

IWA SWWS & ROSA Conference Haifa, 14. – 18.10.2018

Simulation and Visualization of Material Flows in Sanitation Systems for Streamlined Sustainability Assessment

Manfred Schütze
Jens Alex
ifak e. V. Magdeburg, Germany

Alexander Wriege-Bechtold
Matthias Barjenbruch
Technical University Berlin, Germany

Heinrich Söbke
Jörg Londong
Bauhaus University, Weimar, Germany

Imke Wißmann
Matthias Schulz
Susanne Vesper
BCE Björnsen Consulting Engineers, Germany



ifak Magdeburg (Flooding June 2013)



Sanitation systems: New (pre-)planning challenges

- New and alternative sanitation systems (NASS), which often are decentralized, provide new system configuration options
- Increasing importance of sustainability assessment, e.g. EIA, LCA
- Increasing interest in nutrient recovery

-> Discussion and selection of locally appropriate solution becomes more challenging

- Some earlier and related approaches to support this process:
 - Campos *et al.* (2012), Ormandzhieva *et al.* (2014) (visualization)
 - Spuhler *et al.* (2018) (systematic selection process)
 - ... and many more ...



Sanitation systems: New (pre-)planning challenges: (1) Criteria

- How to assess potential options? → Criteria definition
- Requirement: feasible for practical application
- Analysis of other approaches: ESAT (2012), TWIST++ (2017), DWA-A272 (2018), ...

-> Sampsons Criteria Set:

	Criterion	Description	Indicator
	Eutrophication Potential (EP)	Essentials: N, P, COD, NH ₃	kg PO ₄ -eq
	Energy Input	final energy, primary energy use.	MJ
Ecology	Greenhouse Gas Emissions	CO ₂ , CH ₄ , N ₂ O	kg CO ₂ -eq
	pharmaceuticals	ecotoxicological substances (Proxy here: Diclofenac).	%
	Physical Footprint	Surface area required	m ²
Economy	Life-Cycle Cost	Costs and revenues (CAPEX, OPEX)	NPV (€)
Social Issues	Social Acceptance	Qualitative indicator	Rating scale
Flexibility	Flexibility	Regarding changing general conditions	Rating scale

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Sanitation systems: New (pre-)planning challenges: (2) Visualisation

- Numerous discussions (often enthusiastic)
- Earlier attempts: e.g. Excel-based approach
- Easy-to-use, fun-to-use approach missing
- Building and visualising sanitation systems in a model
- Objective here:
 - NOT detailed process simulation (such as in ASM, ADM1 etc.)
 - BUT “quick-and-easy” visualisation of resource fluxes and assessment
- Solution idea here:
 - Setup of building blocks using flexible simulator framework (Simba#) (availability/demand, process models, GUI, LCA – simba.ifak.eu)
 - Provision of Sampsons tool to the enduser

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Resource fluxes and constituents of interest

Resource fluxes (adapted from Tilley et al., 2008, 2014)

Input/Output	Colour	Input/Output	Colour
Urine	Yellow arrow	Blackwater	Black arrow
Faeces	Brown arrow	Sludge	Orange arrow
Drinking water	Blue arrow	Digested sludge	Red arrow
Wastewater	Red arrow	Biogas	Orange arrow
Pre-treated wastewater	Yellow arrow	Biowaste	Black arrow
Treated wastewater	Orange arrow	Digestate	Dark green arrow
Grey water	Grey arrow	Fertilizer	Red arrow
Pre-treated greywater	Light grey arrow	Ash	Red arrow
Treated greywater	Light grey arrow	Rain water	Teal arrow

Constituents of interest:

N, P, K, S, Diclo, COD, TSS

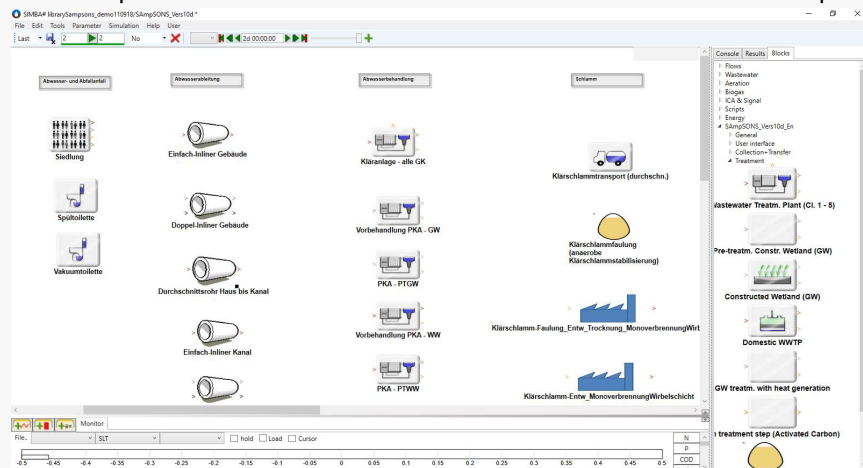
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Sanitation systems: Simulation and Visualisation

Block (module) library: Building your system in a model

Setup: User-interface – Collection&Transfer – Treatment – Use/Disposal



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Sanitation systems: Simulation and Visualisation

- An example block: Act. Sludge Plant (Class 2: 1000 – 5000 PE)
Modelling blocks are built by project team members



This block:

Input: - Wastewater
Outputs: - Treated Wastewater
- Sludge

User parameter dialogue

Parameter categories:

- Normal
- Advanced
- Non-editable

Process description:

Input-Output models, but also states and dynamic modelling possible

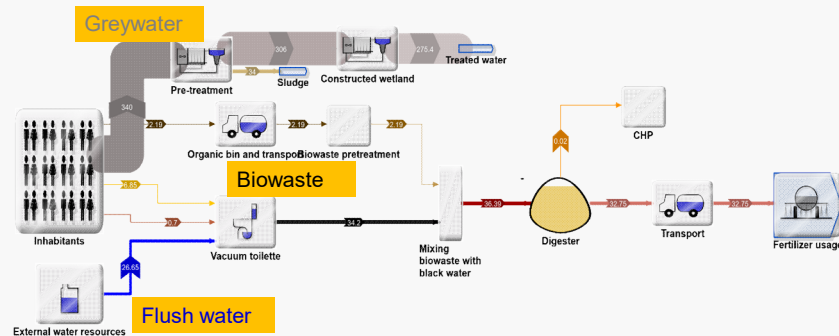
Parameter	General	CriteriaOther	Efficiencies	CriteriaConstruction	CriteriaOperation	CostsCAPEX	CostsOPEX	Invisible
Energy demand can be specified EITHER as kWh/m ³ or as kWh/PE/a								
Energy demand per m ³	0							kWh/m ³
Energy demand per inhabitant and year	42.8							kWh/PE/a
Direct emissions: specify them here ONLY if they leave the system (not going into any other block)								
Direct emissions are used for calculation of GHG/EP/PE								
Direct emissions (during operation) PCO4	0							kg/(PE*a)
Direct emissions (during operation) CH4	0.25							kg/(PE*a)
Direct emissions (during operation) N2O	0.022							kg/(PE*a)
Factor for direct emissions (during operation) NH3: 0.0003								
Direct emissions (during operation) COD	3.7							kg/(PE*a)
Direct emissions (during operation) Total N	3.0							kg/(PE*a)
Direct emissions (during operation) Total P	0.153							kg/(PE*a)

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Sanitation systems: Simulation and Visualisation

- Example model: Co-digestion of biowaste and blackwater
Visualisation of flows [m³/d] as dynamic Sankey diagram

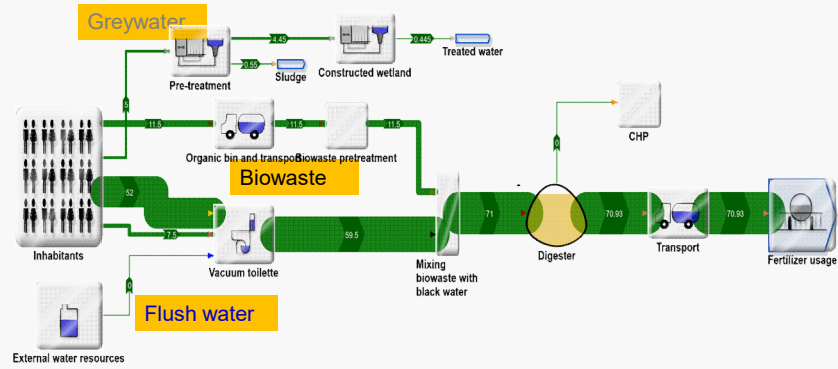


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Sanitation systems: Simulation and Visualisation

- Example model: Co-digestion of biowaste and blackwater
Visualisation of **Nitrogen fluxes [kg/d]** as dynamic Sankey diagram

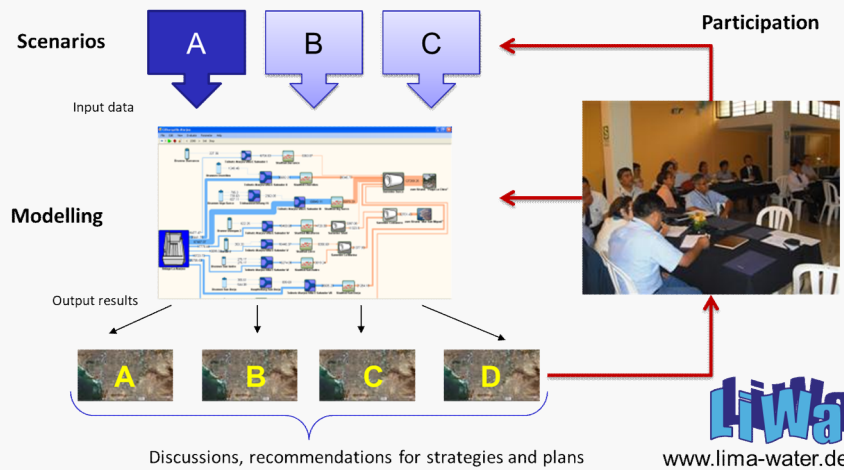


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Sanitation systems: Simulation and Visualisation

- Modelling as a tool to aid stakeholder participation



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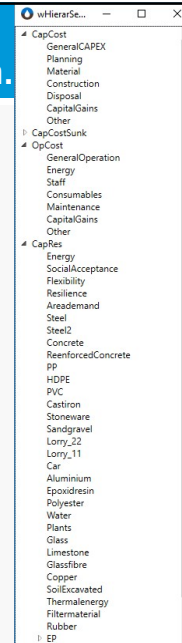
New (pre-)planning challenges (3): LCA Integration of modelling with LCA/assessm.

Requirement: not only simulation and visualisation,
but also sustainability assessment

Categorisation of Sampsons criteria

- Capital costs (overall; planning, construction, ...)
- Operational costs (Overall; maintenance, energy, ...)
- Capital resources (material demands for construction)
- Operational resources (consumption during operation, energy, emissions, ...)

-> Calculation of evaluation criteria for system's life cycle (LCA)



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Integration of modelling with LCA and sustainability assessment

Coupling of process modelling and LCA calculations

- Each block has evaluation functions using global LCA parameters
- Evaluation (aggregation); Output at end of the simulation

Global parameters	
General	EP GHG PE
Factor for calculation of GHG from PO4	0 kgCO2-eq/kg
Factor for calculation of GHG from total N	0 kgCO2-eq/kg
Factor for calculation of GHG from NH3-N	0 kgCO2-eq/kg
Factor for calculation of GHG from NOx	0 kgCO2-eq/kg
Factor for calculation of GHG from total P	0 kgCO2-eq/kg
Factor for calculation of GHG from COD	0 kgCO2-eq/kg
Factor for calculation of GHG from CO2	1 kgCO2-eq/kg
Factor for calculation of GHG from CH4	28 kgCO2-eq/kg
Factor for calculation of GHG from N2O	265 kgCO2-eq/kg
Factor for calculation of GHG from electricity	0.614 kgCO2-eq/kWh
Factor for calculation of GHG from steel	8.5 kgCO2-eq/kg
Factor for calculation of GHG from steel2	2.44 kgCO2-eq/kg
Factor for calculation of GHG from concrete	0.1 kgCO2-eq/kg
Factor for calculation of GHG from reinforced concrete	0.137 kgCO2-eq/kg
Factor for calculation of GHG from PP	1.63 kgCO2-eq/kg
Factor for calculation of GHG from HDPE	1.8 kgCO2-eq/kg
Factor for calculation of GHG from PVC	2.56 kgCO2-eq/kg
Factor for calculation of GHG from cast iron	3.87 kgCO2-eq/kg

Source of LCA
parameters:
GaBi and ecoinvent
databases

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Integration of modelling with LCA and sustainability assessment

Some LCA output and visualisation

Investment costs

CapCost	Description	Value Unit
GeneralCAPEX		
Pre-treatment	Unspecified total investment costs [nicht näher spezifiziert]	0 €
Vacuum toilette	Unspecified total investment costs [nicht näher spezifiziert]	906,75 €
Digester	Unspecified total investment costs [nicht näher spezifiziert]	1097600 €
	GeneralCAPEX total	1098506,75 €
Planning		
Pre-treatment	Specific investment costs Planning	2000 €
Constructed	Capital costs for planning	0 €

Operational costs

OpCost	Description	Value Unit
GeneralOperati on		
Pre-treatment	Unspecified total operational costs [nicht näher spezifiziert]	0 €/a
Constructed wetland	general operational costs	0 €/a
Vacuum toilette	Unspecified total operational costs [nicht näher spezifiziert]	0 €/a
Digester	Unspecified total operational costs [nicht näher spezifiziert]	78929 €/a
	GeneralOperati on total	79029 €/a
Consumables		
Pre-treatment	Specific operational consumables [nicht näher spezifiziert]	0 €/a
Organic bin and transport	Costs for Diesel	8580 €/a
Digester	Specific operational consumables [nicht näher spezifiziert]	0 €/a
Transport	Costs for Diesel	127560 €/a
	Consumables total	136140 €/a
CapitalGains		
Treated	Capital gain	-0 €/a

Values just for illustration!

Resources for construction

CapRes	Description	Value Unit	Welfare [t]
Arbeitsbedarf			
Pre-treatment	Physical footprint (demand on area)	200 m ²	40
Constructed wetland	Physical footprint (demand on area)	1000 m ²	80
Vacuum toilette	Physical footprint (demand on area)	0,5 m ²	10
Digester	Physical footprint (demand on area)	1000 m ²	50
	Arbeitsbedarf total	2763 m ² /a	
Steel			
Pre-treatment	Steel	0 kg	40
Constructed wetland	Steel	0 kg	40
Vacuum toilette	Steel	0 kg	40
Digester	Steel	0 kg	40

Env. Impacts (w/o constr.)

CapEnv	Description	Value Unit
EP		
Pre-treatment	EP_materials	0 kg
Constructed wetland	EP_materials	0 kg
Vacuum toilette	EP_materials	0,01 kg
Digester	EP_materials	0 kg
	EP_materials total	0 kg
EP total		
Pre-treatment	EP total	0 kg
Constructed wetland	EP total	0 kg
Vacuum toilette	EP total	0 kg
Digester	EP total	0 kg
	EP total	0 kg
GHG		
Pre-treatment	GHG_materials	0 kg CO ₂ eq
Constructed wetland	GHG_materials	0 kg CO ₂ eq
Vacuum toilette	GHG_materials	0 kg CO ₂ eq
Digester	GHG_materials	0 kg CO ₂ eq
	GHG_materials total	0 kg CO ₂ eq
GHG total		
Pre-treatment	GHG total	2,02 kg CO ₂ eq
Constructed wetland	GHG total	0 kg CO ₂ eq
Vacuum toilette	GHG total	0 kg CO ₂ eq
Digester	GHG total	0 kg CO ₂ eq
	GHG total	2,02 kg CO ₂ eq

Results
Evaluation

Ressource recovery potential

Recovery	Description	Value Unit
Recovered		
Treated		162,42 kg/a
Sludge		200,75 kg/a
Fertilizer usage		289,18 kg/a
	Recovered total	3954,68 kg/a

Recovered	Description	Value Unit
Treated		82,12 kg/a
Sludge		91,25 kg/a
Fertilizer usage		49,979 kg/a
	Recovered total	593,33 kg/a

Recovered	Description	Value Unit
Treated		1629 kg/a
Sludge		0 kg/a
Fertilizer usage		31759 kg/a

Graphical output:
Yet under development

Example models

Example models, serving for validation

- SCST Berlin-Stahnsdorf
- Sanitation system of Wohlsborn/Thuringia
- "Wastewater-free university campus" of Birkenfeld/Nahe
- ...

Technology fact sheets

Fact sheet example: "Flush toilet"

Factsheet System Component: Flush Toilet						
Status						
Topic	Information	Description	Value	Unit	Reference / Knowledge Source	Comment
Component Name		conventional flush toilet				
Short Name		flush toilet				
Component Description		n.a.				
Capacity		n.a.				
Lifespan			10	year	http://www.sustainableminds.com/showroom/2007/02/02-CommercialWashingToilet.pdf	estimated
Space requirement			0.5	m ²		estimated
Input: Material Flows						
	Material Flow 1	tap water	40	L/PE*Y	http://www.velox.de/themen/wasser01/01a02/	also https://de.wikipedia.org/wiki/Wasserverbrauch
	Material Flow 2	feces	1.6	L/PE*Y	http://www.bauart.com/download/2007/02/02-CommercialWashingToilet.pdf	500 litres of urine and 60 litres of faeces per person per year. (This sentence is reference.)
	Energy Flow 1	n.a.				calculated
Output: Material Flows						
Performance (e.g., Cleaning efficiency)	Material Flow 1	wastewater	41.5	L/PE*Y		calculated
		n.a.				For characterisation of waste water see TWIST data Suggestion: since every system will have some kind of toilet and the environmental impact of the production of the toilets will be comparable, we should consider these effects as equal and therefore omit this information.
Raw and Auxiliary Material Usage						
	Material 1	GWP	20.2	kg/unit		
	Material 2	EP	0.009	kg/unit		
	Material 3	Primary Energy Demand	741.5	MJ/unit	IBU EPD Sanitärkeramik Duravit	exact material composition not known, therefore indication of the environmental impacts of the production (based on a total weight of 27.1 kg)
Energy Usage						
	Energy 1	n.a.				
Direct Emissions						
Costs/revenues - LCC						
	Investment Costs		213.00	€	see Übersicht € WC	estimated via google shopping
	Installation Costs		70	€		estimated one hour installation time by a specialist
	Operational Costs		0	€/a		
	Revenue		0	€		
	Depreciation Period		10	a		according to lifespan
Comments and Assumptions						

Information required:

- Efficiencies of process
- Costs (CAPEX, OPEX)
- Material demand
- Consumables demand
- Energy demand
- Direct emissions
- ...

Based on this information, additional technology blocks can be created

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Example models

Remaining work

- Visualisation of LCA results
- Completion of example models
- Implementation of additional sanitation technologies

And you?

If you are interested in

- Supplying fact sheet** of additional sanitation technologies or
- Using the Sampsons tool** once it is finished,

please, contact us!

Email: manfred.schuetze@ifak.eu

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Thank you!

**Manfred Schütze
Alexander Wriegen-Bechtold
Heinrich Söbke
Imke Wißmann
Matthias Schulz
Susanne Veser
Jörg Londong
Matthias Barjenbruch
Jens Alex**

Email: manfred.schuetze@ifak.eu



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**Bauhaus-
Universität
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Funding:



Deutsche Bundesstiftung Umwelt

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