SIXTH FRAMEWORK PROGRAMME

Neptune FP6 Project

Inclusion of ecotoxicity in life cycle assessment (LCA)

Ozonation and PAC addition as case examples

Henrik Fred Larsen

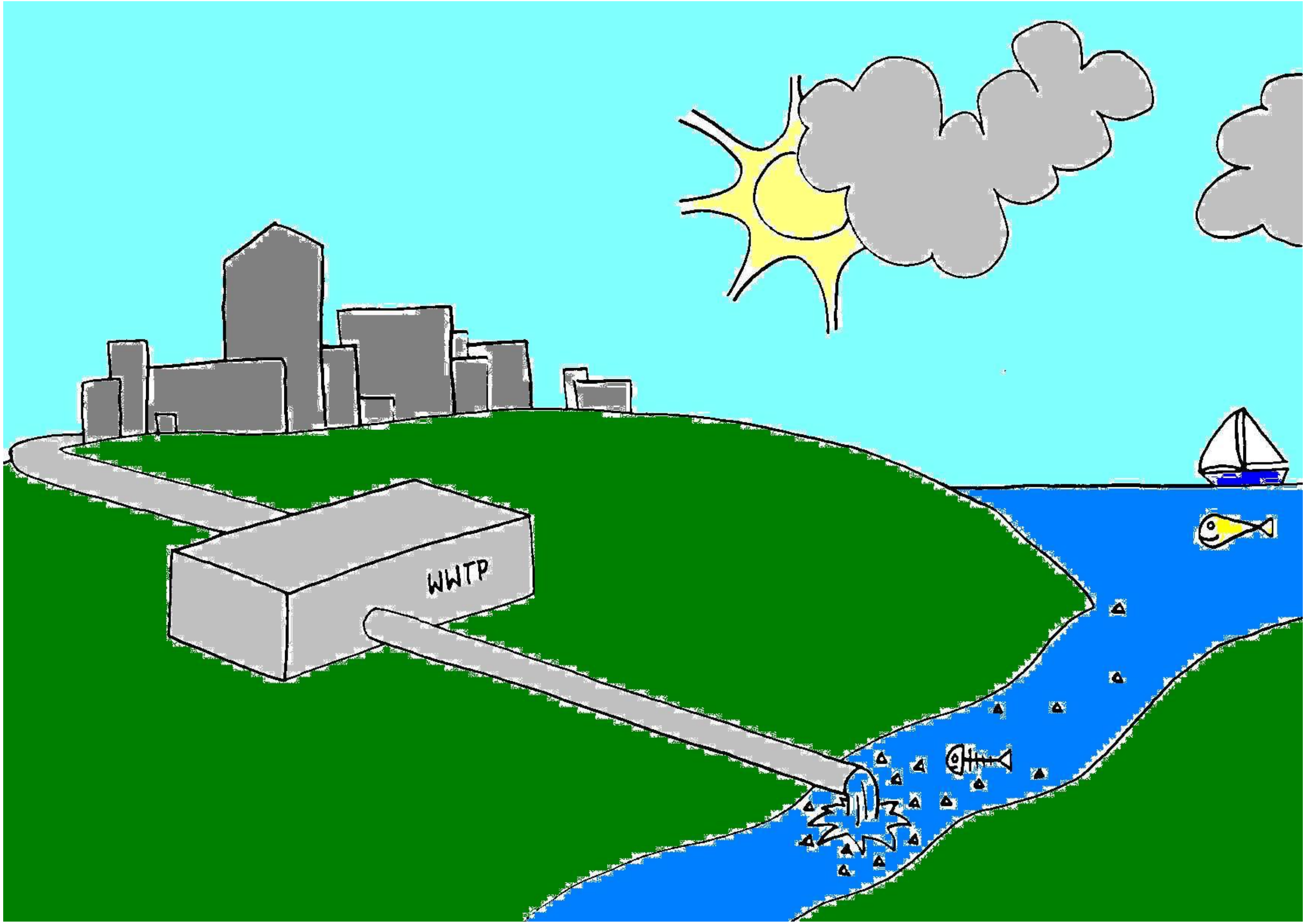
Dissemination Workshop, 25-26 March 2010, Quebec, Canada

DTU

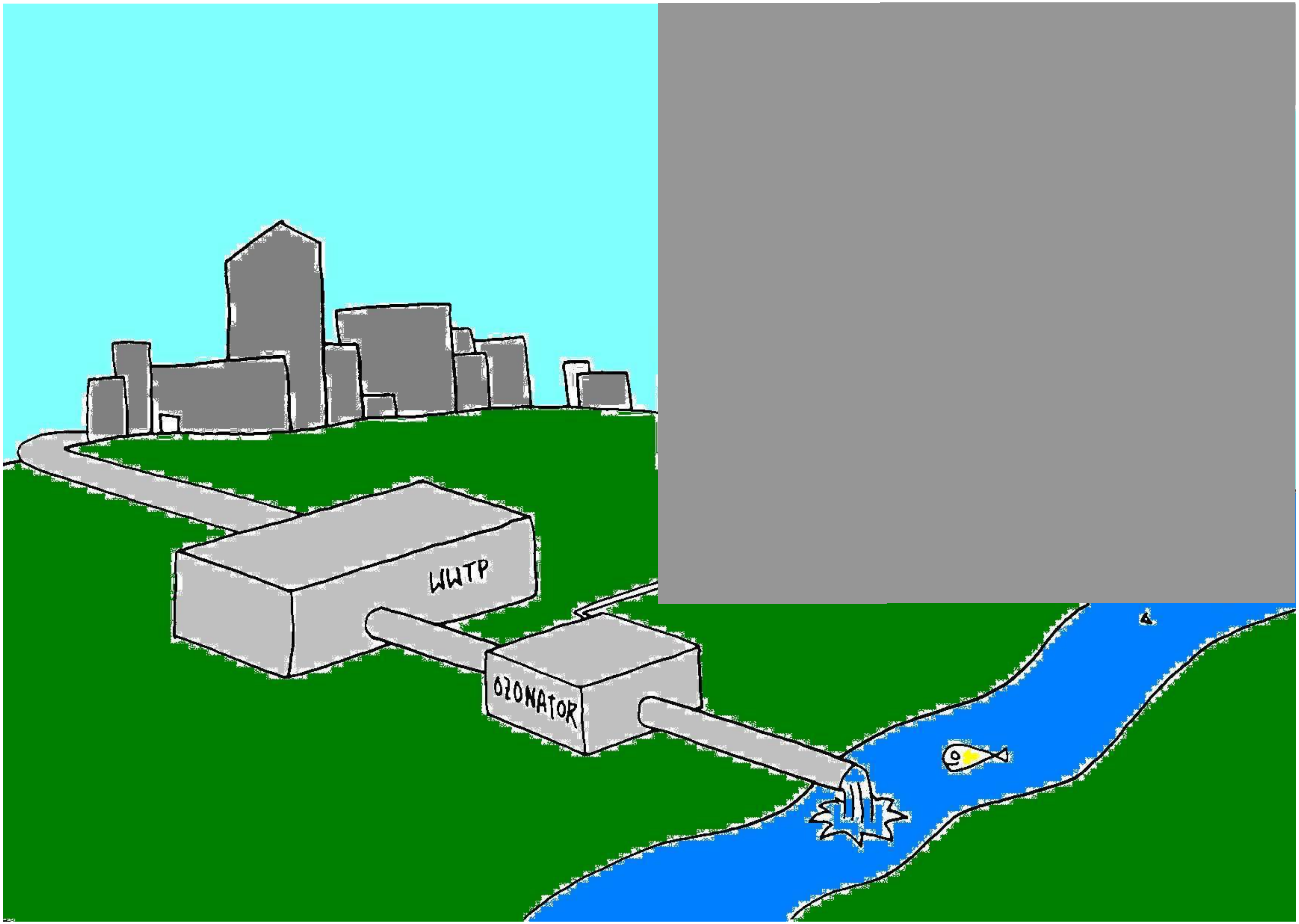
Technical University of Denmark, DTU-MAN, QSA hfl@man.dtu.dk

Outline

- Why include ecotoxicity in LCA when assessing the environmental sustainability of new waste water treatment technologies for micropollutants removal; avoid sub optimisation
- The principle of avoided against induced impacts
- Characteristics of life cycle assessment (LCA) and life cycle impact assessment (LCIA)
- How to include ecotoxicity
- Two main approaches for effect assessment (PNEC and PAF)
- Modeling LCA on ozonation and PAC addition
- Characterisation of incoming water and removal rates
- Environmental sustainability profiles for ozonation and PAC addition
- The effect of including sand filtration
- Conclusion and further research

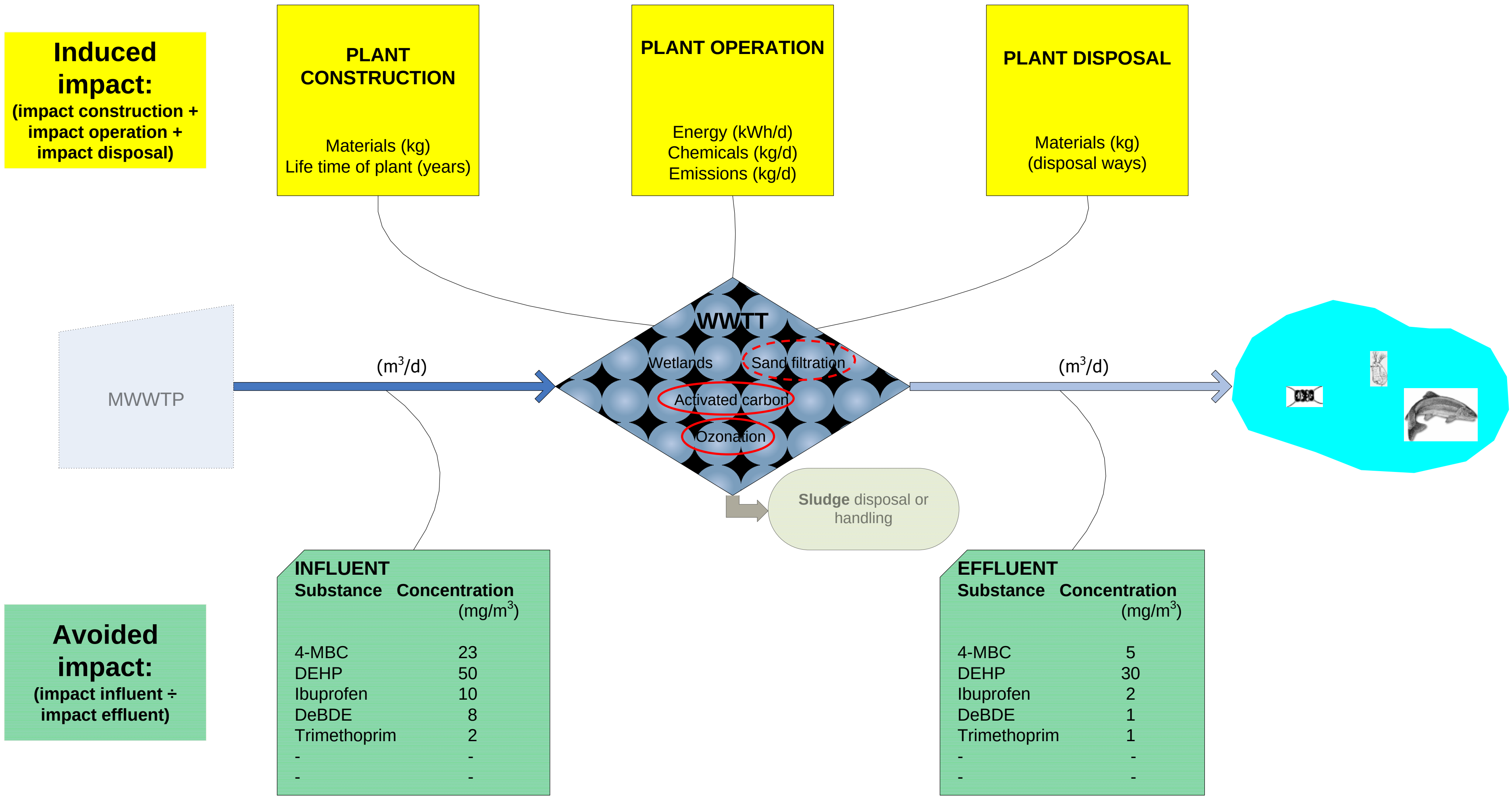


Peter Augusto Hansen

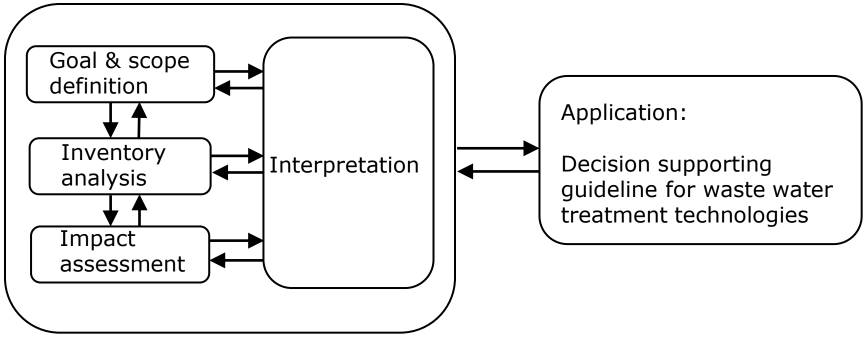


Peter Augusto Hansen

Avoided against induced impacts

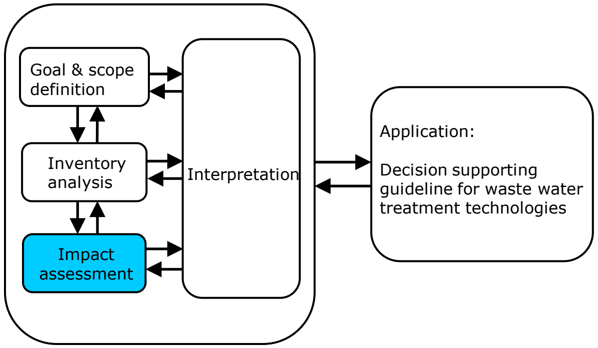


Characteristics of LCA



- A decision supporting tool
- Focus on services typically represented by a product (the “functional unit”, fu). In this case: Treatment of one cubic meter waste water (all impacts related to this unit)
- Comparative (relative statements). In this case: Comparing induced impacts with avoided impacts regarding ozonation and PAC addition
- Holistic perspective
  - life cycle from cradle to grave
  - all relevant potential environmental impacts or damages to ‘areas of protection’. In this case:
    - Global warming
    - Nutrient enrichment (eutrofication)
    - Acidification
    - Ecotoxicity
    - ……..
- Aggregation over time and space
  - life cycle is global
  - life cycle may span over decades or even centuries

Life cycle impact assessment (LCIA)



Classification: *"What does this emission contribute to?"*

- Assignment of emissions to impact categories according to their potential effects
  - Global warming (e.g. CO_2, CH_4)
  - Acidification (e.g. NO_2, SO_3)
  - Ecotoxicity (e.g. pharmaceuticals, heavy metals)
  - Human toxicity (e.g. benzene, PAH's)
  - ………..

Characterisation: *"How much may it contribute?"*

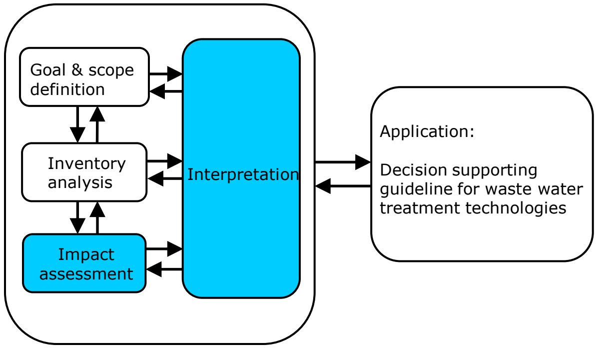
- Quantification of contributions to the different impact categories by estimating impact potentials, IPs (e.g. multiplying the characterisation factors (CFs) for each chemical by the emitted amount (Q) per functional unit (fu):

$$IP = Q*CF$$

- Example (GWP):

Substance	Q (g/fu)	CF (g CO_2-eq/g)	IP (g CO_2-eq/fu)
Carbon dioxid (CO_2)	250	1	250
Methane (CH_4)	10	25	250
Total			500

Life cycle impact assessment (LCIA) and interpretation



Normalisation: *“Is that much?”*

- Expression of the impact potentials relative to a reference situation (person-equivalence, PE), e.g. normalisation reference (NR) for GWP: 8,700 kg CO_2-eq/pers/year. The normalised impact potential (nIP):

$$nIP = IP/NR$$

Impact category	NR (kg CO_2-eq/pers/year)	IP/fu (kg CO_2-eq/fu)	nIP (mPE/fu)
Global warming (GWP)	8700	0,5	0,057

Valuation: *“Is it important?”*

- Ranking, grouping or assignment of weights (weighting factors, WFs) to the different impact potentials (EDIP: political reduction targets), e.g. for global warming a targeted 10 years reduction of 20% => WF=1/(1-0.2) = 1.3. The weighted impact potential (wIP):

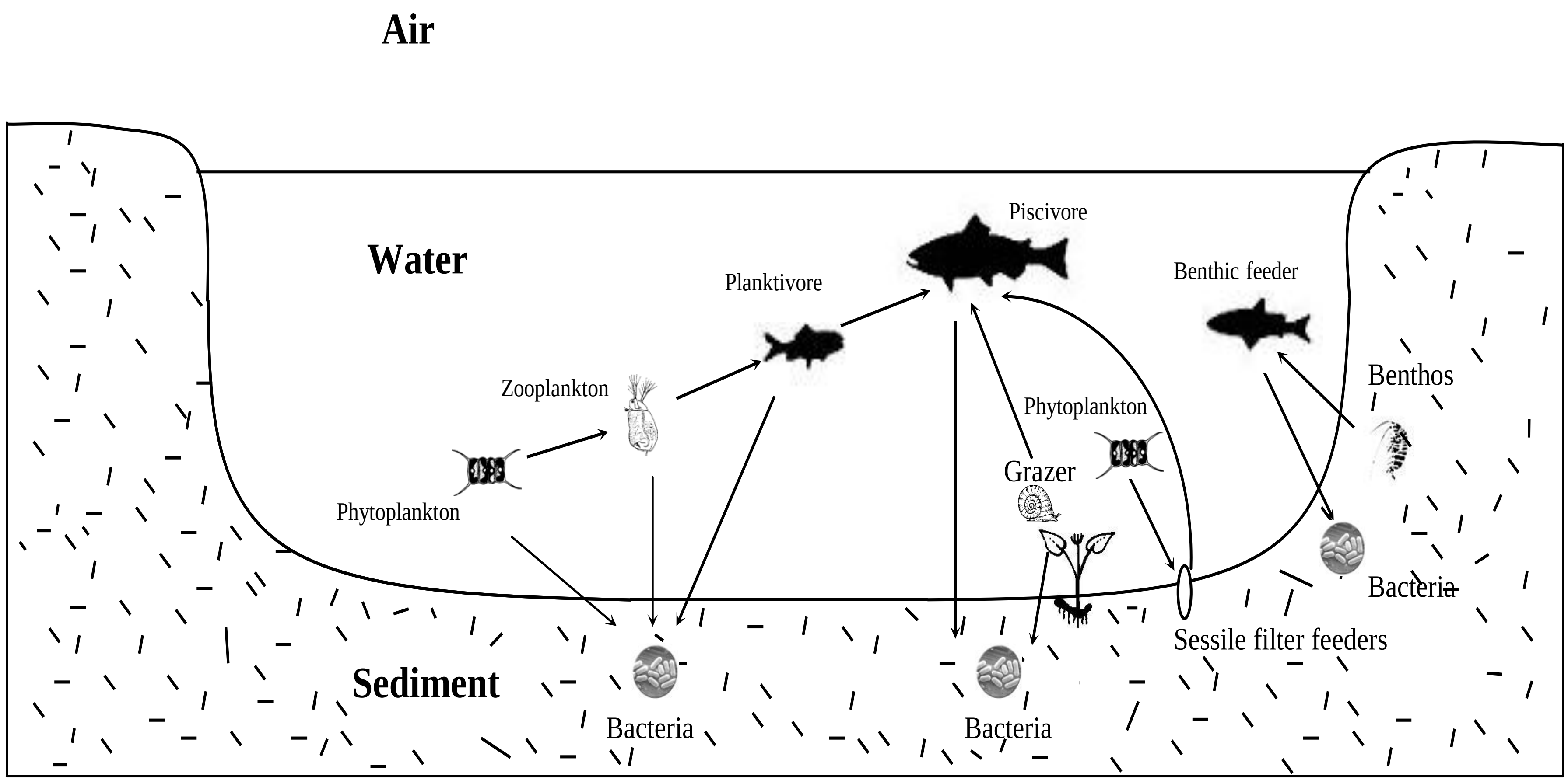
$$wIP = nIP*WF$$

Impact category	WF	nIP (mPE/fu)	wIP (mPET/fu)
Global warming (GWP)	1,3	0,057	0,074

Interpretation: *“Which alternative is better and what determines it?”*

- E.g. is ozonation worth it in an environmental sustainability context or should we avoid it?

Ecotoxicity/ecosystems
What is it we want to protect?



Adapted/modified from Chapman et al. (2003), with permission

Characteristics and constraints of ecotoxicity impact assessment in LCIA

- A general condition for the LCIA models is that the impact potentials must be additive (e.g. critical dilution volume, PAF).
- In contrast to (tiered) risk assessment (RA) the impact potentials shall be a best estimate, i.e. not a conservative estimate.
- In LCIA we assess potential impacts not actual impacts
- Emission of a toxicant mapped in a life-cycle inventory (LCI) is regarded as a single pulse without time duration, and therefore time and space are integrated in the assessment giving further restrictions to the modelling.
- In ordinary LCAs the location of the processes which release toxicants to the environment is usually not precisely known, and therefore site-specific models cannot easily be used. Most often we have to rely on large-scale averages of environmental conditions.
- The large number of substances covered by an LCI calls for a model that relies on relatively few input data in order to make the data gathering feasible.
- The availability of ecotoxicological effect data for the majority of chemicals on the market puts severe restrictions on the data demand of the effect model.

Ecotoxicity characterisation factors (CFs)

- As for all the other impact categories (global warming etc.) the impact potential (IP) for ecotoxicity is estimated the all ready mentioned way:

IP = Q*CF   nIP = IP/NR (normalised)   wIP = nIP*WF (weighted)

- The normalisation reference (NR) and the weighting factor (WF) are estimated according to the same principles as for global warming as shown earlier
- The critical parameter here is the characterisation factor, CF
- The CF for ecotoxicity (m^3 per kg or PAF per kg) for a given substance is estimated as:

$$CF = EEI \cdot \text{Fate-factor}$$

- **EEI** is the ecotoxicity effect indicator (m^3/kg or PAF · m^3/kg)
- The 'Fate-factor' may be expressed as a change in concentration (kg/m^3) of the substance in a model compartment (unit world, multi media model, as in USEtox) or semi-quantitatively and dimensionless by use of key property parameters (distribution factors, biodegradation factors), e.g. for the EDIP method:

$$\text{Fate-factor} = f \cdot BIO$$

f is a distribution factor (Henrys law constant, K_{oc}, atmospheric DT50)
BIO is a biodegradation factor (aquatic readily and inherent biodegradation, or aquatic or soil DT50)

Two main approaches for estimating the ecotoxicity effect indicator, EEI

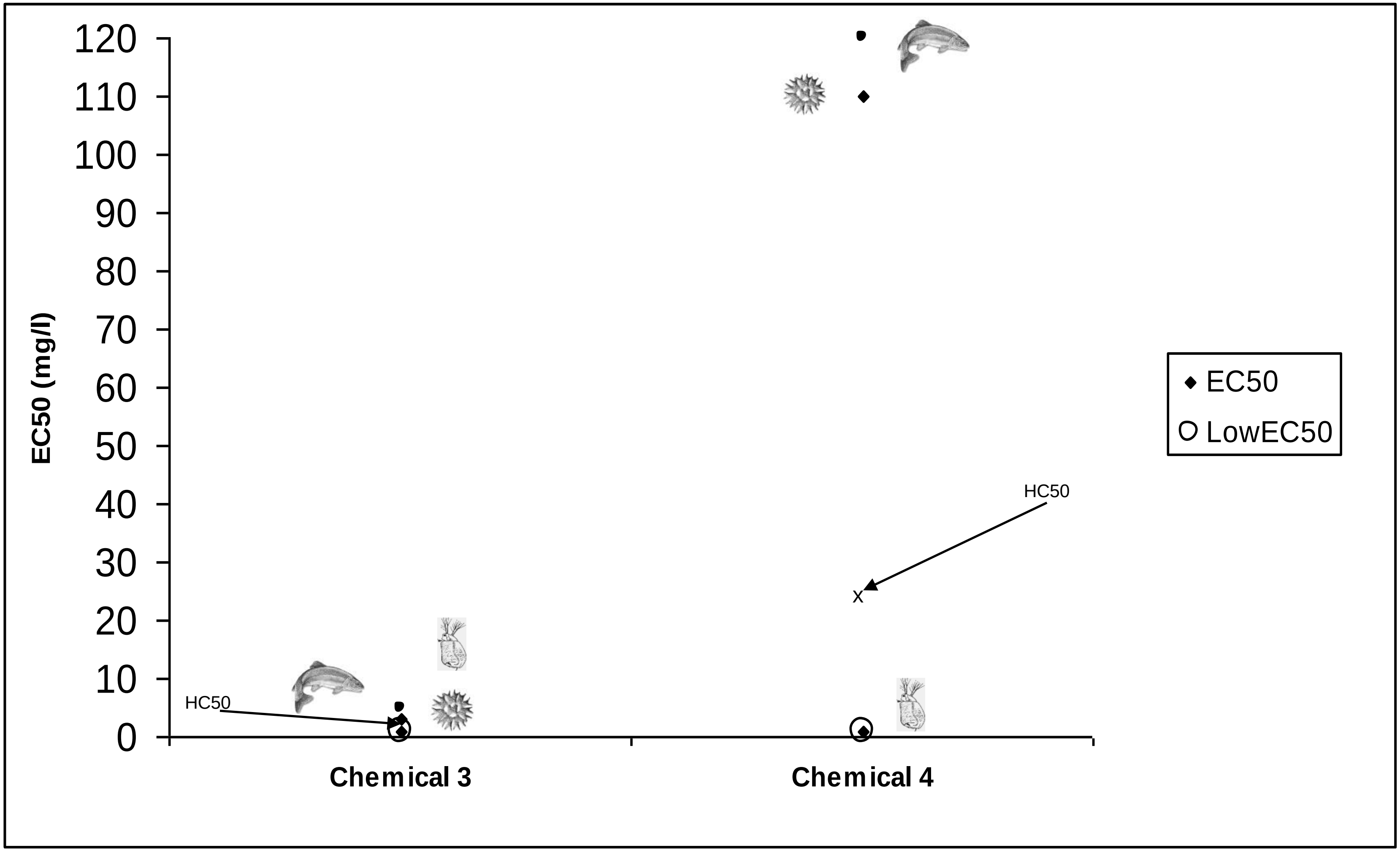
- Assessment Factor based approaches (PNEC); *No effect based (e.g. EDIP97, CML2002):*

$$\mathrm{EEI} = \frac{1}{\mathrm{PNEC}}$$

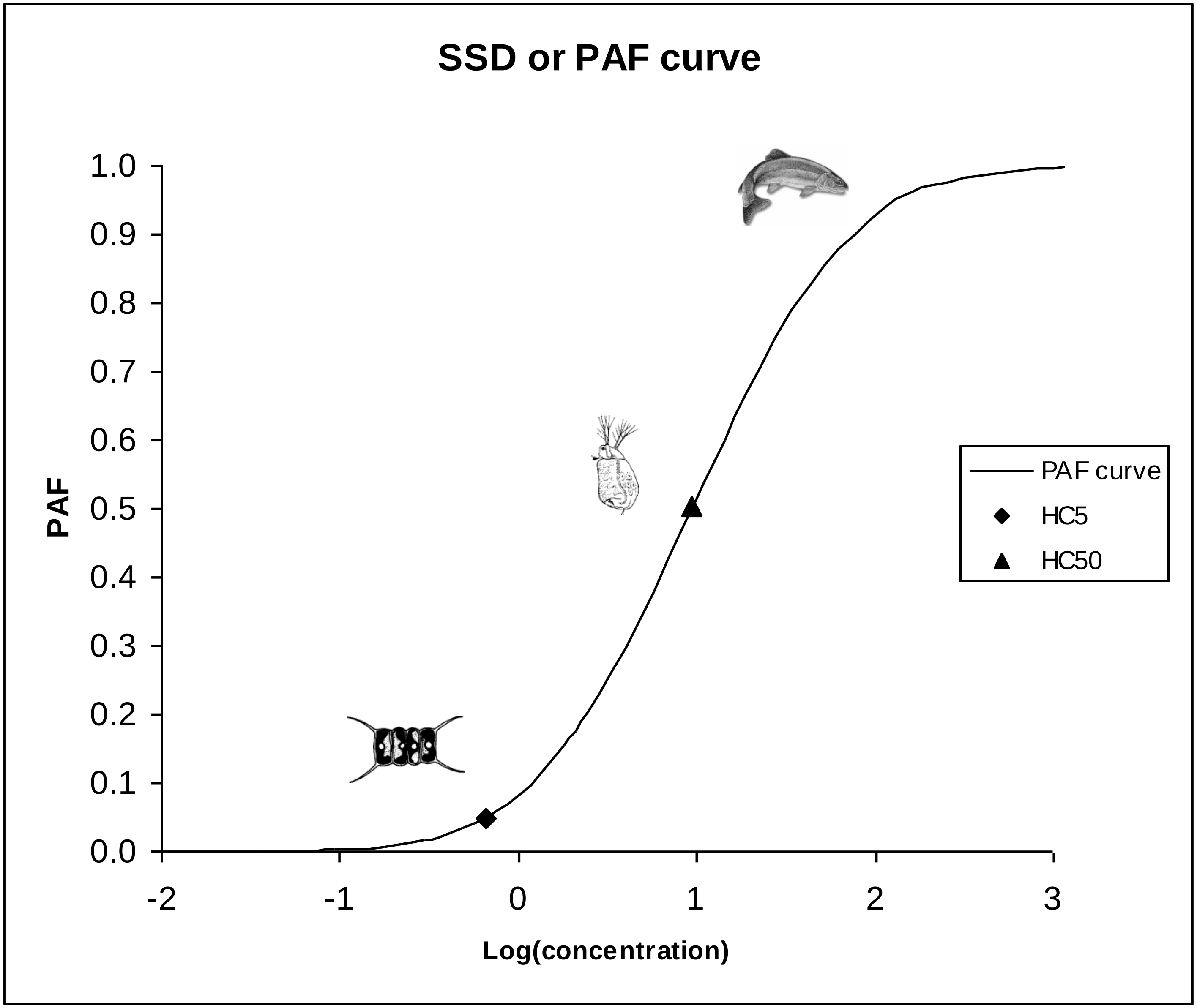
- Species Sensitivity Distribution (SSD) or PAF based approaches; *Effect based*, average approach (e.g. EDIP200X, USEtox)

$$\mathrm{EEI} = \frac{\mathrm{PAF} = 0.5}{\mathrm{HC}_{50}} = \frac{0.5}{\mathrm{HC}_{50}}$$

Problems with PNEC as best estimate



Potentially affected fraction of species (PAF) approach



Ecotoxicity CFs and characteristics of incoming water (sec. effluent) for ozonation and PAC addition

(functional inventory)

	Inlet conc. (ng/L)	Removal rate (3,2 g O_3/m^3)*	Removal rate (20 g PAC/m^3)	PNEC (µg/L)	Conservative RA based PNEC (µg/L)	CF (m^3/kg)	Conservative CF (m^3/kg)
Atenolol	1600	0,80	n.d.	330		2,99E+03	
Bezafibrat	82	0,62	0,38	2,3		4,35E+05	
Carbamazepin	710	1,00	0,79	2,5	0,5	4,00E+05	2,00E+06
Clarithromycin	170	0,96	0,57	0,31		3,23E+06	
Clindamycin	34	0,95	n.d.	8,5		1,17E+05	
Clofibrinsäure	72	0,66	0,42	25	5	4,07E+04	2,00E+05
Diatrizoate	1800	0,00	0,12	11000		9,09E+01	
Diclofenac	1500	1,00	0,42	100	0,1	1,00E+04	1,00E+07
Erythromycin	99	0,80	0,50	0,20	0,02	5,00E+06	5,00E+07
Ibuprofen	91	0,00	0,21	96	3	5,21E+03	1,67E+05
Iohexol	190	0,00	0,00	7400000		1,36E-01	
Iopamidol	1100	0,24	0,90	380000		2,65E+00	
Iopromid	1800	0,26	0,00	100000		1,00E+01	
Metoprolol	410	0,88	n.d.	76	7,3	1,32E+04	1,37E+05
Naproxen	230	0,99	0,00	190		5,18E+03	
NDMA (N-nitrosodimethylamin)	57	-1,71	n.d.	40		2,50E+04	
Primidon	170	0,62	0,48	1400		6,94E+02	
Propanolol	95	0,90	n.d.	0,050		2,00E+07	
Roxithromycin	50	0,82	0,53	2,8		3,56E+05	
Sotalol	430	0,98	n.d.	300		3,33E+03	
Sulfamethoxazol	500	0,95	0,43	0,59	0,15	1,69E+06	6,67E+06
Trimethoprim	130	0,98	0,50	800		1,25E+03	
(*data on removal rates from MicroPoll; personal communication with Juliane Hollender)							

Avoided against induced impacts

Induced impact:
(impact construction + impact operation + impact disposal)

PLANT CONSTRUCTION
Materials (kg)
Life time of plant (years)

PLANT OPERATION
Energy (kWh/d)
Chemicals (kg/d)
Emissions (kg/d)

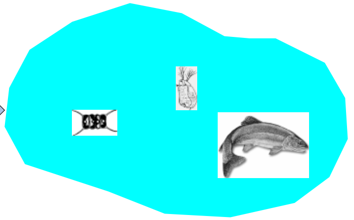
PLANT DISPOSAL
Materials (kg)
(disposal ways)

MWWTP

(m^3/d)

WWTT
Wetlands
Sand filtration
Activated carbon
Ozonation

(m^3/d)



Sludge disposal or handling

Avoided impact:
(impact influent ÷ impact effluent)

INFLUENT

Substance	Concentration (mg/m^3)
4-MBC	23
DEHP	50
Ibuprofen	10
DeBDE	8
Trimethoprim	2
-	-
-	-

EFFLUENT

Substance	Concentration (mg/m^3)
4-MBC	5
DEHP	30
Ibuprofen	2
DeBDE	1
Trimethoprim	1
-	-
-	-

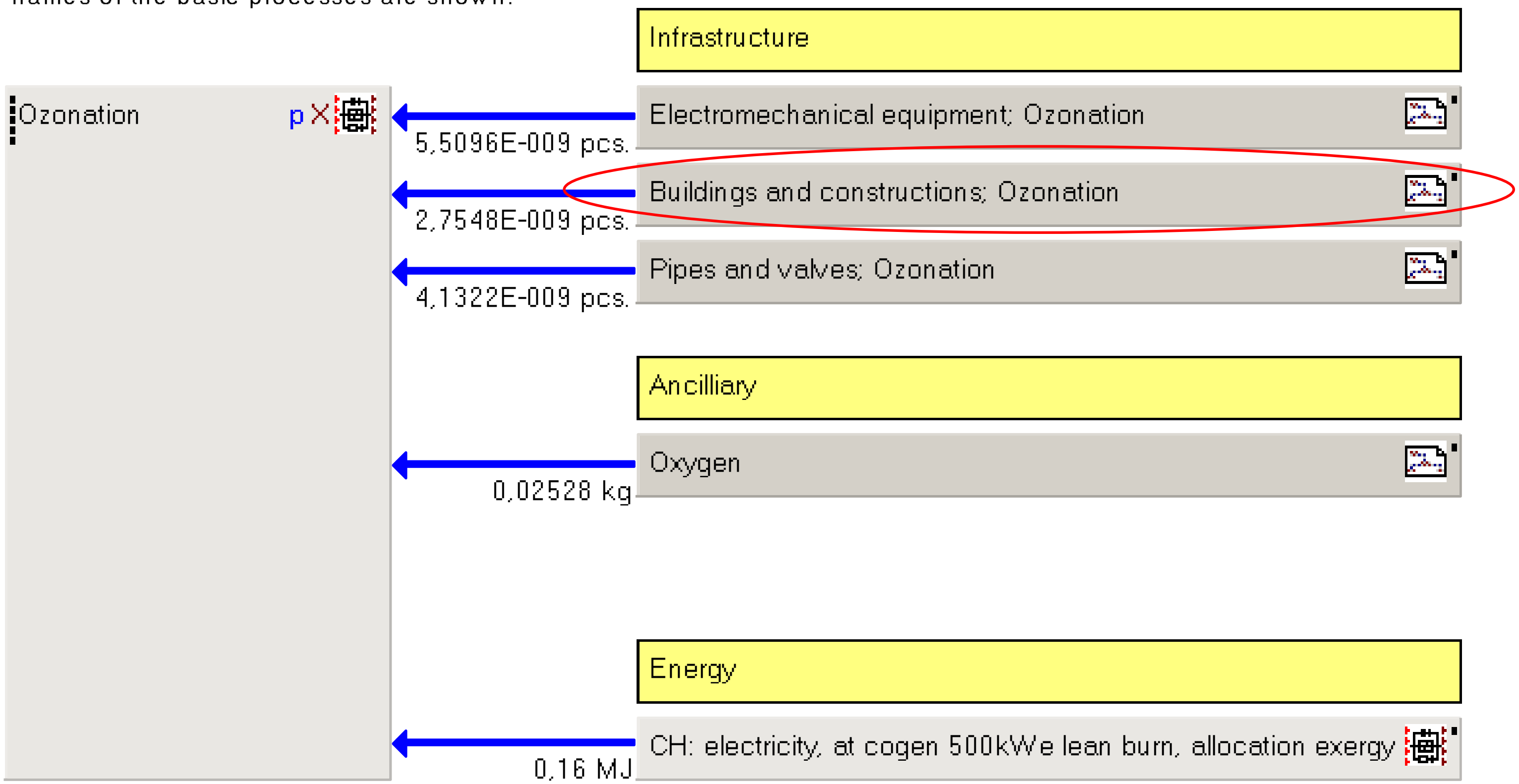
Modelling LCA on ozonation; Main plan

(physical inventory)

Ozonation (3.2gO3/m3WW)

GaBi 4 process plan:Reference quantities

The names of the basic processes are shown.

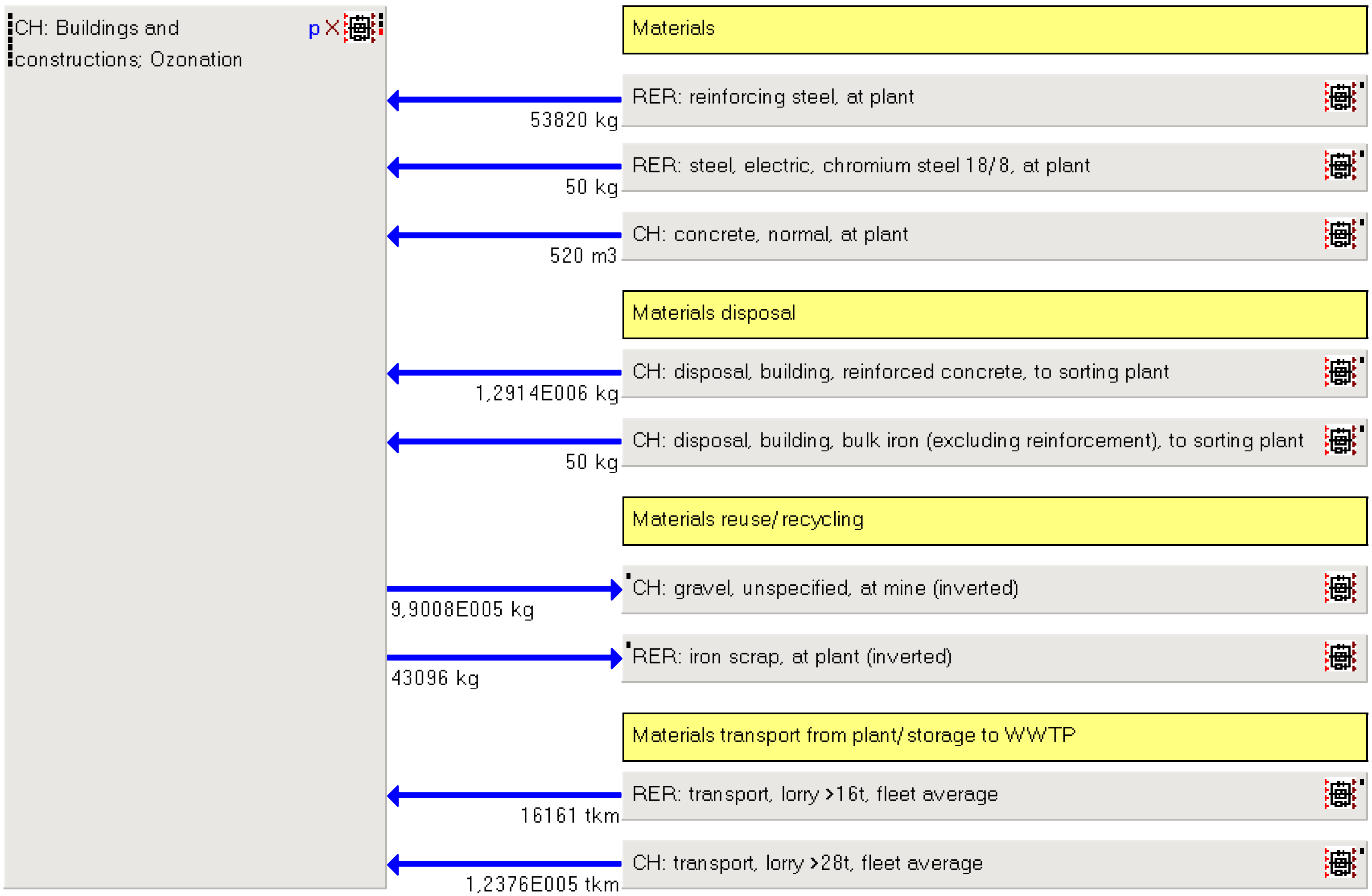


Modelling LCA on ozonation; Sub-plan
(physical inventory)

Buildings and constructions; Ozonation

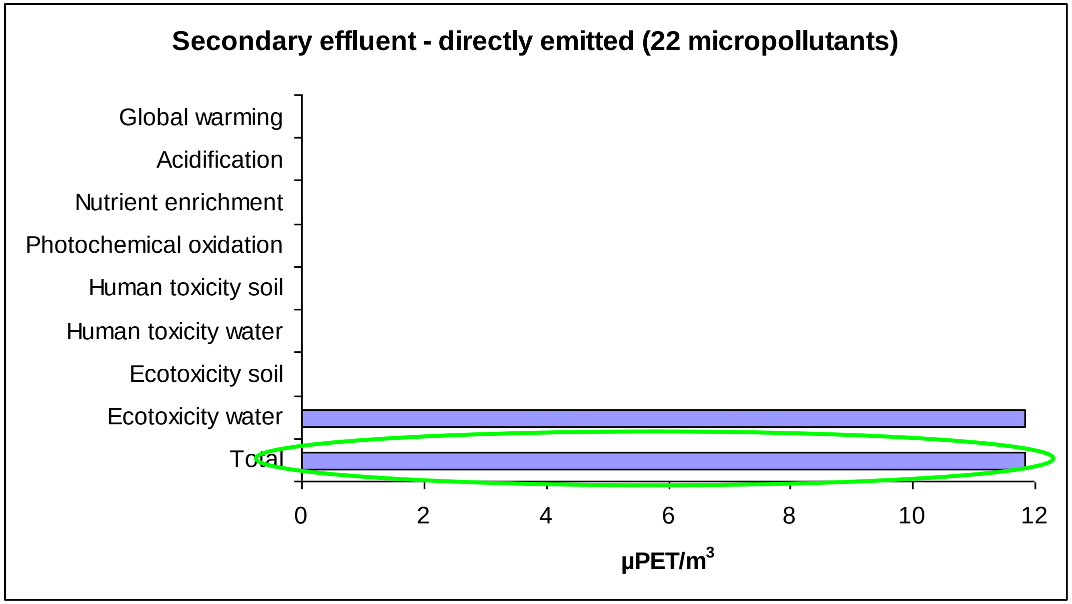
GaBi 4 process plan:Reference quantities

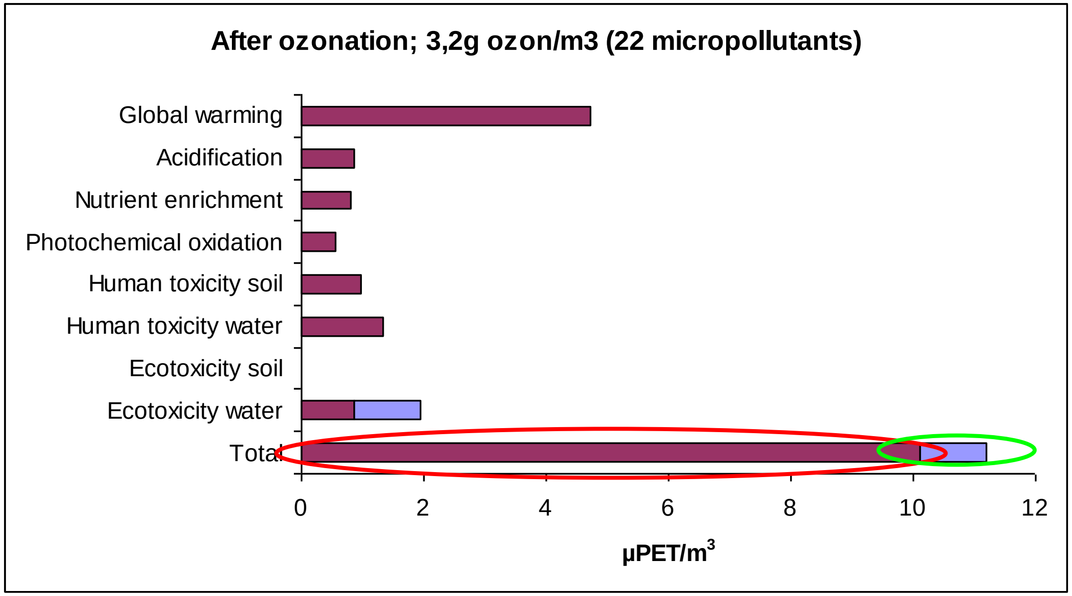
The names of the basic processes are shown.



LCA impact profiles

(weighting factor = 1 for all impact categories)
(non-conservative ecotox CFs)



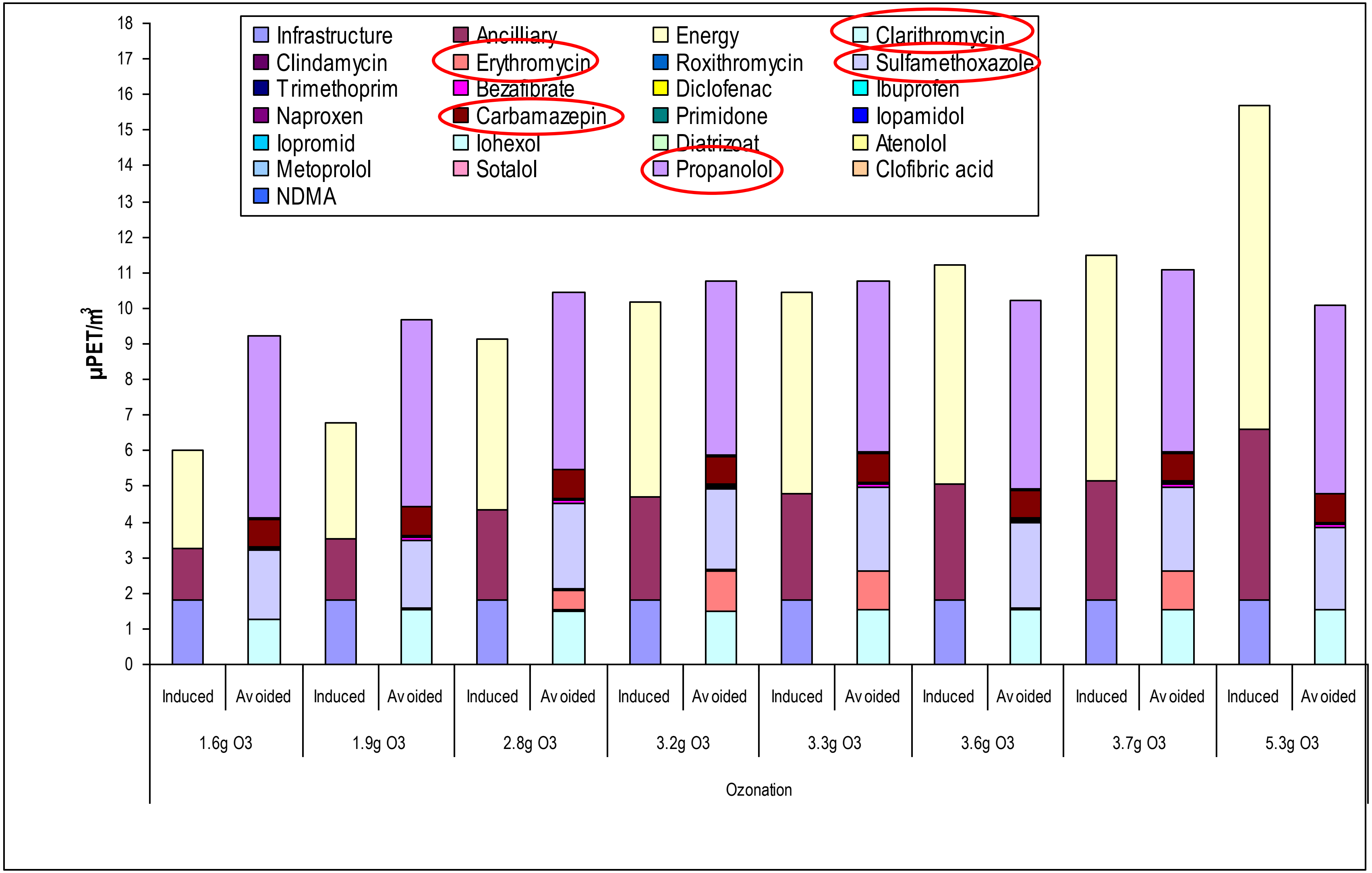


Avoided: 10,7 µPET/m3

Induced: 10,1 µPET/m3

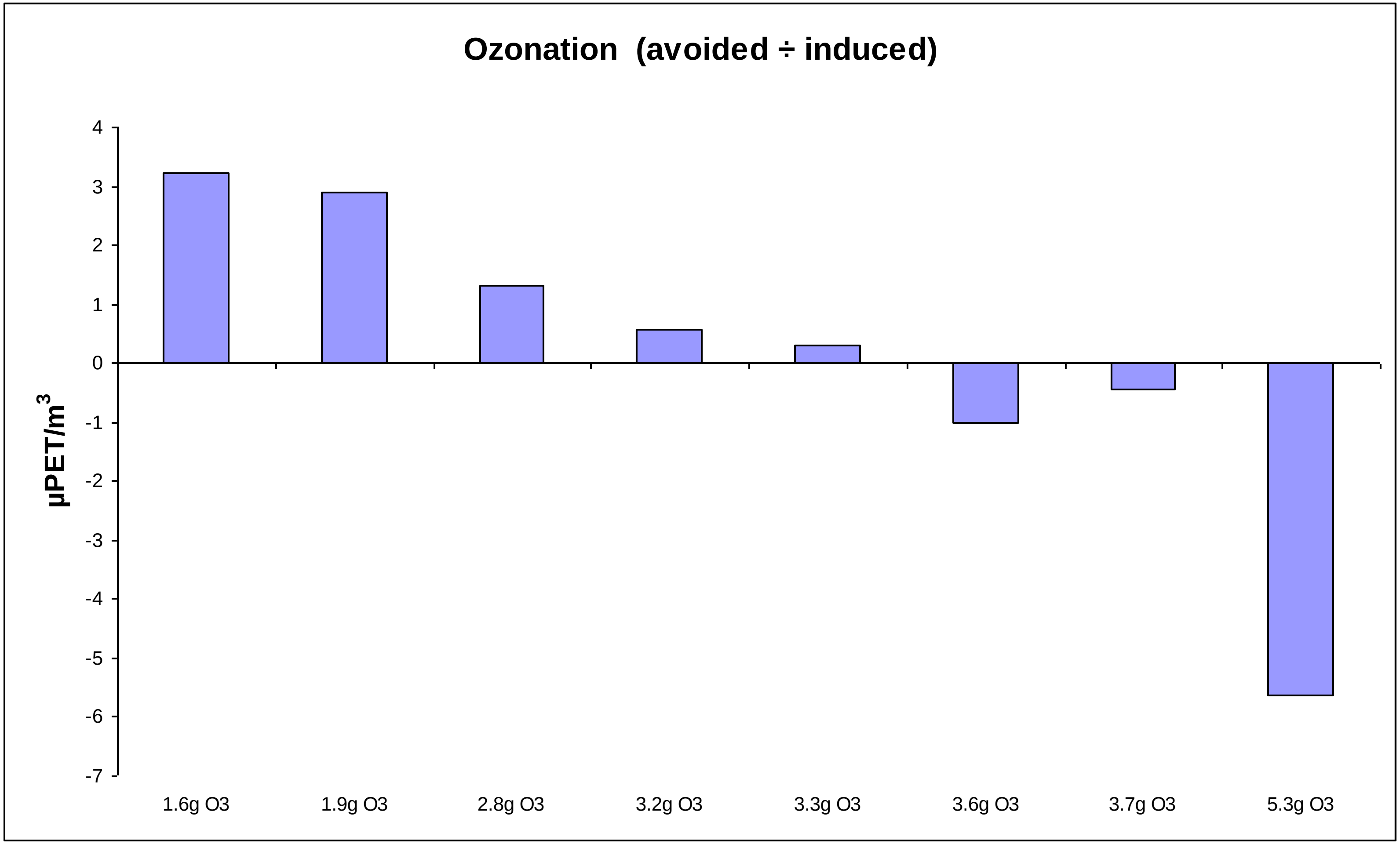
Environmental sustainability profiles; ozonation

(22 micropollutants; weighting factor = 1 for all impact categories)



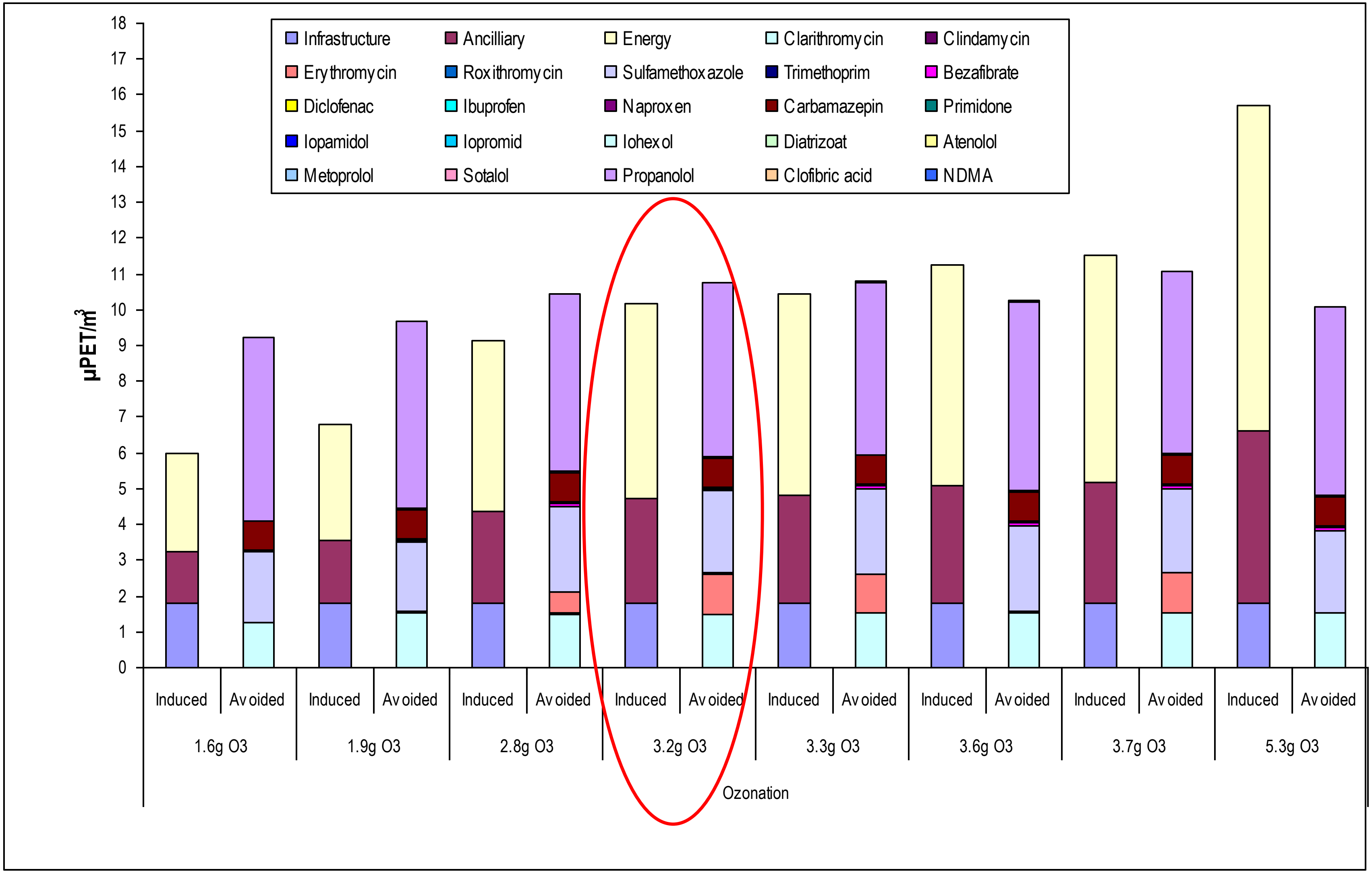
Environmental sustainability profiles; ozonation

(22 micropollutants; weighting factor = 1 for all impact categories)



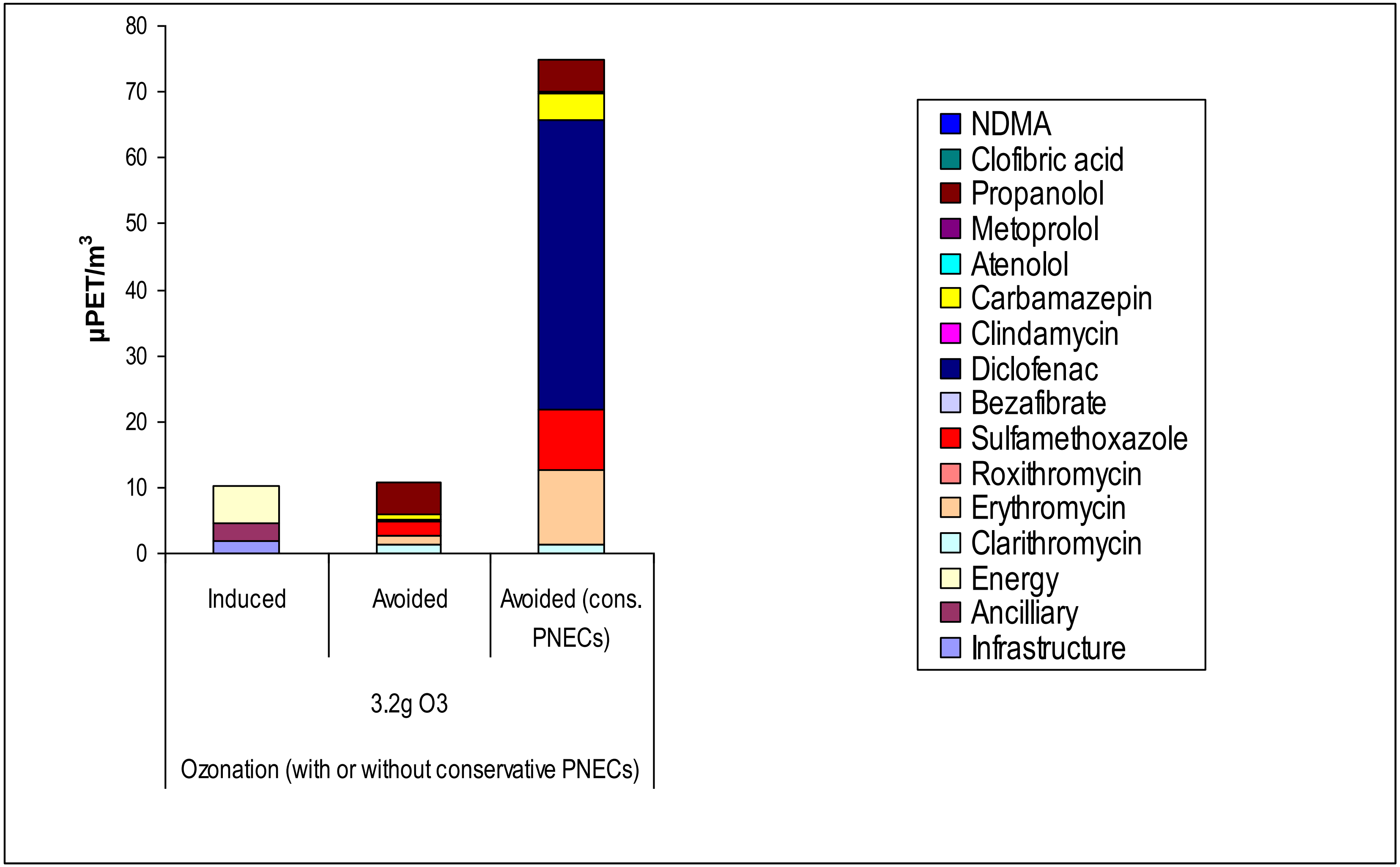
Environmental sustainability profiles; ozonation

(22 micropollutants; weighting factor = 1 for all impact categories)



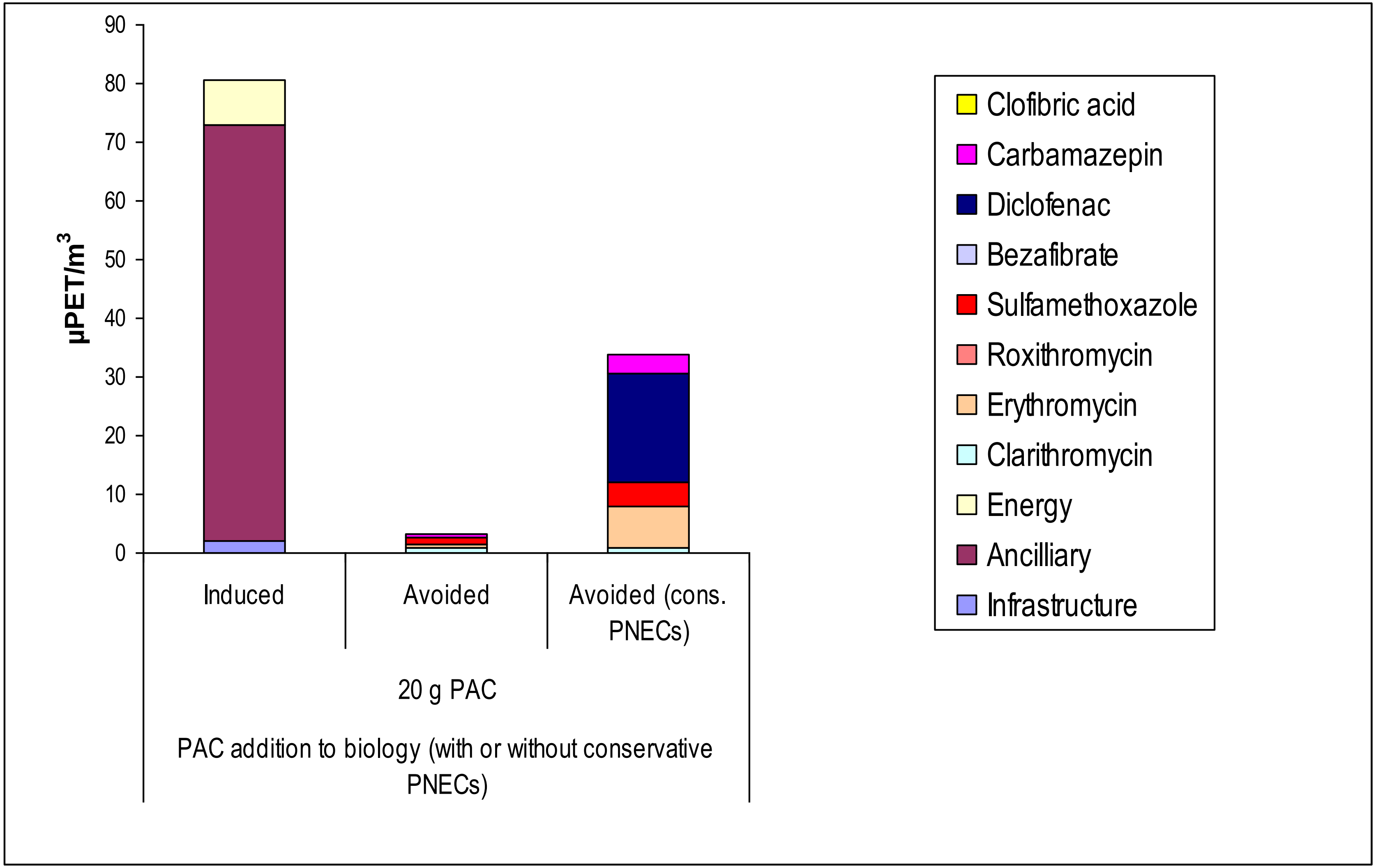
Environmental sustainability profiles; ozonation

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



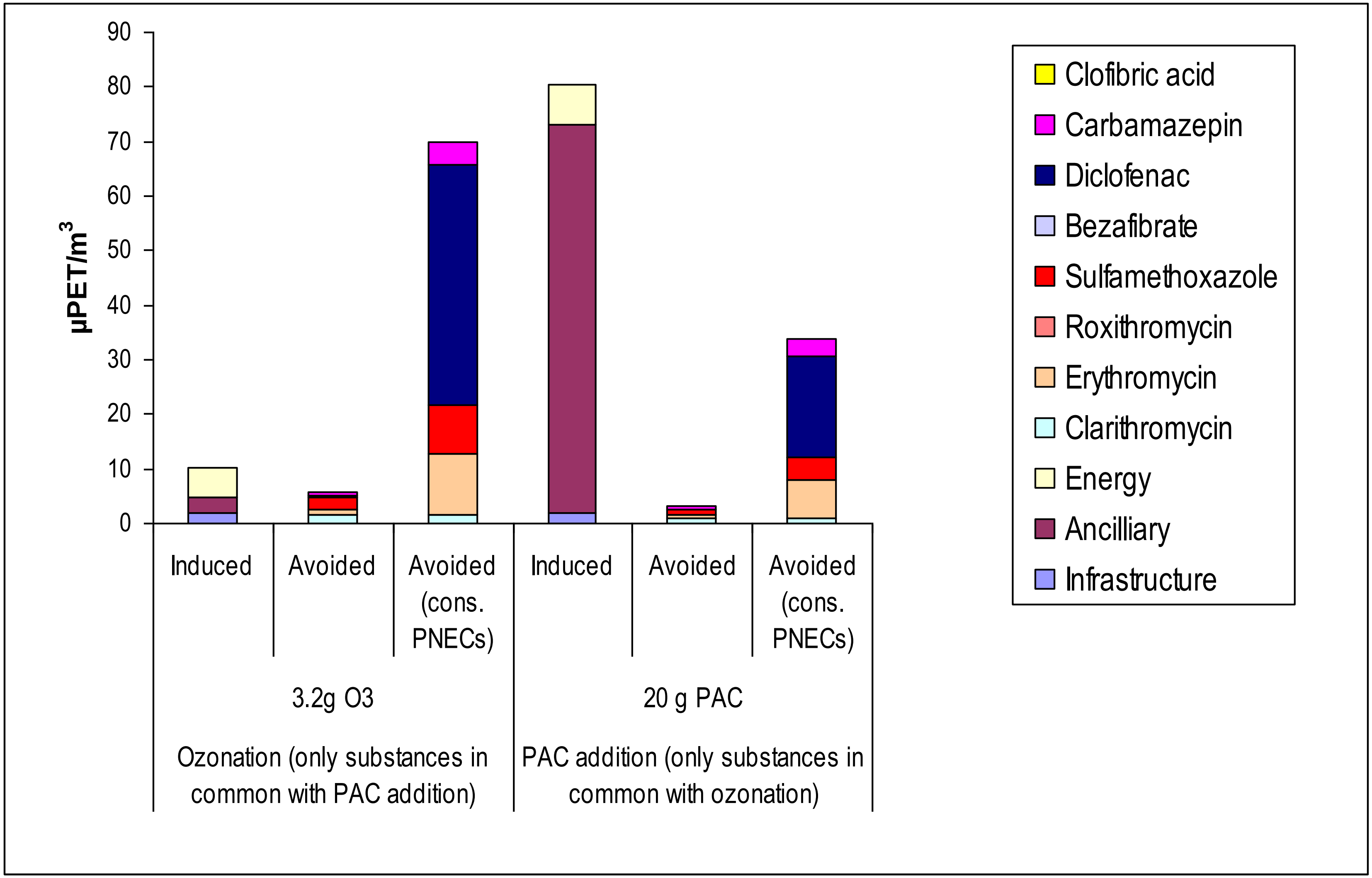
Environmental sustainability profiles; PAC addition to biology

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



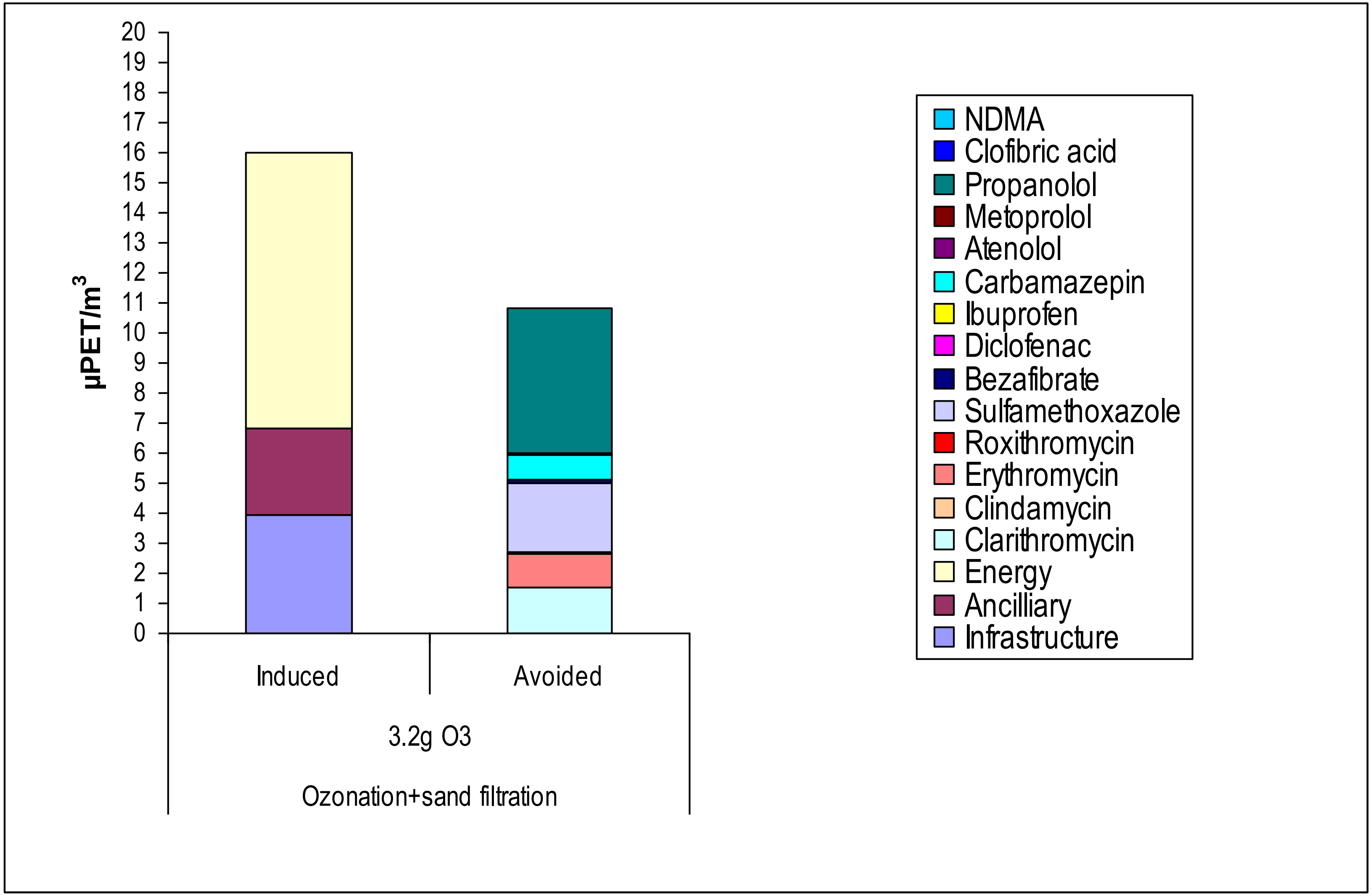
Environmental sustainability profiles; Ozonation as compared to PAC addition to biology

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



Environmental sustainability profiles; ozonation + sand filtration

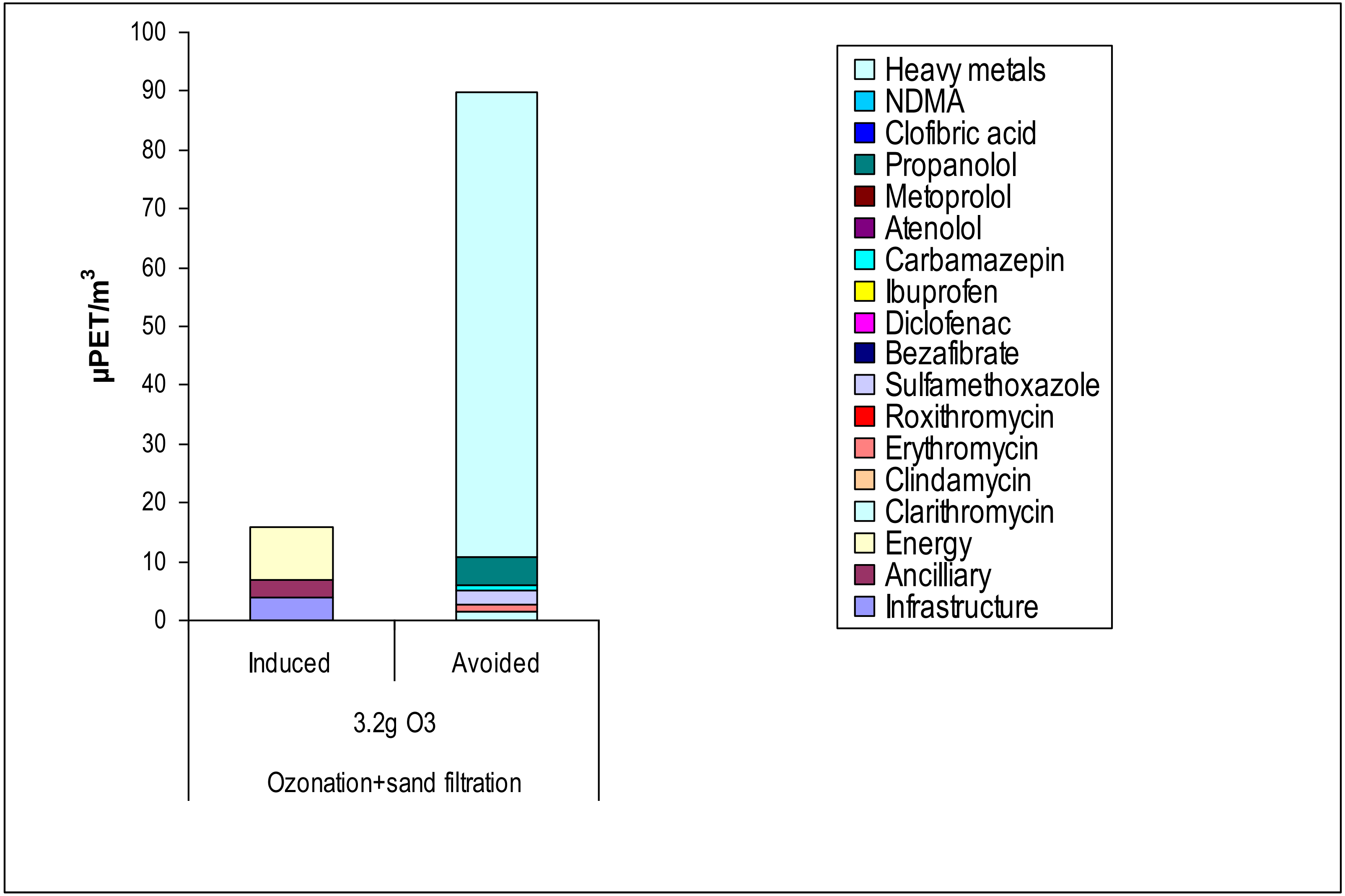
removal of aldehydes and WET (22 micropollutants, (only significant ones shown)
(weighting factor = 1 for all impact categories)



Environmental sustainability profiles; ozonation + sand filtration

(Including removal of metals in sand filter)

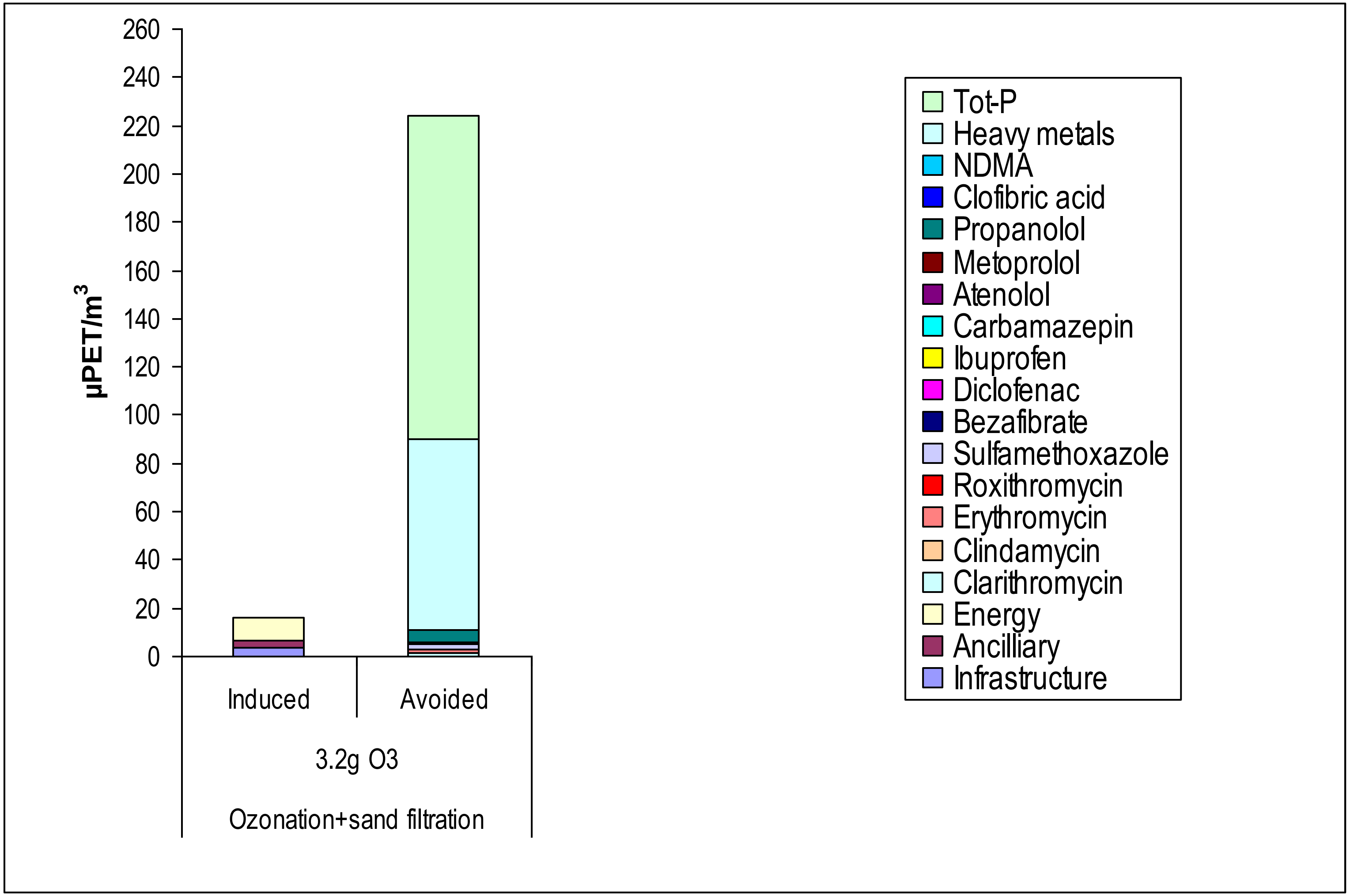
(**31** micropollutants (only significant ones shown); weighting factor = 1 for all impact categories)



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

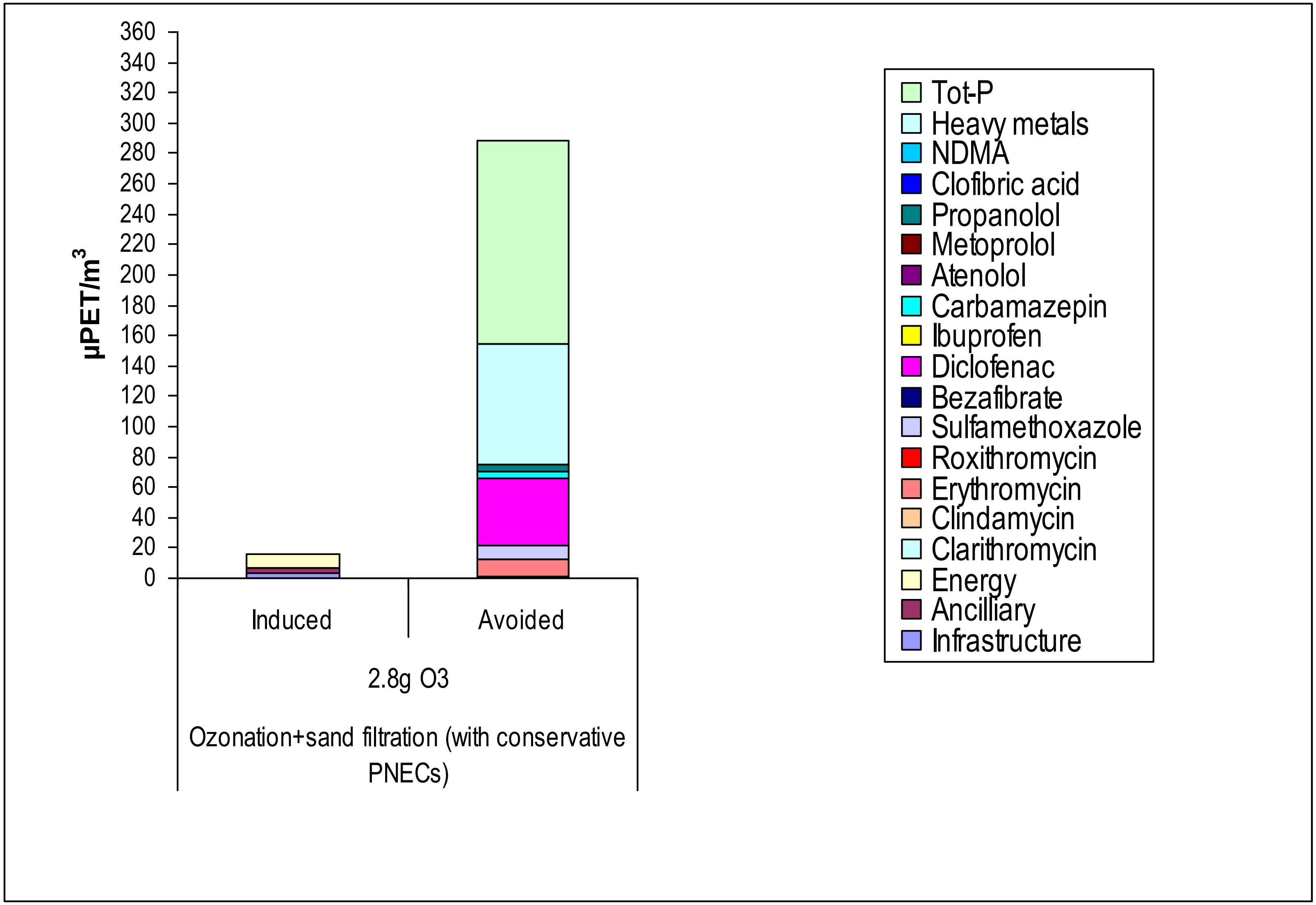
(**31** micropollutants **+ P** (only significant ones shown); weighting factor = 1 for all impact categories)

	Secondary effluent	After sandfiltration	Removal rate
Tot-P (mg/l)	0,8	0,3	0,625



Environmental sustainability profiles; ozonation + sand filtration

(**31** micropollutants **+ P** (only significant ones shown); weighting factor = 1 for all impact categories)
(including CFs based on conservative PNECs)



Conclusions and further research

Conclusions

- ✓ Based on the given assumptions and scoping results indicate that ozonation used for removal of organic micropollutants most probably is environmentally sustainable, i.e. avoided potential impacts are higher than induced potential impacts
- ✓ The environmental sustainability profile for PAC addition to biology is far from as good as for ozonation. However, by including more micropollutants in the analysis it might improve significantly
- ✓ Including sand filtration (removal of heavy metals and tot-P) - and hereby solving a problem with whole effluent toxicity and aldehydes regarding ozonation - significantly improves the sustainability profile
- ✓ Focusing on global warming a weighting factor of at least 20 – 40 is needed in order to reach a break-even between induced and avoided impacts for ozonation combined with sand filtration

Improvements/further research

- ❖ Including more micropollutants
- ❖ Including new methodology on the ecotoxicity impact category (average toxicity, PAF)
- ❖ Including economy (cost-efficiency)

Thank you for your attention

Acknowledgment

- This study was part of the EU Neptune project (Contract No 036845, SUSTDEV-2005-3.II.3.2), which was financially supported by grants obtained from the EU Commission within the Energy, Global Change and Ecosystems Program of the Sixth Framework (FP6-2005-Global-4)