Design of a water reuse network in an industrial site in Kenya

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Eco-industrial Park

Present Industrial Park

Eco-Industrial Park

Source: Lee in Chiu 2015
Example – Kalundborg (DK)


Source: Symbiosis Center Denmark
GECKO Project

• Danida funded 2-year pilot research project

• Duration: April 2018- March 2020

• Aims to provide the scientific knowledge base to develop a national strategy for designing and projecting high-circular eco-industrial parks (industrial symbiosis) in Kenya

Objectives:

• Business research (WP2)
• Governance research (WP3)
• Technical feasibility studies of selected symbiosis solutions (WP4)
• System modeling of symbiosis solutions (WP5)
Ruarka industrial park
Ruaraka industrial park

- Food (animal based): 9%
- Food (vegetable based): 17%
- Beverages: 6%
- Textiles: 3%
- Paper: 3%
- Chemicals: 20%
- Pharma: 6%
- Plastics: 15%
- Metals: 6%
- Minerals: 9%
- Waste collection: 6%
- Minerals: 9%
- Metals: 6%
- Food (animal based): 9%
- Food (vegetable based): 17%
- Beverages: 6%
- Textiles: 3%
- Paper: 3%
- Chemicals: 20%
- Pharma: 6%
- Plastics: 15%
Rainfall in Kenya

(Source: UNEP-NET)

Groundwater level in Nairobi

Ground water in the city of Nairobi

Number of boreholes drilled in Nairobi

Number of boreholes

Groundwater level

Ground water depth [m]


Ruaraka Now!
# Case Study

<table>
<thead>
<tr>
<th>Companies</th>
<th>Units</th>
<th>Water use m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cooling Boiler</td>
<td>1000, 500</td>
</tr>
<tr>
<td>B</td>
<td>Washing</td>
<td>126</td>
</tr>
<tr>
<td>C</td>
<td>Boiler</td>
<td>150</td>
</tr>
<tr>
<td>D</td>
<td>Process</td>
<td>550</td>
</tr>
<tr>
<td>E</td>
<td>Process Boiler</td>
<td>420, 200</td>
</tr>
</tbody>
</table>
Existing Situation

Ground water

Process unit

Effluent treatment

Ground water

Process unit

Effluent treatment
Symbiotic Relationship

Ground water → Reused water treatment → Effluent treatment

Process unit

Ground water → Reused water treatment → Effluent treatment

Process unit
# Water Treatment for Reuse

<table>
<thead>
<tr>
<th></th>
<th>Chemical Treatment</th>
<th>Ultra Filtration</th>
<th>Forward Osmosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD removal</td>
<td>80%</td>
<td>50%</td>
<td>90%</td>
</tr>
<tr>
<td>TSS removal</td>
<td>50%</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>TDS removal</td>
<td>10%</td>
<td>20%</td>
<td>95%</td>
</tr>
<tr>
<td>Unit cost</td>
<td>0.1 $/m³</td>
<td>0.2 $/m³</td>
<td>0.4 $/m³</td>
</tr>
</tbody>
</table>
Cost Functions

Total cost = Annualized capital cost + yearly operating cost

1. Water supply: Borehole drilling + Equipment + Pumping
2. Network = Pipes + Pumps + Treatment Units
   - 12% discount rate
   - 20-year life time
   - Maintenance: 5% of capital cost
Optimization – Model Superstructure
Optimization – Deterministic Approach

Non-Convex Mixed Integer Nonlinear Program (MINLP)

\[
\begin{align*}
\min_x & \quad f(x) \\
\text{subject to:} & \quad Ax \leq b \\
& \quad A_{eq}x = b_{eq} \\
& \quad l_b \leq x \leq u_b \\
& \quad c(x) \leq d \\
& \quad c_{eq}(x) = d_{eq} \\
& \quad x_i \in \mathbb{Z} \\
& \quad x_j \in \{0, 1\}
\end{align*}
\]
Optimization – Metaheuristic Approach

Non-dominated sorting genetic algorithm – NSGA II (Deb et al, 2002)

**Advantages**
- Not problem specific
- “Hill climbing” method
- Higher stability

**Disadvantage**
- Premature convergence
- Near optimum solution

**Further improvements**
- Initialization of population
- Adjusting GA parameters

Solutions – Pareto Front

- Solution 1
- Solution 2
Solution 1

Flow | Pipe diameter
--- | ---
> 100 m³/d | 90 – 160 mm
50 – 100 m³/d | 50 – 75 mm
< 50 m³/d | < 40 mm
Solution 2

Flow | Pipe diameter
-----|-----------------|
> 100 m³/d | 90 – 160 mm
50 – 100 m³/d | 50 – 75 mm
< 50 m³/d | < 40 mm

Company

Unit

Solution 2

Flow consumption %

Fresh water consumption %

Total cost $ / m³
Improving Economic Viability

- Heat recovery?
- Resource recovery?

Challenges
Data quality
Static versus dynamic
The resilience measure
Flexibility
Denmark

Symbiosis Center Denmark

Kenya

Google image
Conclusions

• Metaheuristic optimization approach shows high potential in water saving using water reuse network in an existing Kenyan industrial site

• The economic burden of water reuse can be decreased by recovering heat and valuable components from water (resource recovery)

• The metaheuristic approach can be used to perform uncertainty and flexibility assessments of water reuse networks
A New Danida project in South Africa:
Evaluation of Resource recovery Alternatives in South African water (ERASE)
Thank you for your attention!

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