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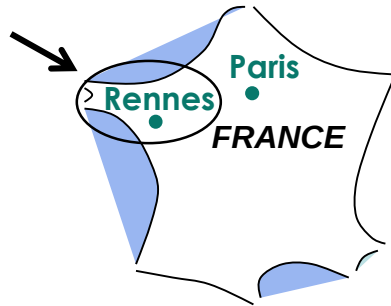
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Multiobjective optimization of a food process based on expert knowledge

Example of 0.1 μm skim milk microfiltration

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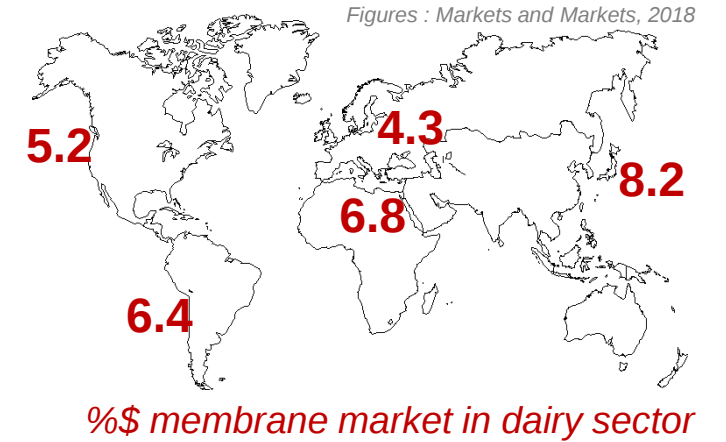
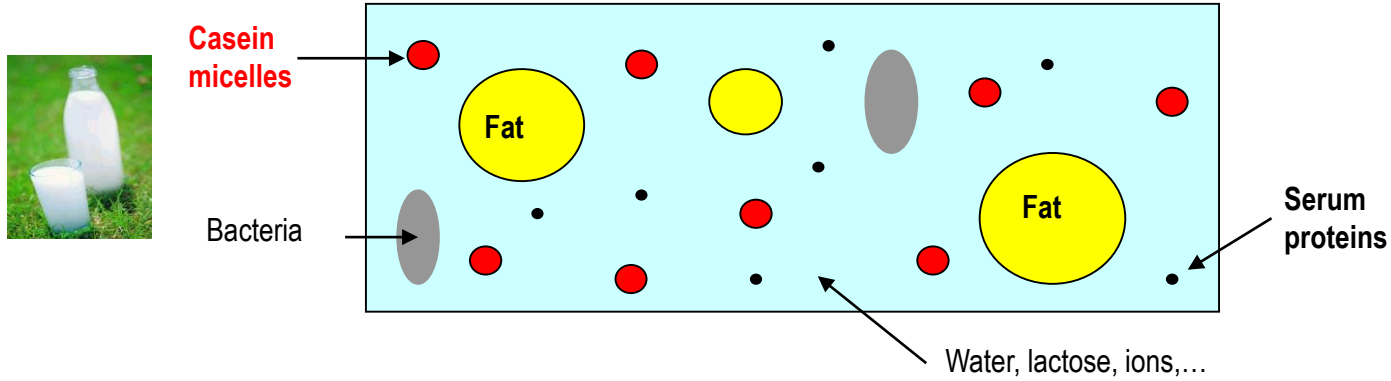
Optimal Project (2017-2020):

Optimized design of membrane processes for the production of dairy ingredients

> Economic context

- Membrane processes

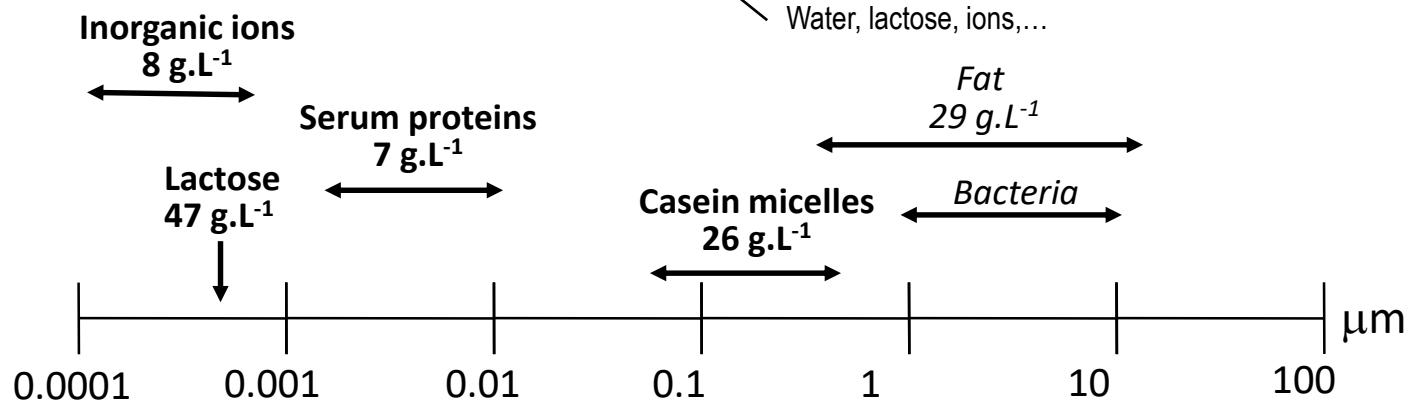
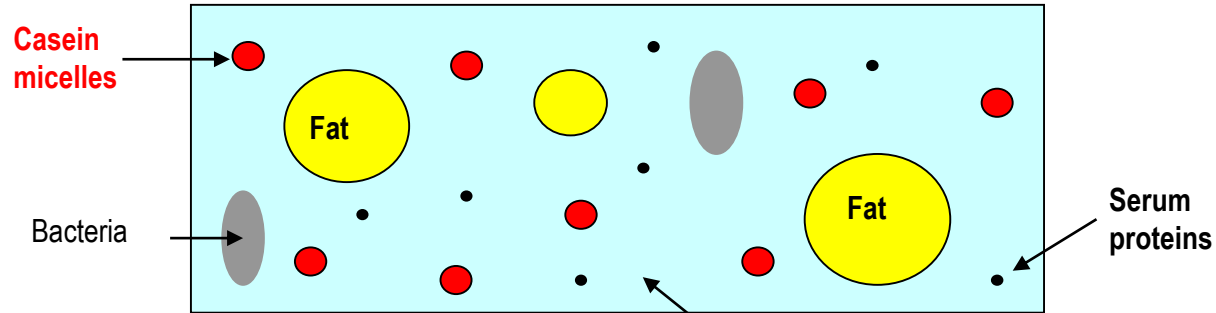
Dairy sector : estimated market growth of 4-8 % between 2018 and 2023



> Economic context

- Membrane processes

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



Microfiltration 0.1 µm

Ultrafiltration 10 kg.mol⁻¹

Nanofiltration

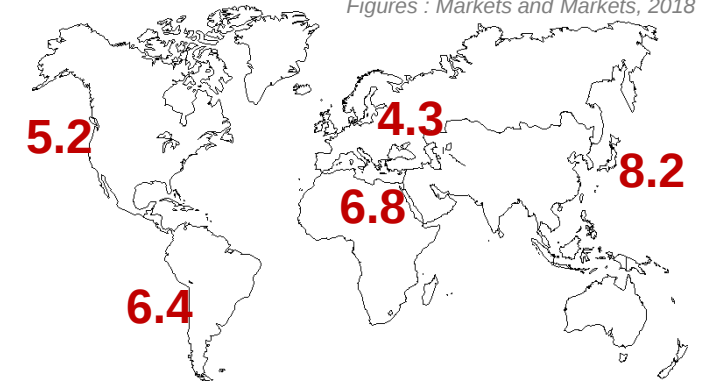
Reverse osmosis

- Concentration of casein micelles → Cheese making

- Production of native serum protein concentrates → Ingredients

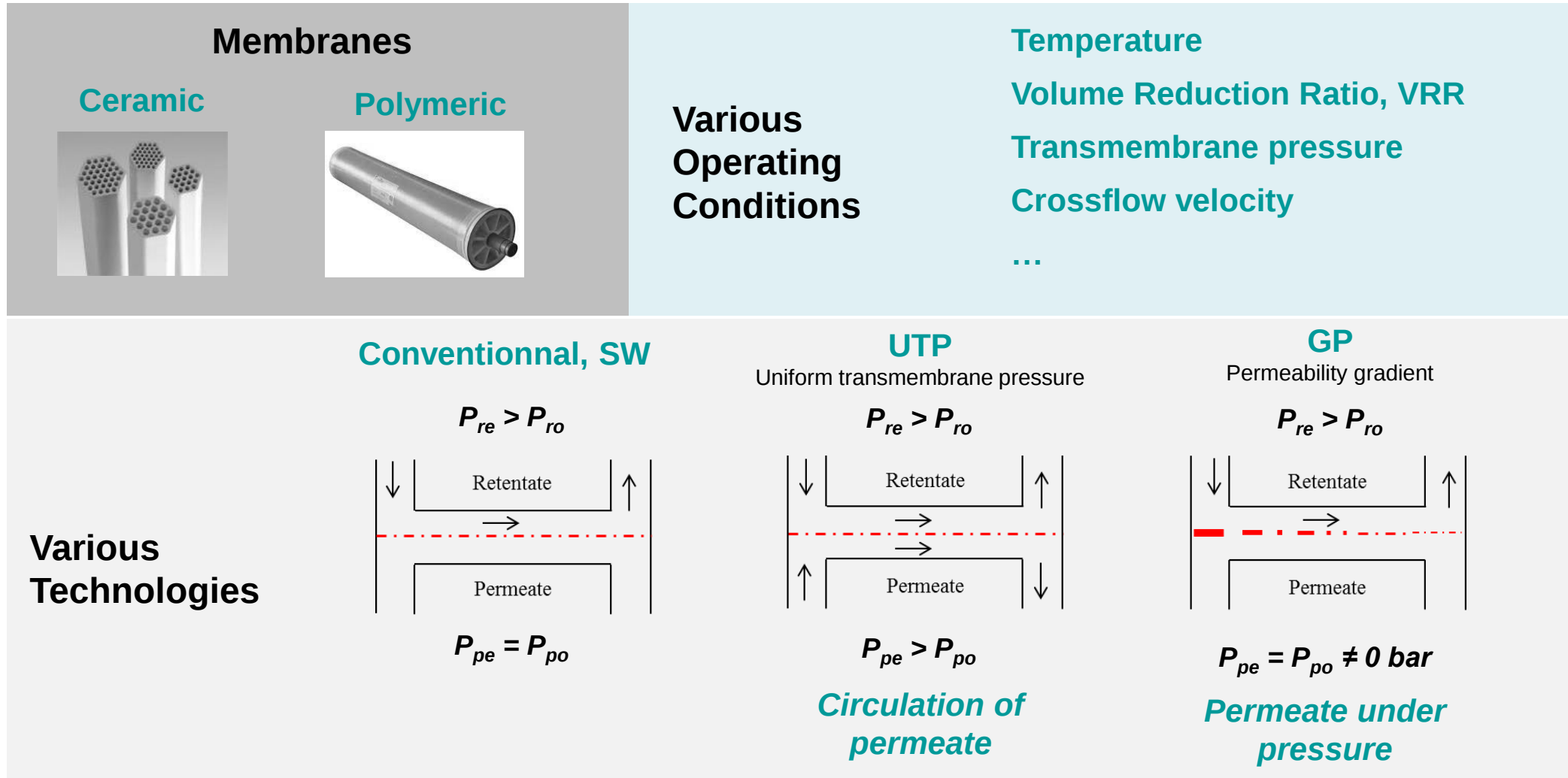


Figures : Markets and Markets, 2018



膜市场在乳制品行业中的百分比

> 0.1 μm Skim milk MF technologies

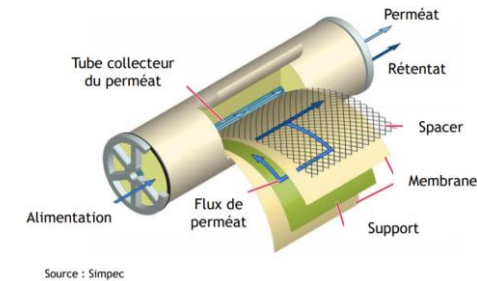
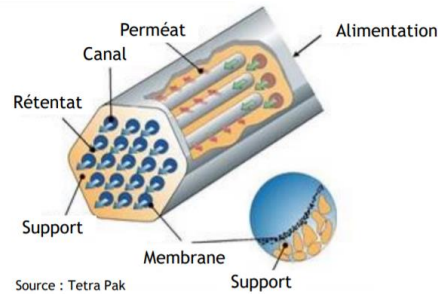


> MF technologies : conflicting objectives

- 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 literature

- Single optimization objective: experiments that reveal the influence of one variable on a group of chosen variables/objectives
- 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 ...

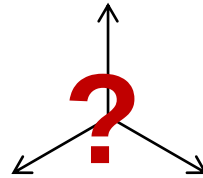
Product **Milk**

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

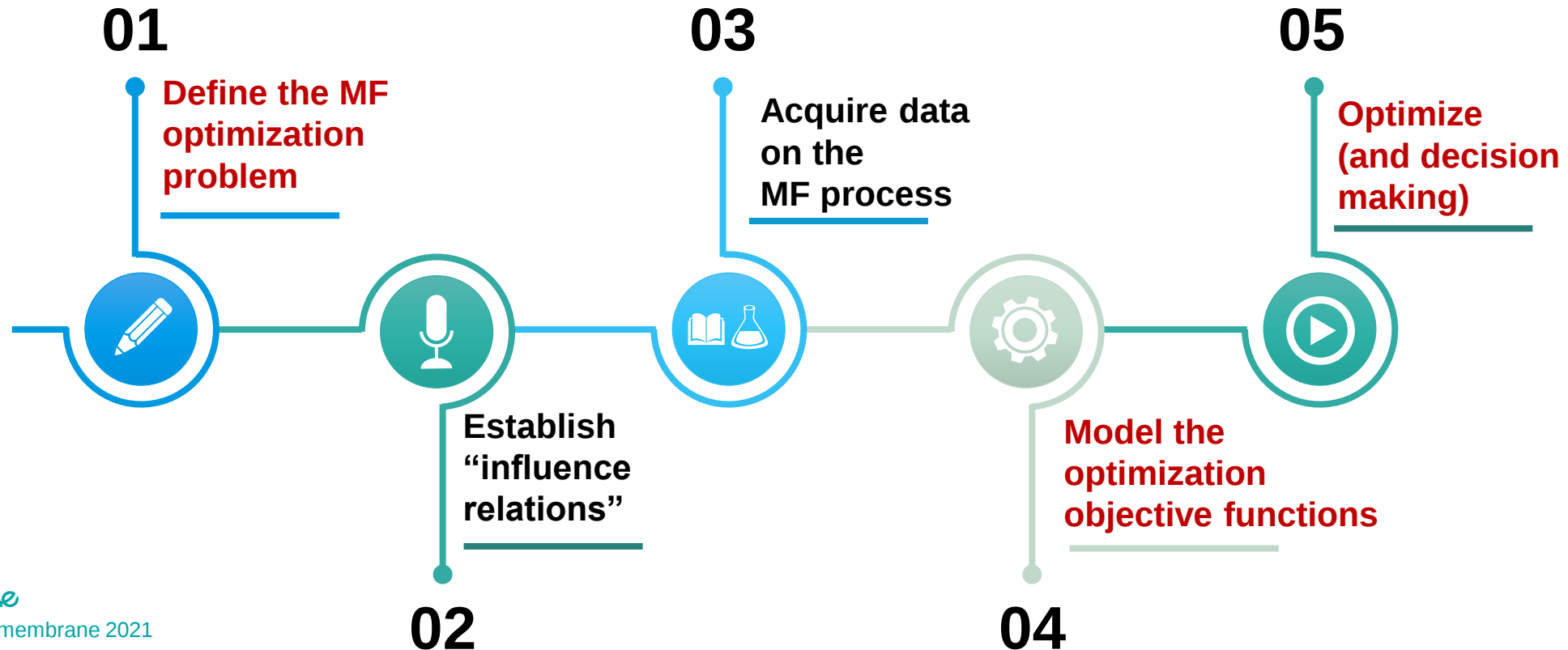
... based on **expert
knowledge integration**

Input of Artificial
Intelligence



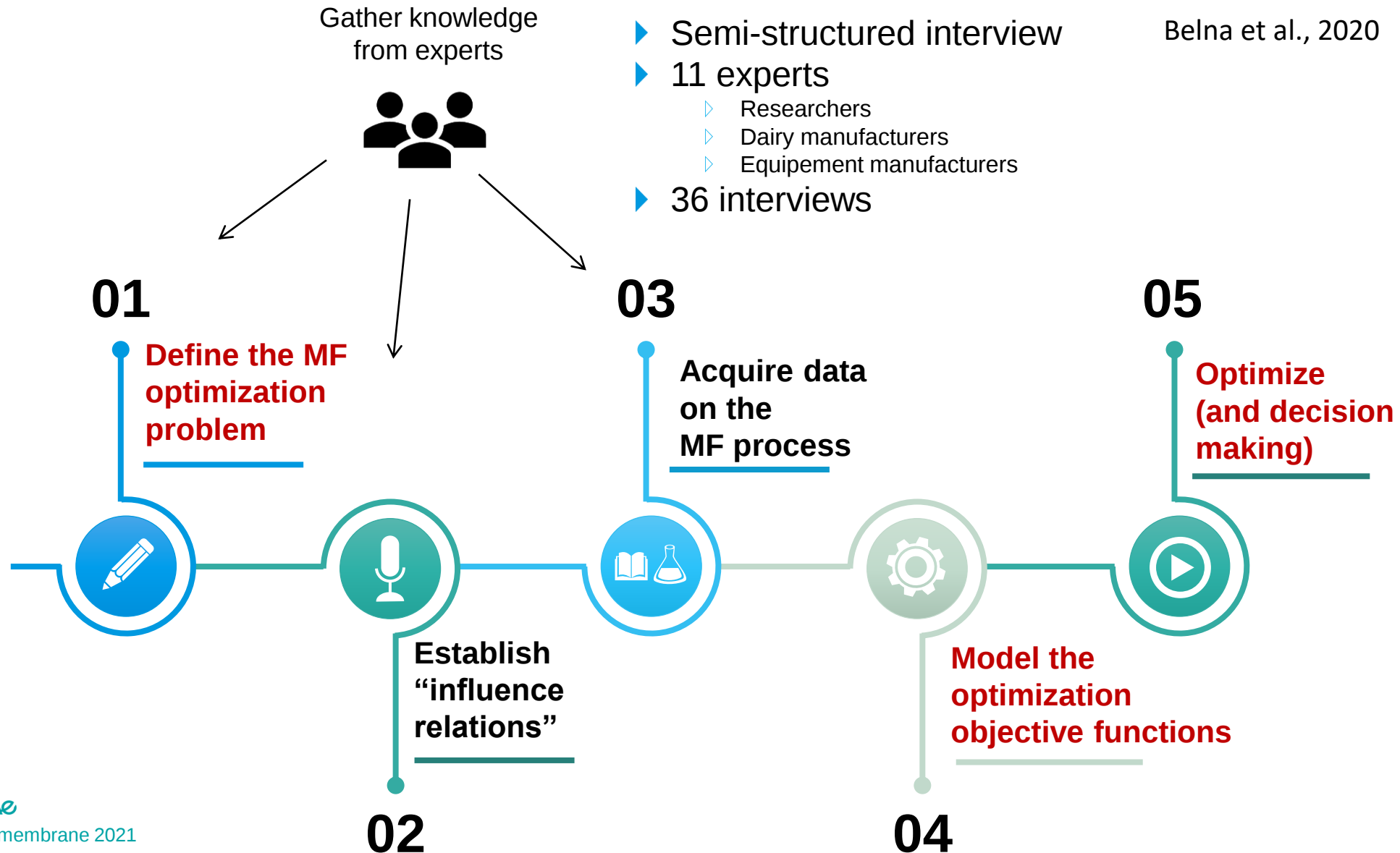
> Methodology

Multi-objective optimization using expert knowledge



> Methodology

Multi-objective optimization using expert knowledge



> 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 & disinfection = efficient and reproducible
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- **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”

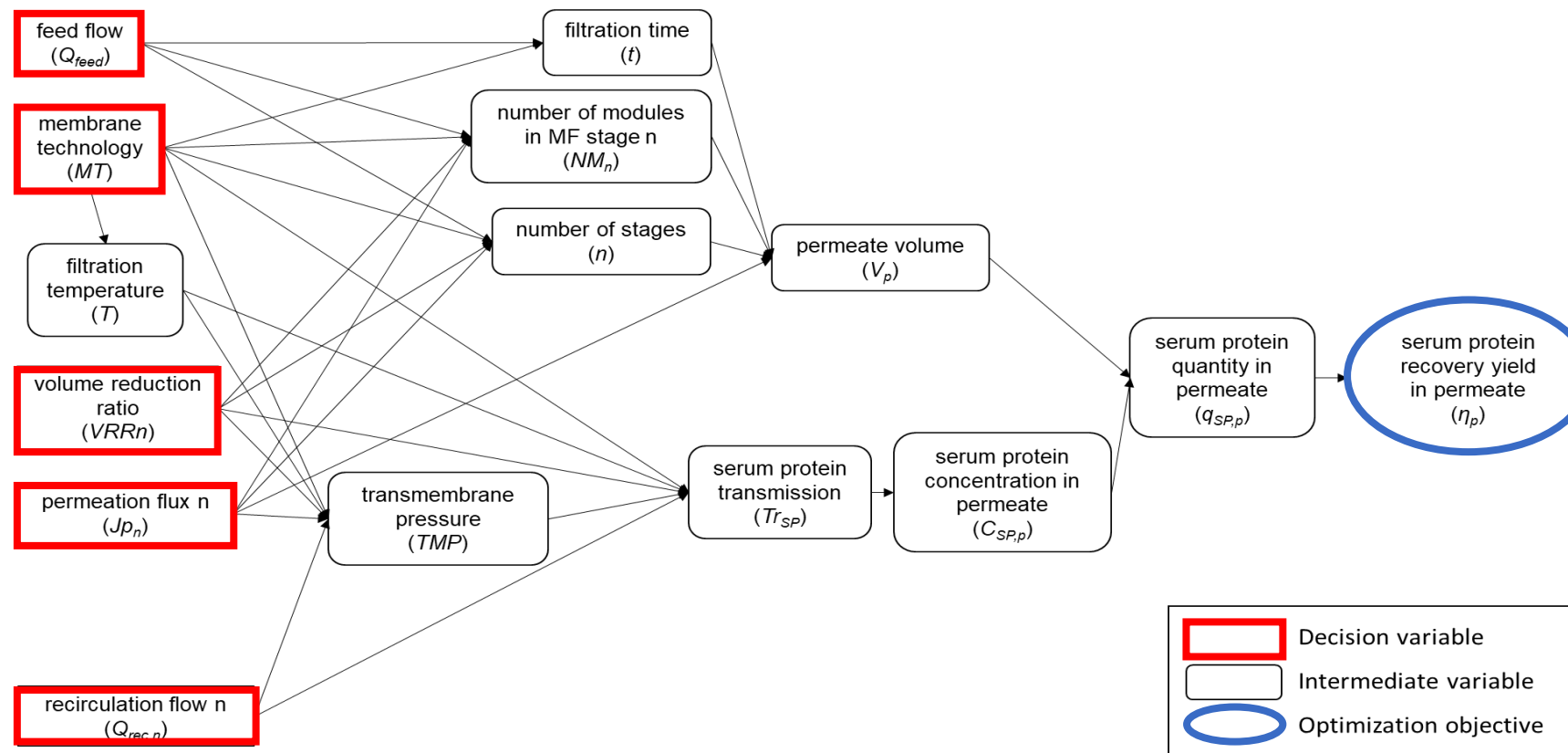
02



Belna et al., 2020



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



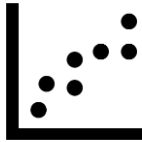
Causal map of the serum protein recovery yield in permeate

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

> Acquire data on MF process



literature



*Industrial
production
datasets*



*Expert
knowledge*



*Pilot-scale
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

Strongly constrained model

04



03



> Optimize MF process



- 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.

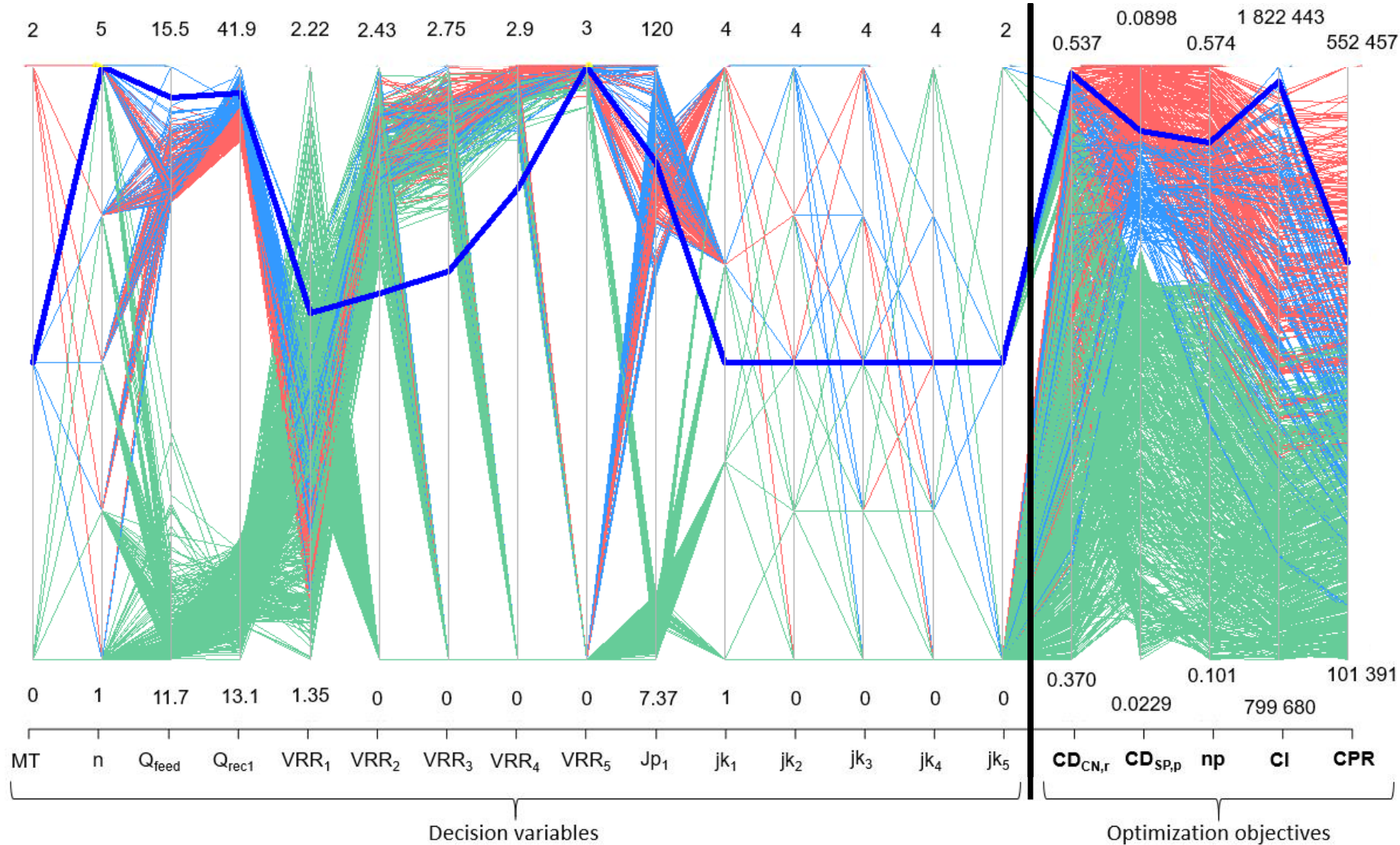
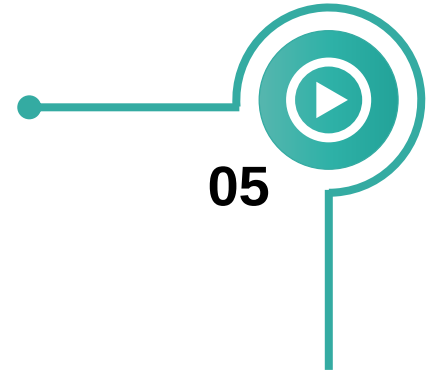
Termination criterion was the maximum number of evaluations, set to 5 000 000.

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

> Results

Industrial process

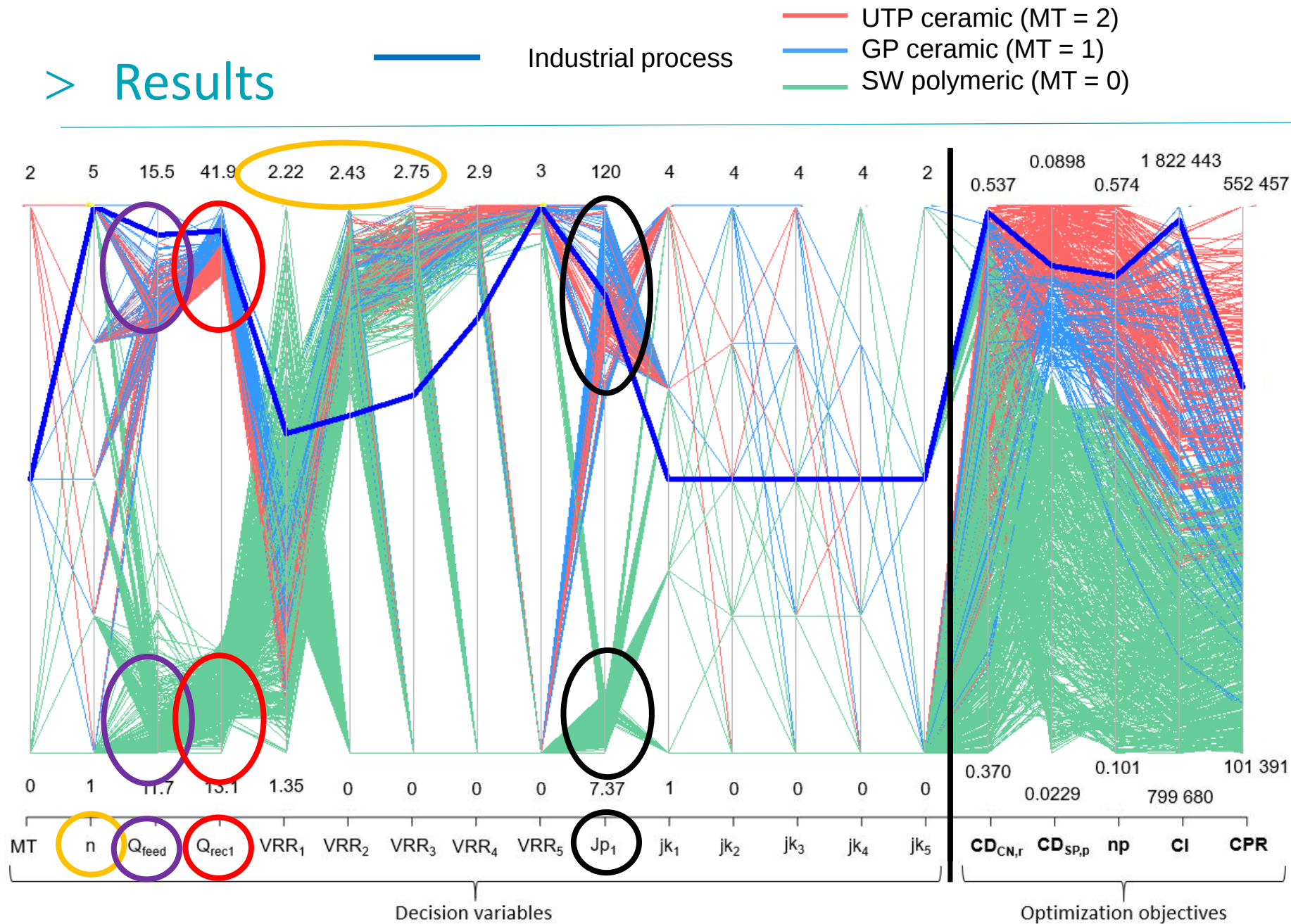
UTP ceramic (MT = 2)
GP ceramic (MT = 1)
SW polymeric (MT = 0)



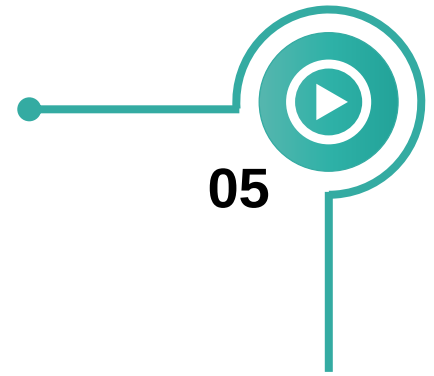
- Over 1000 Pareto-optimal solutions

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

> Results



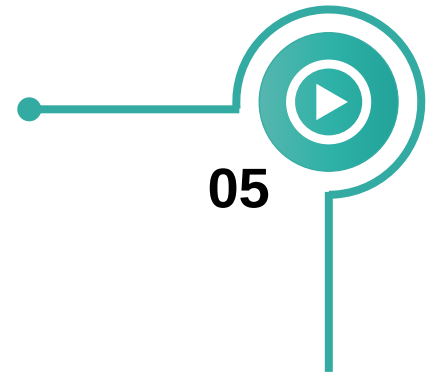
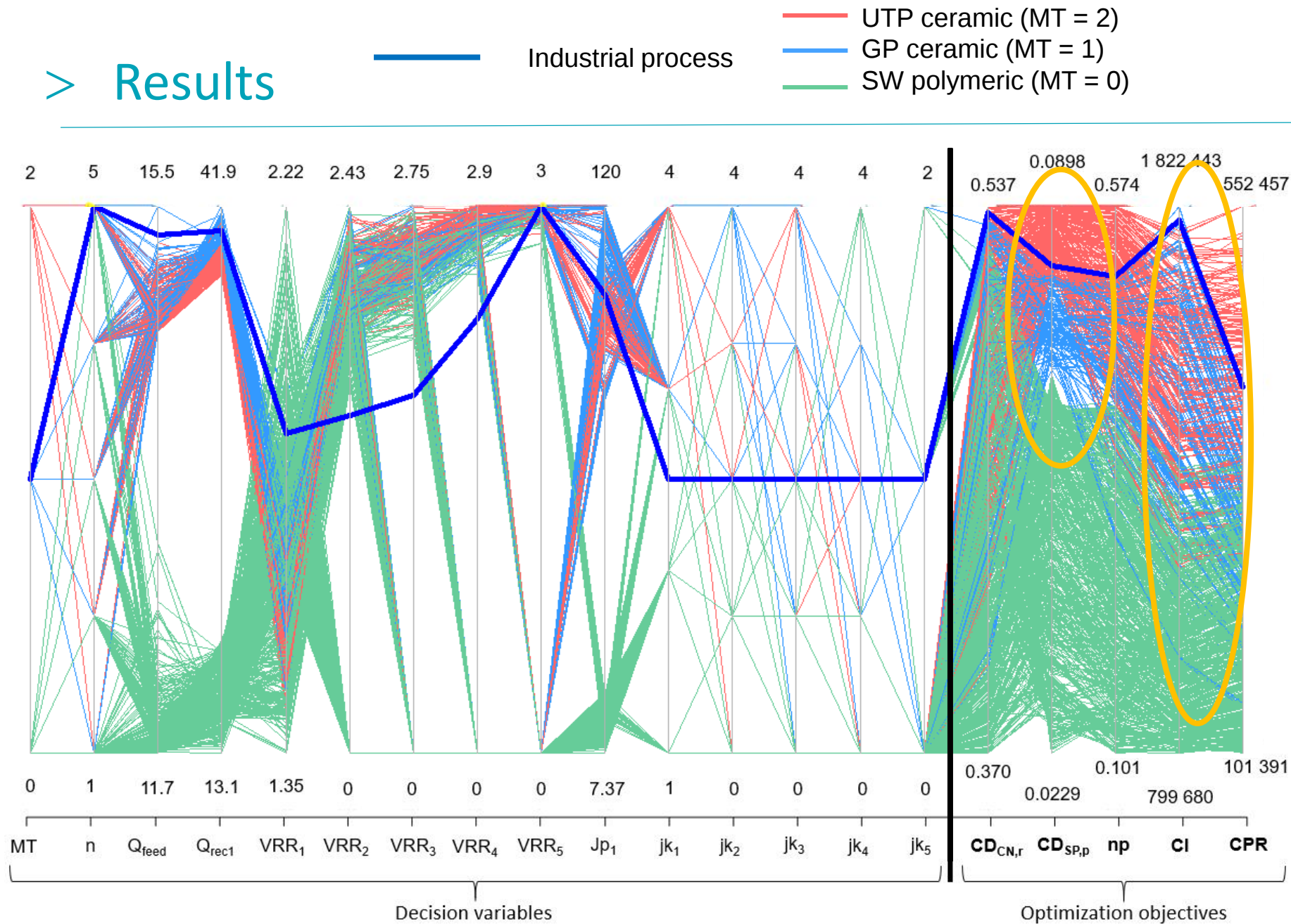
$Q_{feed} (m^3.h^{-1})$; $Q_{rec1} (m^3.h^{-1})$; $Jp_1 (L.h^{-1}.m^{-2})$; $CD_{CNr} (g.kg^{-1} DM)$; $CD_{SPp} (g.kg^{-1} DM)$; $CI (€)$; $CPR (€)$



05

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

> Results

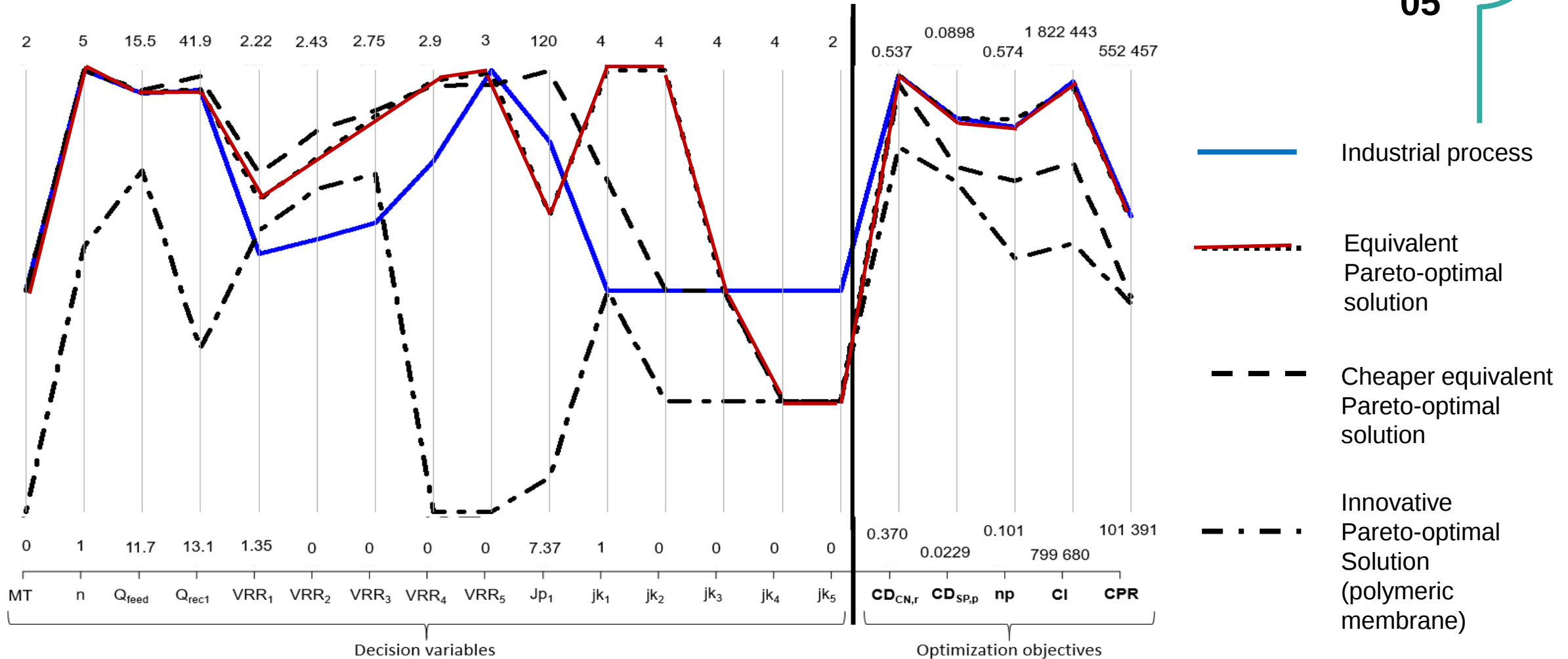
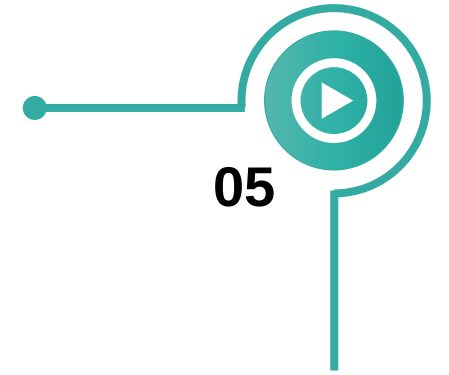


05

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

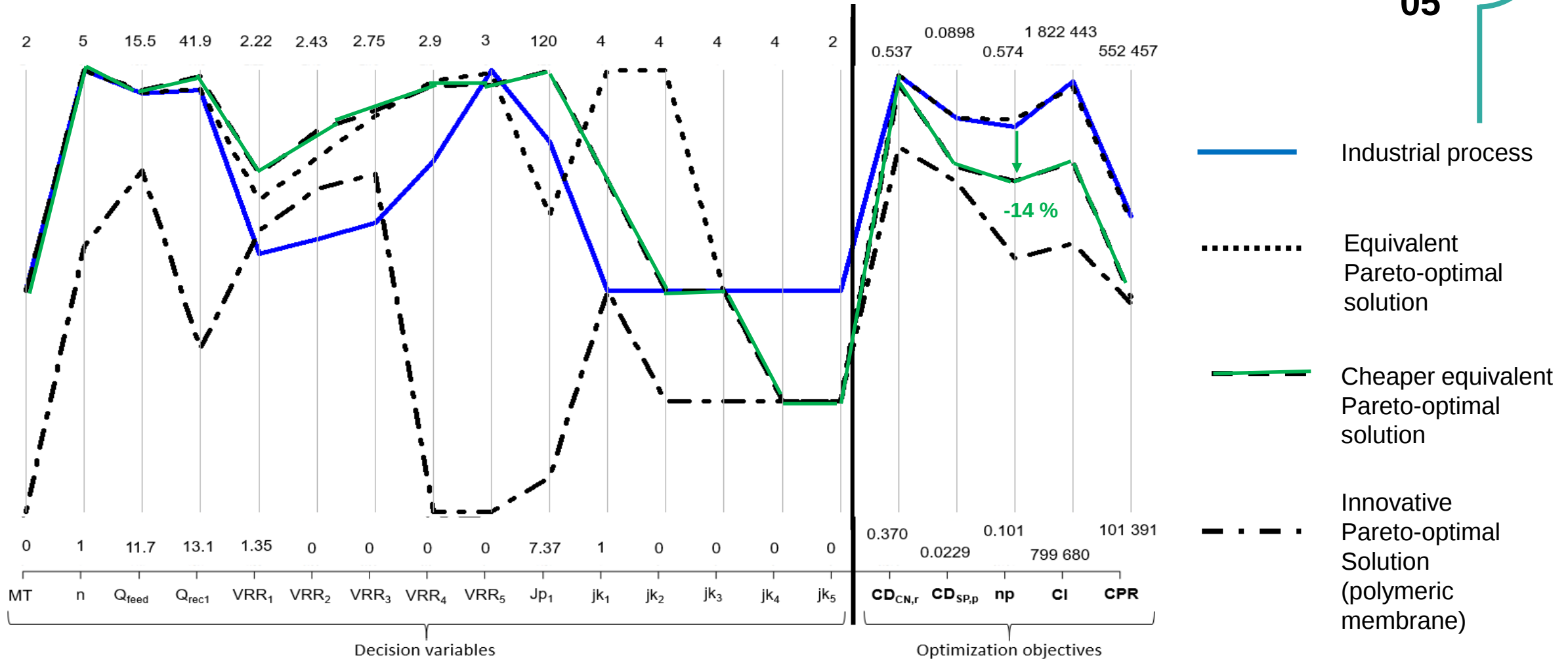
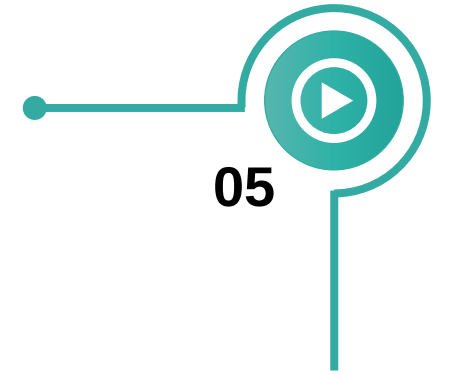
Technical objectives **more efficient**
BUT
More expensive

> Particular Pareto-optimal solutions analysis



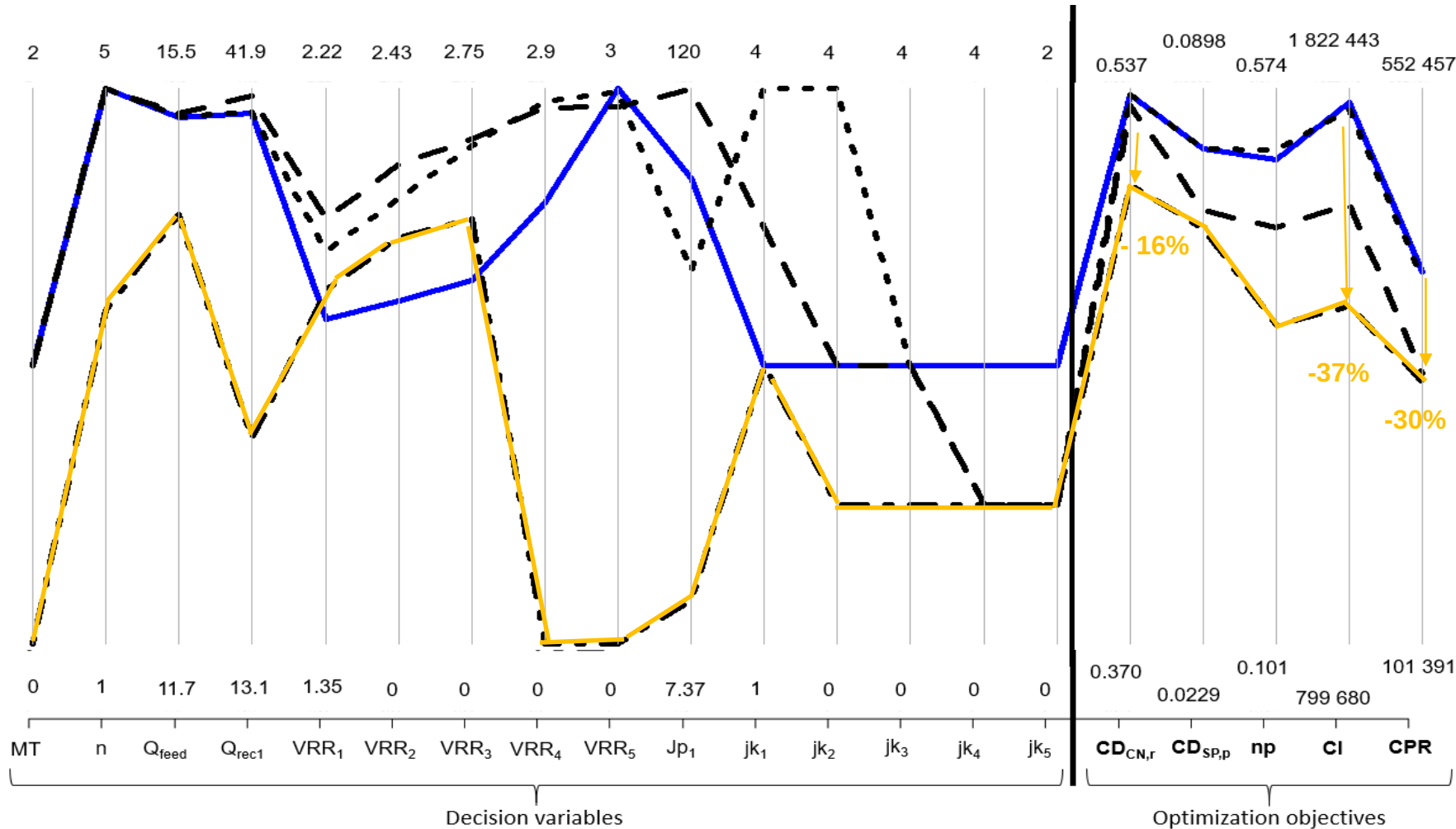
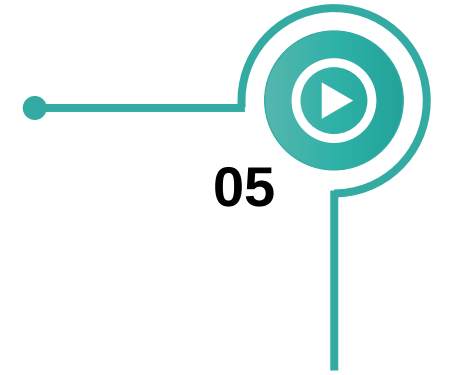
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> Particular Pareto-optimal solutions analysis



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 (€)

> Particular Pareto-optimal solutions analysis



Q_{feed} ($m^3.h^{-1}$) ; Q_{rec1} ($m^3.h^{-1}$) ; Jp_1 ($L.h^{-1}.m^{-2}$) ; $CD_{CN,r}$ ($g.kg^{-1} DM$) ; $CD_{SP,p}$ ($g.kg^{-1} DM$) ; CI (€) ; CPR (€)

> 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 !

