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A second-generation life cycle inventory model for chemicals discharged to wastewater

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Background and aim

- There is a need to better assess the disposal of chemicals via wastewater in LCA taking into account differences in:
  - Specific behaviour of individual chemicals
  - Wastewater collection and treatment levels in different countries
  - Wastewater treatment technologies
  - Sludge disposal practices in different countries

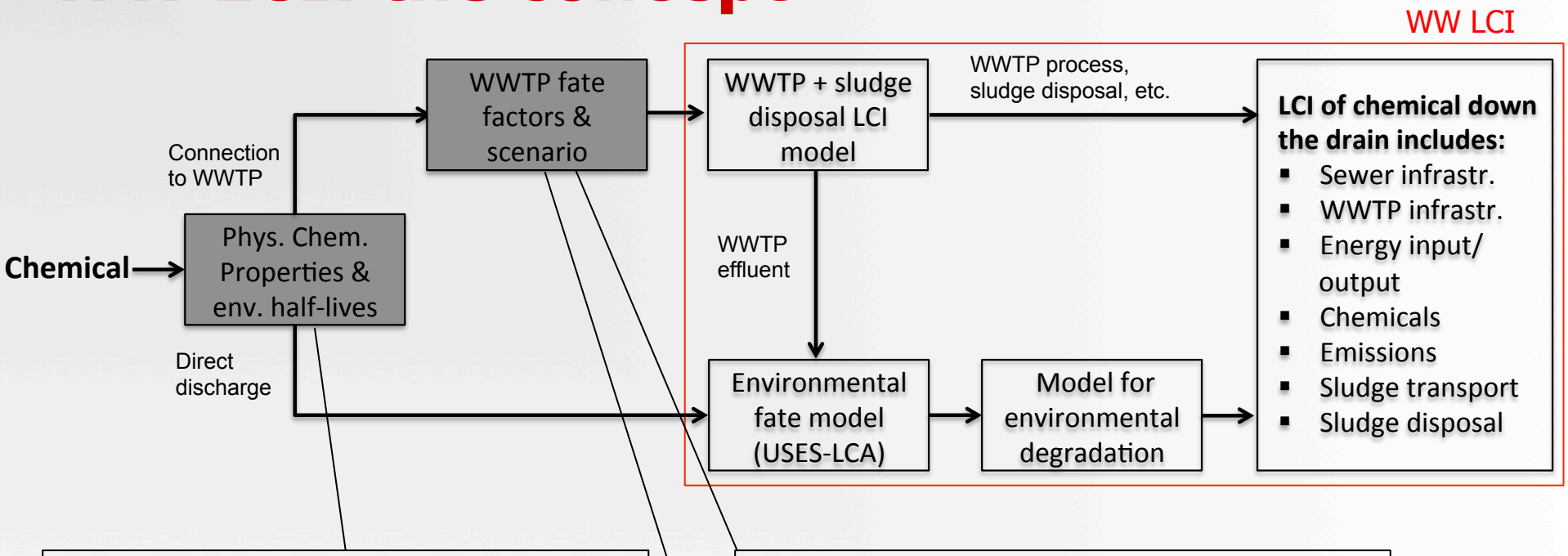
- We recently developed WW LCI, a model that calculates chemical-specific LCIs of chemicals in wastewater[1]

- We present WW LCI v2, where we expand the scope of its predecessor, including features from another model, SewageLCI[2]

[1] Muñoz I, Otte N, Van Hoof G, Rigarlsford G. (2016) A model and tool to calculate life cycle inventories of chemicals discharged down the drain. Int J Life Cycle Assess, DOI: 10.1007/s11367-016-1189-3

[2] Birkved M, Dijkman TJ (2012) SewageLCI 1.0, an inventory model to estimate chemical specific emissions via sewage treatment systems. 6th SETAC World Congress, Berlin 20-24 May 2012.

WW LCI: the concept

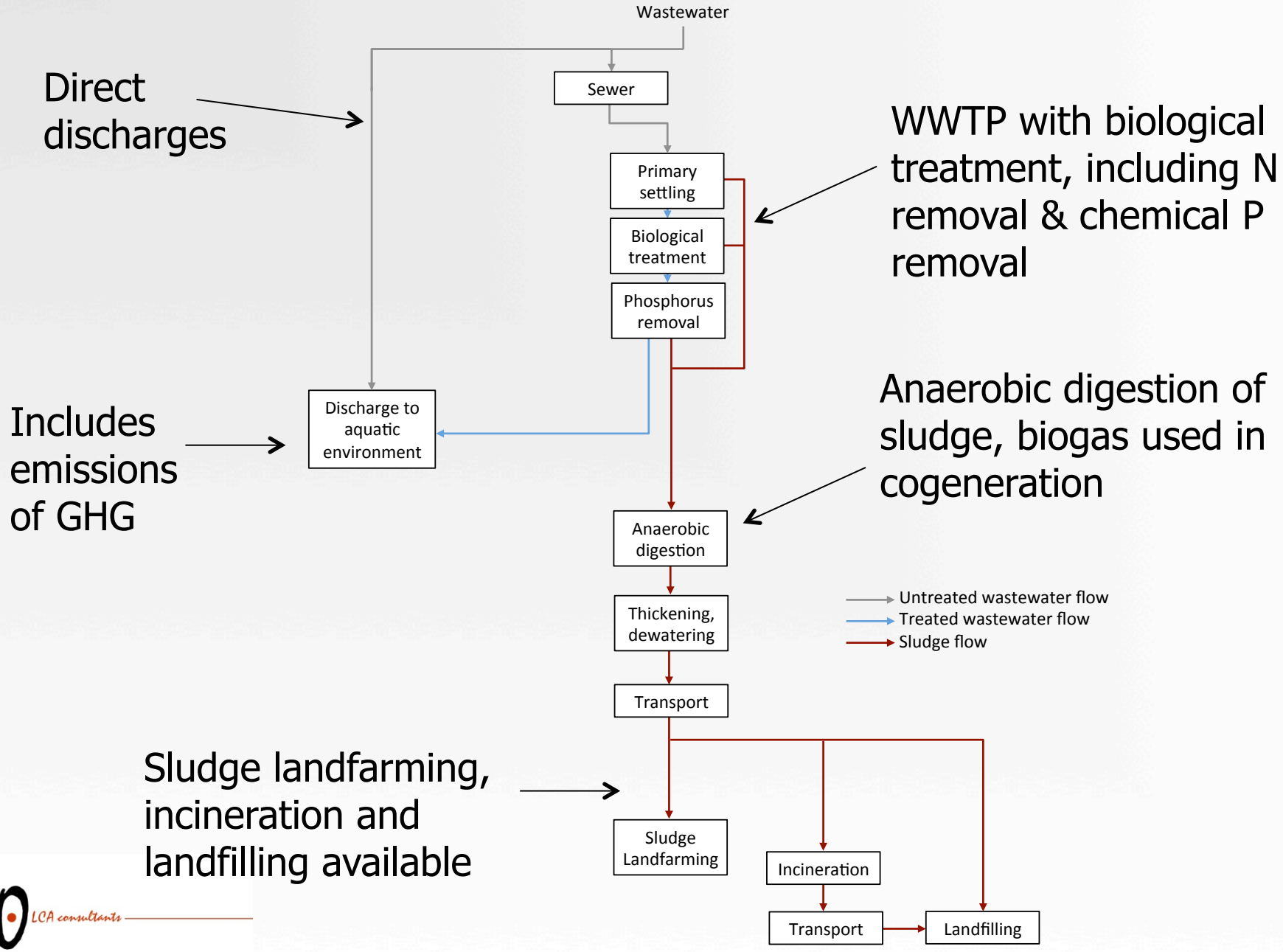


- Organic/inorganic
- Composition (C, H, O, N, S, P, Cl)
- Molecular weight
- Vapour pressure
- Solubility
- Kow
- Half-lives in the environment (soil, water, air)

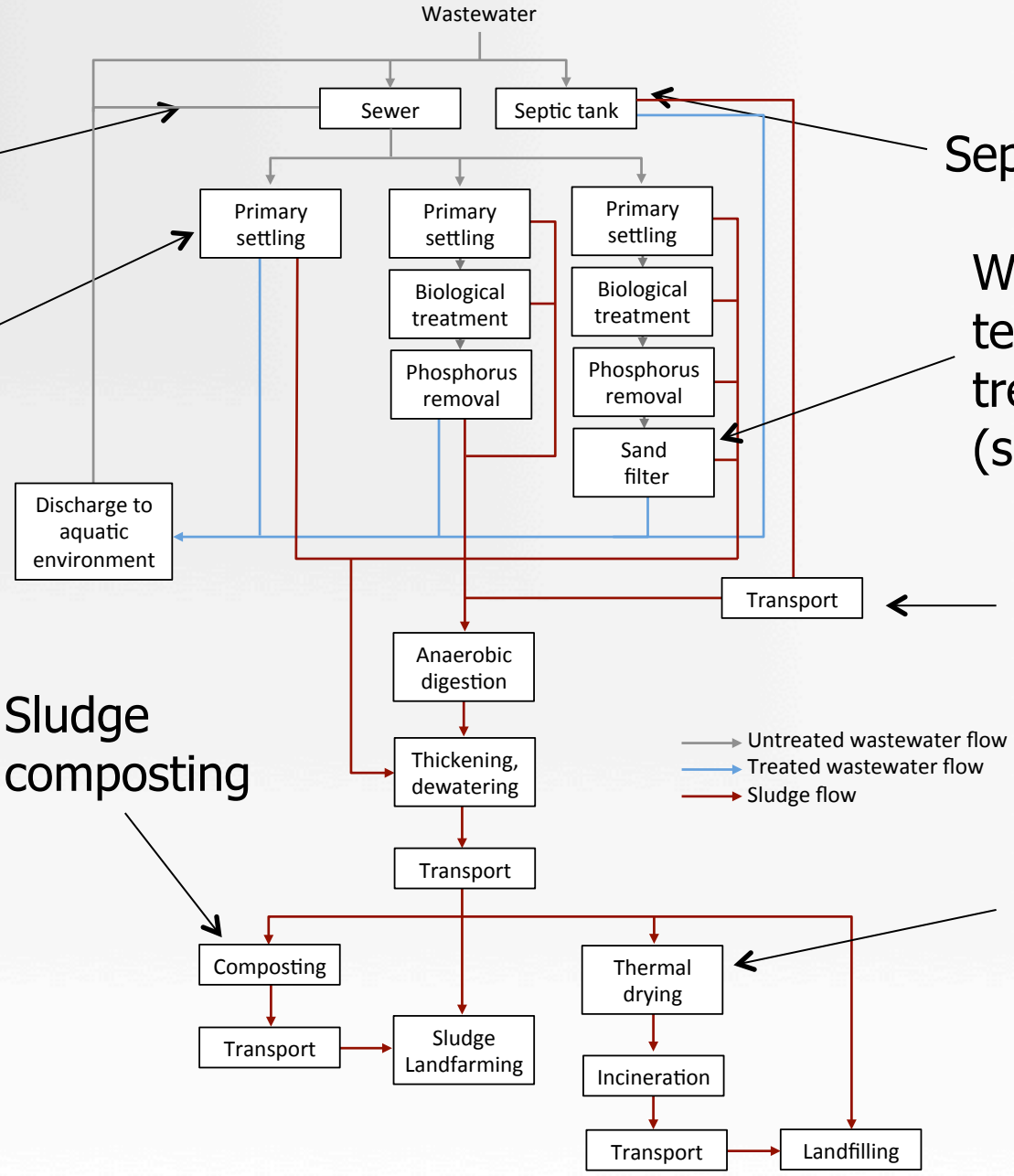
- Fraction degraded
- Fraction volatilized
- Fraction to sludge
- Anaerobic degradability

- % population connected to WWTPs
- WWTP includes N and P removal
- Country
- Sludge disposal scenario

WW LCI (v1): technological scope



WW LCI v2: expanded technological scope



Connection to sewer but no treatment

WWTPs with only primary treatment

Septic tanks

WWTPs with tertiary treatment (sand filter)

Septic tank sludge disposal

Sludge composting

Thermal drying of sludge

Database with wastewater/ sludge treatment practices for 57countries

LCA consultants

WW LCI v2: new processes

- **Septic tanks**
  - Production and installation of septic tank
  - Degradation/removal of chemicals in wastewater:

    $F_{deg,septic} = 0.3 \cdot F_{deg,WWTP}$

    $F_{sludge,septic} = 0.3 \cdot F_{sludge,WWTP}$
  - Transport of sludge (3% dry mass) to WWTP

- **WWTPs with primary treatment only**
  - Lower energy use and land occupation
  - No anaerobic digestion of sludge
  - Degradation/removal of chemicals in wastewater:

    ➔As in septic tanks

WW LCI v2: new processes

- **WWTPs with tertiary treatment**
  - We only include sand filtration
  - Additional energy use, cleaning chemicals and land occupation
  - Removal of chemicals based on chemical-specific sorption to sludge:

$$F_{sludge,tert} = \frac{\rho_{sludge} \cdot K_d}{1 + \rho_{sludge} \cdot K_d}$$

Sludge-water partition coefficient

Sludge solids density

$$K_d = f_{oc} \cdot 0.41 \cdot K_{ow}$$

Fraction of organic carbon in sludge solids

Octanol-water partition coefficient

WW LCI v2: new processes

- **Thermal drying of sludge**
  - Pre-treatment for incineration
  - Electricity and heat demand to evaporate excess water
  - Chemical content assumed unaltered
- **Sludge composting**
  - Optional before application to agricultural soil
  - Open composting only
  - Inputs include composting plant and energy use
  - Complete mass balance:

Mass balance for sludge composting, all amounts in kg

Chemical in sludge	Input			Output								
	Chemical	O_2	Total input	Water to air	CO_2	CH_4	N_2O	N_2	NH_3	NOx	Chemical in compost	Total output
DTPMP (persistent)	1	0	1	0	0	0	0	0	0	0	1	1
TAED (degradable)	1	0.13	1.13	0.58	0.18	0.00172	0.00089	0.00089	0.028	0.013	0.33	1.13

WW LCI v2: country database

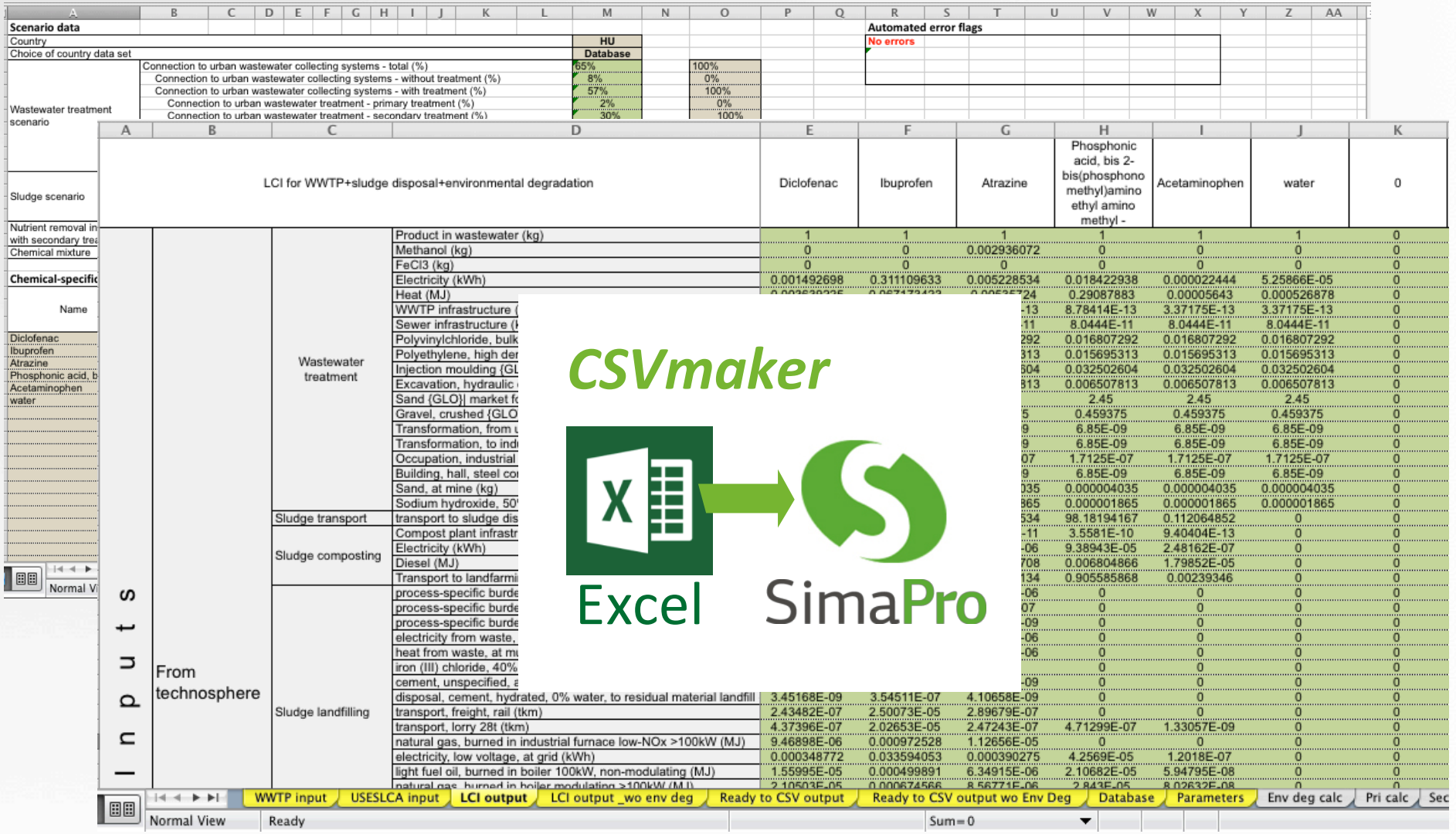
- **Statistics on wastewater treatment (in %):**
  - Connection to sewer
    - Without treatment
    - With treatment - primary
    - With treatment - secondary
    - With treatment - tertiary
  - Connection to independent collection
    - With treatment
    - Without treatment
- **Statistics on sludge disposal (in %):**
  - Composting
  - Landfarming
  - Landfilling
  - Incineration

Europe	Austria, Bosnia Herzegovina, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland Italy, Lithuania, Luxembourg, Latvia, FYR of Macedonia, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia, Turkey, Ukraine, Montenegro
America	Brazil, Canada, Chile, Mexico, Peru, United states
Asia Pacific	Australia, China, Indonesia, India, Iran, Japan, Republic of Korea, Malaysia, Russia, Saudi Arabia, Thailand, Taiwan
Africa	Tanzania, South Africa

WW LCI v2: key features of the Excel tool

- All calculations in a single Excel file: WW LCI.xlsx
- 30 chemicals can be assessed at a time, separately or as a mixture
- Entirely parameterized, all values can be changed by the user
- Resulting LCIs use ecoinvent 3 nomenclature
- WW LCI does not include impact assessment calculations
- LCIs can be exported as CSV files to LCA software: SimaPro

WW LCI v2 in Excel



WW LCI v2 applied to three chemicals

Chemicals

Name	Typical use	Key features	Removal in WWTP (with secondary treatment[1])
Diethylenetriamine penta(methylene phosphonic acid) (DTPMP)	In detergents	Poorly degradable, contains N and P	0% degraded, 85% to sludge
Atrazine	Pesticide	Poorly degradable, contains N	1% degraded, 2% to sludge
Ibuprofen	Pharmaceutical	Degradable	72% degraded, 1% to sludge

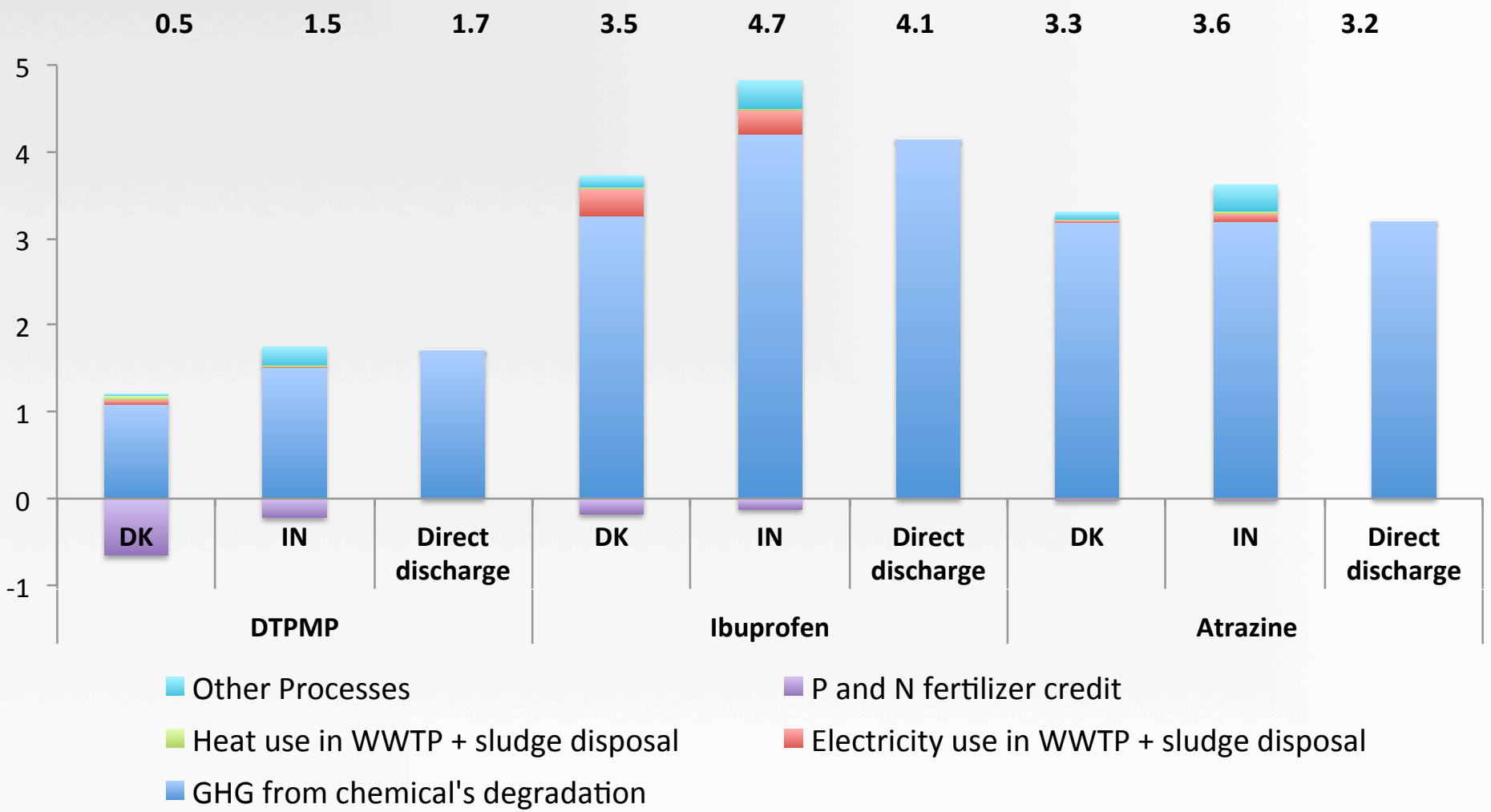
[1] Estimated with the fate model Simpletreat

Country data

		Denmark (DK)	India (IN)
Wastewater treatment scenario	**Connection to sewer**		
	Without treatment	0%	0%
	Primary treatment	2%	0%
	Secondary treatment	3%	21%
	Tertiary treatment	84%	0%
	Connection to independent collection		
	With treatment - septic tank	11%	39%
	Without treatment	0%	39%
Sludge disposal scenario	Composting	6%	0%
	Landfarming	50%	100%
	Landfilling	0%	0%
	Incineration	44%	0%

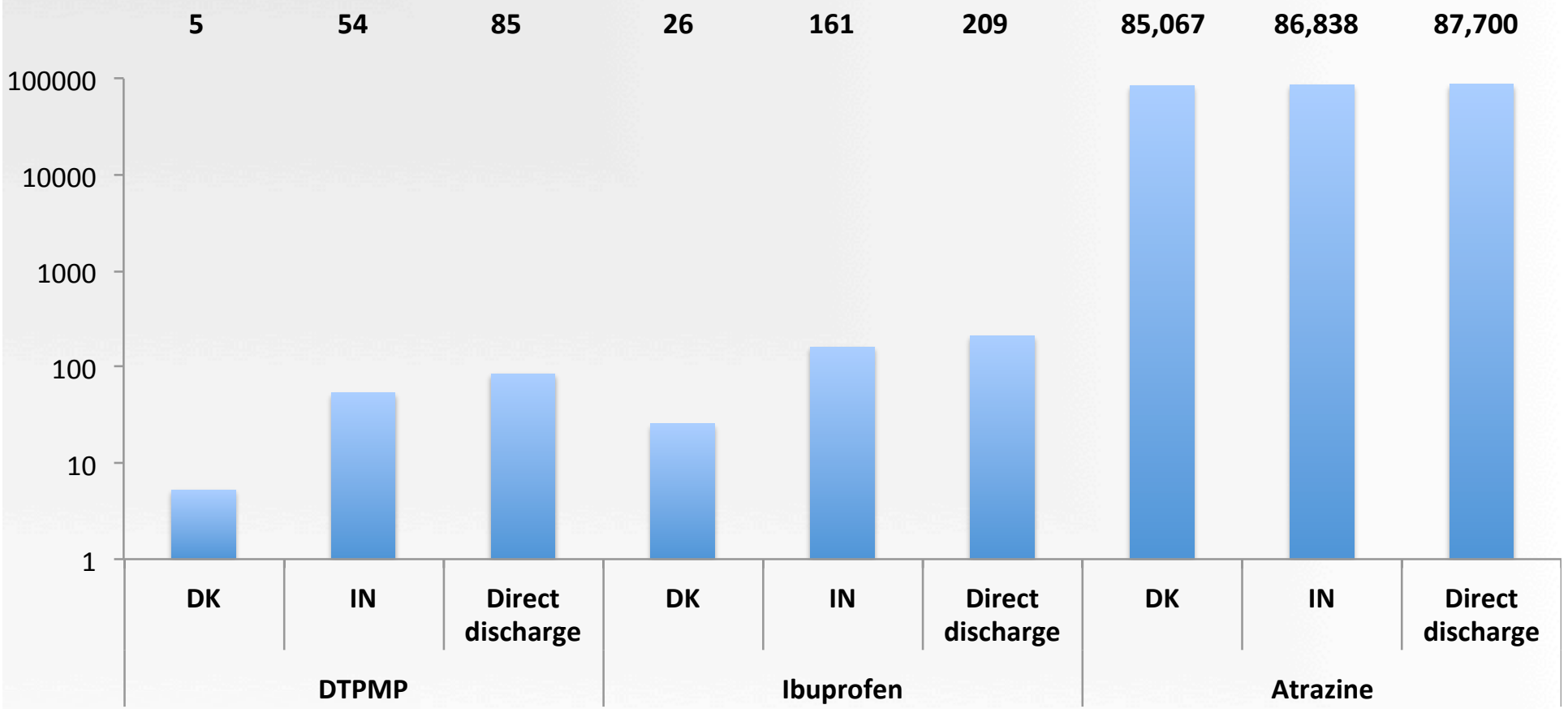
WW LCI v2 applied to three chemicals

GHG emissions, in kg CO_2-eq/kg chemical (IPCC 2013)



WW LCI v2 applied to three chemicals

Freshwater ecotoxicity, in CTU-eq/kg chemical (USEtox)

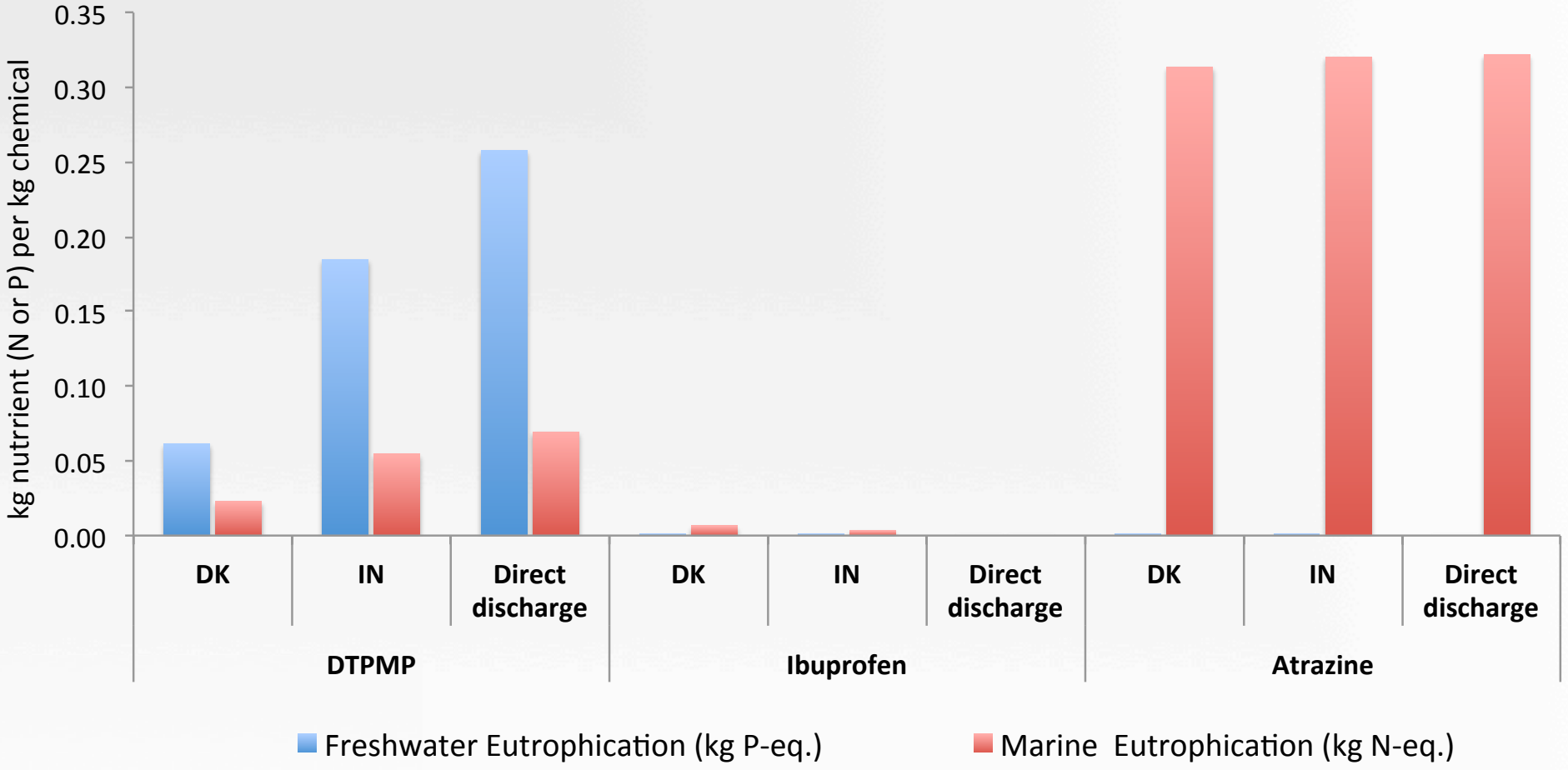


(Log scale)

WW LCI v2 applied to three chemicals

Freshwater eutrophication, in kg P-eq/kg chemical (ReCiPe)

Marine Eutrophication, in kg N-eq/kg chemical (ReCiPe)



Conclusions & options for improvement

- Improvement in modelling the end of life for chemical substances
- Still some limitations:
  - Data-demanding
  - Complete flow analysis only for C, N, P, S and Cl
  - Metals not yet supported
  - No uncertainty quantification
  - Import of data sets only available for SimaPro so far
  - Septic tank sludge scenario is optimistic for developing countries
  - Tertiary treatment includes only sand filter
  - Country database can be expanded

Thank you!

More info:
http://lca-net.com/projects/show/wastewater-lci-initiative/

WW LCI References:

Kalbar P, Muñoz I, Birkved M. ***WW LCI v2: a second-generation inventory model for chemicals discharged to wastewater***. Submitted to the International Journal of Life Cycle Assessment

Muñoz I, Otte N, Van Hoof G, Rigarlsford G. ***A model and tool to calculate life cycle inventories of chemicals discharged down the drain***. International Journal of Life Cycle Assessment. DOI: 10.1007/s11367-016-1189-3