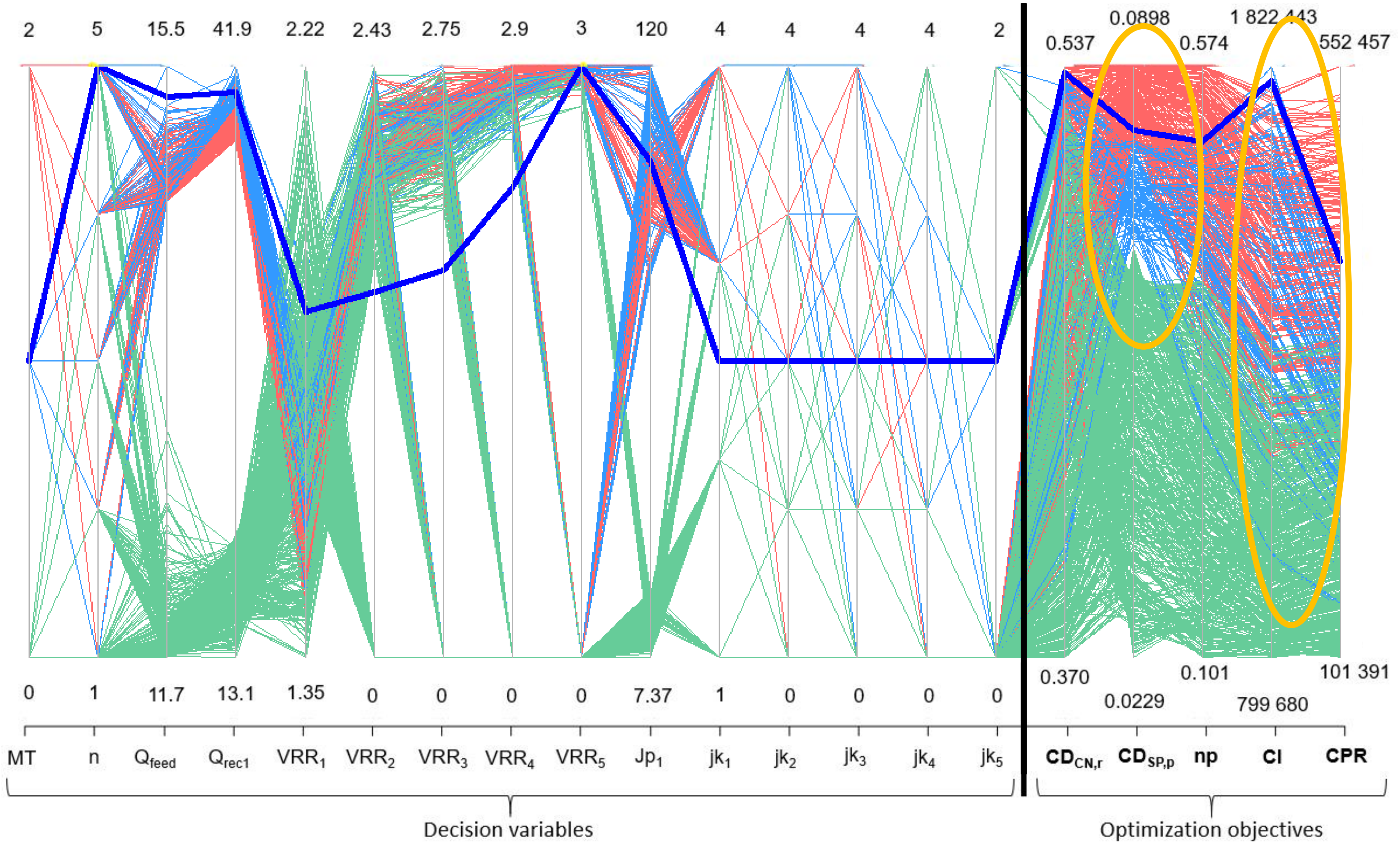
- Over 1000 Pareto-optimal solutions
- Consistent with literature and industrial practices

> Results



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- Over 1000 Pareto-optimal solutions
- Consistent with literature and industrial practices
- Trade-off in the choice of MT: Ceramic membrane compared to polymeric :

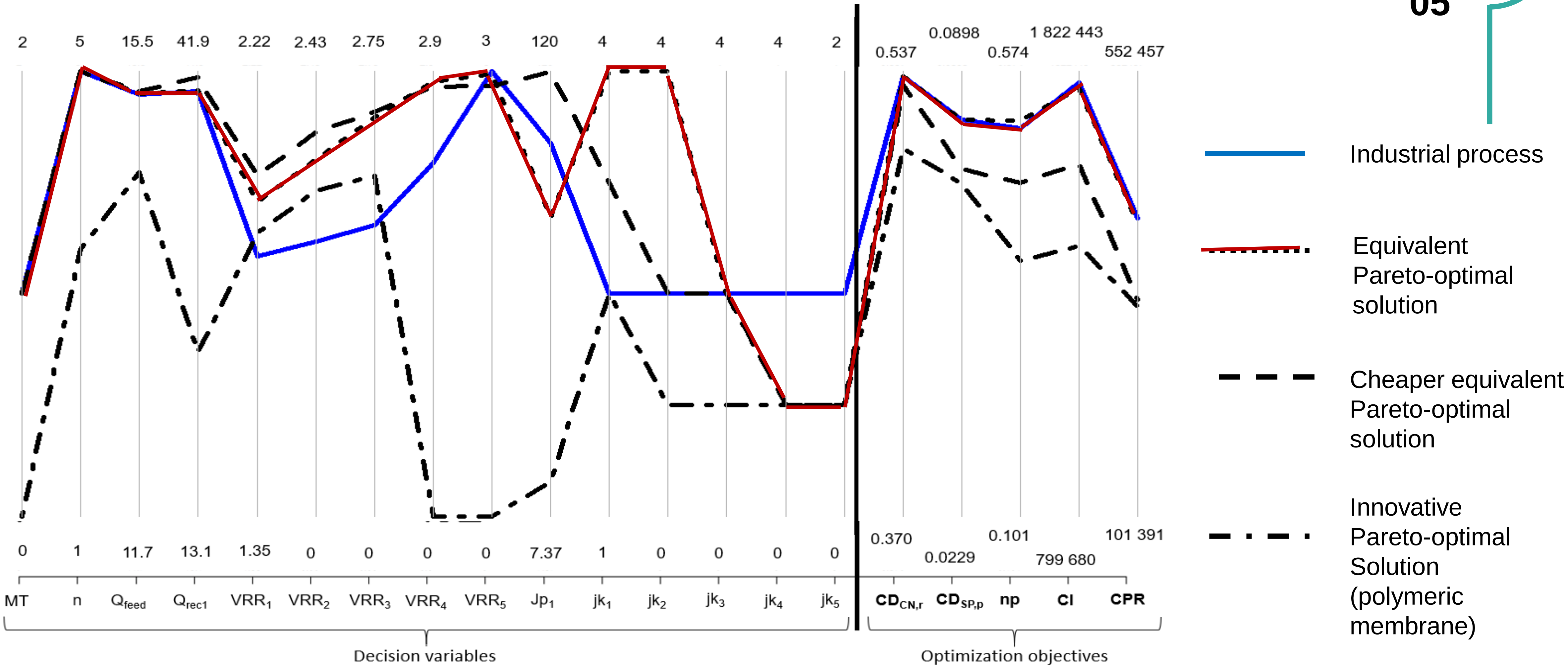
Technical objectives **more efficient**

BUT

More expensive

> Particular Pareto-optimal solutions analysis

05



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> Particular Pareto-optimal solutions analysis

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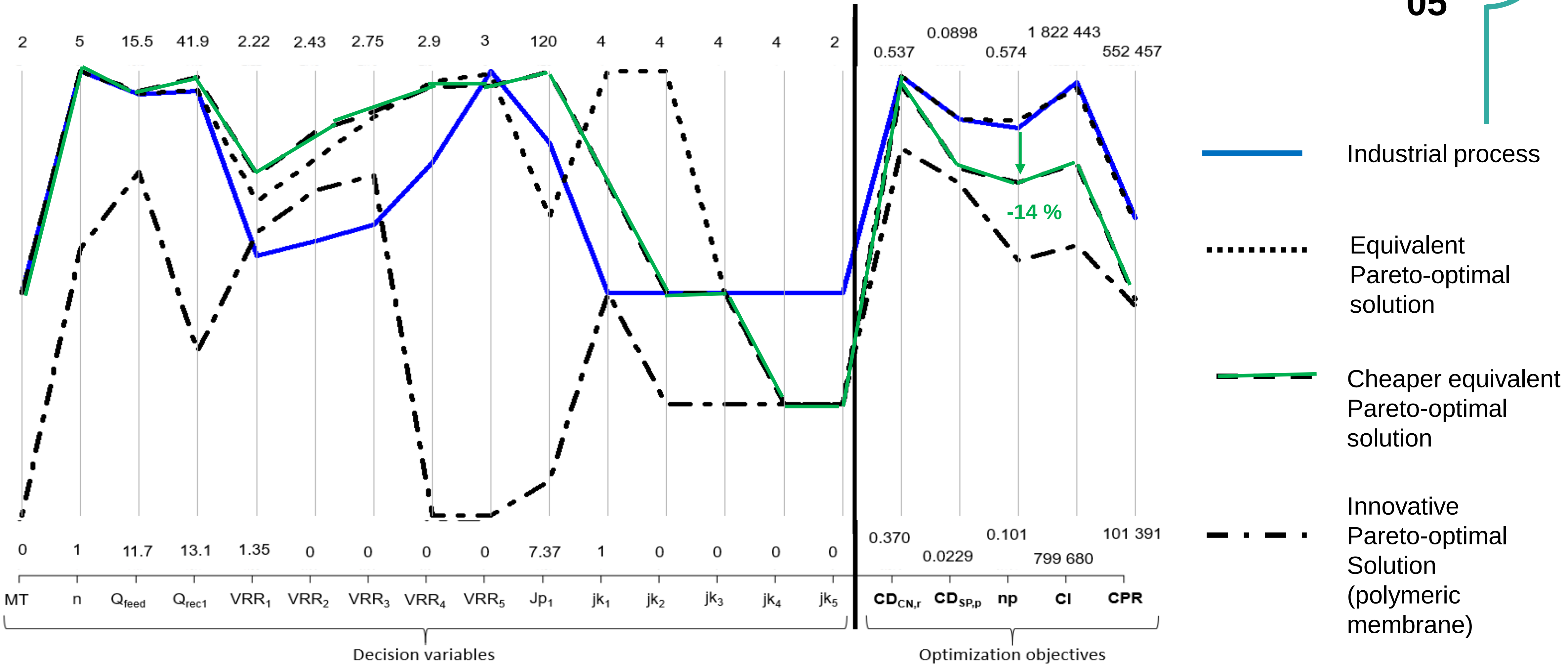

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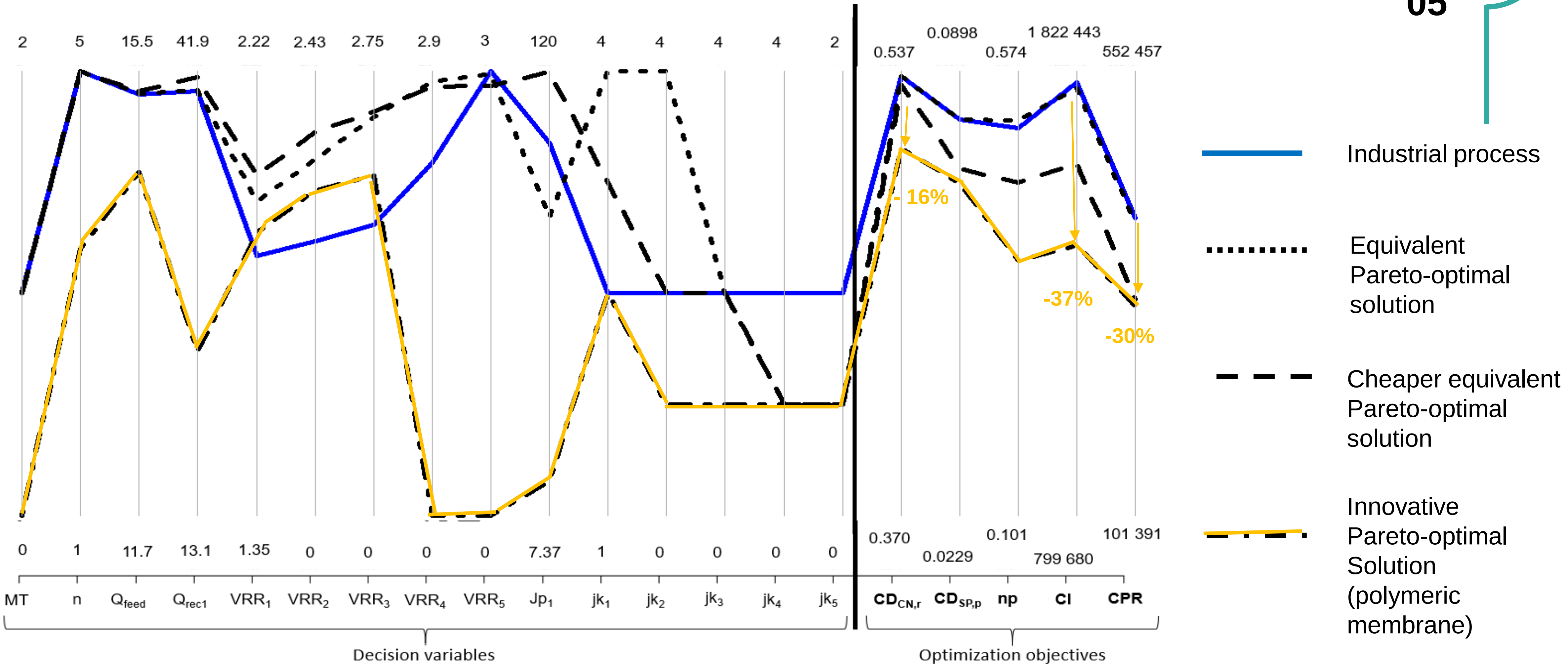

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> Take home Messages

- Proposition of an innovative approach for optimizing milk MF :

  Combining and integrating different types of knowledge
  Modelling the objectives of the optimization problem
  Multiobjective optimization itself

- Optimization provided over 1000 Pareto-optimal solutions

  Solutions close to 'standard ' industrial process
  Solutions with comparable results but at lower costs
  Alternatives and potentially innovative process pathways that need to be validated in order to assess their feasibility at industrial scale

Coupling knowledge integration and optimization is an interesting strategy for solving the multiobjective problem of milk MF
and more generally of any food processes, where the available knowledge is incomplete

On-going work : Multicriteria decision support to guide the decision maker in selection of the preferred solution among the Pareto-optimal solutions

Thank you for your attention !