Contributing global CO$_2$ mitigation by utilisation of food industry heat into smart Croatian DHS via Total Site heat recovery
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Outline

• Introduction
• Objectives
• Methodology
• Case study
• Results
• Summary and future works
Introduction

• To produce 1 J of food energy 10 J of primary energy is required
• The population growth required the annual energy consumption rise on 24 – 40%
• On the other hand it leads to fast deterioration of environment, to CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{x}, dust, soot and other industrial emissions
Croatian Energy Balance for 2012

Total final consumption 6381 thousand tonnes of oil equivalent (ktoe)

Simple site

Heat flow interconnections:
- waste heat
- process heating
- district heating
- hot water supply
Main challenges

• Is it possible to reduce the energy consumption?
• How much we can save?
• What will be the real energy targets?
• How to estimate an investment level?
• What will be the payback time?
Methodology

Process level

• Data extraction
• Set a cost effective targets for industrial processes
• Waste heat identification

Total Site level

• Total Site Profiles
• Site heat recovery targeting
• Calculation of heat transfer area and units numbers
• Economic indicators
Process level

- Data tables
- Cost data
- Composite curves
- Grand Composites
Data collection

<table>
<thead>
<tr>
<th>Process A – industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream</td>
</tr>
<tr>
<td>Stream 1 cooling</td>
</tr>
<tr>
<td>Stream 2 condensation</td>
</tr>
<tr>
<td>Stream 3 condensation</td>
</tr>
<tr>
<td>Stream 4 cooling</td>
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<tr>
<td>Stream 5 cooling</td>
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<table>
<thead>
<tr>
<th>Process B – industrial</th>
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<tbody>
<tr>
<td>Stream</td>
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<tr>
<td>Stream 1 cooling</td>
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<tr>
<td>Stream 2 condensation</td>
</tr>
<tr>
<td>Stream 3 condensation</td>
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<tr>
<td>Stream 4 condensation</td>
</tr>
<tr>
<td>Stream 5 condensation</td>
</tr>
<tr>
<td>Stream 6 evaporation</td>
</tr>
<tr>
<td>Stream 7 evaporation</td>
</tr>
<tr>
<td>Stream 8 heating</td>
</tr>
<tr>
<td>Stream 9 heating</td>
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<tr>
<td>Stream 10 heating</td>
</tr>
<tr>
<td>Stream 11 heating</td>
</tr>
<tr>
<td>Stream 12 heating</td>
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<tr>
<td>Stream 13 heating</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process C – residential and commercial area</th>
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</thead>
<tbody>
<tr>
<td>Stream</td>
</tr>
<tr>
<td>Heating of power substation</td>
</tr>
<tr>
<td>Hot water of residential area</td>
</tr>
<tr>
<td>Hot water of commercial area</td>
</tr>
<tr>
<td>Stream 6 evaporation</td>
</tr>
<tr>
<td>Stream 7 evaporation</td>
</tr>
<tr>
<td>Stream 8 heating</td>
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<tr>
<td>Stream 9 heating</td>
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<tr>
<td>Stream 11 heating</td>
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<td>Stream 12 heating</td>
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<tr>
<td>Stream 13 heating</td>
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</tbody>
</table>

* – latent heat of phase change
Price of hot utility is 366 EUR/kWy (prices of natural gas 0.042 EUR/kWh) [ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_and_natural_gas_price_statistics]

Price cold utility is 36 EUR/kWy

Specific price of heat transfer area is 800 EUR/m2

Installation costs with revamp of 1 heat exchanger are 10,000 EUR

The coefficient of nonlinearity of heat transfer area price is 0.87

Plant life is 5 year

Return on investment employed of 10%.
Selection of optimal $\Delta T_{\text{min}}$

Process A - $\Delta T_{\text{min}}=10 \, ^\circ\text{C}$

Process B - $\Delta T_{\text{min}}=3 \, ^\circ\text{C}$

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Waste heat identification

Process A - $\Delta T_{\text{min}} = 10 \, ^\circ C$

Process B - $\Delta T_{\text{min}} = 3 \, ^\circ C$

Composite curves
$Q_{H\text{min}}$ – heating targets
$Q_{C\text{min}}$
Waste heat identification

(a) – Process A, $Q_{\text{Hmin}}=267$ kW; $Q_{\text{Cmin}}=320$ kW, $Q_{\text{recovery}}=684$ kW;
(b) – Process B, $Q_{\text{Hmin}}=1328$ kW; $Q_{\text{Cmin}}=485$ kW, $Q_{\text{recovery}}=817$ kW.

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Total Site Analysis

- TS profiles construction with use of stream data of individual processes eliminating heat recovery
- Set initial TS $\Delta T_{\text{min}}$ between profiles and definition enthalpy intervals created by Sink and Source Profiles
- Calculation HT area (IM levels) and number of units. For each enthalpy interval minimum heat transfer area and number of heat exchangers are calculated
- Calculation of total cost for defined heat exchangers network considering heat transfer area and number of heat exchangers
- Changing $\Delta T_{\text{min}}$. Increasing the temperature approach between the TS Profiles and repeating the calculation procedure
- Selection of most profitable solution with minimum total cost
Optimum site heat recovery

Example of total cost of site heat recovery system

Minimum total cost (operating + Investment)

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Total Site targets


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Heat transfer area and units number

\[ A_{TSCU} = \sum_{j=1}^{p} \min_{t_{tj} < t_{GU} < t_{tj+1}} \frac{1}{\Delta T_{LM}^C} \left( \sum_{i=1}^{n} \frac{Q_i}{h_i} + \frac{Q_{GU}}{h_{GU}} \right) \]

\[ A_{TSHU} = \sum_{i=1}^{l} \min_{t_{tj} < t_{HU} < t_{tj+1}} \frac{1}{\Delta T_{LM}^C} \left( \sum_{j=1}^{m} \frac{Q_j}{h_j} + \frac{Q_{HU}}{h_{HU}} \right) \]

\[ A_{TSHR} = \sum_{z=1}^{k} \min_{t_{tj} < t_{IM} < t_{tj+1}} \left( \frac{1}{\Delta T_{LM}^H} \left( \sum_{i=1}^{n} \frac{Q_i}{h_i} + \frac{Q_{IM}}{h_{IM}} \right) + \frac{1}{\Delta T_{LM}^C} \left( \sum_{j=1}^{m} \frac{Q_j}{h_j} + \frac{Q_{IM}}{h_{IM}} \right) \right) \]

\[ N_{HR} = \sum_{i=1}^{k} n_i^h + n_i^c \]

\[ N_{GU} = \sum_{i=1}^{p} n_i^h \]

\[ N_{HU} = \sum_{i=1}^{l} n_i^c \]

Heat transfer area targets

Number of heat exchangers

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Total Site Profiles – case study

Source Site Profile

Cooling water
800 kW

Sink Site Profile

Temperature T, °C

150 Hot utility 2433 kW

100

50

0

1

2

ΔH x 10^-3, kW

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Total Site Profiles – heat recovery

$\Delta T_{\text{min}} = 5^\circ \text{C}$
Hot utility = 1689 kW
Cooling water = 56 kW
$Q_{\text{recovery}} = 744 \text{ kW}$
## Results

<table>
<thead>
<tr>
<th></th>
<th>Hot utility (kW)</th>
<th>Cold utility (kW)</th>
<th>Recovery (kW)</th>
<th>Heat transfer area, m²</th>
<th>No of heat exchanger</th>
<th>Investment (EUR)</th>
<th>Saving (EUR)</th>
<th>Payback time (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing site</td>
<td>2,433</td>
<td>800</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Retrofitted site</td>
<td>1,689</td>
<td>56</td>
<td>744</td>
<td>272</td>
<td>8</td>
<td>297,600</td>
<td>182,490</td>
<td>19.6</td>
</tr>
</tbody>
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Conclusion and future work

- District heating systems can be integrated with industrial systems by Total Site Analysis
- Fuel consumption and harmful emissions can be reduced by site heat recovery
- Heat transfer area and number of units can be targeted
- Conceptual design for technical realisation can be proposed
- Possible future integration and interactions with renewables, CHP units accounting different energy prices
- Potential application not only for Croatian energy systems
Acknowledgements

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