Environmental assessment of a photocatalytic degradation of contaminated water

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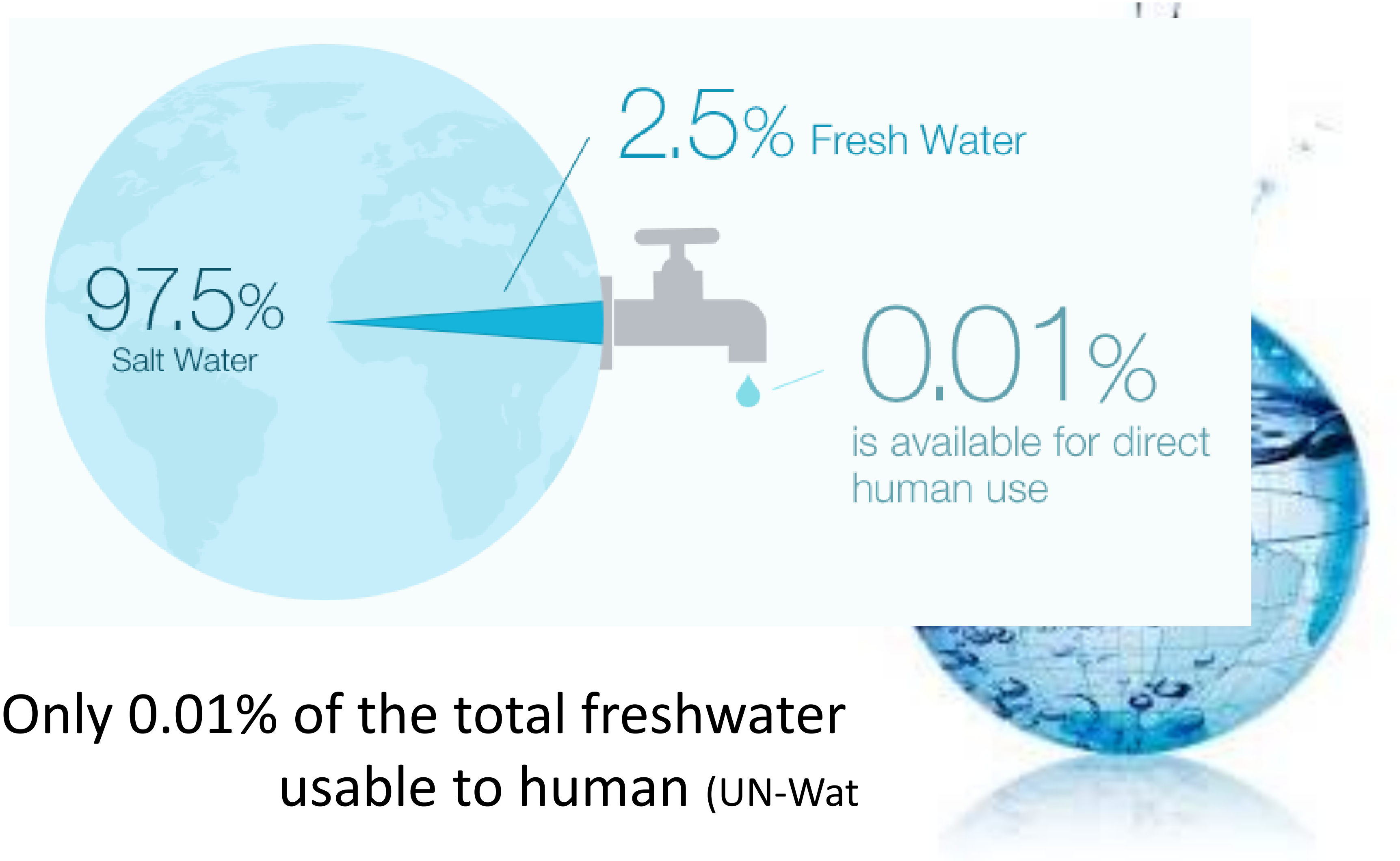
Water: A rare and precious resource



Only 0.01% of the total freshwater usable to human (UN-Wat

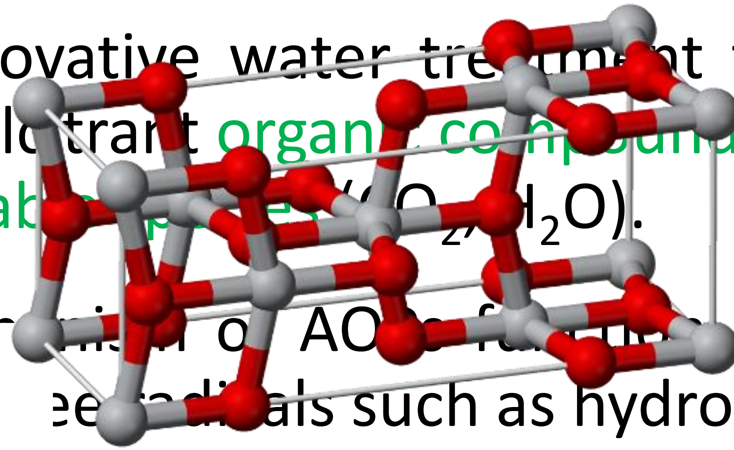
Wastewater: human-made phenomenon

- The *excessive use* and *continued mismanagement* of freshwater resources for industrial growth are increasing the contamination of the wastewater.

- A wide range of *organic compounds* is detected in industrial and municipal wastewater.

- Some of these compounds pose severe problems in biological treatment systems due to their resistance to biodegradation.

Advanced Oxidation Processes (AOPs)



- AOPs is an innovative water treatment technology used for destroying recalcitrant organic compounds transforming them into biodegradable species (CO_2, H_2O).
- The main mechanism of AOPs function is the generation of highly reactive free radicals such as hydroxyl radicals ($OH^•$).
- One … effective methods of AOPs is the … ray and oxidant such as H_2O_2, O_3, and TiO_2.

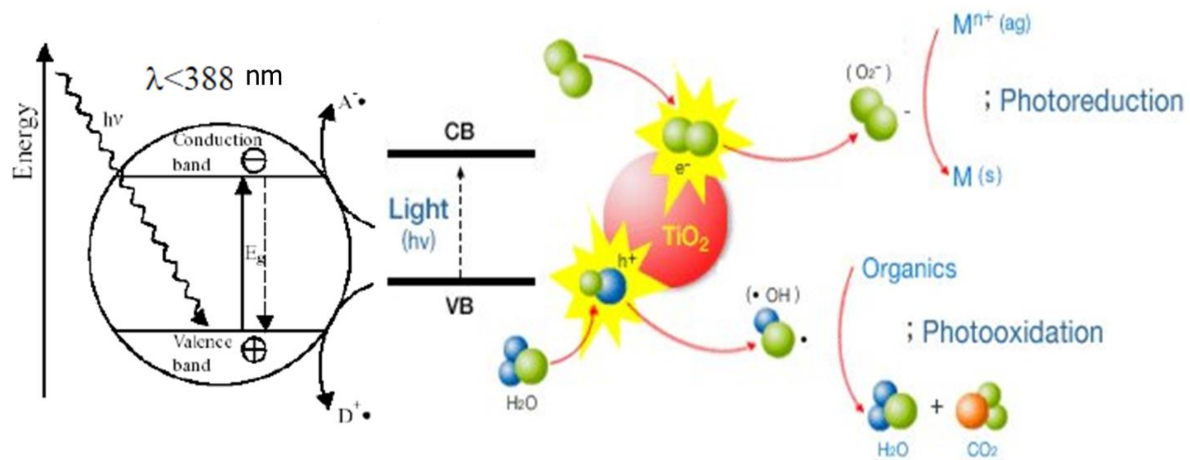
TiO_2

OH• semi-permanently
Only photoenergy use

H_2O_2 / UV
O_3 / UV
O_3 / H_2O_2 / UV
UV / TiO_2 (Photocatalytic oxidation)

Titanium dioxide photocatalyst

- TiO_2 is a metallic oxide well known for its unique photocatalytic properties and ability to degrade organic matters.
- TiO_2 is very stable both chemically and photochemically, relatively low cost, nontoxic and insoluble in water.
- TiO_2 nanoparticles thanks to their small particle size can lead to the increase of surface area of the catalyst and *improve the photocatalytic activity* (more catalytic reactions can occur at the same time).



TiO_2 nanoparticles for wastewater treatment
Prototype phase

- Cylindrical photoreactor having a substrate coated with nanoTiO_2 and activated with proper UV irradiation;
- Laboratory scale
  Reactor dimensions:
  external glass tube h=450 mm, Ø=56 mm
  internal quartz tube h=400 mm, Ø=35mm
- UV-A lamp (15 W) is collocated inside the internal tube;
- O_3 has been blown through the bottom opening to enhance the oxidation process of nanoTiO_2;
- Photocatalytic support: aluminum oxide (Al_2O_3) microspheres coated with nanoTiO_2 ;

Material Lab - Department of Industrial Engineering – University of Parma, Italy

TiO_2 nanoparticles for wastewater treatment Prototype phase

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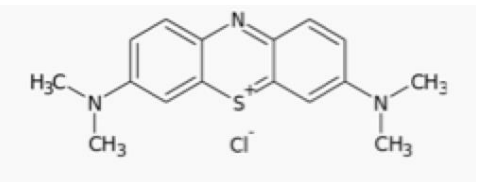
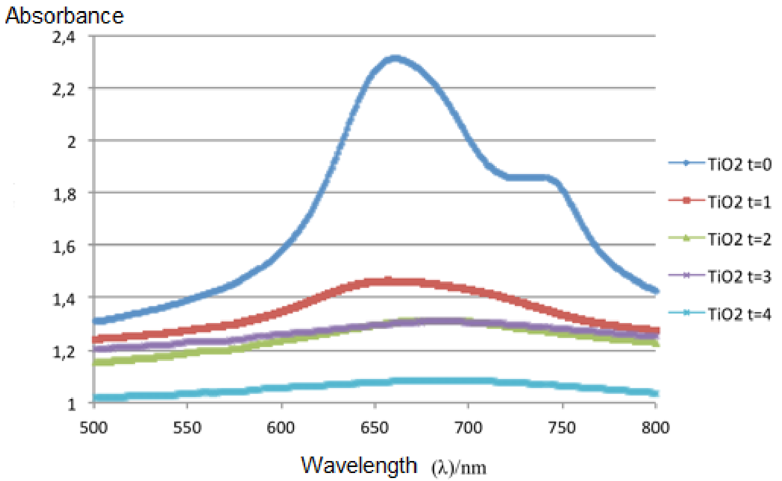


Methylene blue

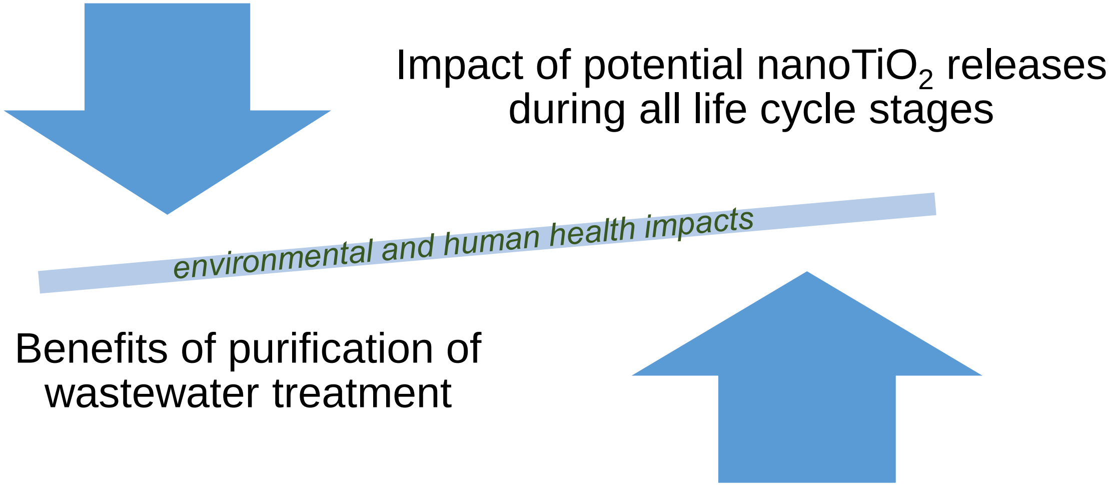
$C_{16}H_{18}ClN_3S \cdot xH_2O$



- The photoreactor has been tested with synthetic wastewater sample;
- Mode of operation: batch mode or semi-continuous mode to ensure the adequate contact time for the photocatalytic degradation.

Life Cycle Assessment *ISO 14040/44*

- The aim of this study is to assess the *environmental* and *human health* impacts of the scale up of the developed photoreactor and the related wastewater purification treatment.



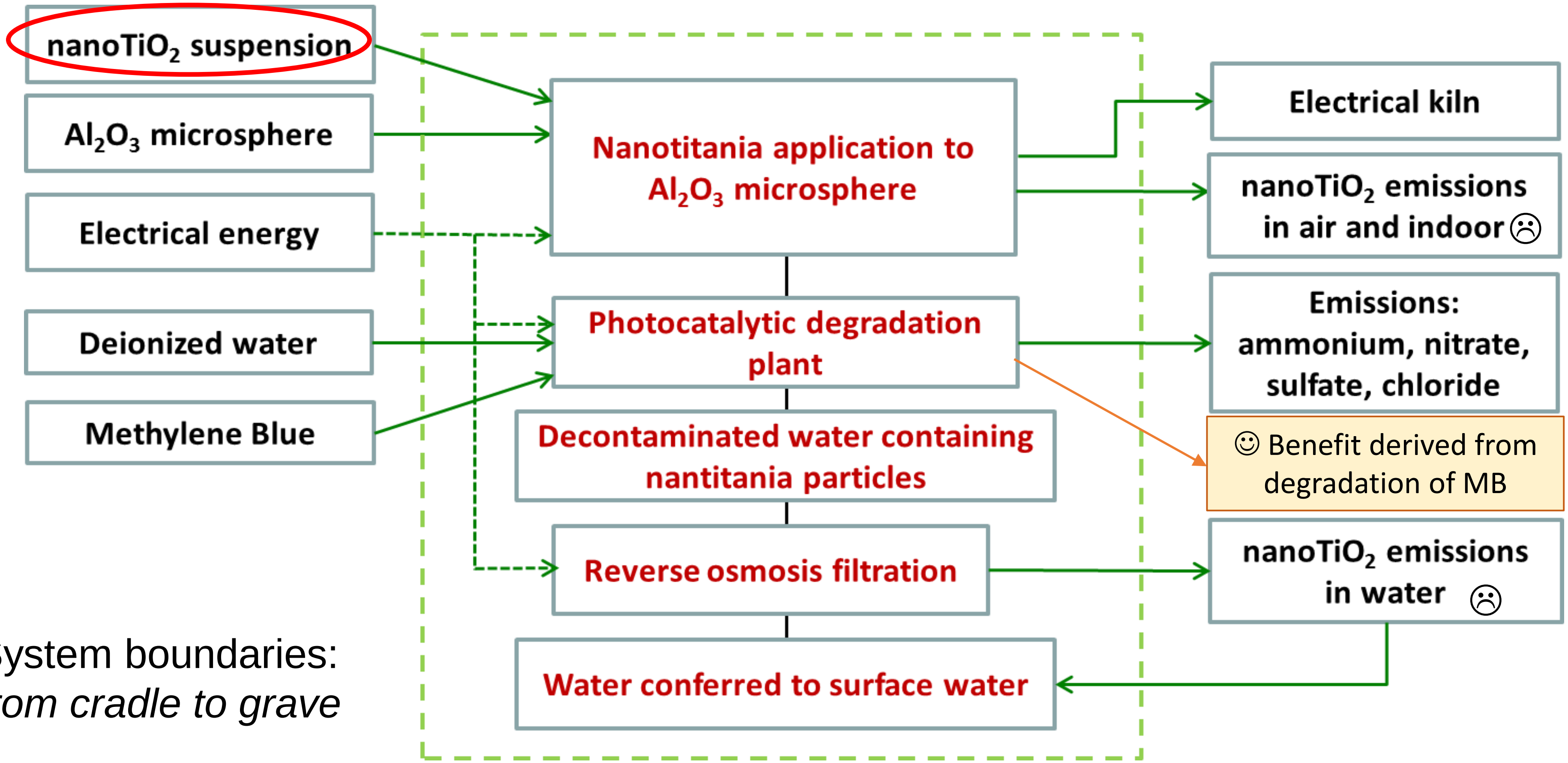
- Functional unit: volume of the synthetic wastewater sample= 6917 cm^3
  Photoreactor internal volume: 7170 cm^3; Total spheres volume: 253 cm^3

- Data quality:
  - ✓ primary data supplied by the *Material lab, University of Parma - Italy* has been used;
  - ✓ secondary data obtained by Ecoinvent database v3 have been adopted to model the background processes (as electricity and heat productions and transports);
  - ✓ lab-scale data has been scaled up adopting a linear rate.

Life Cycle Assessment

Colorobbia S.p.A. *Patent: US 2008/0317959 A1, Baldi G. et al. 2008*

Pini et al., 2015. Green Chemistry 17 (1), 518 – 531.



System boundaries:
from cradle to grave

Software: Simapro 8

LCIA Method: USEtox™ modified

USEtox^{TM} modified method

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EMPA Materials Science & Technology

- Human health CFs for TiO_2 nanoparticles

Pini M, Salieri B, Ferrari AM, Nowack B, Hischier R (2016), "Human health characterization factors of nano-TiO_2 for indoor and outdoor environments", *Int J Life Cycle Assess*, 21(10), 1452-1462. DOI: 10.1007/s11367-016-1115-8.

Human health effect	Indoor CFs [cases/$kg_{emitted}$]	Outdoor CFs [cases/$kg_{emitted}$]
Carcinogens	1,43E-2	1,34E-4
Non-carcinogens	5,87E-7	5,5E-9

- Freshwater ecotoxicity CF for TiO_2 nanoparticles

Salieri B, Righi S, Pasteris A, Olsen SI (2015), "Freshwater ecotoxicity characterisation factor for metal oxide nanoparticles: A case study on titanium dioxide nanoparticle", *Science of Total Environment*, 505, 494–502. DOI: 10.1016/j.scitotenv.2014.09.107.

Freshwater ecotoxicity
CF= 0,28 PAF*day*m^3*kg^{-1}

Ecodesign approach

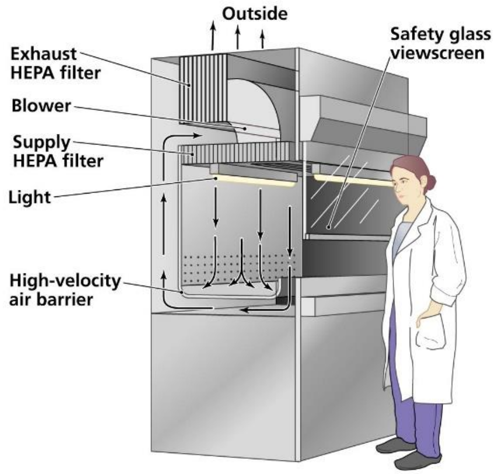
- Application phase → 1% nanoTiO_2 emissions release in **air**

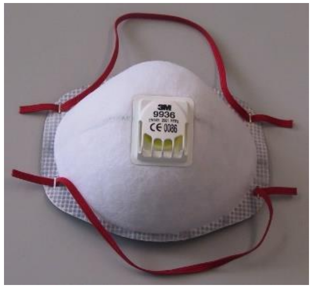
99.97% retained by HEPA filter (High Efficiency Particulate Air)

0.03% released into the production room

95% retained by face mask filter (FFP3)

EoL of HEPA and face mask filters: landfill for residual materials





European Standard EN149:2001+A1:2009

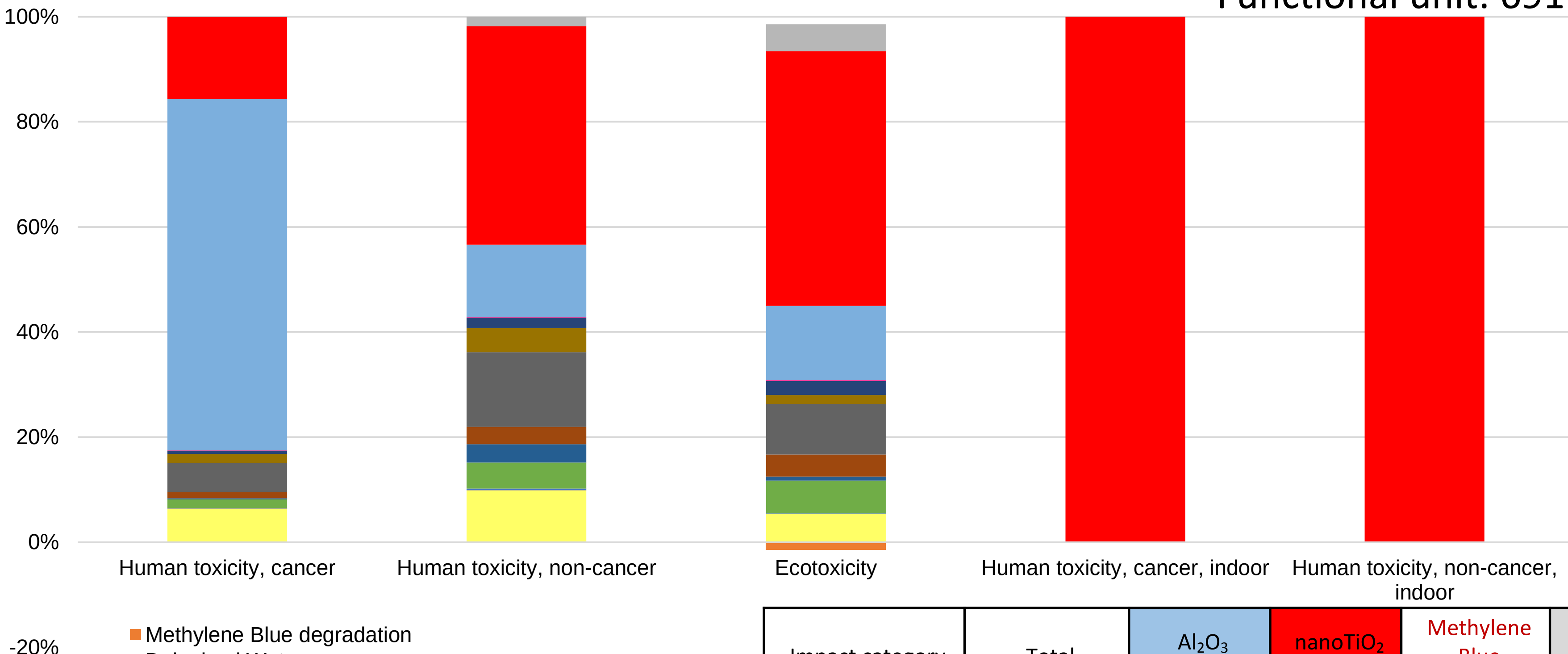
- Reverse osmosis filtration → 0.1% nanoTiO_2 emissions releases in **water**

99.97% retained by filter

0.03% released into water

Environmental results of the scale-up of photocatalytic wastewater purification treatment

Functional unit: 6917,3 cm^3



Impact category	Total	Al_2O_3 microspheres	$nanoTiO_2$ application	Methylene Blue degradation	$nanoTiO_2$ emission
Human toxicity, cancer (outdoor)	2,54E-08 CTUh	66,90%	15,60%		0,13%
Human toxicity, non-cancer (outdoor)	2,89E-08 CTUh	13,73%	41,52%		1,79 E-6%
Ecotoxicity	4,1 CTUe	14,58%	49,84%	-1,45%	5,67 E-5%
Human toxicity, cancer, indoor	6,14E-14 CTUh	/	100%		/
Human toxicity, non-cancer, indoor	2,51E-18 CTUh	/	100%		/

Conclusions and next steps

- The life cycle assessement of the scale up of the cylindrical photoreactor to treat wastewater has been performed.
- The new freshwater and human health CFs developed following USEtox framework have been implementing in the USEtox method to carried out the LCIA results.
- Al_2O_3 microspheres production and nanoTiO_2 application are the life cycle stages with higher environmental loads.
- Standardization of nanoTiO_2 toxicological data and development of protocols for nanoparticle emissions measurement are urgently required.
- Due to the still uncertainty of toxicological effects of nanoTiO_2, during the scaling up phase a ecodesign approach has been use.
- Benefit derived from the Methylene blue degradation is higher than the damage of nanoTiO_2 emission in surface water (Ecotoxicity impact category).
- Next steps: adopting the Gavankar's upscaling process for engineered nanomaterials

Gavankar et al., 2015. The Role of Scale and Technology Maturity in Life Cycle Assessment of Emerging Technologies - A Case Study on Carbon Nanotubes. J .Ind. Ecol. 19, 51-60.

parametric analysis to model different nanoTiO_2 emissions scenarios

Thank you for your attention

In collaboration with Prof. Federica Bondioli and Dr. Maria Vittoria Grandi
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