



## Towards a Standard Method for Life Cycle Assessments of Wastewater Treatment

Corominas, LI; Foley, J; Guest JS, JS; Hospido A, A; Larsen, Henrik Fred; Shaw, A

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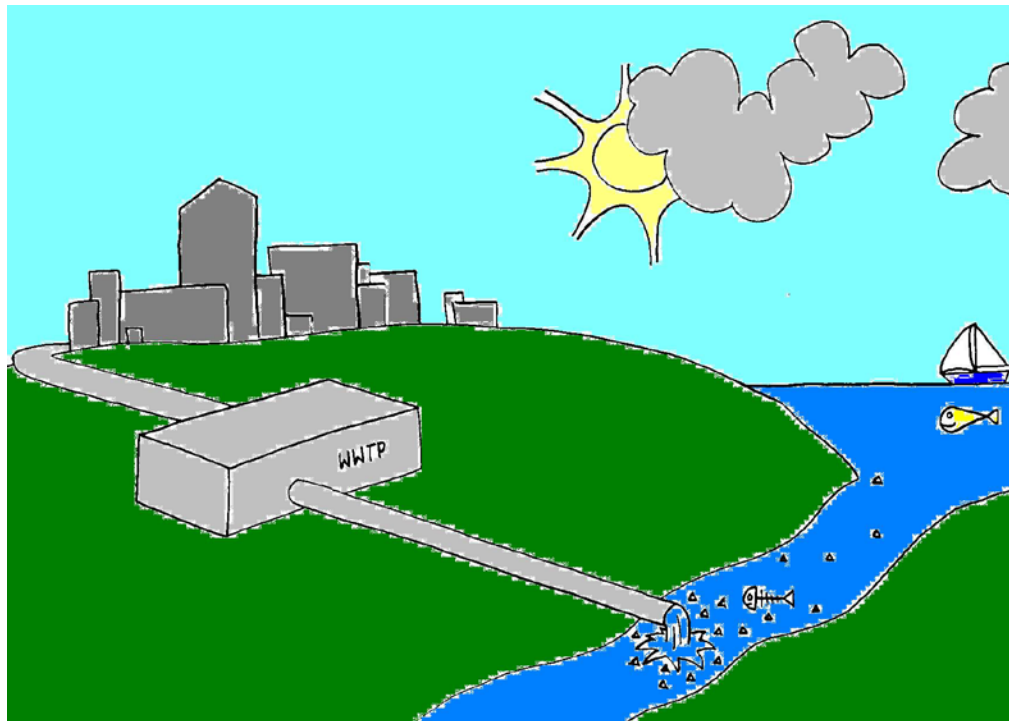
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# Towards a Standard Method for Life Cycle Assessments of Wastewater Treatment

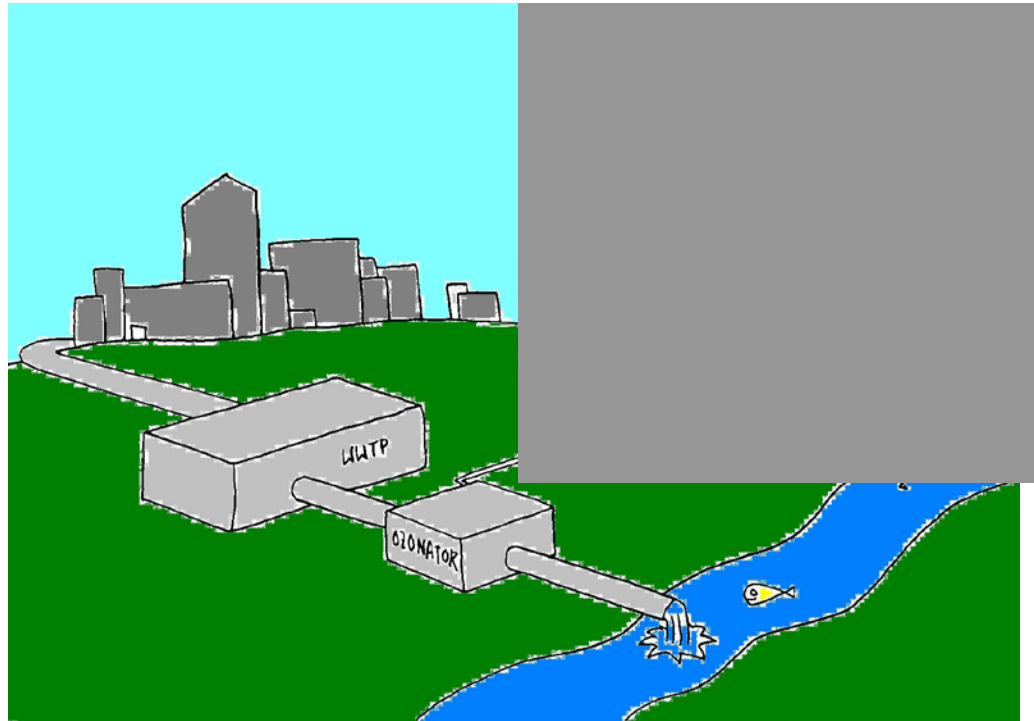
Ll. Corominas, J. Foley, J.S.  
Guest, A. Hospido, H.F.  
Larsen, A. Shaw

Watermatex 2011,  
20th June  
San Sebastian  
(Spain)

# Life Cycle Assessment



# Life Cycle Assessment



# Problem statement



- 1960s: Beginning of this technique
- 1990s: Pressure to standardize → ISO 14040 and 14044
- 2010s: Increase of popularity



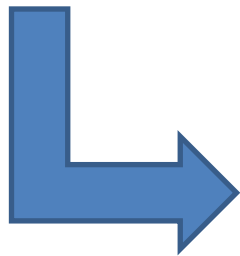
Increase of information: databases  
Software tools, models, etc

# Problem statement



## In WASTEWATER field

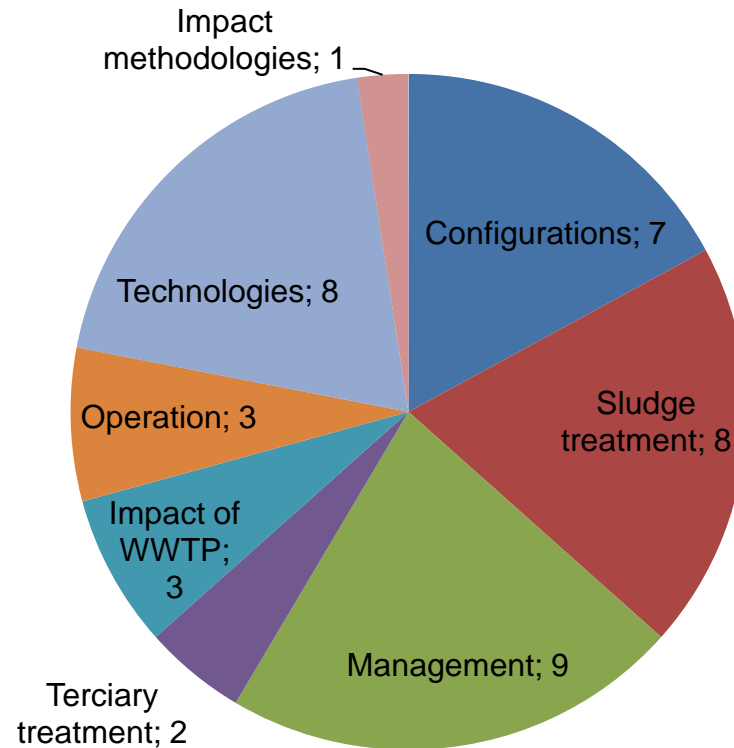
- 1990s: Flückiger and Gubler (1994); Emmerson et al. (1995); Fahner et al. (1995); Zimmermann et al. (1996); Roeleveld et al. (1997)
- Until now, about 41 published papers in peer-reviewed journals (+ conference papers)



It is now time to make a review  
What have we learned  
Where should we go?

# What have we learned?

- Applications



# What have we learned?

- Boundaries

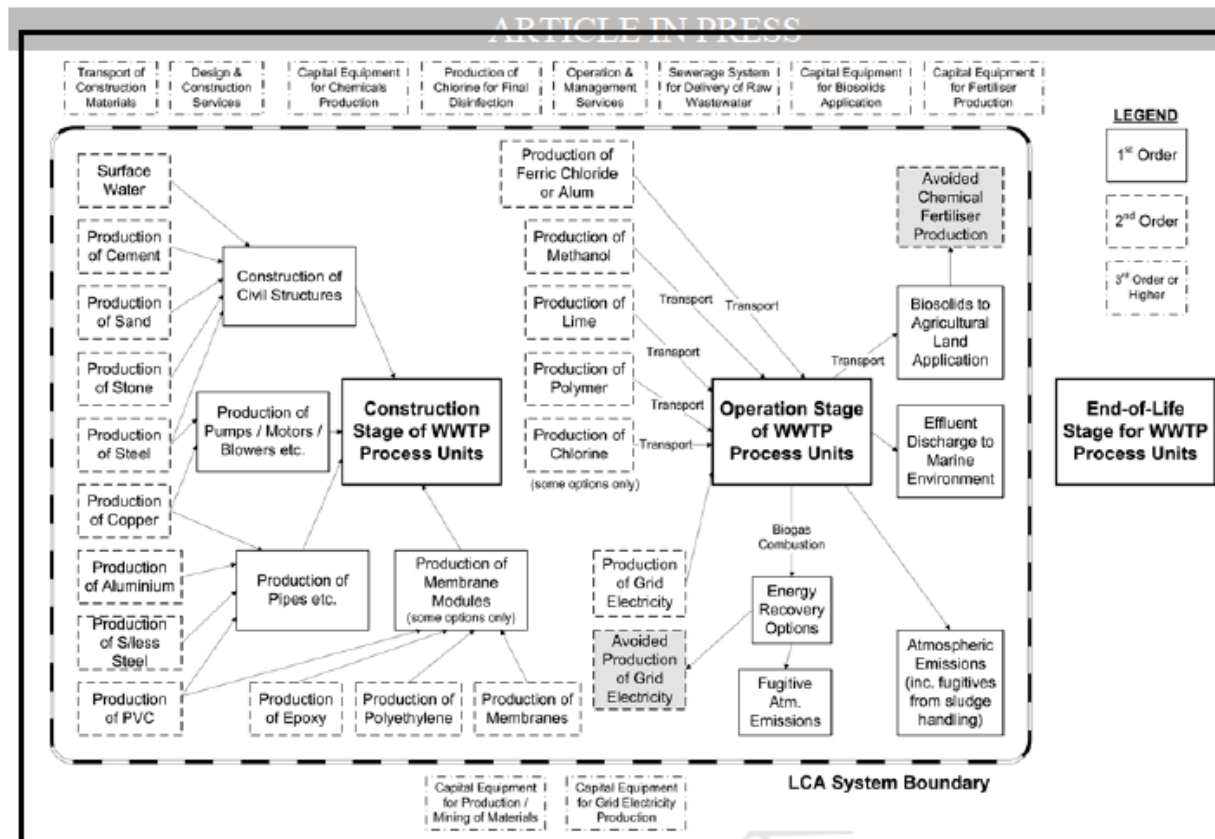


Figure 2. System boundary for life cycle inventory of WWTP scenarios



# What have we learned?

- Main Outcomes

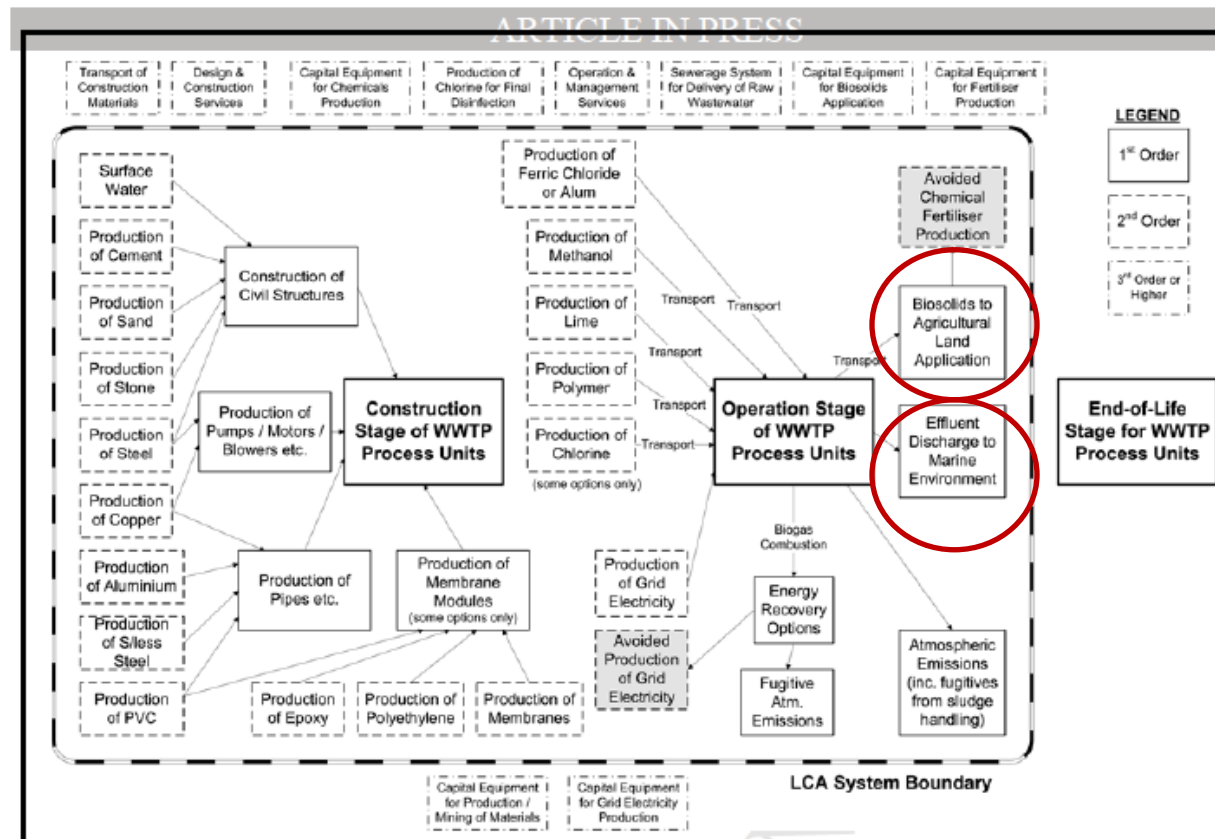


Figure 2. System boundary for life cycle inventory of WWTP scenarios

# What have we learned?



- Outcomes
  - Impact of WWTP → water discharge and sludge application
  - Technologies → Avoided vs induced impact (constructed wetlands and sand filtration appropriate)
  - Configurations → Better N removal but Resources depletion, global warming, acidification, human toxicity
  - Operation → Better N and P removal and increase energy efficiency

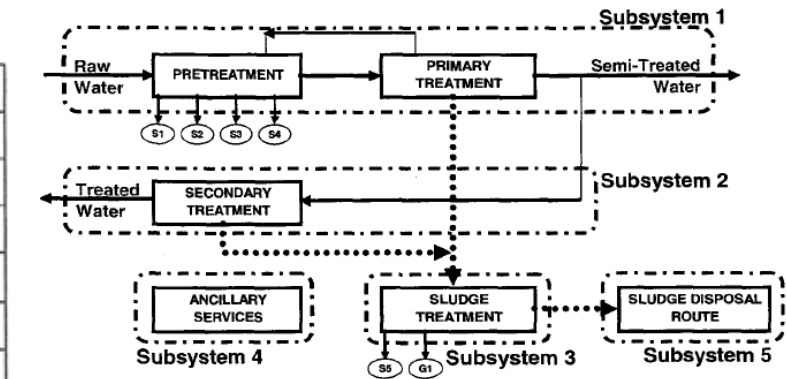
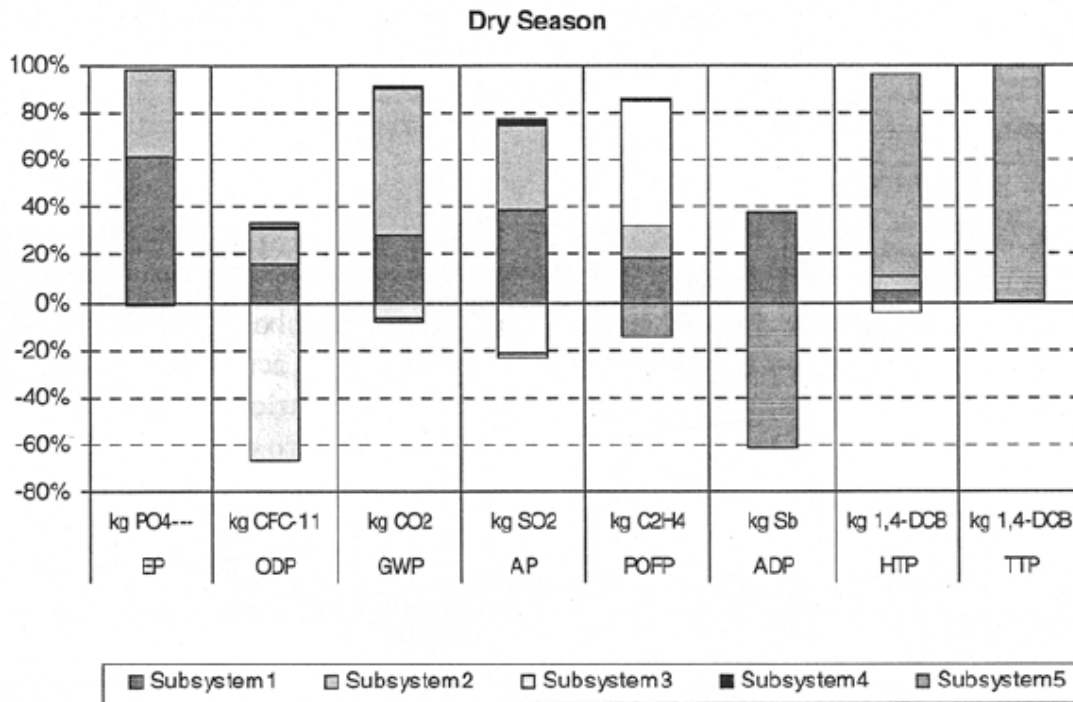
# What have we learned?



- Outcomes
  - Separation systems (urine) have environmental advantages (avoided fertilizers)
  - Sludge treatment → Anaerobic digestion combined with electricity production. Incineration and land application are acceptable (but minimization of heavy metals from sludge)
  - Impact methodologies → For GHG emissions, acidification, eutrophication, resource depletion not a critical issue

# What have we learned?

## WWTP impact



Hospido et al., 2004

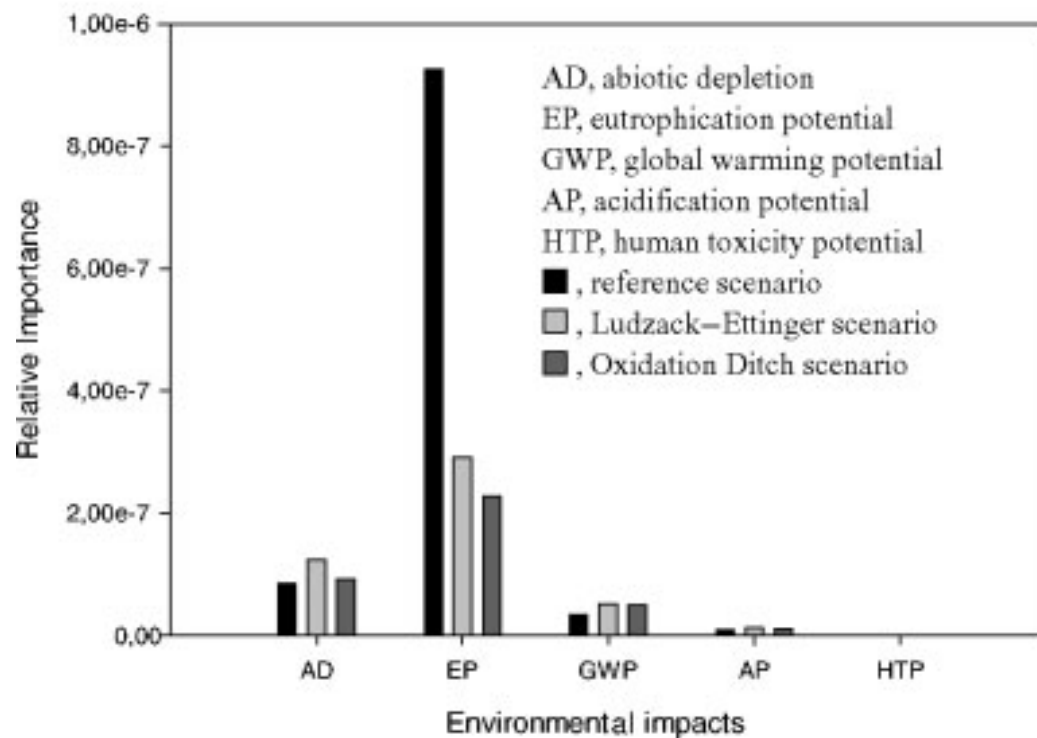
**Fig. 2:** Characterisation profiles for both Functional Units. Subsystem 1 is represented in dark grey, subsystem 2 in light grey, subsystem 3 with dots, subsystem 4 in black and subsystem 5 with oblique lines

# What have we learned?



## Configurations

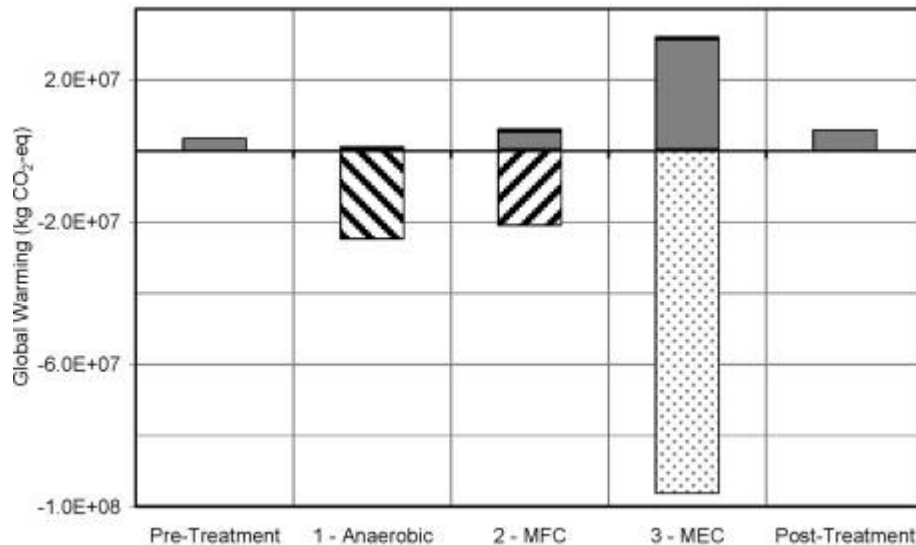
### Environment impacts normalisation



Vidal et al., 2002

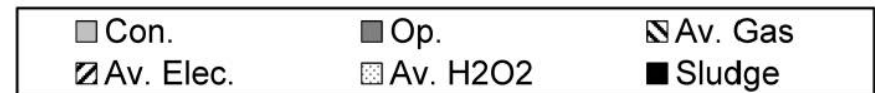
# What have we learned?

## Technologies

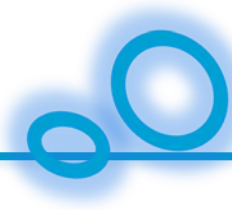


Foley et al., 2009

FIGURE 4. Selected midpoint life cycle impact assessment results, disaggregated into the following: "Con.", construction phase; "Op.", operational phase (i.e., power, chemicals, transportation); "Av. Gas", avoided natural gas from operational phase of anaerobic reactor (Option 1 only); "Av. Elec", avoided electricity from operational phase of MFC (Option 2 only); "Av. H2O2", avoided AO hydrogen peroxide from operational phase of MEC (Option 3 only); and "Sludge", sludge dewatering and disposal from operational phase. The results are expressed in terms of a reference unit for each environmental impact category (e.g., kg CO<sub>2</sub>-eq for global warming, kg C<sub>2</sub>H<sub>3</sub>Cl-eq for carcinogens). Positive values indicate an adverse environmental impact (i.e., the higher the value, the worse is the impact), and negative values indicate an environmental benefit.



# What have we learned?



*Sludge treatment*

# Discrepancies

- Inclusion/ exclusion of infrastructure

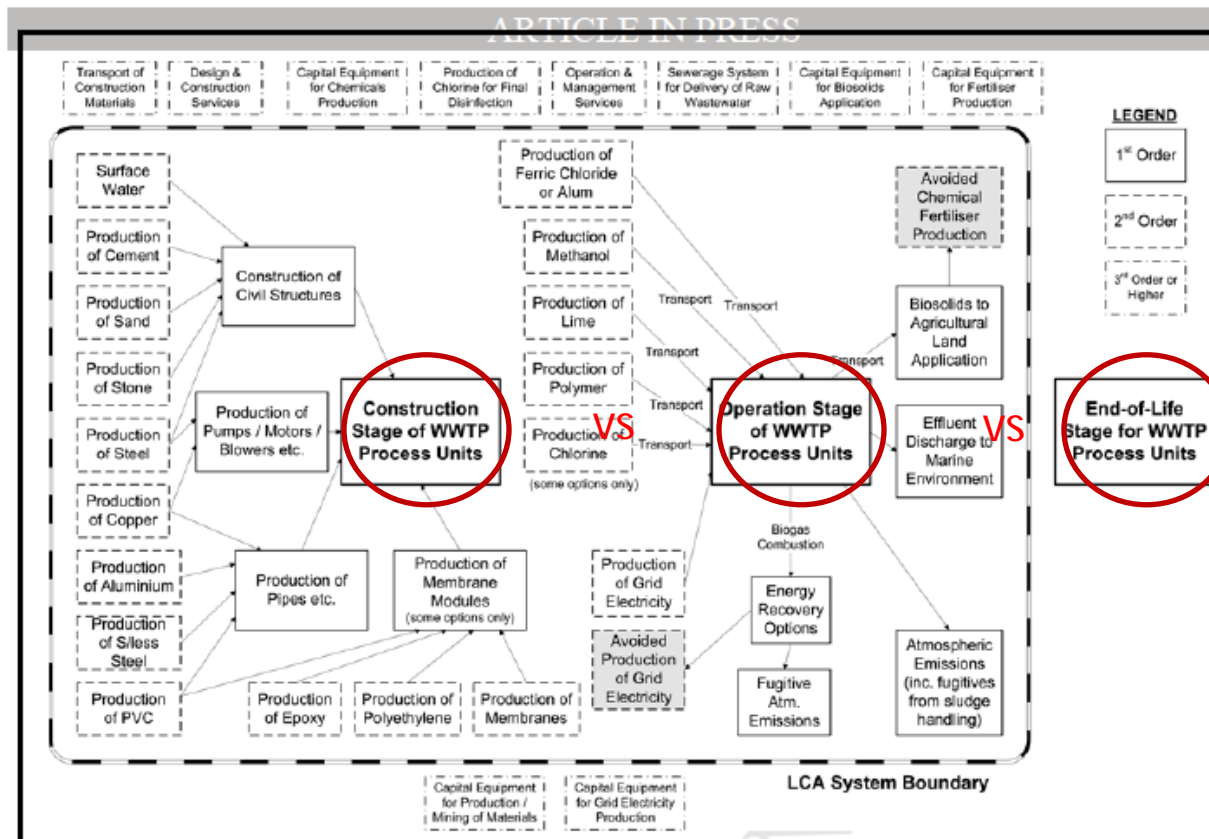


Figure 2. System boundary for life cycle inventory of WWTP scenarios



# Discrepancies

- The importance of including disposal of waste

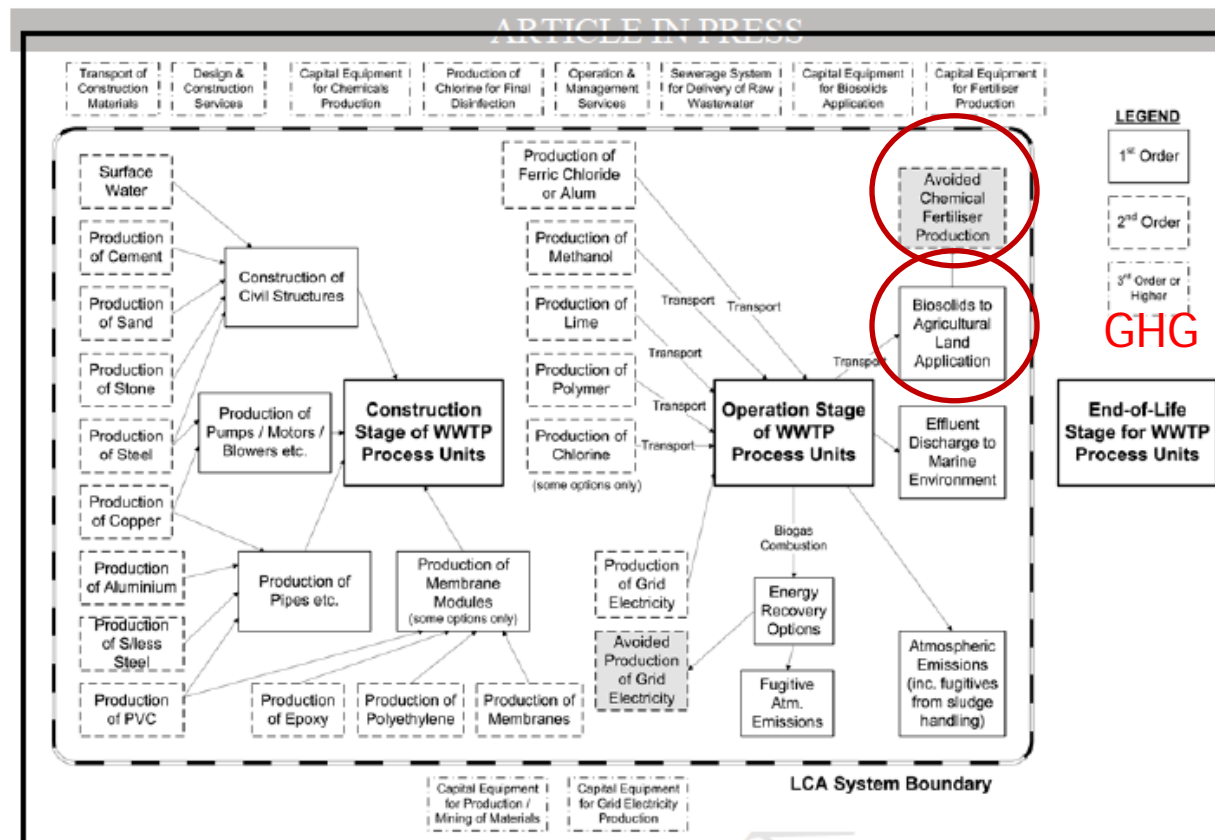
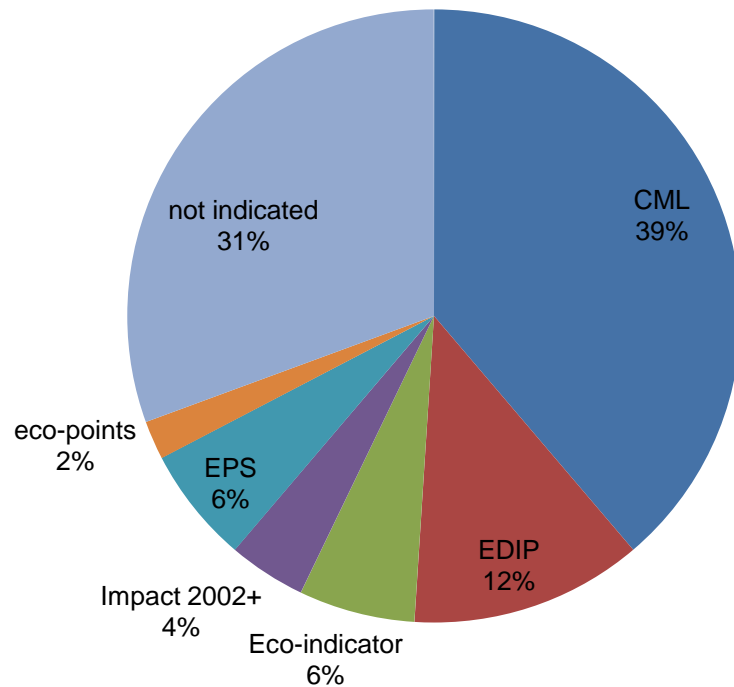


Figure 2. System boundary for life cycle inventory of WWTP scenarios

# Discrepancies



- Selection of impact methodology



# Discrepancies



- Selection of categories

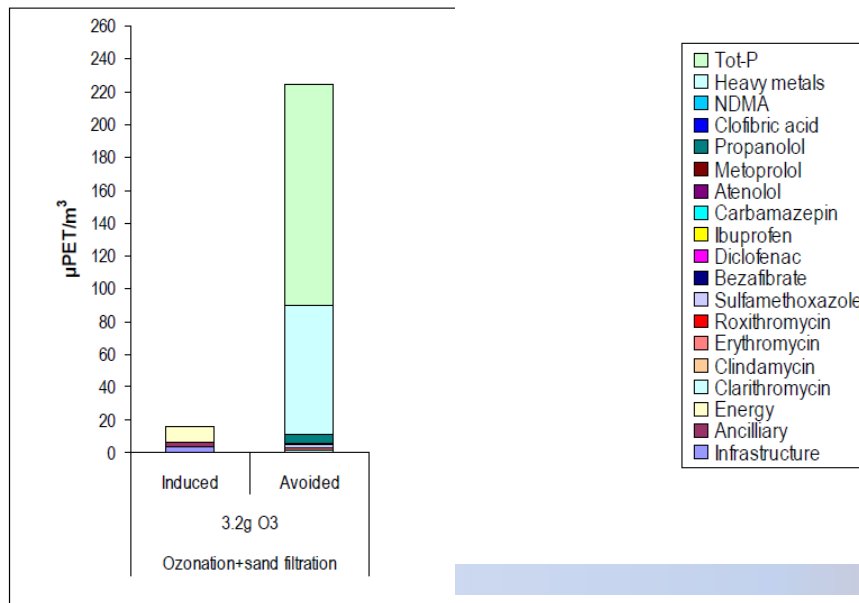
	N° papers including category	N° CML papers including category	N° CML papers indicating relevant category
Global warming potential	43	16	7
Acidification potential	27	15	6
Freshwater eutrophication potential	25	15	8
Marine eutrophication potential	3	2	1
Human Toxicity	19	11	4
Terrestrial eco-toxicity	18	10	6
Photochemical oxidation	19	12	3
Fresh water eco-toxicity	14	6	5
Marine eco-toxicity	6	4	3
Fossil energy depletion	17	12	3
Material depletion	7	2	1
Ozone layer depletion	14	9	2
Land Occupation	2	1	0
Others	8	2	0

# Where should we go?

- Developments in toxicity-related categories

Environmental sustainability profiles; ozonation + sand filtration  
(including both metal and phosphorus removal)

(31 micropollutants + P (only significant ones shown); weighting factor = 1 for all impact categories)



Larsen et al., 2010

# Where should we go?

- Provide local factors, e.g. eutrophication

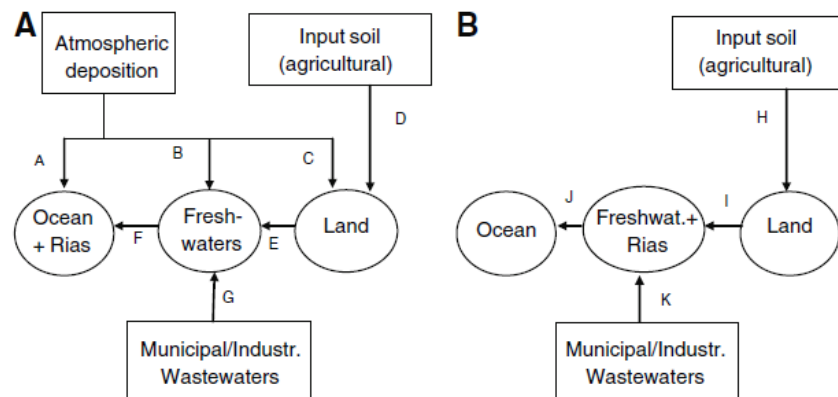
**Table 4** Characterization factors for N and P contained in wastewaters

Substance ( <i>j</i> )	Water area ( <i>i</i> )	$\gamma_i$	$\epsilon$	$\mu_{j,i}$	$Eqvj^a$	$C_{j,wastewater,i}^a$ (Eq.4)
N	Maritime waters <sup>b</sup>	0.80	0.7	1	0.42	0.24
	Freshwaters	0.80	0.7	0 <sup>c</sup>	0.42	0.00
P	Ocean	0.87	1	0 <sup>c</sup>	3.06	0.00
	Freshwaters + rias	0.87	1	1	3.06	2.66

<sup>a</sup> Expressed as kilogram  $PO_4^{3-}$  equivalent per kilogram substance *j* emitted

<sup>b</sup> Maritime waters = ocean + rias

<sup>c</sup> The ocean is considered N limited and the freshwaters P limited



**Fig. 2** Principal pathways considered for N (a) and P (b) transport in Galicia

Gallego et al., 2010

# Where should we go?

- Better data quality (evaluation of uncertainty)

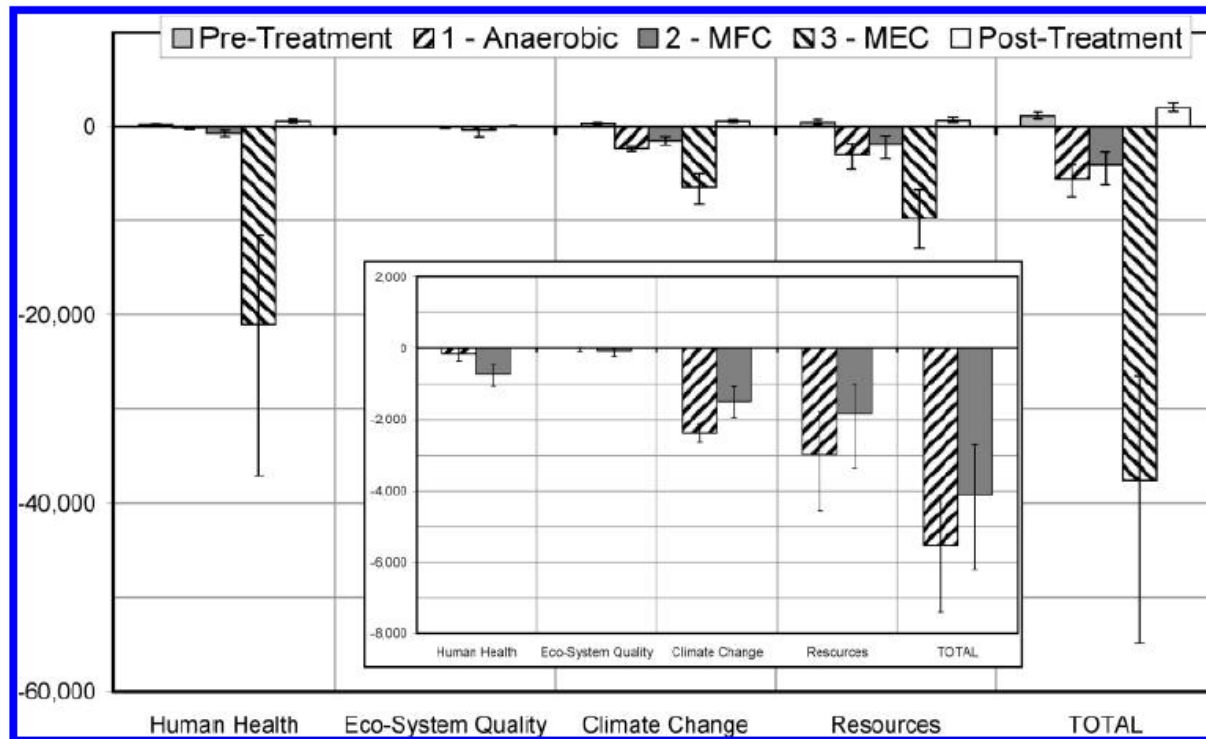


FIGURE 6. Comparison of IMPACT 2002+ normalized end-point scores, including Monte Carlo analysis uncertainty ranges. Inset shows a magnification of the comparison between Option 1 (anaerobic) and Option 2 (MFC). Error bars (95% confidence interval) indicate the uncertainty inherent in the background inventory data for the three options. This uncertainty range is generated using a Monte Carlo analysis (1000 runs) on each option in SimaPro.

# Where should we go?

- Decision-making (link with economic and social criteria)

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