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Consequential LCI modeling of chemicals in wastewater: including avoided nutrient treatment

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Background

- Nowadays most urban wastewater treatment systems rely on biological treatment

$$\textit{Organic matter} + O_2 + N + P \rightarrow \textit{Biomass} + CO_2$$

- Urban wastewaters contain (more than) enough nutrients for microorganisms to thrive

Table 3.7 Typical content of nutrients in raw municipal wastewater with minor contributions of industrial wastewater (in g/m^3)

Parameter	High	Medium	Low
N total	100	60	30
Ammonia N	75	45	20
Nitrate + Nitrite N	0.5	0.2	0.1
Organic N	25	10	15
Total Kjeldahl N	100	60	30
P total	25	15	6
Ortho-P	15	10	4
Organic P	10	5	2

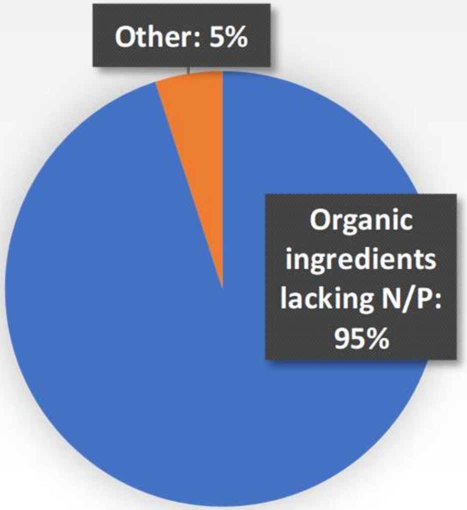
Henze M. et al. (Eds.) Biological Wastewater Treatment: Principles Modelling and Design. IWA Publishing, London.

Background

- In LCA we often need to model the impact of wastewaters with specific compositions and not the 'average'
- Such specific wastewaters are often N and/or P deficient

Example: washing machine detergent

Mass of ingredients in a concentrate washing detergent formulation, excl. water*

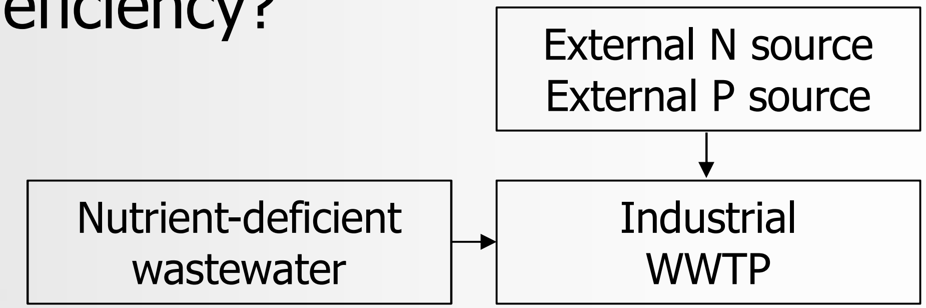


- N deficient by 94%
- P deficient by 100%

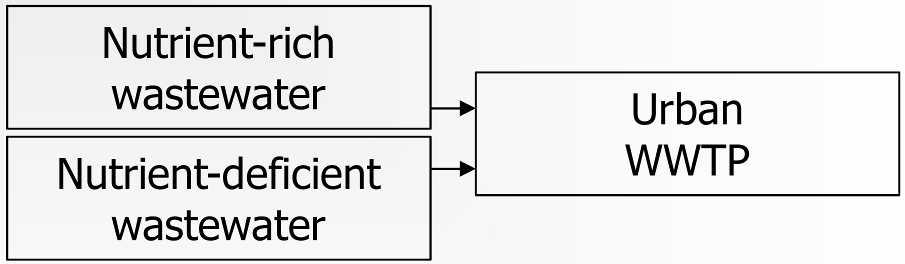
* Van Hoof, G. et al. Ecotoxicity impact assessment of laundry products: comparison of USEtox and Critical Dilution Volume methods. IJLCA, 2011, 16(8), 803-818

Background

- How to model this deficiency?
  - Industrial WWTP:



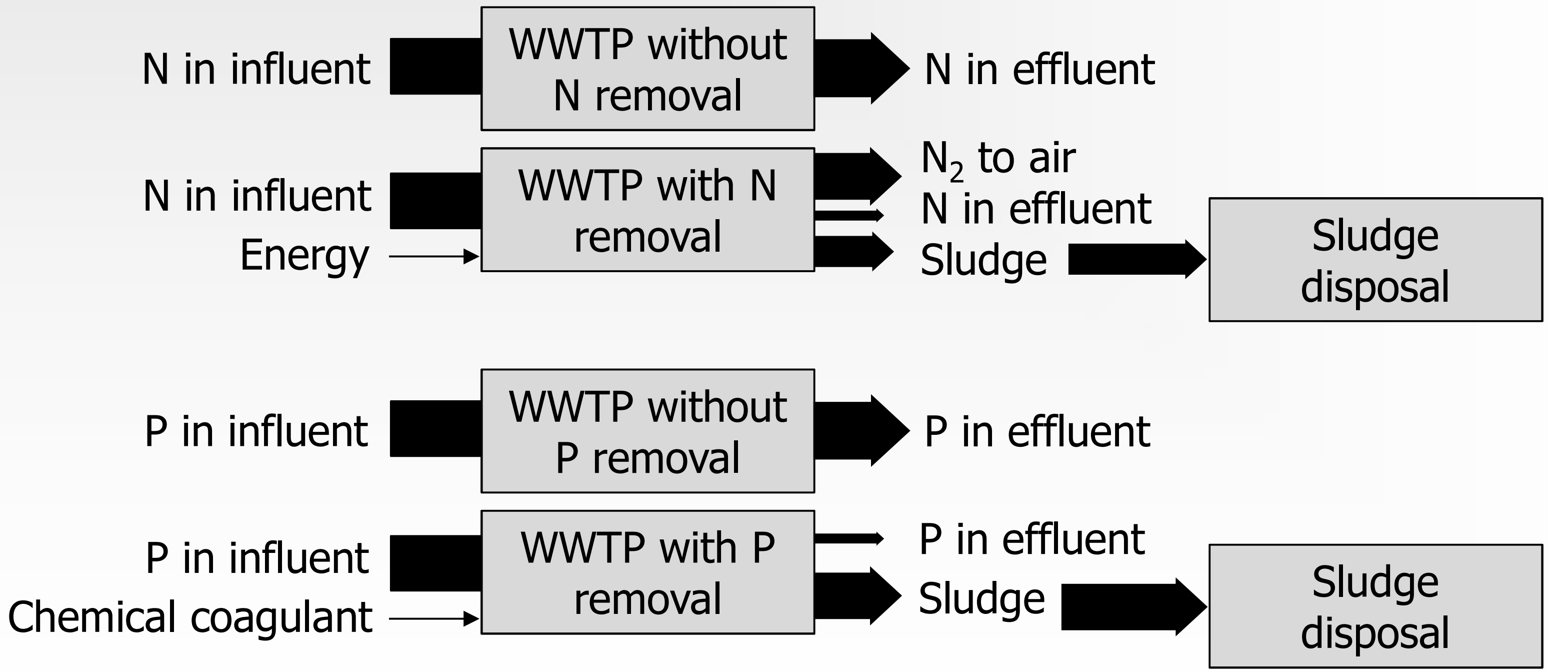
  - Urban WWTP:



- in urban wastewater, N and P are ‘freely’ available
- Does that mean the impact of consuming this N and P is zero (i.e. Waste materials are ‘burden-free’)?

Background

- Nutrients in urban wastewater are an example of 'not fully utilized' materials
- Additional demand for these nutrients displaces their disposal:



Goal and scope

- Our goal is to quantify the environmental effects of a marginal discharge of nutrient-deficient wastewater to urban wastewater systems

- As a case study, we assess the effects of discharging **1 kg ethanol** (C_2H_6O) to the sewer:
  - In Denmark
  - In India

- We use the model **WW LCI v2** to quantify the environmental effects of an ethanol discharge and those of nutrient consumption

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WW LCI v2

- WW LCI calculates chemical-specific LCIs of chemicals discharged in wastewater

Phys-chem data:
- Organic/inorganic
- Composition (C, H, O, N, S, P, Cl)
- Molecular weight
- Vapour pressure
- Solubility
- Kow
- Half-lives in the environment

Fate in WWTP data:
- Fraction degraded
- Fraction volatilized
- Fraction to sludge
- Anaerobic degradability

Scenario data:
- % population connected to WWTPs
- N removal/ P removal
- Country
- Sludge disposal scenario

WW LCI

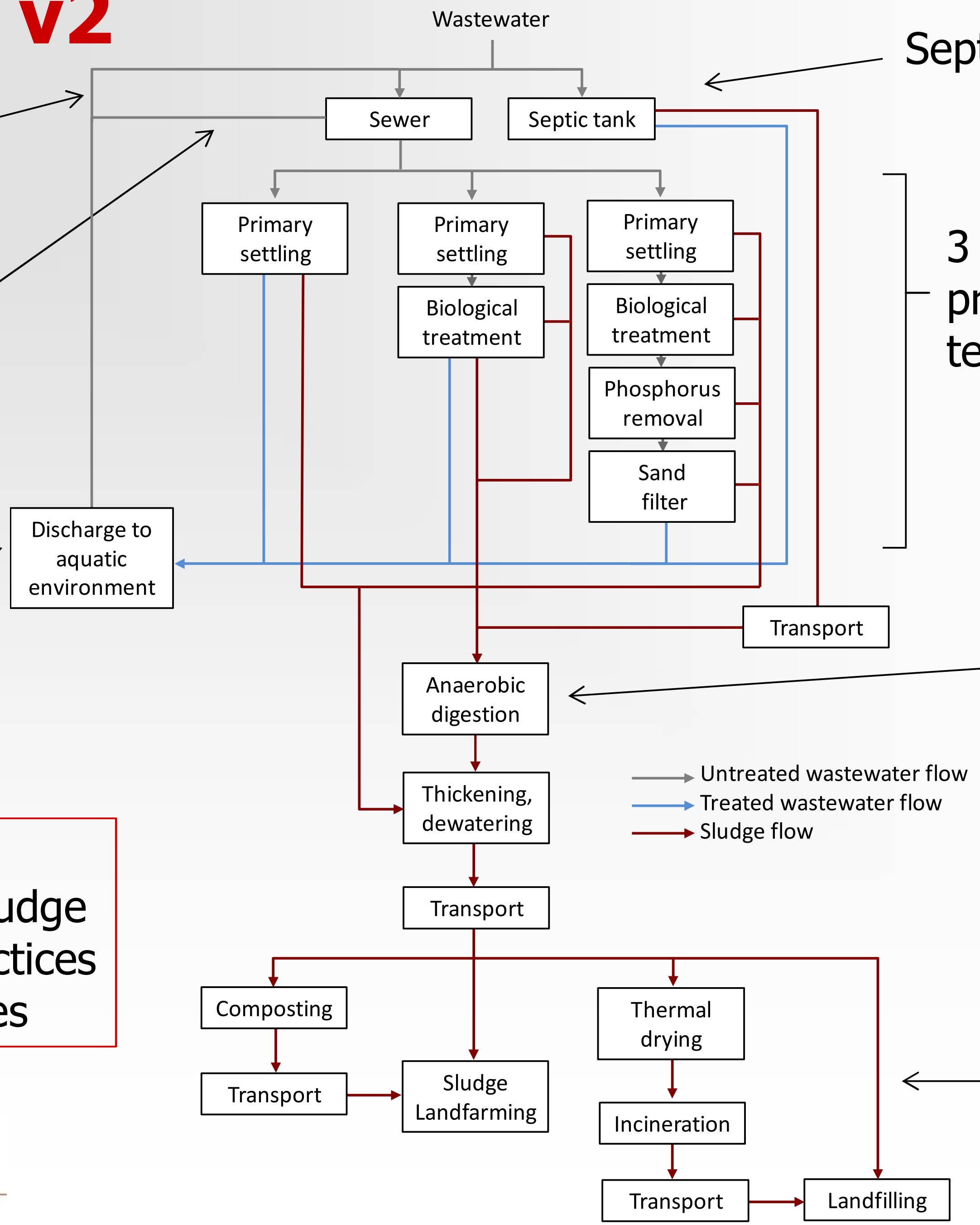
Life cycle inventory for chemical 'x' discharged in wastewater:
- Sewer infrastructure
- WWTP infrastructure
- Emissions to air and effluent from WWTP
- Energy use in WWTP
- Sludge transport
- Sludge disposal infrastructure
- Sludge disposal emissions to air, water and soil
- Emissions to air and water from direct discharges to environment

WW LCI v2

Direct discharges

Connection to sewer but no treatment

Includes emissions of GHG



Septic tanks

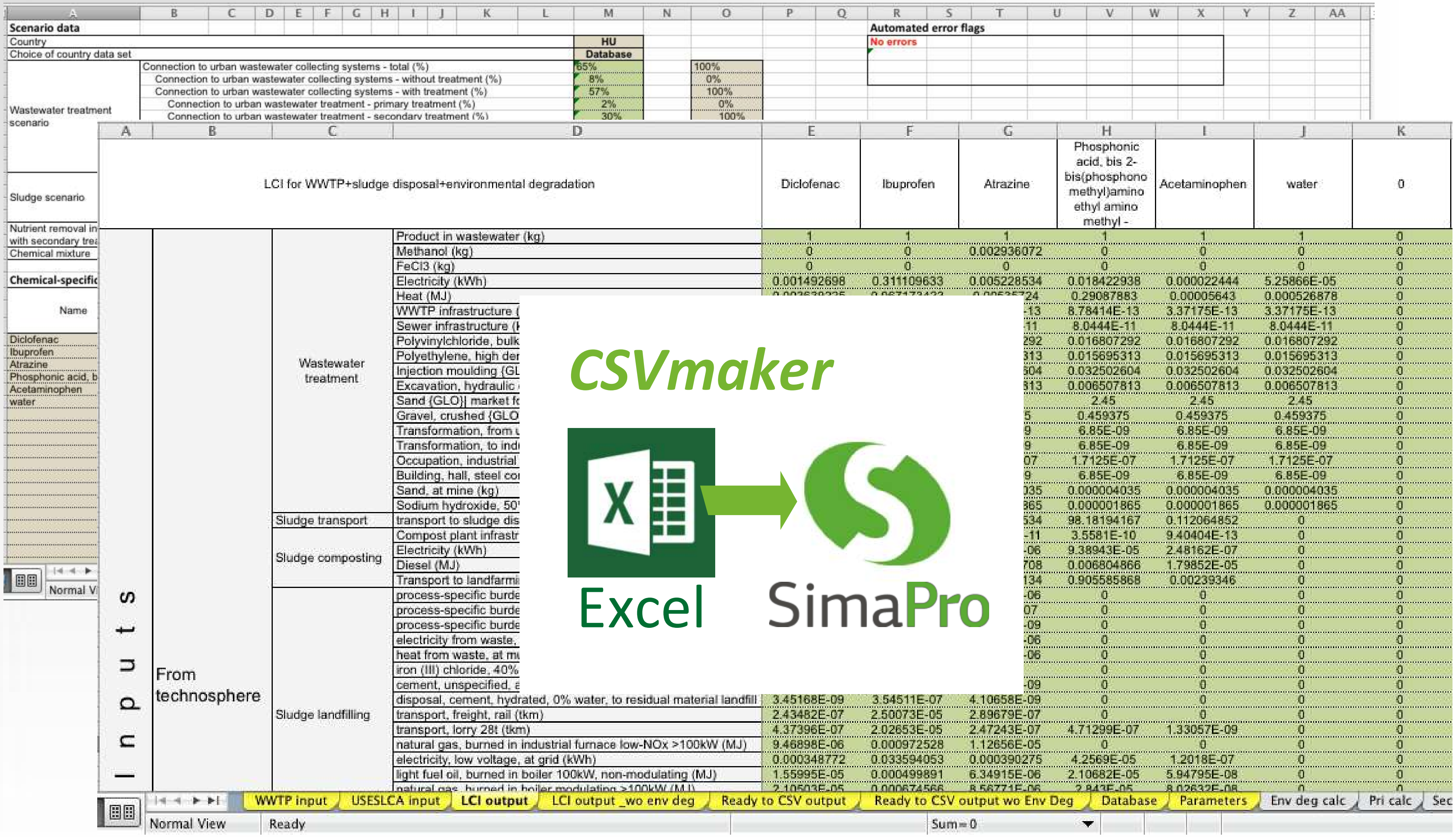
3 WWTP levels: primary, secondary, tertiary

Anaerobic digestion of sludge, biogas used in cogeneration

Sludge disposal

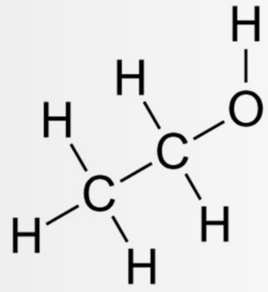
Database with wastewater/sludge treatment practices for 62 countries

WW LCI v2 in Excel



Case study

- Test chemical:
  - Ethanol, bio-based
  - Ethanol, fossil-based



Treatment	Fate of ethanol in wastewater treatment			
	Fair	Fdeg	Fsludge	Feffluent
WWTP with secondary or tertiary treatment *	0.4%	87.1%	0.0%	12.5%
WWTP with primary treatment **	0.0%	26.1%	0.0%	73.9%
Septic tank **	0.0%	26.1%	0.0%	73.9%

* Simulation with Simpletreat fate model

** Assumption in WW LCI: Fdeg & Fsludge = 30% of the value in Simpletreat; Fair = 0

$$C_2H_6O + 1.96\ O_2 + 0.22\ NH_4 + 0.016\ P\text{-}PO_4 \rightarrow 0.22\ C_5H_7NO_2P_{0.074} + 0.9\ CO_2 + 2.7\ H_2O$$

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Case study

- Wastewater and sludge treatment in DK and IN according to WW LCI's database:

Wastewater treatment and sludge disposal scenario		Denmark	India
Wastewater treatment scenario	Connection to WWTP - primary treatment	2%	
	Connection to WWTP - secondary treatment	3%	21%
	Connection to WWTP - tertiary treatment	84%	
	Connection to septic tank	11%	39%
	Direct discharge (no treatment)		39%
Sludge disposal scenario	Composting	6%	
	Agriculture	50%	100%
	Landfilling		
	Incineration	44%	

Case study

- WW LCI does not provide a systematic calculation of credits associated to consumption of nutrients
- They can be calculated ‘manually’ by:
  1. Obtaining the LCIs for treating ammonium, phosphate, and ethanol, separately
  2. Linking to the LCI of ethanol the inputs of -X kg ammonium and -Y kg phosphate consumed

Denmark	Primary WWTP	Secondary WWTP	Tertiary WWTP	Septic tank	Total
NH4 cons. (kg/kg ethanol)	0.00045	0.0022	0.0629	0.0025	**0.068**
PO4 cons. (kg/kg ethanol)	0.00017	0.0009	0.0245	0.0009	**0.027**

India	Primary WWTP	Secondary WWTP	Tertiary WWTP	Septic tank	Total
NH4 cons. (kg/kg ethanol)	0	0.0159	0	0.0088	**0.025**
PO4 cons. (kg/kg ethanol)	0	0.0062	0	0.0034	**0.010**

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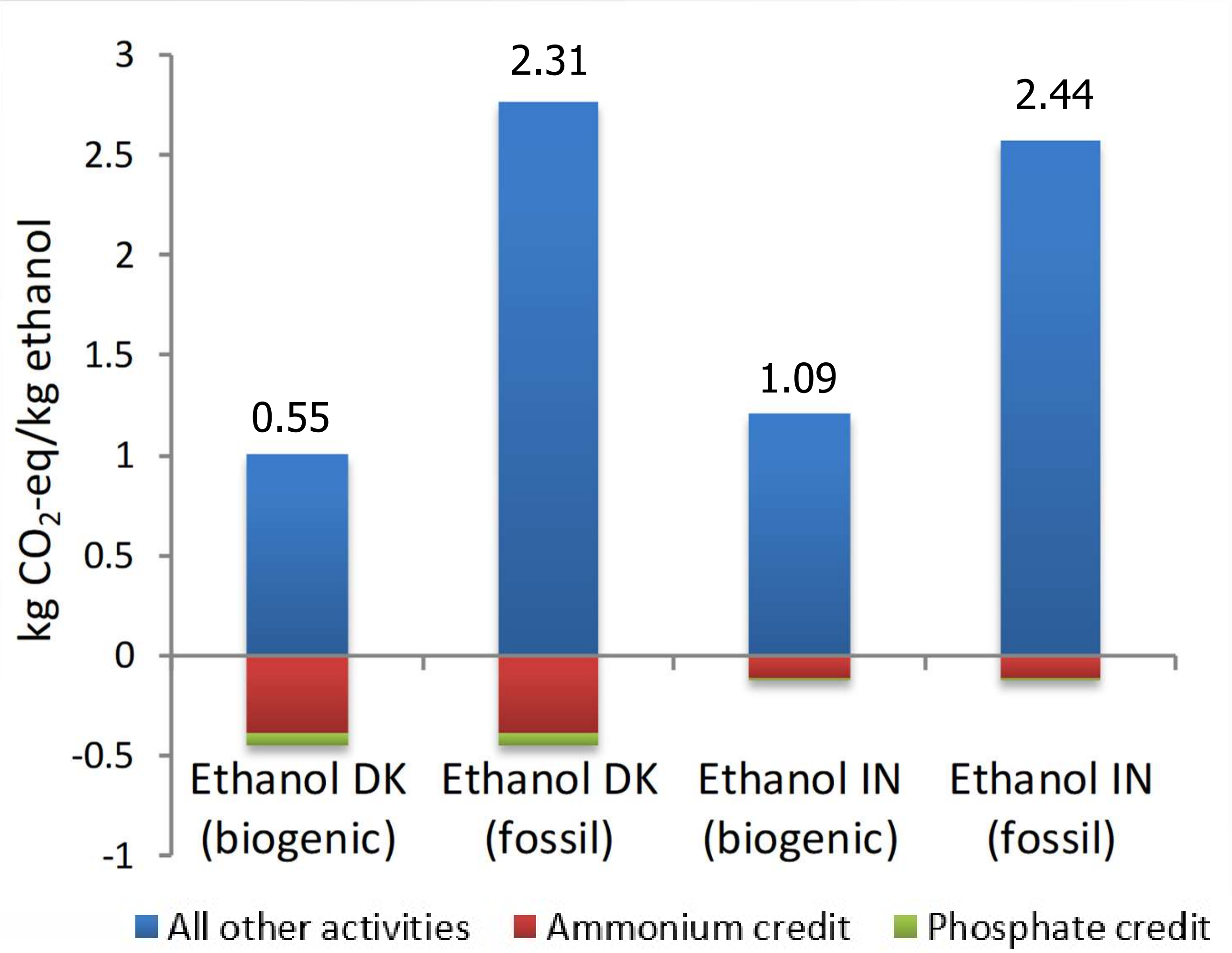
Results: greenhouse-gas emissions

GWP100, IPCC 2013, biogenic CO_2 assumed neutral



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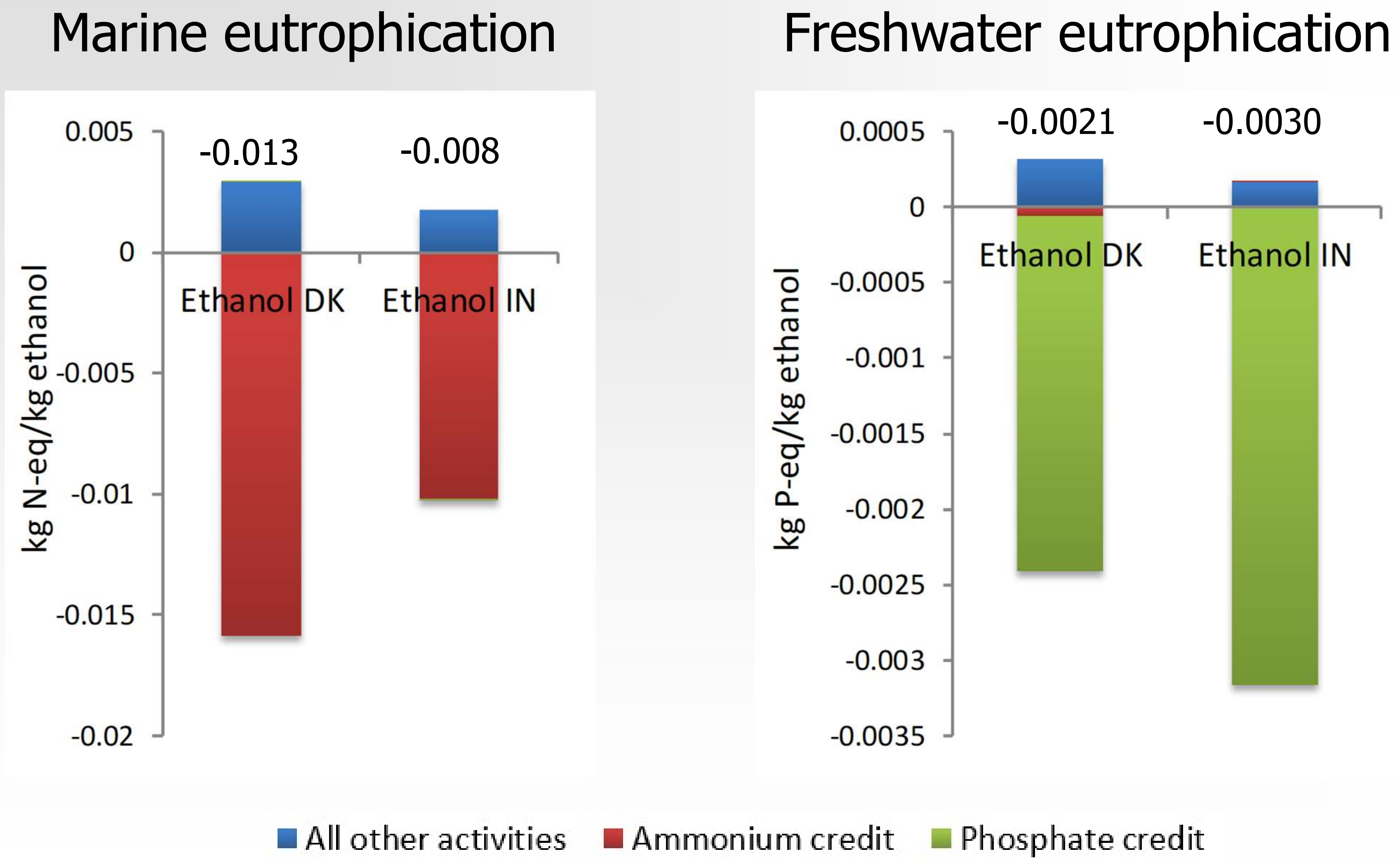
Results: eutrophication, ReCiPe midpoint



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Conclusions

- Consumption of available N and P in urban wastewater by organic chemicals avoids the disposal of these nutrients
- Credits for this avoided disposal are higher than those from by-products (energy recovery, sludge fertilizer, etc.)
- The magnitude of these credits is dependent on the local wastewater treatment situation, as seen for DK and IN
- These credits only apply for organic chemicals which:
  - Are expected to degrade in WWTPs
  - Do not contain N and/or P

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Thank you!

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

WW LCI References:

Kalbar P, Muñoz I, Birkved M. (2017) ***WW LCI v2: a second-generation inventory model for chemicals discharged to wastewater systems***. Science of the Total Environment, https://doi.org/10.1016/j.scitotenv.2017.10.051

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***. International Journal of Life Cycle Assessment. DOI: 10.1007/s11367-016-1189-3