

Decision making tool for industrial dairy sludge management: A real case study.

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Introduction



- 9th largest exporter of dairy products
- The fourth most important item of Uruguayan exports

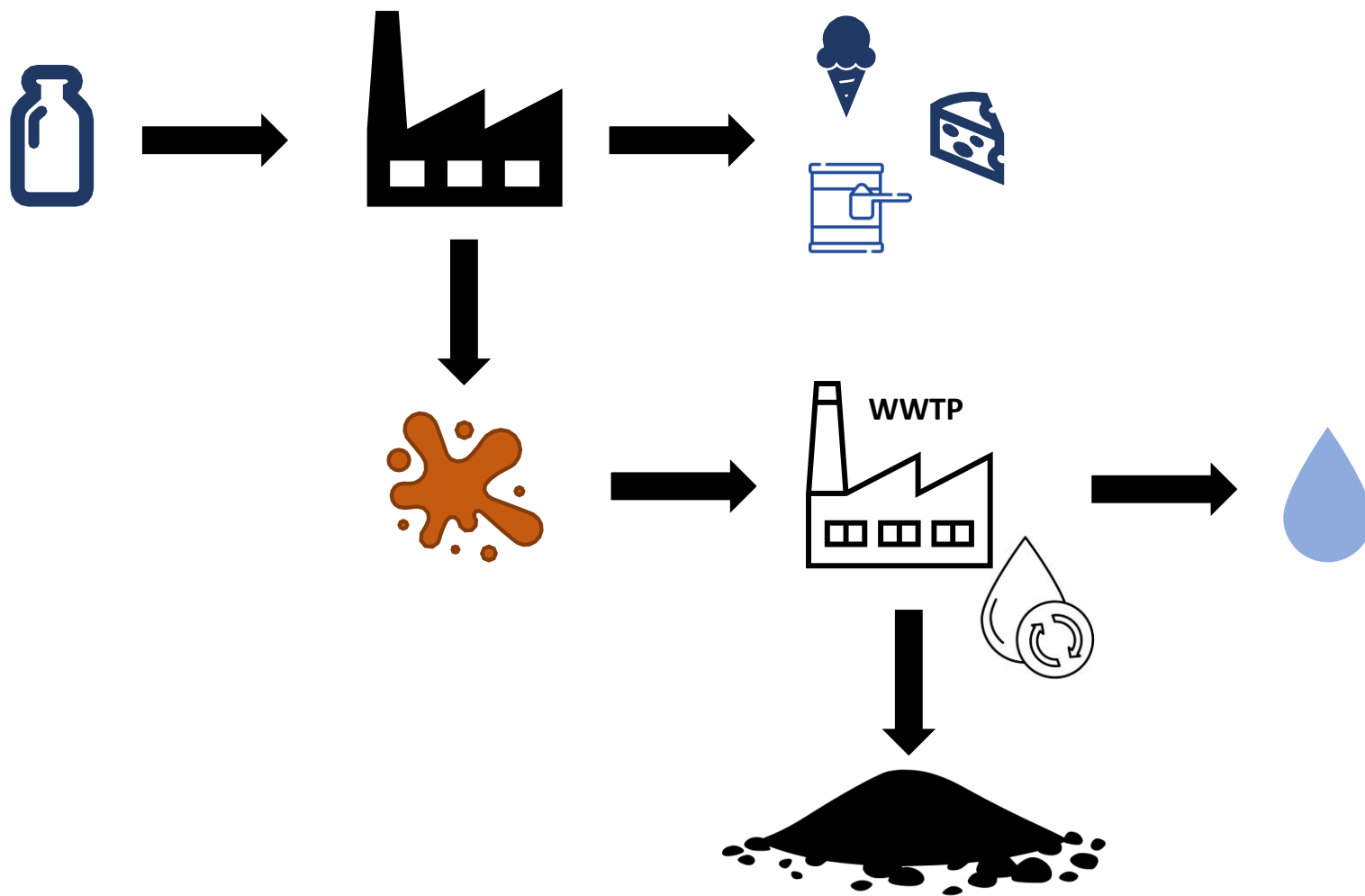


~3,5 M

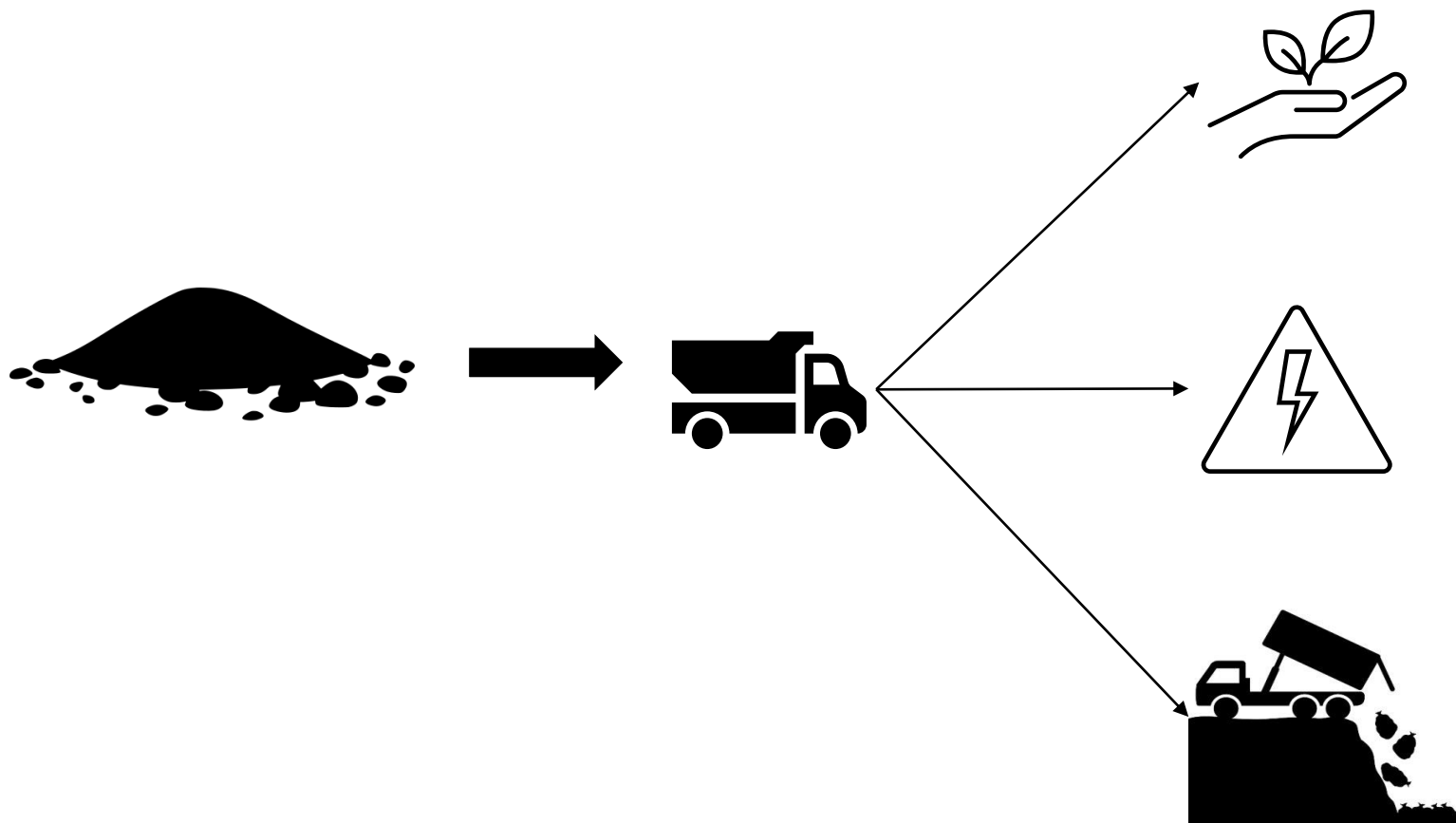


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Introduction



Introduction



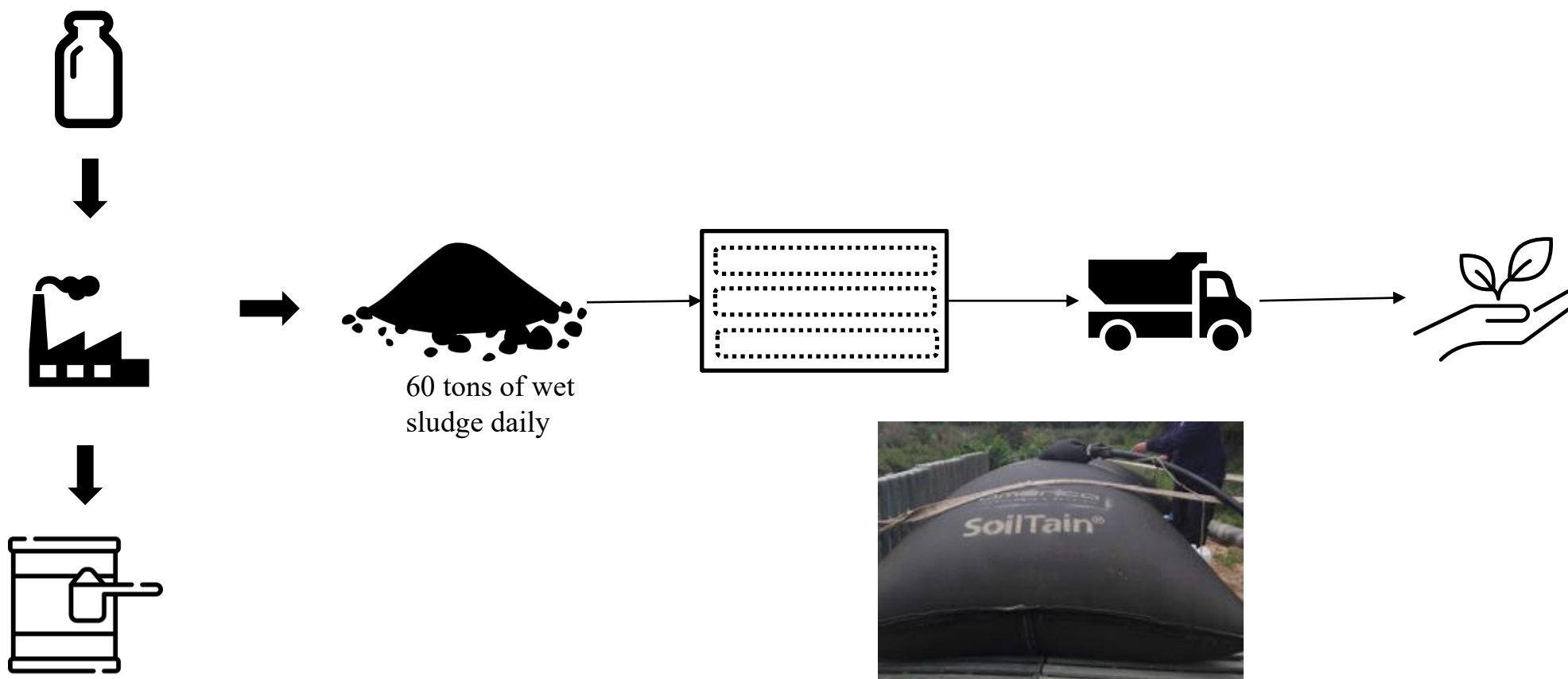
Production cost



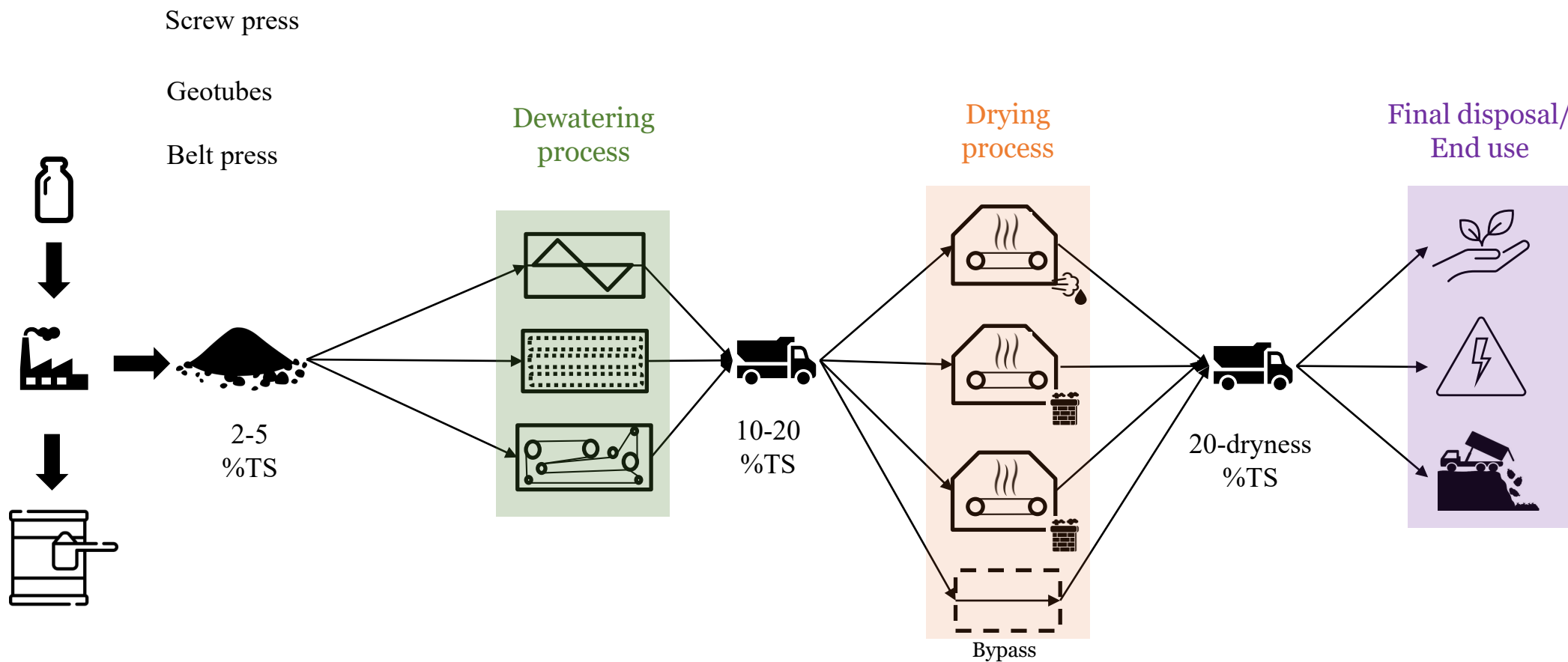
Competitiveness

How to select the most suitable path to minimize economic impact?

Base case - Powdered milk production



Process synthesis problem modelling



Framework development

minimize $Cost_{Total}$

MINLP problem

Subject to:

$$Cost_{Total} = \sum_{k_{DH}} Cost_{k_{DH}} * y_{k_{DH}} + \sum_{k_{Dry}} Cost_{k_{Dry}} * y_{k_{Dry}} + \sum_{k_{FD}} Cost_{k_{FD}} * y_{k_{FD}} + Cost_{trans}$$

$$Cost_{k_{DH}} = \$_{k_{DH}} * \sum_c F_{in,k_{DH},c} \quad Cost_{k_{Dry}} = \frac{Q_{k_{Dry}} * \$_{Energy,k_{Dry}}}{\epsilon_{Energy,k_{Dry}}} + \$_{Add,k_{Dry}} * W_{k_{Dry},water}$$

$$Cost_{k_{FD}} = \$_{FD,k_{FD}} * \sum_c \alpha_c F_{in,k_{FD},c} + \frac{F_{in,boiler,water} * \lambda_0 - F_{in,boiler,sludge} * LHV_{sludge}}{LHV_{fuel}} * \$_{fuel} * y_{boiler}$$

$$Cost_{trans} = \sum_k \sum_{kk} \sum_c \frac{F_{in,kk,c} * \$_{trans} * d_{k,kk} * y_k}{Cap_{trans}}$$

$$F_{0,c} = \sum_{k_{DH}} F_{in,k_{DH},c} \quad \sum_{k_{Dry}} F_{out,k_{Dry},c} = \sum_{k_{FD}} F_{in,k_{FD},c} \quad \sum_{k_{DH}} F_{out,k_{DH},c} = \sum_{k_{Dry}} F_{in,k_{Dry},c}$$

$$F_{in,k,c} + R_{k,c} = F_{out,k,c} + W_{k,c}$$

$$F_{out,k,sludge} = \epsilon_{Ret_k} * F_{in,k,sludge}$$

$$F_{out,k_{DH},water} = \frac{F_{out,k_{DH},sludge} * (1 - X_{sol,k_{DH}})}{X_{sol,k_{DH}}}$$

$$R_{k,c} = \delta_{k,c} * \sum_{cc} F_{in,k,cc}$$

$$F_{out,k,sludge} = \epsilon_{Ret_k} * F_{in,k,sludge}$$

$$F_{out,k_{Dry},water} = \frac{F_{out,k_{Dry},sludge} * (1 - X_{sol,k_{Dry}})}{X_{sol,k_{Dry}}}$$

$$Q_{k_{Dry}} = \lambda_0 * W_{k_{Dry},water}$$

$$\frac{F_{in,k_{Dry},water}}{F_{in,k_{Dry},water} + F_{in,k_{Dry},sludge}} \leq X_{max,k_{Dry}} \quad \sum_{k_{Dry}} X_{k_{Dry}} * y_{k_{Dry}} \leq X_{critical}$$

$$\frac{F_{in,boiler,water} + (m_{boiler} - F_{in,boiler,water} - F_{in,boiler,sludge}) * X_{fuel}}{m_{boiler}} \leq X_{max,boiler}$$

$$\frac{F_{in,boiler,sludge} * LHV_{sludge} + (m_{boiler} - F_{in,boiler,water} - F_{in,boiler,sludge}) * LHV_{fuel}}{m_{boiler}} \leq LHV_{min,boiler}$$

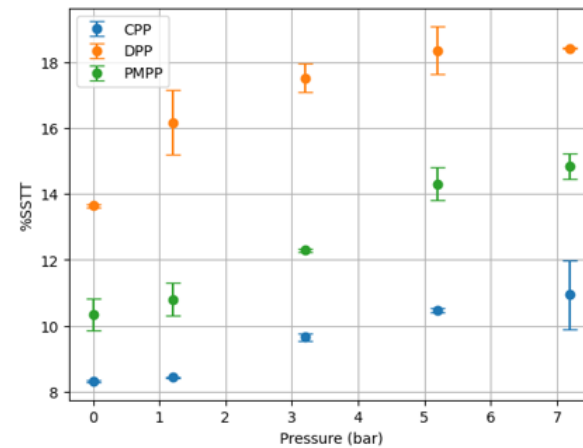
$$\sum_{k \in Dry} y_k \leq 1 \quad F_{out,k,c} < M * y_k$$

$$\sum_{k \in DW} y_k \leq 1 \quad F_{in,k,c} < M * y_k$$

$$\sum_{k \in FD} y_k = 1 \quad \sum_c F_{in,k_{FD},c} \geq m * y_{k_{FD}}$$

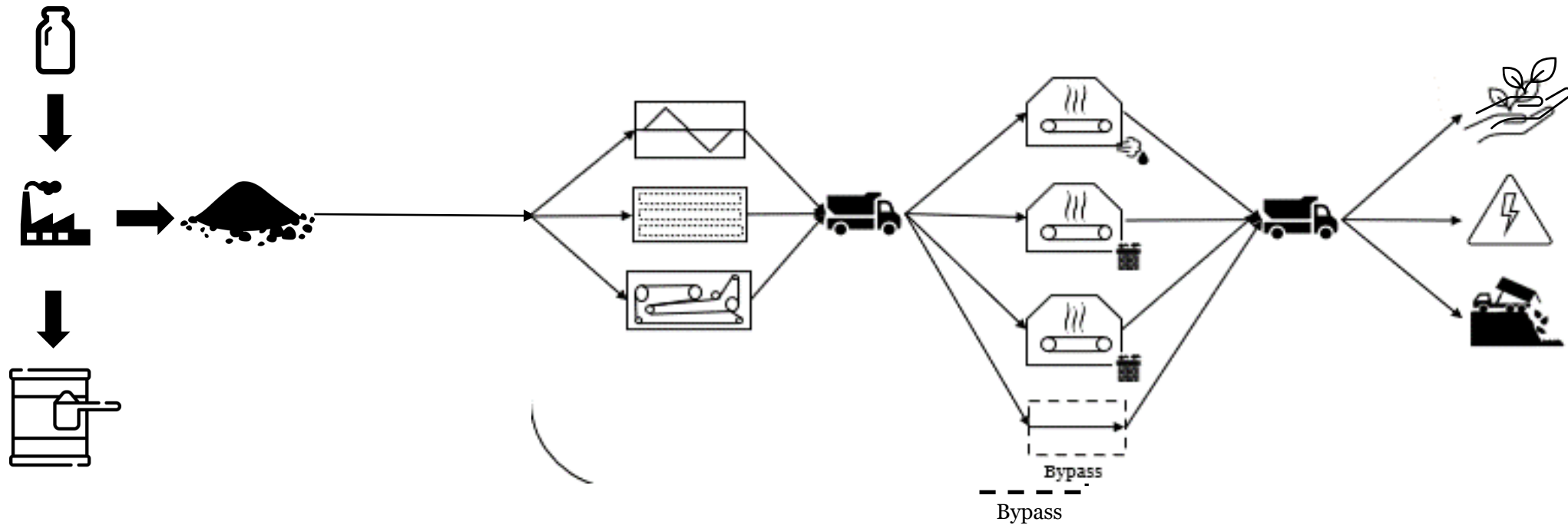
Parameters

Name	Description	Value	Unit	Source
$F_{0,c}$	Initial mass flow of the component c	-	ton/day	Plant data
$\epsilon_{Ret,k}$	Solid retention efficiency of the process k	-	ton/ton	Estimated from plant data
$X_{sol,k_{DH}}$	Solid content of the out of dewatering process k_{DH}	-	ton/ton	Estimated from experimental and plant data
$\delta_{k,c}$	Relation between flocculant and sludge produced	-	ton/ton	Plant data
$\$_{k_{DH}}$	Single cost of dewatering process k_{DH}	-	USD/ton	Estimated from company data
$\$_{Energy,k_{Dry}}$	Calorific energy cost of the drying process k_{Dry}	-	USD/KJ	Estimated from Aspen Plus database
$\$_{FD,k_{FD}}$	Cost of disposal per ton of solid to treat	-	USD/ton	Company data
$d_{k,kk}$	Distance between k and kk	-	Km	Company data
α_c	Component contribution to the disposal cost	-	-	Plant data
λ_0	Enthalpy of water vaporization	2257	KJ/ton	Bibliography
$\epsilon_{Energy,k_{Dry}}$	Calorific energy efficiency of the drying process k_{Dry}	0.6	-	Estimated based on expert judgment
$\$_{Add,k_{Dry}}$	Auxiliary cost per ton of evaporated water	10-15	USD/ton _{water}	Estimated based on catalogs and expert judgment



Plant	Sludge type	Sludge characteristics	Dewatering process	Total Solids at the outlet	# samples
DPP	Physicochemical sludge from a dessert processing plant	Lipid and protein-rich, undigested sludge	Screw press	16±3%	9
CPP	Anaerobic sludge from a cheese processing plant	Anaerobic pond digested sludge from activated sludge treatment, high salt (Cl-1.5 g-L-1) content	Belt filter	11±1%	3
PMPP	Anaerobic digester sludge from a powdered milk processing plant	Anaerobic digester for secondary sludge	Geotextile tubes	14±1%	6

Results



Results

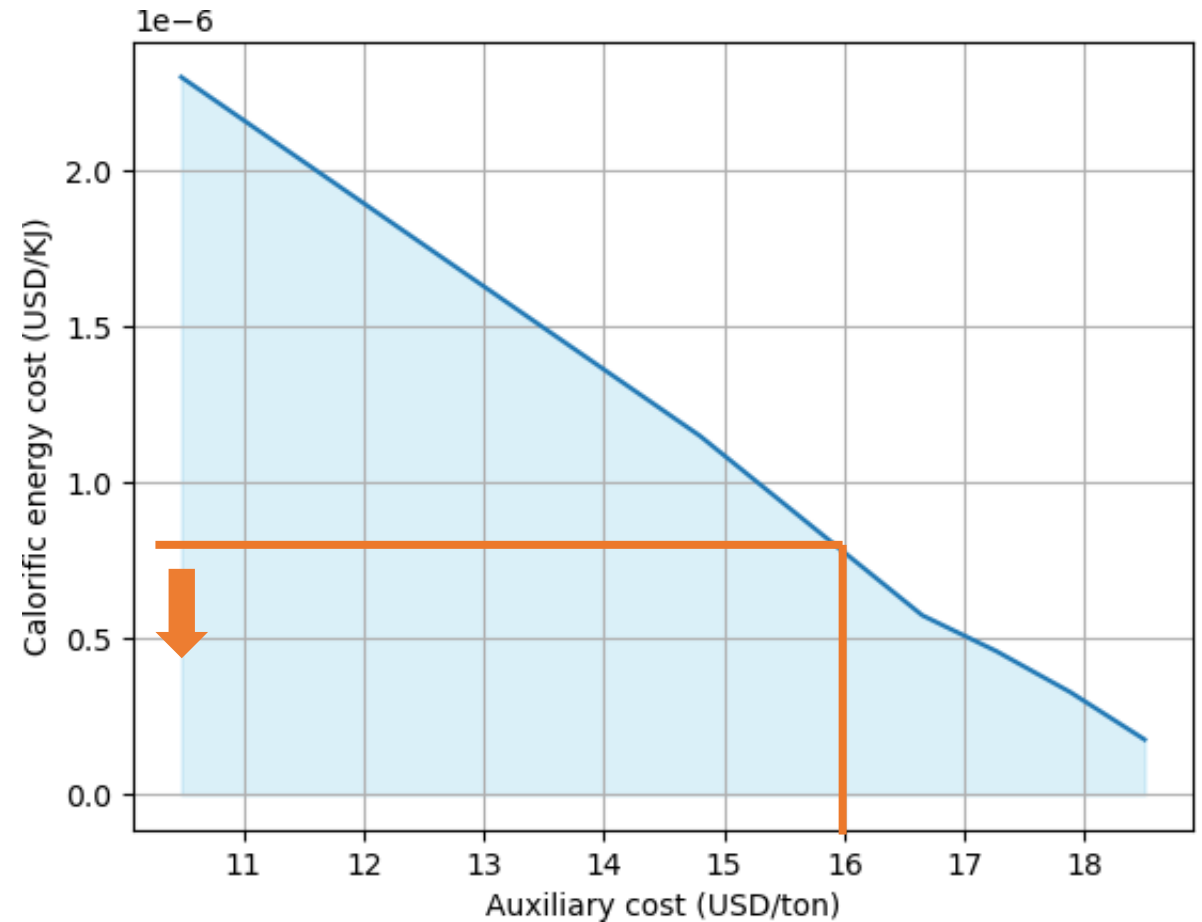
Ranking	Management alternative	Relative total cost
Base	Geotextile - Soil amendment	1
Optimal solution	Geotextile - Boiler <i>flue gas</i> dryer 1 – Boiler	0.79
1	Screw press - Boiler <i>flue gas</i> dryer 1 – Boiler	0.84
2	Geotextile - Boiler <i>flue gas</i> dryer 2 - Boiler	0.87
3	Screw press - Boiler <i>flue gas</i> dryer 2 - Boiler	0.90
4	Belt filter - Boiler <i>flue gas</i> dryer 1 – Boiler	0.92
5	Geotextile - Boiler <i>flue gas</i> dryer 1 – Soil amendment	0.94
	Geotextile– Steam dryer 1 – Boiler	1.93

Sensitivity analysis

$$Cost_{k_{Dry}} = \frac{Q_{k_{Dry}} * \$_{Energy,k_{Dry}}}{\epsilon_{Energy,k_{Dry}}} + \$_{Add,k_{Dry}} * W_{k_{Dry},water}$$

Auxiliary equipment:

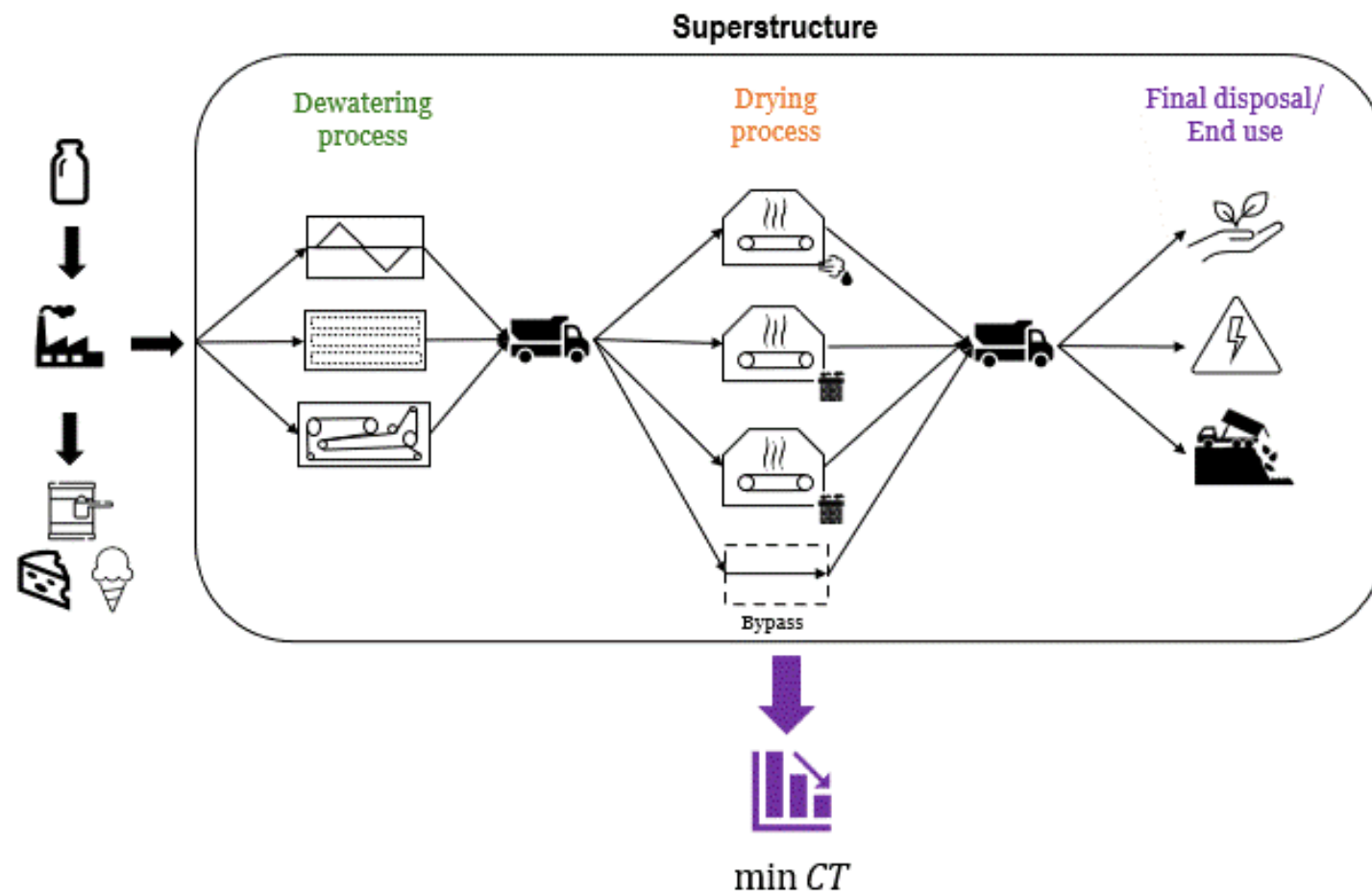
- Gas treatment
- Solid movement
- Gas movement



Conclusion

- The results obtained evidence the possibility of achieving a reduction in waste management costs of up to 20% for the case studied
- A decision-making tool was developed for sludge management, integrating experimental data and information collected at a real scale plant as a case study.

Decision-making tool



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