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Input-Dependent Life Cycle Inventory Model of Industrial Wastewater Treatment

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Starting Point

- Overall prevention and reduction of impacts on the environment as a whole required for technological systems (e.g., EU IPPC Directive)
- shift of environmental burdens (cross-media effect) to be avoided
- Strict purification requirements for industrial wastewater

➔ Holistic approach of **life cycle assessment** needed

BUT:

- Detailed life cycle inventory (LCI) data only available for municipal wastewater treatment
(e.g., ecoinvent database: www.ecoinvent.org)
- Wastewater-specific LCI data on unit-procss level for the purification of industrial wastewater is very scarce

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Objectives

Overall objective:

- Develop a wastewater-input specific gate-to-gate inventory model for large-scale industrial wastewater treatment in the chemical and related sectors

Specific objectives:

- Enable calculation of inventory parameters as a function of
  - wastewater composition (organic & inorganic contaminants)
  - technologies applied
- Provide unit-process inventories for modular set-up of entire treatment systems
- Establish model that allows for adequate assessment of different organic and inorganic emissions to water and air

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Treatment Processes under Study & Data Basis

- State-of-the-art, large-scale treatment technologies
  - Reverse osmosis
  - Extraction
  - High-pressure wet-air oxidation
  - Activated sludge treatment

  (Reverse osmosis, Extraction, High-pressure wet-air oxidation: Physico-chemical treatment; Activated sludge treatment: Mechanical-biological treatment)

- Data collected from chemical industry on:
  - Energy and auxiliaries' consumption
  - Emissions to water and air
  - Wastewater composition (inflow and outflow of each unit process)
  - Operational requirements (e.g., biodegradability, TOC-load range, …)
  - Process parameters (e.g., temperature, pressure, …)
- Data basis: monthly data from years 2000 - 2004

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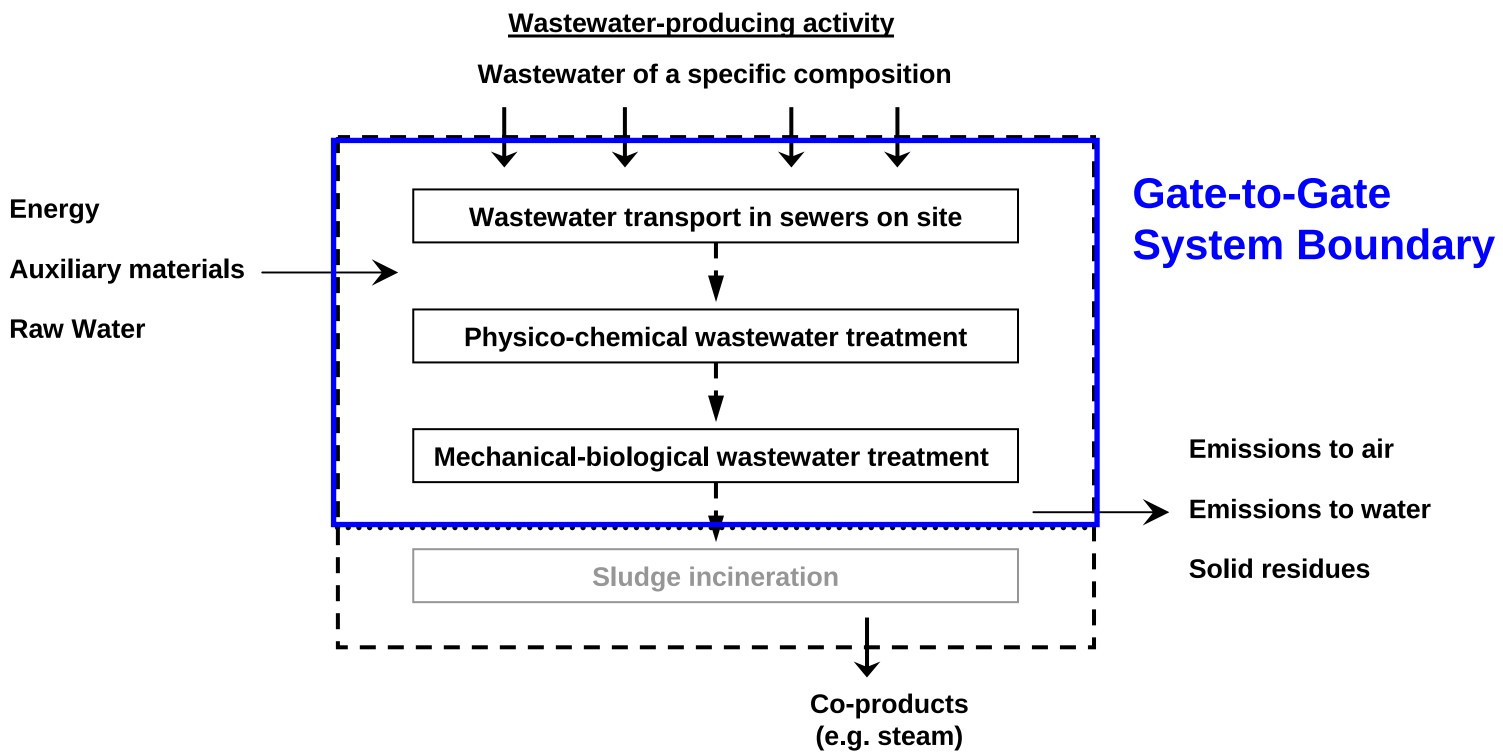
Scope of the Inventory Model

- Gate-to-gate system boundaries



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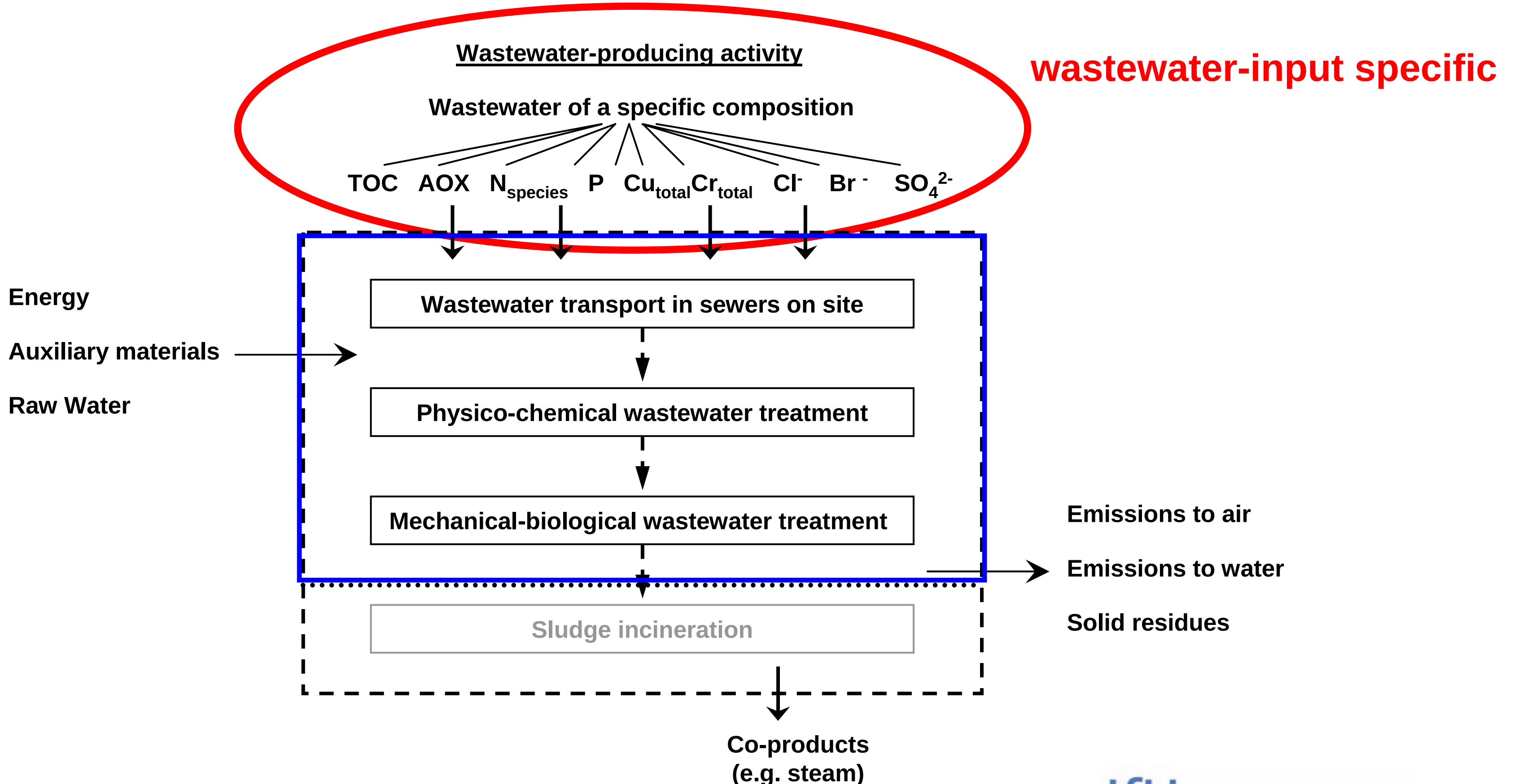
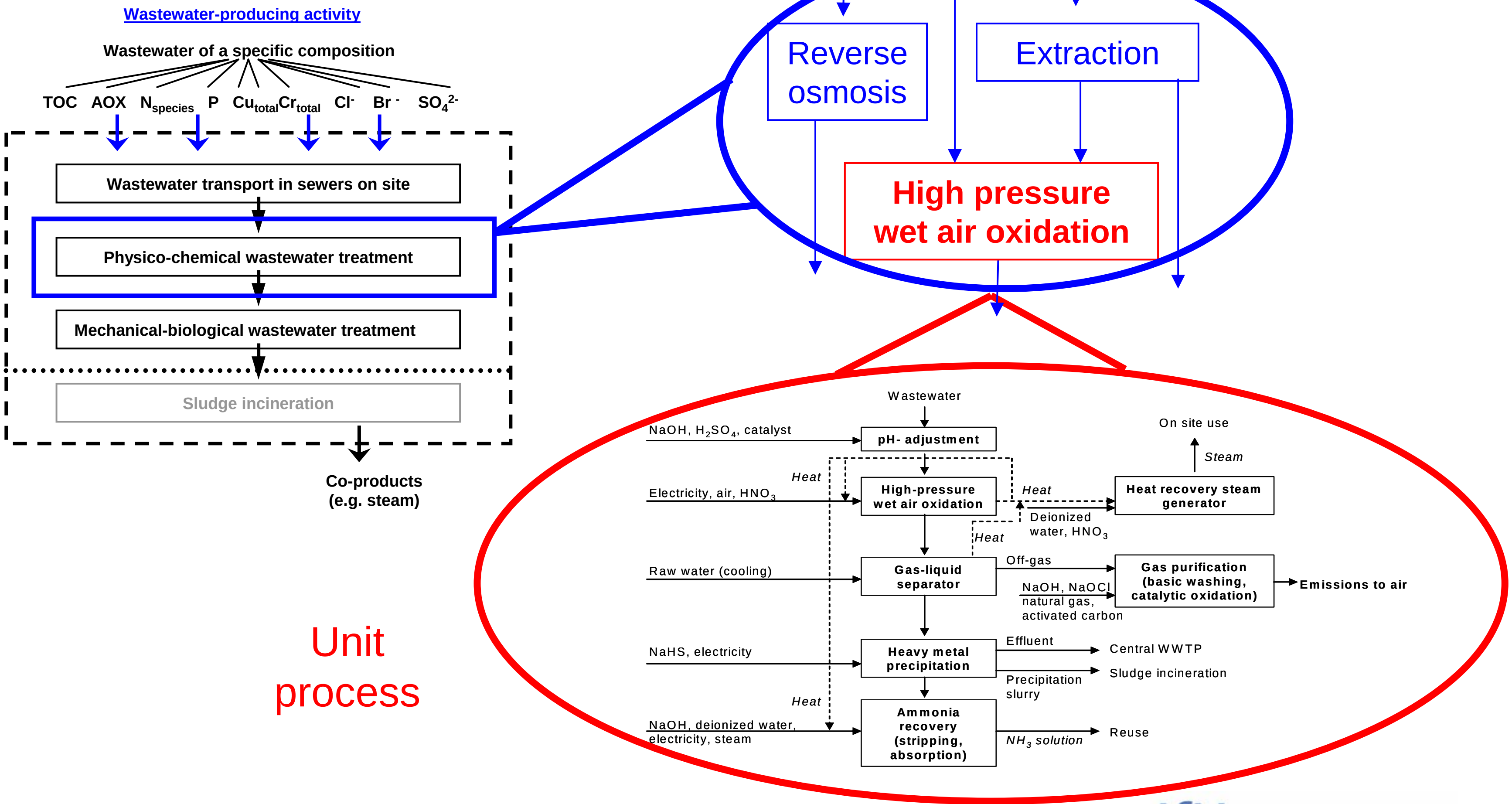
Scope of the Inventory Model cont.

- Functional unit:
  Treatment of a certain volume of industrial wastewater with a certain composition being characterized by 14 wastewater parameters



Modular Model Set-Up

- Combination of diverse treatment units possible depending on characteristics of wastewater



Model Design & Parameter Allocation

Consumption factors *cf*

- Process-dependent allocation

$$cf_{A,\ process} = \frac{consumption_A}{volume_{wastewater}} \quad [\mathbf{consumption\ unit\ /\ m^3}]$$

- Product-dependent allocation

$$cf_{A,\ product,\ i} = \frac{consumption_A}{mass_i} \quad [\mathbf{consumption\ unit\ /\ kg}]$$

A: Energy carrier / auxiliary material
i: wastewater parameter

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Model Design & Parameter Allocation cont.

Transfer coefficients $tc_{i,j}$

- Technology-specific matrices

$$\begin{pmatrix} m_1 \\ m_2 \\ \ldots \\ m_n \end{pmatrix} \bullet \begin{pmatrix} tc_{11} & tc_{12} & \ldots & tc_{1m} \\ tc_{21} & tc_{22} & \ldots & tc_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ tc_{n1} & tc_{n2} & \ldots & tc_{nm} \end{pmatrix} = \begin{pmatrix} z_{11} & z_{12} & \ldots & z_{1m} \\ z_{12} & z_{22} & \ldots & z_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ z_{n1} & z_{n2} & \ldots & z_{nm} \end{pmatrix}$$

m_i: input mass of wastewater parameter i in feed wastewater
$z_{i,j}$: output mass of wastewater parameter i in output stream

➔ Wastewater-input specific inventories for different processes

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Consumption Factors & Transfer Coefficients

- Average values + standard deviation
- Generic data ranges for LCI parameters provided for all treatment technologies

Transfer coefficients for 14 wastewater parameters

pollutants in the wastewater input	extraction (system 1 & 2) (n=42)[a]		reverse osmosis (system 1) (n=36)[a]		reverse osmosis (system 2) (n=6)[a]		high-pressure wet-air oxidation (system 1) (n=36)[a]				mechanical-biological treatment (system 1 & 2) (n=42)[a]		
	extract to WAOP/SI[b]	raffinate to MBTP	concentrate to WAOP	permeate to MBTP	concentrate to SI	permeate to MBTP	effluent to MBTP	precipitation slurry to SI[b]	recovery as NH_3 solution	emission to air	emission to water	emission to air	sludge to SI
TOC_{total}	89.5 (±1.6)	10.5 (±1.6)	55.9 (±4.7)	44.1 (±4.7)	73.1 (±6.8)	26.9 (±6.8)	7.7 (±1.9)	0.1[c] (±0.1)		92.2[d] (±1.9)	22.8 (±5.9)	23.0[e] (±5.9)	54.2 (±5.9)
$TOC_{degradable}$	61.9 (±13.3)	38.1 (±13.3)	23.7 (±9.1)	76.3 (±9.1)	41.2 (±14.1)	58.8 (±14.1)	25.2 (±9.8)	0.1[c] (±0.1)		74.7 (±9.8)		28.6[e] (±5.6)	71.4 (±5.6)
$TOC_{refractory}$	96.5 (±1.3)	3.5 (±1.3)	73.0 (±5.7)	27.0 (±5.7)	80.2 (±5.2)	19.8 (±5.2)	2.0 (±1.0)	0.1[c] (±0.1)		97.9 (±1.0)	100.0[f] (±1.0)		
AOX	91.8 (±5.4)	8.2 (±5.4)	45.1 (±22.3)	54.9 (±22.3)	66.3 (±15.1)	33.7 (±15.1)	14.4 (±6.1)	0.1[c] (±0.1)		85.5[g] (±6.1)	36.5 (±20.7)		63.5 (±20.7)
N_{total}	65.2 (±6.1)	34.8 (±6.1)	12.4 (±10.1)	87.6 (±10.1)	29.6 (±7.4)	70.4 (±7.4)	30.4 (±13.2)	0.1[c] (±0.1)	23.9[h] (±1.2%)	45.6[i] (±13.2)	44.0 (±11.9)	32.9 (±11.9)	23.1 (±11.9)
NH_4^+-N	61.5 (±4.5)	38.5 (±4.5)	14.1 (±10.8)	85.9 (±10.8)	15.3 (±12.2)	84.7 (±12.2)	28.5 (±17.3)	0.1[c] (±0.1)	26.6[h] (±1.4)	44.8[i] (±17.3)	51.6[j] (±18.8)	28.9[k] (±18.8)	19.5 (±18.8)
NO_3^--N	28.2 (±25.5)	71.8 (±25.5)	11.2 (±4.6)	88.8 (±4.6)	14.0 (±7.5)	86.0 (±7.5)	68.4 (±16.1)	0.1[c] (±0.1)		31.5[l] (±16.1)	26.7 (±17.5)	70.1[m,n] (±17.5)	3.2 (±17.5)
NO_2^--N	90.2 (±2.3)	9.8 (±2.3)	10.0 (±3.0)	90.0 (±3.0)	11.8 (±7.5)	88.2 (±7.5)	99.9[o] (±1.0)	0.1[c] (±0.1)			59.9[p,n] (±15.0)	38.4 (±15.0)	1.7 (±15.0)
PO_4^{3-}-P	6.6 (±17.5)	93.4 (±17.5)	47.5 (±3.2)	52.5 (±3.2)	49.6 (±3.5)	50.4 (±3.5)	99.9[q] (±1.0)	0.1[c] (±0.1)			8.2 (±7.9)		91.8 (±7.9)
Cu_{total}	50.4 (±35.4)	49.6 (±35.4)	60.1 (±25.7)	39.9 (±25.7)	68.3 (±21.7)	31.7 (±21.7)	35.2[r,s] (±26.9)	64.8[r] (±26.9)			21.9 (±14.3)		78.1[t] (±14.3)
Cr_{total}	16.1 (±25.0)	83.9 (±25.0)	52.8 (±28.7)	41.3 (±28.7)	71.3 (±12.5)	28.7 (±12.5)	45.6[r] (±18.1)	54.4[r] (±18.1)			33.2[u] (±15.1)		66.8[t] (±15.1)
Br^-	22.4 (±27.3)	77.6 (±27.3)	8.1 (±6.2)	91.9 (±6.2)	34.1 (±6.4)	65.9 (±6.4)	97.8 (±21.9)	2.1[v] (±21.9)		0.1[v] (±0.1)	99.5 (±15.0)		0.5 (±15.0)
Cl^-	3.7 (±6.6)	96.3 (±6.6)	6.4 (±5.7)	93.6 (±5.7)	21.3 (±10.4)	78.7 (±10.4)	95.6 (±9.4)	4.3[v] (±9.4)		0.1[v] (±0.1)	98.6 (±7.9)		1.4 (±7.9)
SO_4^{2-}	1.0 (±1.0)	99.0[w] (±1.0)	24.5 (±12.7)	75.5 (±12.7)	40.4 (±8.0)	59.6 (±8.0)	99.5[w] (±1.0)	0.5 (±1.0)			99.5 (±3.8)		0.5 (±3.8)

average (±stdev) (in %)

Model Applicability

- First input-dependent modular systems model of an integrated industrial wastewater treatment system with very high degree of complexity
- Applicable to wastewaters generated by various industries:
basic chemicals, specialty chemicals, and pharmaceutical production
- Applicable to wastewater of multi-production mix enterprises and small companies producing few chemical products
- Selection and combination of different unit operations according to technical feasibility and regulatory requirements
- For end-of-pipe treatment **and** systems including process-integrated measures

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Representativeness of Process Modules

- Model entirely based on industry data
  - Broad empirical data
  - Comprehensive sets of measurement data
- Mechanical-biological treatment: generic inventory
  - Similar to inventory models of municipal wastewater treatment (e.g., ecoinvent)
- Wet-air oxidation & reverse osmosis: ((semi-))generic inventory
  - Ranges of some consumption factors dependent on feed-wastewater composition
- Extraction: site-specific inventory
  - Optimized process design for removal of a specific contaminant group
  - BUT: inventory can be adapted to similar applications

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Conclusions

- Representative generic data ranges of high validity
- Parameterized inventory model based on disaggregated unit processes
- Wastewater-specific inventories for alternative treatment options

➔ Bridging data gaps when primary data on industrial wastewater treatment is not available

➔ In-depth analysis of environmental benefits and burdens

➔ Assistance in system's retrofit by implementing process-integrated measures

➔ For decision-support in practice

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Thank you for your attention!

Further information:

Köhler, A. (2006): Environmental Assessment of Industrial Wastewater Treatment Processes and Waterborne Organic Contaminant Emissions. *Ph.D. thesis No.16367*, ETH Zürich. http://e-collection.ethbib.ethz.ch/diss/

Köhler, A., Hellweg, S., Recan, E. and K. Hungerbühler (2006): Input-Dependent Life-Cycle Inventory Model of Industrial Wastewater-Treatment Processes in the Chemical Sector. *Submitted to Environmental Science and Technology.*

Köhler, A., Hellweg, S., Escher, B.I. and K. Hungerbühler (2006): Organic Pollutant Removal versus Toxicity Reduction in Industrial Wastewater Treatment. *Environmental Science and Technology 40(10).*