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

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Eco-industrial Park

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

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)
Ruara 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%
- Waste 6%

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

Image: A large blank world map with oceans marked in blue.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1446486

Rainfall in Kenya

(Source: UNEP-NET)

Groundwater level in Nairobi

Ground water in the city of Nairobi

Groundwater level

Number of boreholes

(Source: UNEP-NET)
# 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
- Process unit
- Reused water treatment
- Effluent treatment
- Ground water
- Process unit
- Reused water treatment
- Effluent treatment
# 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

Fresh water consumption % vs. Total cost $ / m³
## Solution 1

### Flow vs. Pipe diameter

<table>
<thead>
<tr>
<th>Flow</th>
<th>Pipe diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 100 m³/d</td>
<td>90 – 160 mm</td>
</tr>
<tr>
<td>50 – 100 m³/d</td>
<td>50 – 75 mm</td>
</tr>
<tr>
<td>&lt; 50 m³/d</td>
<td>&lt; 40 mm</td>
</tr>
</tbody>
</table>

### Company Unit Matrix

<table>
<thead>
<tr>
<th>Company</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
</tr>
</tbody>
</table>

### Graph

- **Fresh water consumption %** vs. **Total cost $ / m³**
- **Solution 1**

[Map showing Solution 1 with connections between units A, B, C, D, E.]
Solution 2

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