OSMOSE-Lua – A Unified Approach to Energy Systems Integration with Life Cycle Assessment

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The system vision of the energy usage
The system vision of the energy usage
The system vision of the energy usage

Socio - ecologic - economic environment
The system vision of the energy usage

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Socio - ecologic - economic environment
The system vision of the energy usage

Socio - ecologic - economic environment
Energy system design

Socio - ecologic - economic environment

Conversion systems

Raw materials

Resources

Demand

Products & Energy services

Price

Waste Emissions

Availability

Price
Problem definition

• **Characterise** and **localise** the technologies to be used to supply the energy services and the products needed over the lifetime of the system’s element at the time they are needed with the resources that are available

  • Decisions to be taken
    • Technology: choice, size and location
    • The operating strategy
    • The services that are provided
    • The resources that are used

  • Criteria
    • Minimum cost = OPEX + APEX
    • Maximum profit = NPV (i, lifetime, cost)
    • Minimum environmental impact = LCIA
    • Max renewable energy integration

  • Constraints
    • Mass & Energy Balances
    • Context specs
    • Bounds

\[ Y_{u,l}, S_{u,l}, f_{u,l,t(p)} \quad \forall p, u, l \]
\[ f_{u \rightarrow s,l,t(p)} \quad \forall p, u, l, s \]
\[ f_{r \rightarrow u,l,t(p)} \quad \forall p, u, l, r \]
The energy systems engineering methodology

Energy services
Resources
Context & Constraints

Results analysis
- Exergy analysis
- Composite curves
- Sensitivity analysis
- Multi-criteria

Technology options
Models
Superstructure

Heat & Mass integration

Solutions

System boundaries

Decision variables

System performances indicators
- Economic
- Thermodynamic
- Life cycle environmental impact

Thermo-economic Pareto

Multi-objective Optimization
Solving method

Out=F(In,P)

Investment
Emissions
Infeasible

Thermoeconomic Pareto

Exergy analysis
Composite curves
Sensitivity analysis
Multi-criteria
Energy systems integration: multi-scale problem

- Model the interactions
- Identify the synergies
- Implement the interactions
  => Network or Grid
- Multi scale problem
- Systematic framework

Details

- Technologies
- Processes
- Materials

- Industrial Clusters
- Regions
- Districts

Technologies

- Models the interactions
- Identifies the synergies
- Implements the interactions

Scale

- Technologies
- Processes
- Materials

Context

- Literature review
- Problematic
- 1st year research

Research plan

- Materials

Materials

- Technologies
- Processes

Systematic approach

- Methodologies
- Tools

Industrial Clusters

- Districts
- Regions

Step 1

- Energy consumption profile determination
- Energy performance evaluation
- Energy baseline generation
- Identification and evaluation of improvement options
- Implementation and monitoring

Step 2

- Systematic approach
- Methodologies
- Tools
The energy technology building block

- Model of the interconnectivity (mass, heat, energy)
- Model of the emissions (Equipment, Emissions)
- Model of the cost (size => cost, maintenance)
Energy technology approach

• Advantages
  • Expert developed model
    • Flowsheeting model and tool
    • Level of detail
  • Independent of the energy systems integration
  • Model data base can be developed

• Difficulties
  • Remote access of models
    • Use of surrogate models
  • Consistency of the models in the energy systems
    • from black box to white box
  • Model data base
    • Confidence for reusing the models
    • Documentation
    • Certification of the model quality
Energy Technologies Encapsulation

Common interface of a module for system integration

Model encapsulation

- Thermo-chemical conversion
- Decision parameters
- Variables

Unit model report
- Summary of results
- Important data
- Errors
- Validity

Unit execution handler
- Input data
- Calculation engines
- Existing flowsheeting software
- Mimetic models
- Output data
- Integration/interconnectivity
- Costing
- LCA => Ecoinvent LCI

Unit connectivity
- Layers connections

Layer ontology
- Data base

Model
- Data base

Model ontology
- Flowsheeting tools
  - BELSIM-VALI
  - gPROMS
  - ASPEN plus
  - HYSYS
  - Matlab
  - Simulink
  - (CITYSIM)
  - MODELICA
  - Others possible
    - CAPE-OPEN
    - PROSIM

Data base
- Knowledge

- Electricity
- Heat transfer requirement
- LCA models
- Life cycle emissions
- Water streams
- Material streams
- Waste streams
- Equipment sizing model
- Cost estimation
- Maintenance investment cost
- Production
- Dismantling
- Decision parameters
- Variables
- Heat transfer requirement
Ontology of a value in OSMOSE LUA

\[ \dot{m}_{u,l}(t), Y_{i,u,l}(t), X_{i,u,l}(t), \Pi_{i,u,l}(t), KPI_k, \dot{m}^*_{u,l}, Y^*_{i,u,l}, X^*_{i,u,l}, \Pi^*_{i,u,l} \]

A variable is the smallest data structure handled by OSMOSE. A variable is defined by

1. **Name** or **tagname** that literally identifies the variable
2. **ID** that is tagging the variable
3. **Parent** indicates the **module** to which the variable belongs
4. **Value** that defines one instance of the variable \( \Rightarrow \) Matrix
   - A priori value of the variable will exist for any **time** in the **time sequence**, for any **period** and for any **scenario** in which the system is calculated.
5. **MinimumValue** and a **MaximumValue** that defines the bounds for the value of the variables
6. **DistributionType** and **DistributionParameters** that defines the uncertainty of the value
7. **DefaultValue** that defines the value of the variable when it is created. This is also the recommended order of magnitude of the value recommended for the calculations
8. **PhysicalUnit** that defines the physical unit of the value of the variable
9. **DefaultPhysicalUnits** that defines the physical unit with which the calculation have to be made. It means that a preprocessing phase will have to convert the value from the **PhysicalUnits** to the **DefaultPhysicalUnits** as well as a post-processing phase that is going to convert from the **DefaultPhysicalUnits** to the **PhysicalUnits**.
10. **Status** that identifies if the variable has a fixed value or a value that will be calculated. The status should identify as well if the value is calculated for each time or if it is constant or if it requires recalculation for each time. Status is equivalent to **ISVIT** in OSMOSE.
   - \( x = 1 \) : value is unique for the scenario (i.e. 1 value/scenario)
   - \( x0 = 2 \) : value is period dependent (i.e. 1 value/period and / period) The value may calculated during preprocessing phase using the model (i.e. constant that is period dependent).
   - \( x00 = 3 \) : the value is time dependent (i.e. 1 value/time and period and scenario).
   - where \( x = \)
   - \( 1 : \) for constant to be fixed by the user or the optimizer
   - \( 2 : \) for constant fixed by the user or the optimizer otherwise use the default value
   - \(-1 : \) for values calculated by the model
11. **Dependence Matrix** a dependence matrix that identifies the dependence of the value with respect to the other values of the problem is stored. Each of the dependence includes the mention if the dependence is **linear**, in which case the value of the dependence is stored in the field as a couple (ID, numerical value), or it can be stored as a reference to a non linear dependence that could be a surrogate model or the access to the model that calculates the dependence.
Superstructure definitions

- Explicit
  - In flowsheeting software

- Automatic
  - Based on the connectivity description
  - Restricted matches
  - Routing

- Implicit
  - Heat cascades

- Combined
  - Mass and Energy
Geographical information

At a given location: combination of energy technologies
Geographical information

At a given location: combination of energy technologies

Location 1, \((x_1, y_1, z_1)\)

Location 2, \((x_2, y_2, z_2)\)

Location \(i\), \((x_i, y_i, z_i)\)
Geographical information

At a given location : combination of energy technologies

- Coordinates attributed to locations
  - GIS data base => POSTGRE SQL
  - GIS Level of details
    - Roads, district heating network, electricity grid
  - GIS Tools : Routing, Layers, Representations
  - GIS Data
    - Buildings
    - Resources
    - Topology
Geographical information

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- Link between GIS data and Models
  - Link with unit models parameters
  - Access to GIS tools in the workflow
Geographical information

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Energy system design: problem definition

Given a set of energy conversion technologies:
Where to locate the energy conversion technologies?
How to connect the buildings?
How to operate the energy conversion technologies?

\[ C^{gas} = \sum_{e=1}^{n_e} \sum_{k=1}^{n_k} \sum_{t=1}^{n_p} H_t \frac{Q_{e,k,t}}{e_{t,k}} \]

Networks superstructure

Investment

Maintenance

\[ C^{inv} = \sum_{e=1}^{n_e} \sum_{k=1}^{n_k} a_e + a_e \cdot S_{e,k} \]

Project data base

Saved user data

Energy technologies in locations

Problems
GIS data base

Work flow
Models
Solving methods

OSMOSE LUA

Problem data base

Predefined data

Modules
Default values

Thermodynamic
Sizing
Costing

Life Cycle Inventory
Ecolinvent

Layer Ontology
Superstructure

Results data base

\[ Y_{i,u,l}(p(t)) = F_{u}(X_{i,u,l}(p(t)), \Pi_{i,u,l}(p(t))) \]
MILP process integration model @location k

Heat exchange by heat cascade model

Electricity balance

Existence : w in location k

Storage system

Buildings inertia

Water: $m_i$, $T_{in}$, $h_{in}$

return : $m_o$, $T_{out}$, $h_{out}$

Water: $m_o$, $T_{in}$, $h_{in}$

return : $m_i$, $T_{in}$, $h_{in}$

Technologies $w$, @location k period s and time t(s)

Demand @location k, period s and time t(s)

Subject to : Heat cascade constraints

$$\sum_{w=1}^{n_w} f_w q_{w,r} + \sum_{s=1}^{s_r} Q_{s,r} + R_{r+1} - R_r = 0 \quad \forall r = 1, ..., n_r$$

Feasibility

$$R_r \geq 0 \quad \forall r = 1, ..., n_r; R_{r+1} = 0; R_1 = 0 \quad E^+ \geq 0; E^- \geq 0$$

Electricity consumption

$$\sum_{w=1}^{n_w} f_w e_w + E^+ - E^- \geq 0$$

Electricity production

$$\sum_{w=1}^{n_w} f_w e_w + E^+ - E^- - E^- = 0$$

Energy conversion Technology selection

$$f_{min_w} y_w \leq f_w \leq f_{max_w} y_w$$

$$y_w \in \{0, 1\}$$

Units for heat integration

HEX: Heat exchangers
HL: Heat losses

Layers models / automatic superstructure

- Mass balance

\[ \sum_{u=1}^{n_u} \sum_{l=1}^{n_l} k_{u,l,t}^+ \cdot f_{u,l,t}(p) = 0 \quad \forall t(p) \quad \forall p \]

- Mass/heat distribution

\[ \sum_{u=1}^{n_u} k_{u,l,t}^+ \cdot f_{u,l,t}(p) = \sum_{j=1}^{n_l} e_{u,l,j,t}(p) \quad \forall t(p) \quad \forall p \forall l \]

\[ \sum_{u=1}^{n_u} k_{u,l,t}^- \cdot f_{u,l,t}(p) = \sum_{j=1}^{n_l} e_{u,j,l,t}(p) \quad \forall t(p) \quad \forall p \forall l \]
Process integration models

**MILP (Mixed Integer Linear Programming) models**
- Integer => Selection/Usage
- Continuous => Level of usage in t(period)
- Parametrised (T)
  - Discretisation
  - Decomposition

**Applications**
- Utility integration (Papoulias et al., 1983, Marechal et al., 1991)
  - Combined Heat and Power + Steam network (Marechal et al., 1997)
  - Refrigeration Cycle (Marechal et al., 2000)
  - ORC systems (Bendig, 2015)
- Multi-period (Marechal et al., 2003)
- Multi period + Multi time (Weber et al., 2008)
- Multi period + Multi time + Storage (Fazlollahi et al., 2012)
- Multi period + Multi time + Multi-location+Storage (Fazlollahi et al., 2014)
- Multi period + Multi time + Multi-location+Storage+Seasonal Storage (Rager et al., 2015)
- Bio-refineries (Ensinas, 2015)
- Industrial ecology (Gerber, 2013)
- Restricted Matches (Becker et al., 2012)
- Heat and Mass (Kermani et al., 2014)
- Heat load distribution (Marechal et al., 1989)
- Heat load Distribution multi-period (Mian et al., 2014)
- Heat load Distribution site scale (Pouransari et al., 2014)
- Hydrogen Network (Girardin et al., 2006)

**MINLP (Mixed Integer Non Linear Programming) models**
- Heat Exchanger Network Design (Grossmann et al., Mian et al., 2014)
- Heat Exchanger Network Design Multi-period (Mian et al., 2014)
Access to solvers

- MILP/MINLP solvers
  - Mathematical Programming Language
    - GLPK (MILP-Open source)
    - AMPL (MILP and MINLP - Proprietary)
  - Solvers
    - LPSOLVE (Open Source)
    - Gurobi
    - CPLEX
    - BONMIN
    - Baron
    - NLPSOL

- Evolutionary algorithms
  - MOO (EPFL)
  - Dakota

- Parallelisation
  - MPI => grid computing
Computational platform - OSMOSE

- Evolutionary, multi-objective optimisation algorithm (MINLP master problem)
  - Decision variables
  - Performances

1. **Energy- and material-flow models superstructure**
   - Detailed models: flowsheeting software
   - Average models: LCI database

2. **State variables**

3. **Energy & mass integration (MILP slave sub-problem)**
   - Process integration software
   - Supply chain synthesis

4. **Economic model**

5. **LCA models**

6. **Impact assessment**

7. **Process units**
   - Background processes
   - Unit processes
   - Elementary flows
   - Components

**LCI database (ecoinvent)**

EPFL-SCI-STI-FM (IPESE)
OSMOSE : Computer Aided Platform

Diagram:

- **Optimisation**
  - Decision variables
  - Thermodynamic targets
  - Performances

- **Equipment rating cost, impact**
  - State variables
  - Decision variables
  - Thermodynamic targets

- **Process flow model Superstructure**
  - State variables
  - Heat exchange requirements

- **Energy integration Optimisation**
  - State variables
OSMOSE: Computer Aided Platform

Data Structuring

GUI: Spreadsheets, Matlab

- GIS database
- Industrial ecology
- Urban systems

Technology models data base
- Energy conversion
- Sharing knowledge

Optimisation

Equipment rating costing, impact

Decision variables
- Thermodynamic targets

State variables

Decision variables
- Thermodynamic targets

Process flow model Superstructure

Energy integration Optimisation

State variables
- Heat exchange requirements

State variables
OSMOSE: Computer Aided Platform

Data Structuring

GIS database
Industrial ecology
Urban systems

GUI: Spreadsheets, Matlab

Technology models database
Energy conversion
Sharing knowledge

Flowsheeting tools
- Belsim-VALI
- gPROMS
- ASPEN plus
- HYSYS
- Matlab
- Simulink
- (CITYSIM)
- MODELICA
- Others possible
  - CAPE-OPEN?
  - PROSIM
  - UNISIM?

Energy technology database
- Data/models interfaces
- Simulation
- Process integration interface
- Costing/LCIA performances
- Reporting/documentation
- Certified dev procedure

Modeling tools integration

Optimisation

Energy integration

Process flow model
Superstructure

Equipment rating
costing, impact

Decision variables
Thermodynamic targets

State variables
Heat exchange requirements

Perfomances

Decision variables
Thermodynamic targets

Optimisation

Energy integration

Optimisation

Energy integration

Optimisation
OSMOSE: Computer Aided Platform

**Data Structuring**

- GIS database
  - Industrial ecology
  - Urban systems

- Technology models database
  - Energy conversion
  - Sharing knowledge

- Flowsheeting tools
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- GUI: Spreadsheets, Matlab

- Energy technology data base
  - Data/models interfaces
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- Process flow model Superstructure

- Process integration

- Energy integration

- Optimisation
  - Equipment rating costing, impact
  - State variables
  - Heat exchange requirements

- Decision variables
  - Thermodynamic targets

- Performances
  - DTmis

- Sizing/costing database
  - LCIA database (ECOINVENT)

- MILP/MINLP models
  - Heat/mass integration
  - Superstructure
  - HEN synthesis models

- Optimal control models
  - MILP/AMPL or GLPK
  - Multi-period problems

**Modeling tools integration**

- GUI: Spreadsheets, Matlab

- Data Structuring

- Technology models database

- Flowsheeting tools

- GIS database

- Energy technology data base

- Process flow model Superstructure

- Process integration

- Energy integration

- Optimisation

- Decision variables

- Performances

- Sizing/costing database

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- GUI: Spreadsheets, Matlab
OSMOSE: Computer Aided Platform

Data Structuring

- GIS database
  - Industrial ecology
  - Urban systems

- Technology models database
  - Energy conversion
  - Sharing knowledge

- Flowsheeting tools
  - BELSIM-VALI
  - gPROMS
  - ASPEN plus
  - HYSYS
  - Matlab
  - Simulink
  - (CITYSIM)
  - MODELICA
  - Others possible
    - CAPE-OPEN ?
    - PROSIM
    - UNISIM ?

GUI: Spreadsheets, Matlab

Modeling tools integration

- Energy technology database
  - Data/models interfaces
  - Simulation
  - Process integration interface
  - Costing/LCIA performances
  - Reporting/documentation
  - Certified dev procedure

- Decision support
  - Multi-objective optimisation
    - Evolutionary - Hybrid
    - Problem decomposition
    - Uncertainty

- Process integration
  - MILP/AMPL or GLPK
  - Multi-period problems

- Grid computing
  - Optimal control models
  - MILP/ MINLP models
    - Heat/mass integration
    - Sub systems analysis
    - Superstructure
    - HEN synthesis models

- Decision variables
  - Thermodynamic targets

- Equipment rating costing, impact

- Optimisation

- Process flow model
  - Superstructure

- State variables
  - Heat exchange requirements

- Energy integration
  - Optimisation

- Performances

- State variables
Results analysis

- Graphical representations
  - Composite curves
  - Sankey diagrams
- PDF reports
- Sensitivity analysis
- Pareto curves => data base of solutions
- Decision variables values
- Uncertainty analysis => most probable optimal solutions
Case study

Context of the project

PF(E)$^3$ project:
Calculation PlatFom for Energy Efficiency and Environmental optimisation

• Started in January 2013, duration of 30 months
• Tool for design and decision making based on the notion of cost/benefit
• Use of OSMOSE platform from EPFL’s IPESE group
Case study

A city of 100,000 habitants

<table>
<thead>
<tr>
<th>Resource</th>
<th>Price</th>
<th>Units</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (wood)</td>
<td>0.05</td>
<td>€/kWh</td>
<td>±30%</td>
</tr>
<tr>
<td>Biomass import</td>
<td>0.10</td>
<td>€/kWh</td>
<td>±30%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.078</td>
<td>€/kWh</td>
<td>±30%</td>
</tr>
<tr>
<td>Electricity (grid)</td>
<td>0.20</td>
<td>€/kWh</td>
<td>±30%</td>
</tr>
<tr>
<td>Oil</td>
<td>1.05</td>
<td>€/kg</td>
<td>±40%</td>
</tr>
<tr>
<td>Diesel</td>
<td>1.80</td>
<td>€/kg</td>
<td>±40%</td>
</tr>
<tr>
<td>Petrol</td>
<td>1.88</td>
<td>€/kg</td>
<td>±40%</td>
</tr>
<tr>
<td>DME</td>
<td>0.65</td>
<td>€/lit</td>
<td>±50%</td>
</tr>
<tr>
<td>FT diesel</td>
<td>0.125</td>
<td>€/kWh</td>
<td>±50%</td>
</tr>
<tr>
<td>MeOH</td>
<td>0.323</td>
<td>€/lit</td>
<td>±50%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Services</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>36.1</td>
<td>pkm/s</td>
</tr>
<tr>
<td>Electricity</td>
<td>22,000</td>
<td>kW</td>
</tr>
<tr>
<td>Hot water</td>
<td>24,210</td>
<td>kW</td>
</tr>
<tr>
<td>Space heating</td>
<td>117,623</td>
<td>kW</td>
</tr>
<tr>
<td>Wastewater</td>
<td>0.95</td>
<td>m3/s</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>2.23</td>
<td>kg/s</td>
</tr>
<tr>
<td>Municipal organic waste</td>
<td>0.51</td>
<td>kg/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industry</th>
<th>Size</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawmill</td>
<td>100,000</td>
<td>m³ wood in./y</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>12,000</td>
<td>tonnes tomatoes produced/y</td>
</tr>
<tr>
<td>Laundry service</td>
<td>20,000</td>
<td>tonnes dirty clothes washed/y</td>
</tr>
<tr>
<td>DME plant</td>
<td>50</td>
<td>MW_{thBM}</td>
</tr>
<tr>
<td>FT plant</td>
<td>100</td>
<td>MW_{thBM}</td>
</tr>
<tr>
<td>MeOH plant</td>
<td>50</td>
<td>MW_{thBM}</td>
</tr>
</tbody>
</table>
Case study

Models
Case study

Models

Urban system
Case study

Models

Urban system

Industries
- Sawmill
- Greenhouse
- Industrial laundry
- Biorefineries

Energy services
- Space heating
- Domestic hot water
- Electricity
- Transport

Waste treatment
- Municipal solid waste
- Municipal organic waste
- Wastewater

Energy services
- Electricity
- Transport

Waste treatment
- Wastewater

Units
- Unit U

Products
- Product 4
- Product 5

Resources
- Biogas
- Diesel
- Electricity
- Heat
- Mobility
- Natural gas (biogenic)
- Natural gas (fossil)
- Oil
- Organic waste
- Petrol
- Solid waste
- Wood biomass
- Industry main product(s)
Case study

Models

Available resources

Indigenous resources
- Water
- Biomass (wood)

Imported resources
- Natural gas
- Oil
- Diesel
- Petrol
- Electricity import
- Imported biomass (wood)

Urban system

Industries
- Sawmill
- Greenhouse
- Industrial laundry
- Biorefineries

Energy services
- Space heating
- Domestic hot water
- Electricity
- Transport

Waste treatment
- Municipal solid waste
- Municipal organic waste
- Wastewater

Required 1
Alternative 2
Alternative 3
Unit U
Product 4
Product 5

Biogas
Diesel
Electricity
Heat
Mobility
Natural gas (biogenic)
Natural gas (fossil)
Oil
Organic waste
Petrol
Water
Solid waste
Wood biomass
Industry main product(s)
Case study

Models

Available resources

Indigenous resources
- Water
- Biomass (wood)

Imported resources
- Natural gas
- Diesel
- Electricity import
- Oil
- Petrol
- Imported biomass (wood)

Conversion technologies
- Boilers
- Cars
- Engines
- Turbines
- Dryers
- Gasifiers
- Biomethanation
- Biogas purification
- Incineration
- Wastewater treatment
- Synthetic natural gas production

Urban system

Industries
- Sawmill
- Greenhouse
- Industrial laundry
- Biorefineries
- Municipal solid waste
- Municipal organic waste

Energy services
- Space heating
- Domestic hot water
- Electricity
- Transport
- Wastewater

Waste treatment

Models

Required 1
Alternative 2
Alternative 3

Unit U

Product 4
Product 5

Biogas
- Diesel
- Electricity
- Heat

Mobility
- Natural gas (biogenic)
- Natural gas (fossil)
- Oil

Organic waste
- Wastewater
- Petrol
- Water
- Solid waste
- Wood biomass

Industry main product(s)
Case study

User-interface
Case study

Assumptions

Business as usual (BAU)

- **Space heating**¹
  - Heat recovery from MSWI
  - 57% fuel oil, 18% natural gas, 14% biomass (wood), 11% electricity

- **Hot water**
  - Assumed same as space heating

- **Transport**²
  - 24% diesel, 76% petrol

- **Industries**
  - Biorefineries self-sufficient
  - Others → heat from natural gas

- **Electricity**
  - From MSWI
  - From grid (UCTE)
## Case study

### Assumptions

<table>
<thead>
<tr>
<th>Business as usual (BAU)</th>
<th>Optimisation constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Space heating</strong>¹</td>
<td><strong>Space heating and hot water</strong></td>
</tr>
<tr>
<td>– Heat recovery from MSWI</td>
<td>– Possible heat recovery from MSWI, WWTP, industries (refineries, laundry service), organic waste (OW) biogas</td>
</tr>
<tr>
<td>– 57% fuel oil, 18% natural gas, 14% biomass (wood), 11% electricity</td>
<td></td>
</tr>
<tr>
<td><strong>Hot water</strong></td>
<td><strong>Transport</strong></td>
</tr>
<tr>
<td>– Assumed same as space heating</td>
<td>– 56% diesel / petrol</td>
</tr>
<tr>
<td><strong>Transport</strong>²</td>
<td>– 44% non fossil fuel driven</td>
</tr>
<tr>
<td>– 24% diesel, 76% petrol</td>
<td><strong>Industries</strong></td>
</tr>
<tr>
<td><strong>Industries</strong></td>
<td>– Heat recovery when possible</td>
</tr>
<tr>
<td>– Biorefineries self-sufficient</td>
<td><strong>Electricity</strong></td>
</tr>
<tr>
<td>– Others → heat from natural gas</td>
<td>– From MSWI, WWTP, OW biogas</td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>– Remainder from grid (UCTE)</td>
</tr>
<tr>
<td>– From MSWI</td>
<td></td>
</tr>
<tr>
<td>– From grid (UCTE)</td>
<td></td>
</tr>
</tbody>
</table>

¹ Space heating
² Transport

Optimisation constraints are applied to existing energy systems, focusing on efficiency improvements.

Assumptions:
- Business as usual (BAU) scenario with current energy sources and technologies.
- Optimisation constraints aim to enhance energy efficiency and sustainability.

Heat recovery from MSWI, WWTP, industries (refineries, laundry service), organic waste (OW) biogas is considered a key measure for energy optimization.
Case study

Result of optimization

Monte Carlo simulation

• Prices of resources are subjected to uncertainty
• Finding the most resilient solutions

Probability of being the best solution in 800 Monte Carlo simulations
Case study

Result of optimization

Monte Carlo simulation

• Prices of resources are subjected to uncertainty
• Finding the probability of being among the top 10 best solutions
Case study

Result of optimization

Monte Carlo simulation

- Prices of resources are subjected to uncertainty
- Finding the probability of being among the top 10 best solutions
Case study

Result of optimization (one solution in the set)

Total environmental impacts = 492,000 tons of CO$_2$-eq/yr
Total operating cost = 226.8 million CHF/yr

The thicknesses represent the size of the connection in “kW” (except for connections to mobility which are scaled up to be visible).
Each colour represents one type of connection, e.g. electricity, heat, natural gas, wood, mobility, …
Case study

Climate change (tons CO₂-eq/yr)

- Total
- Electricity (grid)
- Petrol
- Diesel
- Fuel oil
- Natural gas
- Biomass (import) for biorefineries
- Biomass (import) for SNG production
- Biomass (import) for sawmill
- Biomass (indigenous) for sawmill

Optimised system compared to Business as usual.
Case study

Climate change (tons CO\textsubscript{2}-eq/yr)

<table>
<thead>
<tr>
<th>Imported resources</th>
<th>Optimised system</th>
<th>Business as usual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (import) for biorefineries</td>
<td>62'500</td>
<td>200'000</td>
</tr>
<tr>
<td>Biomass (import) for SNG production</td>
<td>125'000</td>
<td>400'000</td>
</tr>
<tr>
<td>Biomass (import) for sawmill</td>
<td>187'500</td>
<td>600'000</td>
</tr>
<tr>
<td>Biomass (indigenous) for sawmill</td>
<td>250'000</td>
<td>800'000</td>
</tr>
</tbody>
</table>

- Total
Conclusions and future work

- Data management platform
  - Data bases
    - Technology Models => Ontology
    - Connectivity => Ontology
    - Geographical information system => SQL
    - Life Cycle Inventory => SQL
    - Costing
- Tools integration and handlers
  - Flowsheeting tools
  - Routing algorithms
  - Data analysis and processing
    - Clustering
    - Statistical analysis
  - MILP problem formulation
  - Problem decomposition & methods
  - MILP/MINLP solvers
Conclusions

• Workflow organisation => list of tasks
  • Aggregation/disaggregation
  • Super-structure definition & models
  • Optimisation problems
    • Multi-objective
    • MI(N)LP
  • Parallel computing
  • Decision support & uncertainty

• Applications
  • Process design
  • Process integration & HEN design
  • Site scale integration
  • Industrial Symbiosis development
  • Urban Energy Systems development
  • Industrial ecology
  • Region-City scale development
  • Autonomous systems (Ships, cars)
Thank you for your attention!
Appendices
A1. Life Cycle Impact Assessment (LCIA) in Osmose-Lua