PROCESS INTEGRATION IN A DAIRY FACTORY CONSIDERING THERMAL ENERGY STORAGES - A COMPARISON OF TWO DIFFERENT APPROACHES

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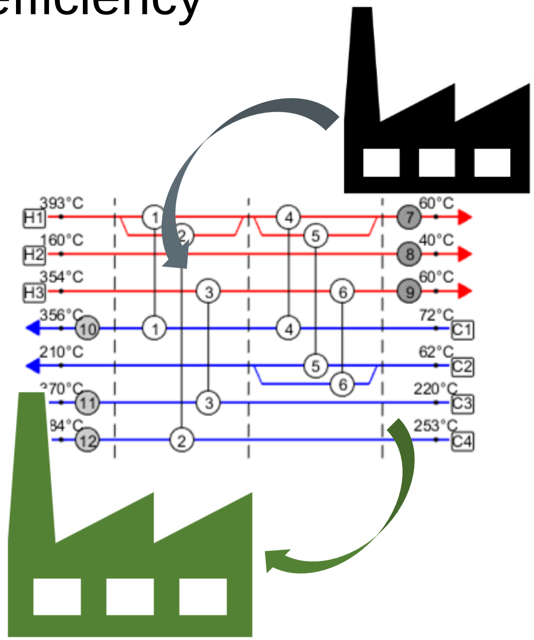
klima+ energie fonds

BACKGROUND

Climate Change, governmental regulations but also economic benefits give incentives for industries to increase energy efficiency

Heat exchanger network synthesis (HENS) proofed to be an effective way to increase energy efficiency



Two major approaches for HENS

- Pinch-Analysis & related technologies
- Mathematical Optimization

For processes with time-dependent behavior advanced methods are necessary

RESEARCH QUESTIONS

Two different approaches for heat integration were developed with capability of storage integration

- AIT: **MP Procedure,** optimization based (mathematical programming)
  - Based on simultaneous MINLP superstructure formulation
  - Includes linearizations, simplifications and tighter model formulations

- AEE INTEC: **SOCO**, heuristics & thermodynamics (Pinch-Analysis)
  - Based on pinch-principles and thermodynamics
  - Includes flowsheet representation of HEN and simulation of the flowsheet

RESEARCH QUESTIONS

- AIT: **MP Procedure,** optimization based (mathematical programming)
  - Beck, A. & Hofmann, R., 2017. *Tightening of MINLP Superstructure Relaxation for Faster Solution of Heat Exchanger Network Synthesis Problems.* Dubrovnik, -.
  - Beck, A. & Hofmann, R., 2018. A Novel Approach for Linearization of a MINLP Stage-Wise Superstructure Formulation. *Computers & Chemical Engineering*, Band 112, p. 17–26.
  - Beck, A. & Hofmann, R., 2018a. *Extensions for Multi-Period MINLP Superstructure Formulation for Integration of Thermal Energy Storages in Industrial Processes.* Graz, Austria, Elsevier.
  - Beck, A. & Hofmann, R., 2018b. How to tighten a commonly used MINLP superstructure formulation for simultaneous heat exchanger network synthesis. *Computers & Chemical Engineering*, Band 112, p. 48–56.

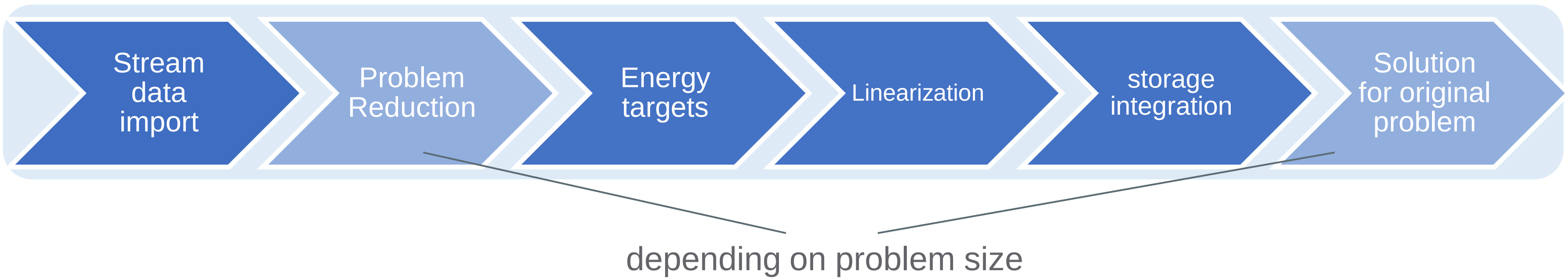
- AEE INTEC: **SOCO**, heuristics & thermodynamics (Pinch-Analysis)
  - Fluch, J., Brunner, C. & Muster-Slawitsch, B., 2012. Storage Optimisation Concept in Industries, Commerce and District Heating Businesses. *Chemical Engineering Transactions*, pp. 493-498.
  - Muster-Slawitsch, B., Brunner, C. & Fluch, J., 2014. Application of an advanced pinch methodology for the food and drink production. *Wiley Interdisciplinary Reviews: Energy and Environment*, 3(6), p. 561–574.
  - …

RESEARCH QUESTIONS

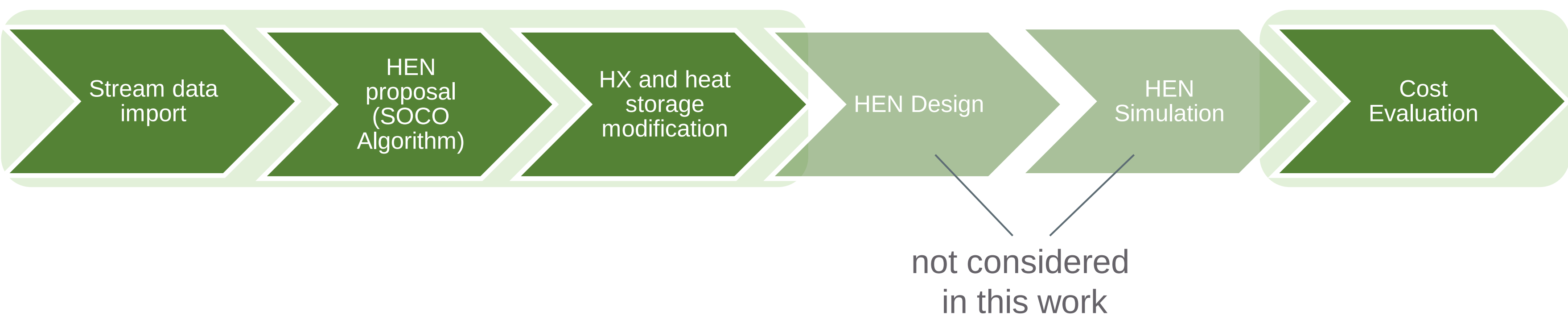
- What are the different **workflows**?
- What **inputs** are necessary for the different approaches?
- How do the **results** compare for the presented case-study?
- What **potential synergies** are there?

FLOWCHARTS

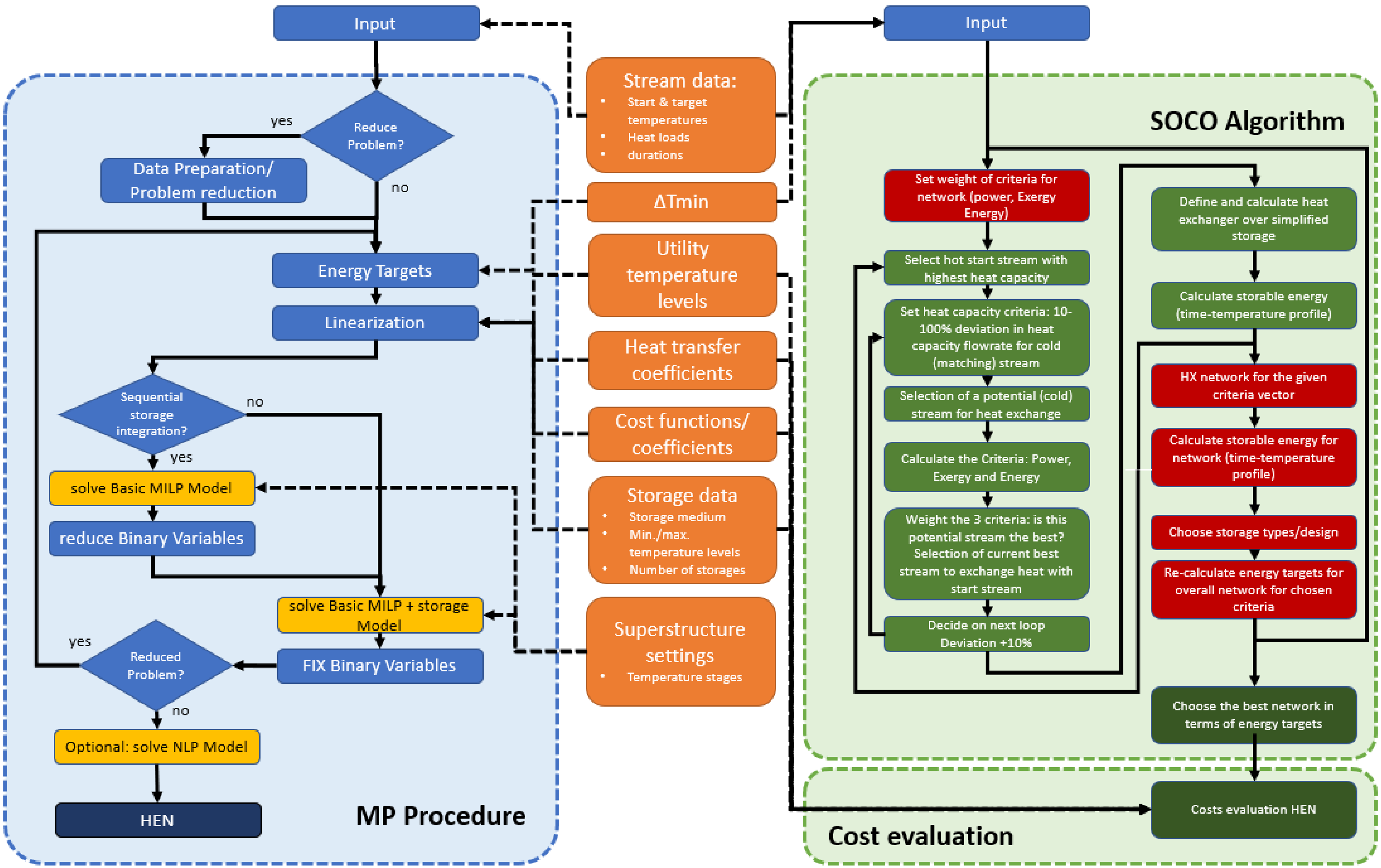
- AIT: **MP Procedure,** optimization based (mathematical programming)



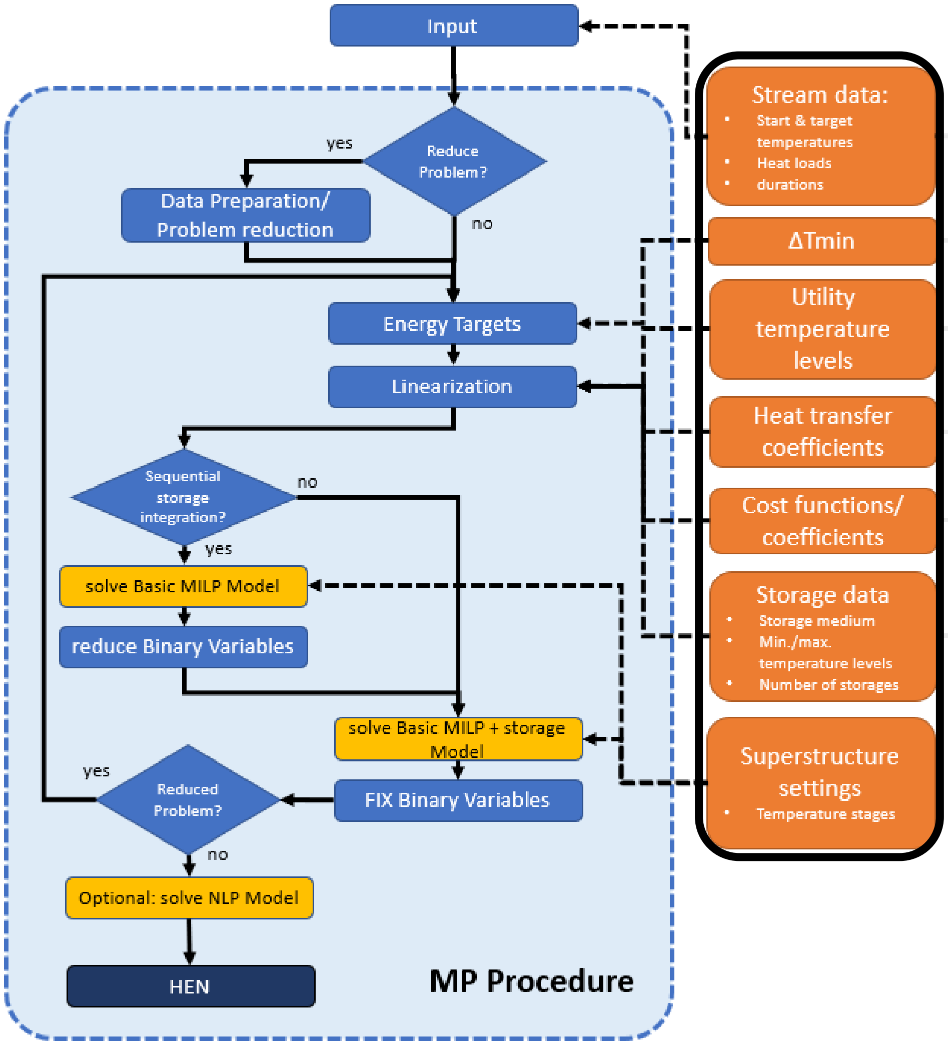
- AEE INTEC: **SOCO**, heuristics & thermodynamics (Pinch-Analysis)



FLOWCHARTS


Input
Reduce Problem?
yes
Data Preparation/ Problem reduction
no
Energy Targets
Linearization
Sequential storage integration?
no
yes
solve Basic MILP Model
reduce Binary Variables
solve Basic MILP + storage Model
FIX Binary Variables
Reduced Problem?
yes
no
Optional: solve NLP Model
HEN
MP Procedure
Stream data:
Start & target temperatures
Heat loads
durations
ΔTmin
Utility temperature levels
Heat transfer coefficients
Cost functions/ coefficients
Storage data
Storage medium
Min./max. temperature levels
Number of storages
Superstructure settings
Temperature stages
Input
SOCO Algorithm
Set weight of criteria for network (power, Exergy Energy)
Select hot start stream with highest heat capacity
Set heat capacity criteria: 10-100% deviation in heat capacity flowrate for cold (matching) stream
Selection of a potential (cold) stream for heat exchange
Calculate the Criteria: Power, Exergy and Energy
Weight the 3 criteria: is this potential stream the best? Selection of current best stream to exchange heat with start stream
Decide on next loop Deviation +10%
Define and calculate heat exchanger over simplified storage
Calculate storable energy (time-temperature profile)
HX network for the given criteria vector
Calculate storable energy for network (time-temperature profile)
Choose storage types/design
Re-calculate energy targets for overall network for chosen criteria
Choose the best network in terms of energy targets
Costs evaluation HEN
Cost evaluation

INPUT DATA



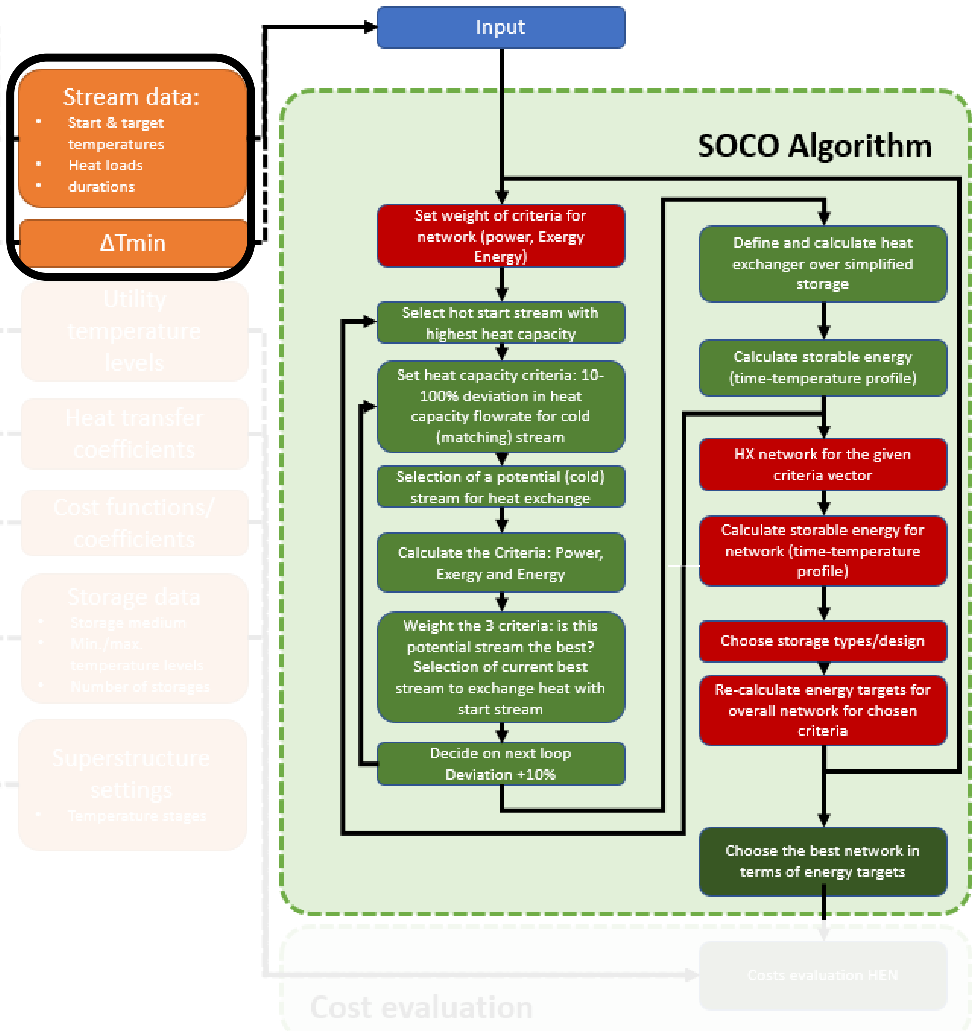
Necessary Input

- Stream data
- ΔTmin
- Heat transfer coefficients
- Cost functions/coefficients
- Storage data/parameters
- Superstructure Settings

INPUT DATA

Necessary Input for HEN Proposal

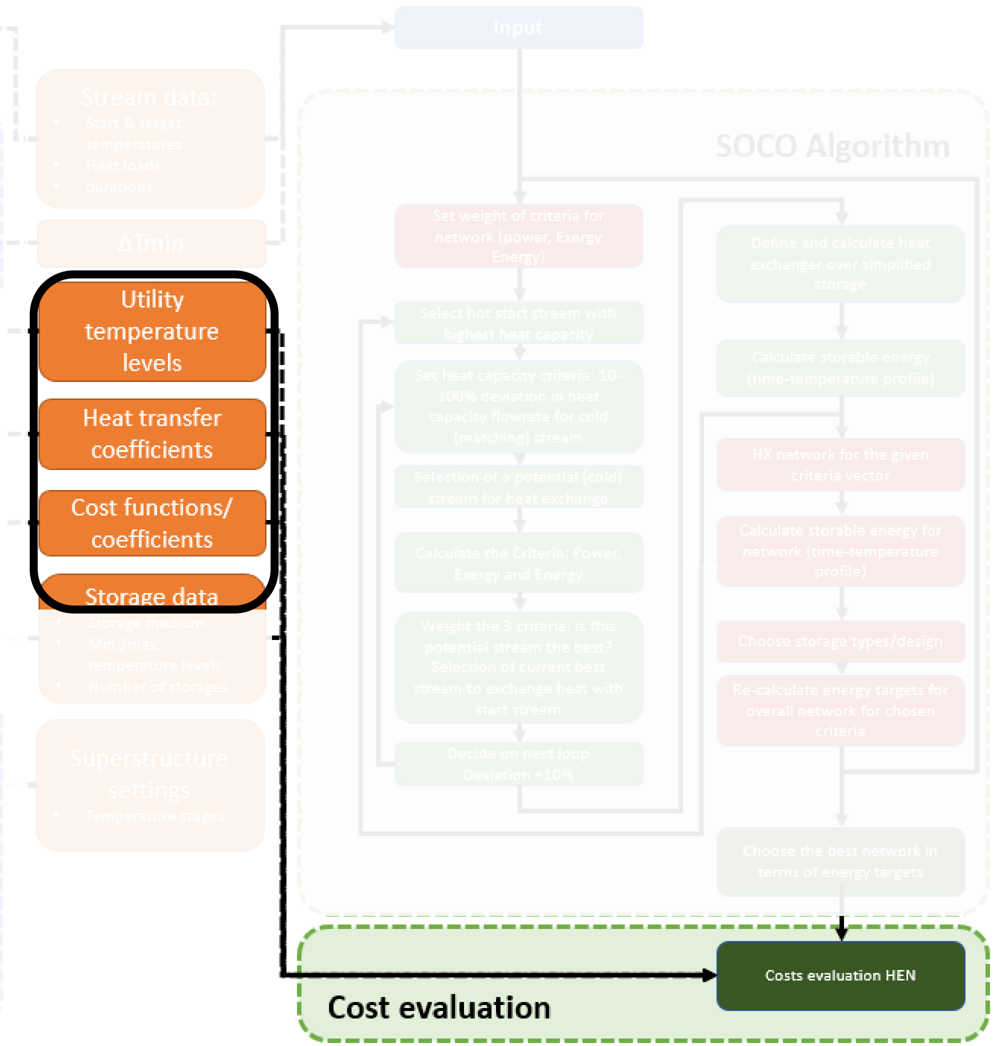
- Stream data
- ΔTmin
- Decision Factors:
  - Power
  - Energy
  - Exergy



INPUT DATA

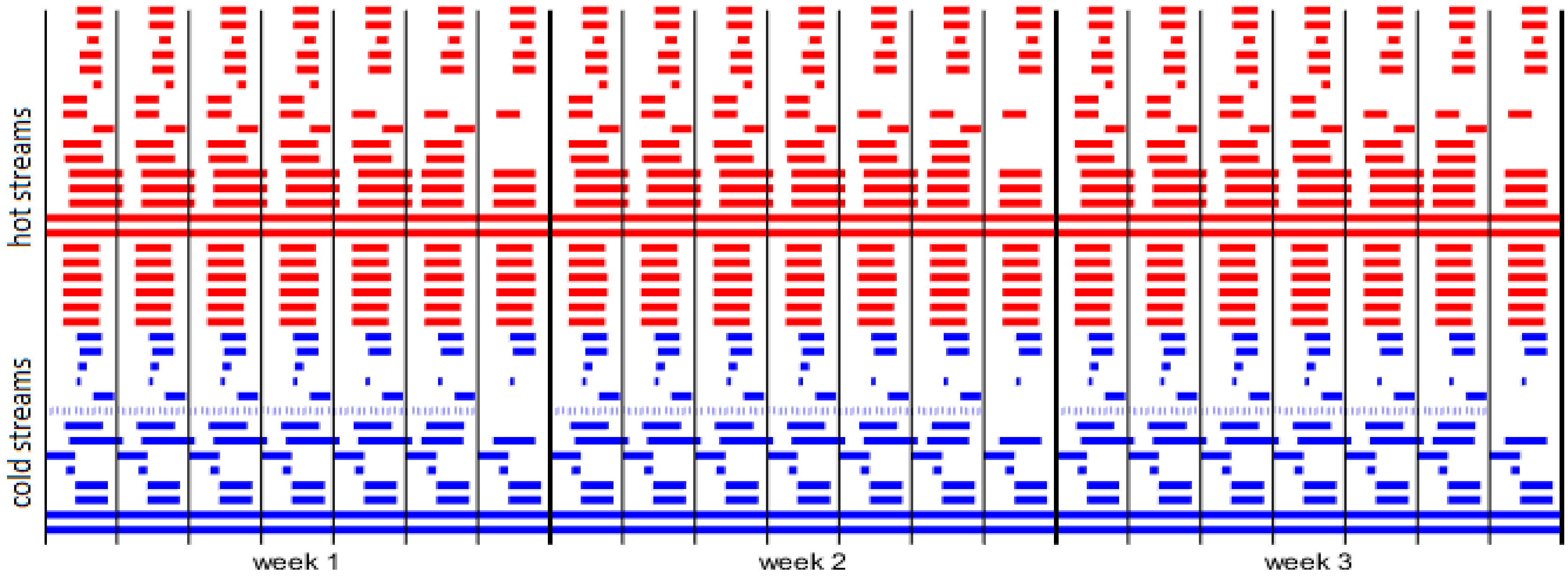
Necessary Input for cost evaluation

- Heat transfer coefficients
- Cost functions/coefficients
- Storage data/parameters



TEST CASE

- Heat integration in a dairy factory
  - 36 Process streams,
  - Most of them non-continuous,
  - Potential for storage integration
- Stream data for every 10 minutes (provided by AEE INTEC)
- Over a period of 3 weeks



TEST CASE

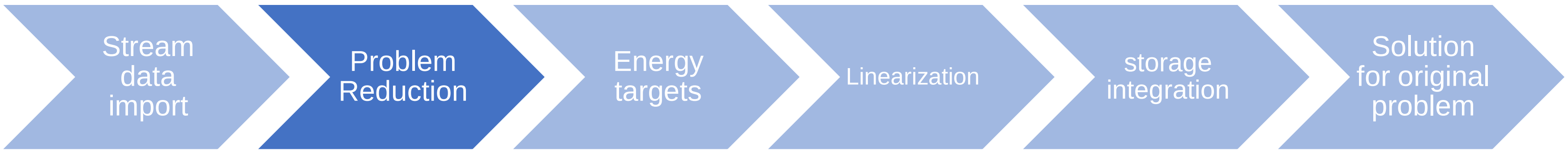
Table 1: Stream data and cost parameters for use case

	Tin (°C)	Tout (°C)	m [kg/s]	cp [kJ/kgK]		Tin (°C)	Tout(°C)	m [kg/s]	cp [kJ/kgK]
H1	8	4	11.11	3.77	**H21**	44.9	>30	0.02-0.38	4.19
H2	11	4	9.89	3.77	**H22**	30	>10	0.07-1.47	4.19
H3	5	3	6.94	3.77	**C1**	33-87	40-94	11.11	3.77
H4	55	8	1.39	2.88	**C2**	105	110	1.39	2.88
H5	13	8	1.39	2.88	**C3**	8	21	3.33	2.88
H6	21	11	3.33	2.88	**C4**	11	28	8.52	3.77
H7	11	6	2.05	3.77	**C5**	6	70	6.68	3.77
H8	28	6	0.32	3.91	**C6**	10	40	0.74/1.48	4.19
H9	70	32	6.68	3.77	**C7**	8	50	3.94	4.09
H10	42	8	3.94	4.09	**C8**	8	81.5	3.03	4.09
H11	50	8	3.94	4.09	**C9**	25	90	0.33	3.00
H12	70	5	0.92	4.19	**C10**	50	77	0.39	4.19
H13	48	5	2.22	4.19	**C11**	15	65	0.23	4.19
H14	53	5/25	0.22/0.4	3.8/3	**C12**	15	65	0.54	4.19
H15	140	>60	6.18	1.11	**C13**	12	102	0.93	4.19
H16	216	>60	0.29	1.11	**C14**	90	102	0.26	4.19
H17	62.9	>30	0.01-0.3	4.19					
H18	30	>10	0.12-2.58	4.19	**HU**	150	150		
H19	75	>15	0.06-0.55	4.19	**CU1**	15	18		
H20	15	>10	3.85-34.69	4.19	**CU2**	-5	0		

Overall heat transfer coefficient: 4kW/m²K; Utility costs: HU 262.8 €/kW/y, CU1 10 €/kW/y, CU2 292 €/kW/y, Heat exchanger costs: 6133.5*[Area]$^{0.219}$/y; Storage costs: (756.2*[Volume]+1760)/y; Annualization factor y=3; dTmin=2°C

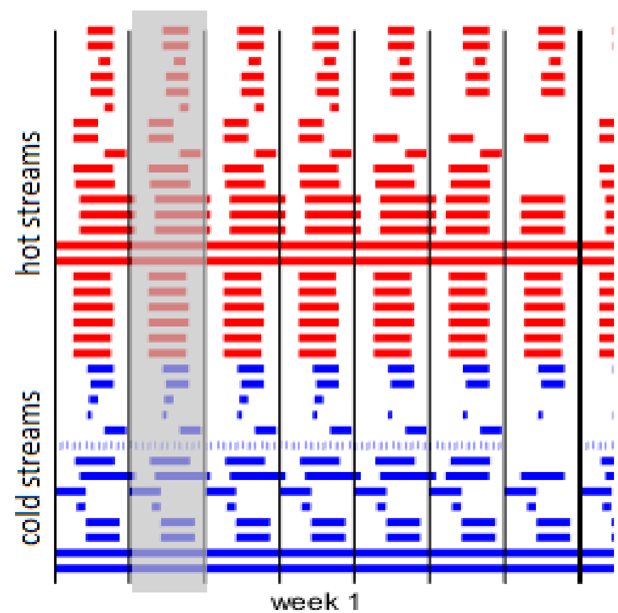
- Streams H15-H22 are soft streams
- Two cold utilities: Tout > 20°C -> cooling water, Tout < 20°C -> chillers

PROBLEM REDUCTION



Problem needs to be reduced for **MP Procedure**

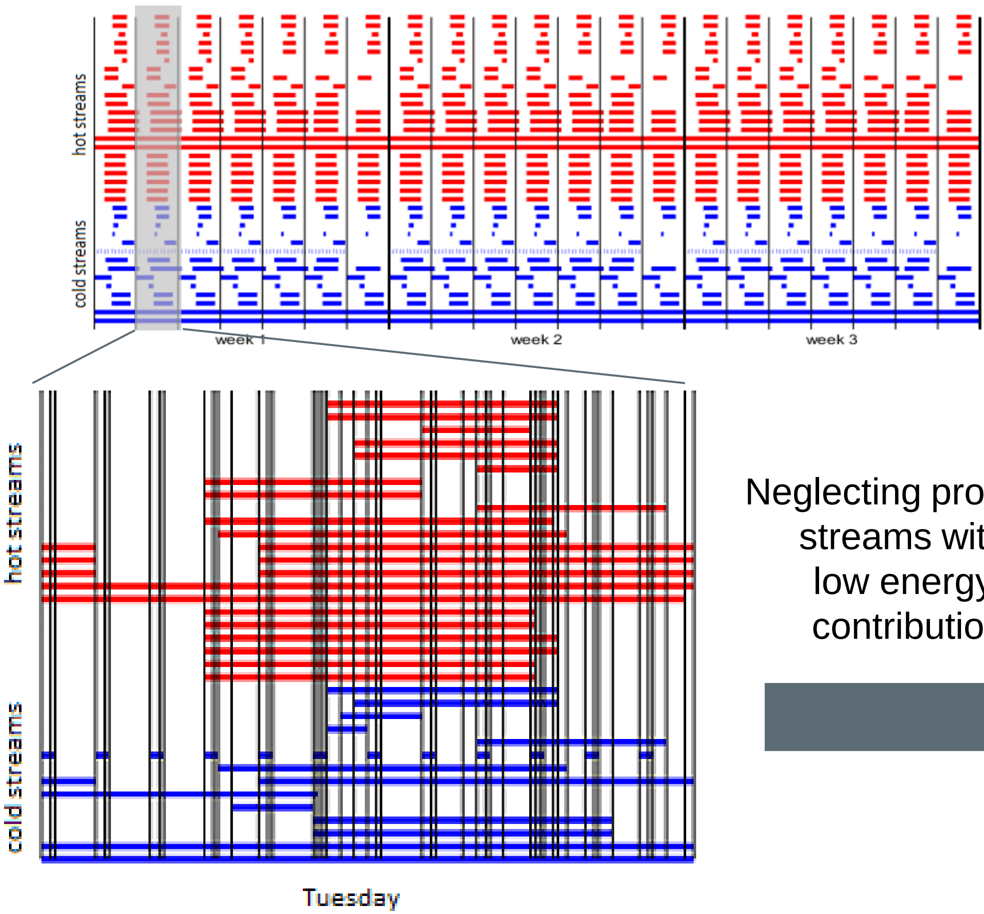
- too many time-intervals and
- too many process streams to find a solution in reasonable time



Reduction:

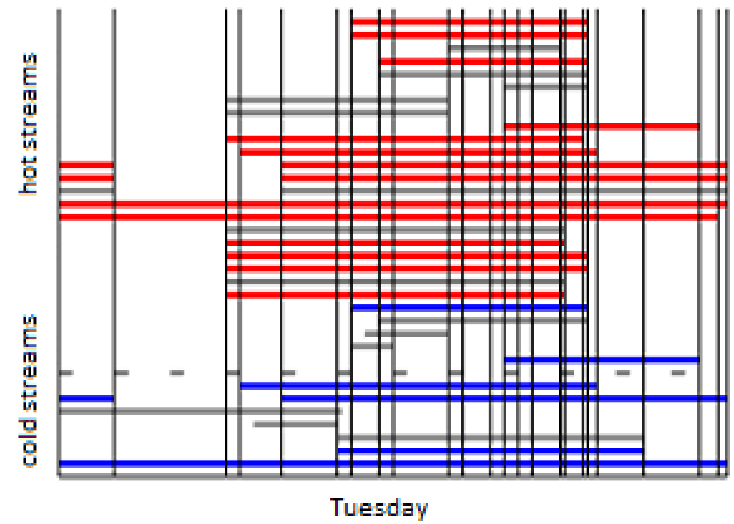
- All weeks are equal,
- Tuesday identified as representative day

PROBLEM REDUCTION



36 Streams, 45 Operating Periods
100% Energy content

Neglecting process streams with low energy contribution

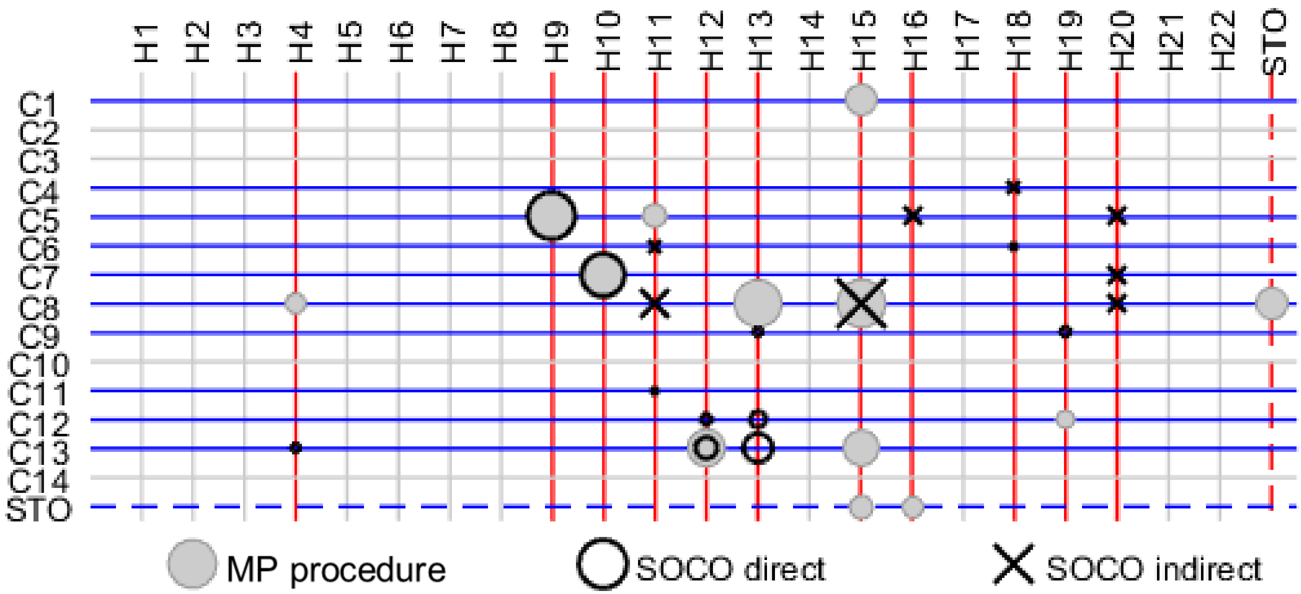


20 Streams, 23 Operating Periods
~95% Energy content

RESULTS

In **SOCO** storages specifically connect two streams

In **MP Procedure** the storage is charged and discharged independently



Number of heat exchangers, storage sizes, heat recovery and computation time for both approaches

	HX utility	HX streams	HX storage	Storages / Vol.	Heat recovery MWh/a	Max. direct/mixed MWh/a	Computation time
MP	26	10	3	1 / 43.14 m³	13,975.4	14,894.13/16,725.58	rd. 24 hours
SOCO	28	9	15	5 / 449 m³	12,088.0	14,894.13/16,725.58	rd. 1 second

Annual Costs

	OP	HX streams	HX utility	HX storage	Storages	Total
MP	229.6 k€ (68.1%)	35.3 k€ (10.5%)	48.7 k€ (14.4%)	8.9 k€ (2.6%)	14.9 k€ (4.4%)	337.3 k€
SOCO	355.7 k€ (52.1%)	28.6 k€ (4.2%)	74.4 k€ (10.9%)	107.6 k€ (15.8%)	116.2 k€ (17.0%)	682.5 k€

RESULTS

MP procedure

\+ Lower costs

\+ Simpler HEN

\+ Smaller storage

\+ Higher heat recovery

\- Significant reduction of the problem necessary

\- Cost parameters needed for HENS

\- Computationally expensive

SOCO

\+ Fast solution process

\+ No problem reduction needed

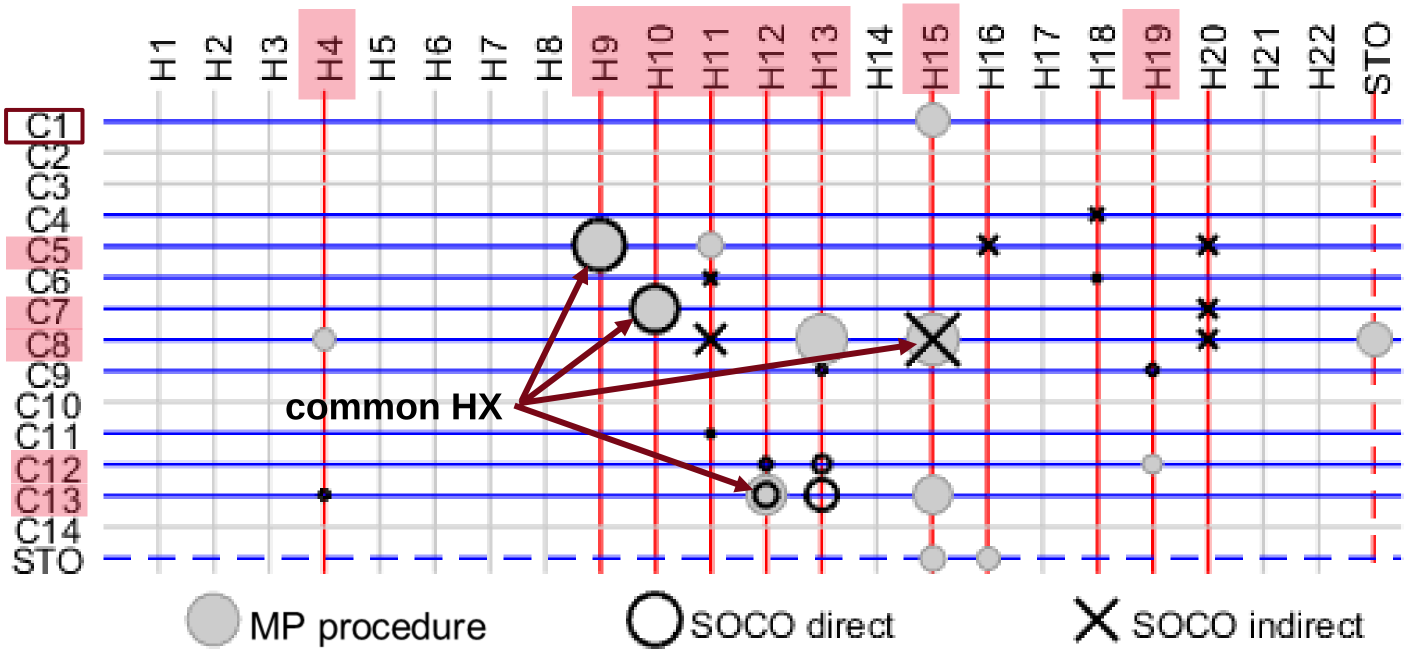
\+ Possibility to alter HEN in a flowsheet environment

\+ Simulation of the Flowsheet

\- Sub-optimal HENs in terms of total annual costs

\- Large number of storages after HEN proposal

RESULTS



Streams considered by **MP procedure** and **SOCO**

Streams considered only by **MP procedure**

- Only 4 common HX
- **13/14** streams considered by **MP procedure** were also considered by **SOCO**
- **20** streams considered by **SOCO**
- **20** streams used in the reduced problem for the **MP Procedure**

SYNERGIES

- **SOCO‘s** HEN proposal used most of the streams that were considered within the reduced problem for the **MP procedure**, thus SOCO could be used to efficiently reduce the problem for the optimization based **MP procedure**.
- Solutions proposed in **SOCO‘s** HEN proposal stage could be used to initialize the **MP procedure** to speed up its solution process
- The **SOCO** flowsheet could be used to manually alter and adapt the solution produced by the **MP proceduce** with little computational effort

CONCLUSION/OUTLOOK

- With both approaches it was possible to come up with a heat integrated HEN with storages
- **SOCO** is able to find solutions in very short time and without problem reduction, no cost data need to be provided
- The **MP procedure** was able to find a more cost efficient HEN with higher heat recovery, although computational time was much higher

- Combination of mathematical programming techniques and heuristics seems promising to reduce computational complexity

THANK YOU

FOR YOUR ATTENTION!

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