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Life Cycle Assessment applied to remediation technologies: methodological and practical issues

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Outline of the work

- Remediation technologies can be often associated with relevant costs (both economic and environmental) and technical issues

in some cases it may affect the cost effectiveness and feasibility of remediation

- **Objective of the study:** evaluating the environmental performance of
  - an innovative biotechnology (a modified Permeable Reactive Barrier, PRB), developed within the framework of EU **Minotaurus** project (Microorganism and enzyme Immobilization: NOvel Techniques and Approaches for Upgraded Remediation of Underground-, wastewater and Soil, Work Package 5: Evaluation of socio Economic-suitability of tested treatment technologies)
  - a permeable reactive barrier filled with Zero Valent Iron (ZVI)
  - a Pump and Treat System (PTS)

by a comparative Life Cycle Assessment (LCA) approach

LCA methodology

"Life Cycle Assessment *is a process to evaluate the environmental burdens associated with a* ***product or process*** *by identifying and quantifying energy and materials used and wastes released to the environment*"

Society of Environmental Toxicology and Chemistry - 1993

UNI EN ISO 14040:2006

- Principles and framework

UNI EN ISO 14044:2006

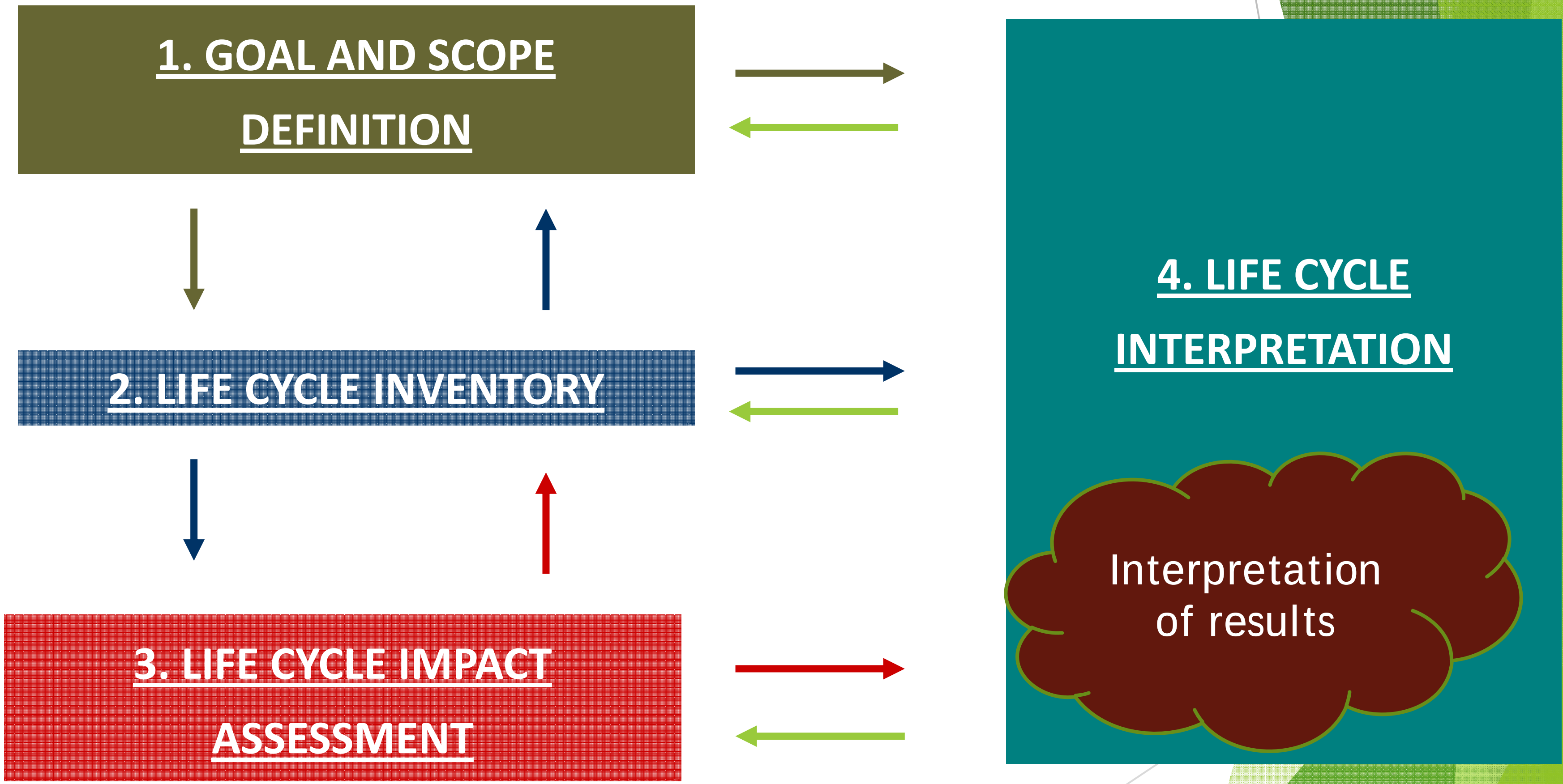
- Requirements and guidelines

Nederlandse norm

NEN-EN-ISO 14044
(en)

Environmental management - Life cycle assessment - Requirements and guidelines
(ISO 14044:2006,IDT)

LCA phases



Methodology

LCA – Goal & Scope

- Comparison of environmental performance provided by an innovative bioremediation technology (BER) and two benchmark remediation technologies (PRB, PTS);
  - Functional unit: 1 m^3 of groundwater remediated from chlorinated compounds
  - Design assumption: same remediation time and goal. Design has been tuned accordingly
  - "cradle to grave" approach, cutting off end of life disposal of the materials, due to
    - lack of information regarding passive treatment facilities' (BER and PRB) fate once their remediation goals are accomplished
    - different longevity of the materials involved, reactive media in particular
- Life cycle Assessment boundaries thus included:
    - Production and transport for all raw materials;
    - Energy flows used for building facilities;
    - Use phase energy demand

Bio-electrochemical system, an overview

- Design: funnel & gate model
- Reactive medium: granular graphite, supposed to work both as a substrate for bacteria and as an electrical conductor for potential difference used to optimize bacterial reductive dechlorination
- The potential difference is supposed to be applied through electrodes directly driven through the soil and into the gate

Source of electrical power: photovoltaic panels

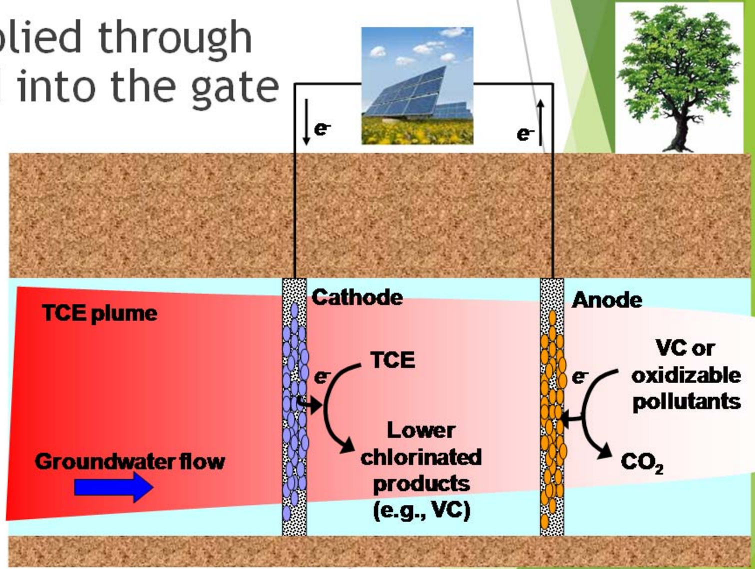


Figure 1: Full scale Bioelectrochemical system [2].

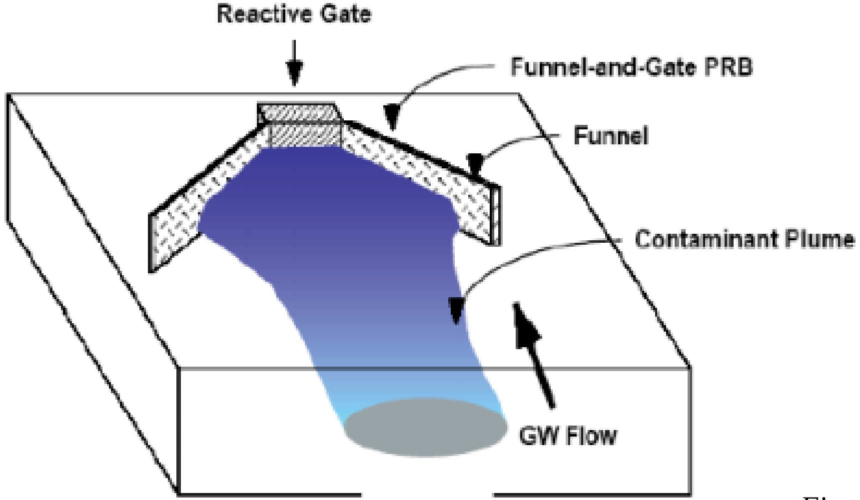


Figure 2: Funnel and gate design [4].

LCA application: challenges

1. **Full scale design**: a full scale **modified PRB** had to be designed in order to allow comparison with reference technologies → the new system has been modeled introducing graphite instead of ZVI as a reactive medium

2. **Process Database**: Ecoinvent database does not include a specific process to address the discharge of treated groundwater as surface water in the PTS, thus not allowing the evaluation of the **impact** resulting from the **depletion of a non-renewable** (in the short medium term) **resource** → post treatment water has been modelled as if it were wastewater with a slight degree of contamination

3. **Calculation method**: a first run of results produced through EDIP/UMIP 97 method showed a particular emphasis on ecological and human toxicity impact categories → Following International reference Life Cycle Data System (ILCD [5]) recommendation, another run of results has been produced through IMPACT 2002+ method

LCA – application: methodological issue

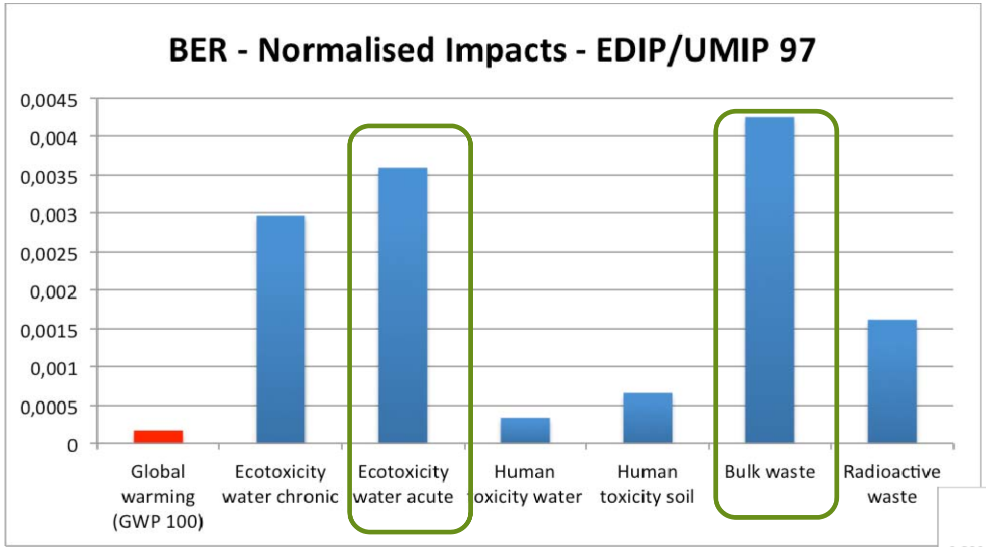


Figure 3: Normalised Impacts for the bioelectrochemical system (EDIP/UMIP 97)

EDIP/UMIP 97 attributes a heavy score to

- bulk waste
- ecotoxicity

Thus outweighting the relevance of other categories including **Global Warming Potential**, which is the highest scoring category according to Impact 2002+ calculations

⇩

Impact 2002+ was chosen for Impact Assessment and results' interpretation

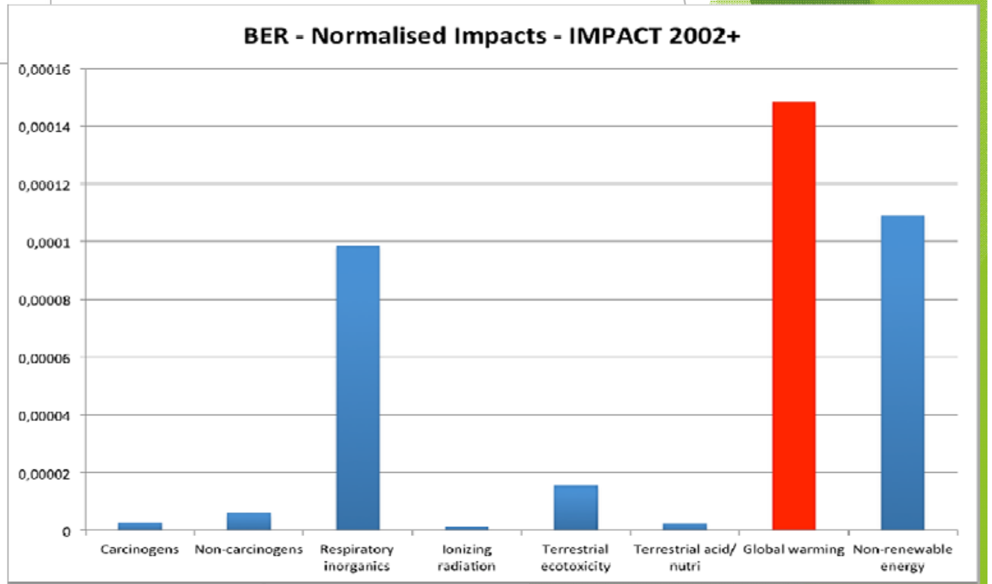


Figure 4: Normalised impacts for the bioelectrochemical system (IMPACT 2002+)

LCA – Results and interpretation

Impact of the system’s subprocesses on the overall environmental performance:

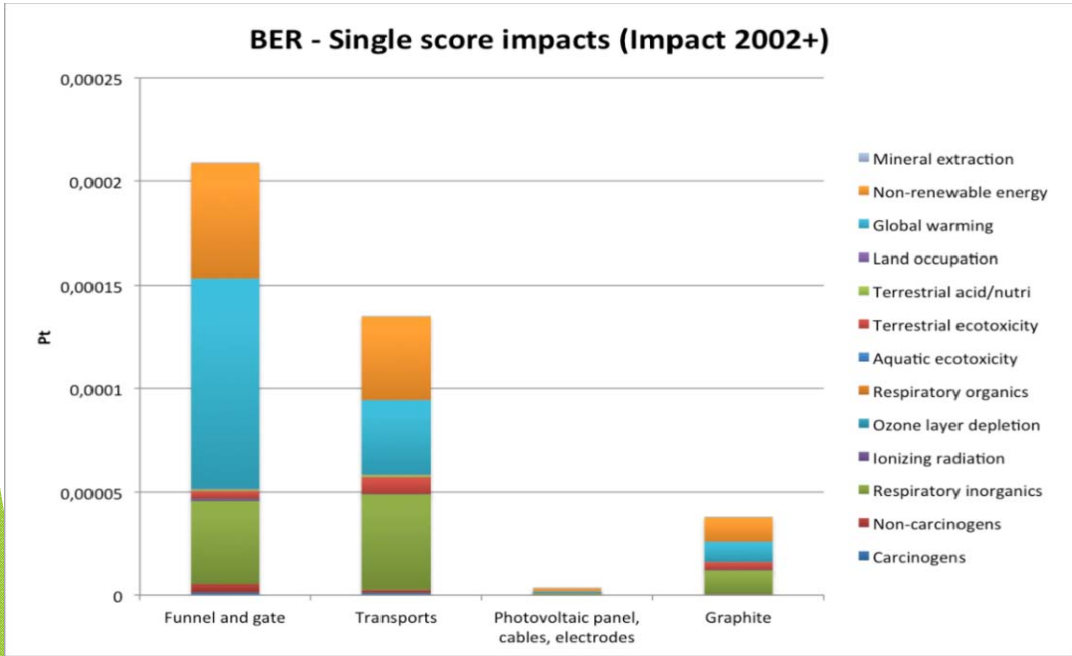


Figure 5: Single score impacts (IMPACT 2002+)

- BER
  - The most relevant contributions to the total score (in Ecopoints) are related to funnel and gate building and to materials’ transport
  - Reactive medium (graphite) production plays a minor role and energy related contribution is negligible

✓ the most affected categories are
- ✓ Global Warming,
- ✓ Nonrenewable energy
- ✓ Respiratory inorganics

LCA – Results and interpretation

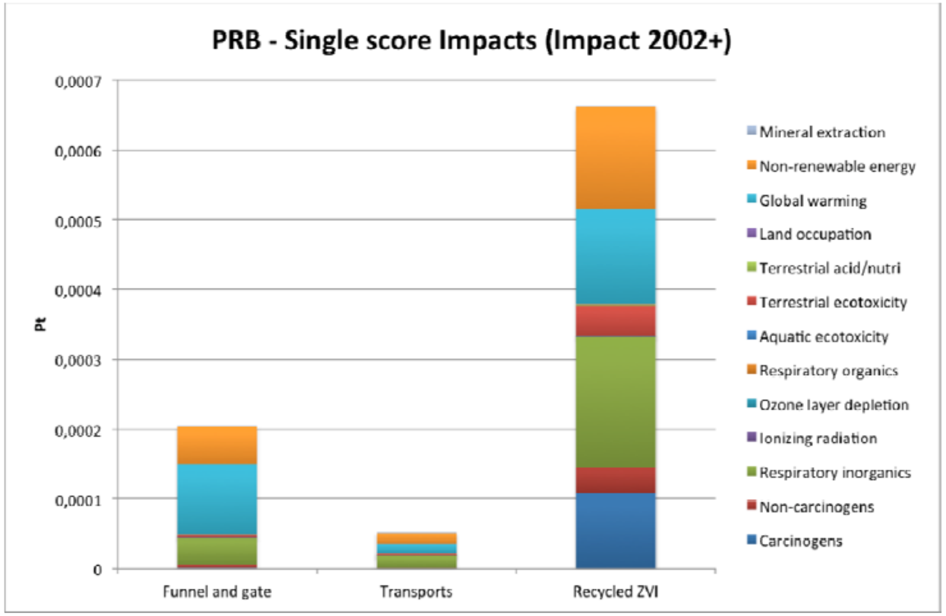


Figura 6: PRB - Single score impacts (IMPACT 2002+)

- ✓ The most concerning impact categories are
  - ✓ Global warming
  - ✓ Nonrenewable energy
  - ✓ Respiratory inorganics
  - ✓ Carcinogens

- PRB
  - huge impact of Zero valent Iron production on the permeable reactive barrier’s performance
    - even modeling part of this item as recycled Iron, ZVI production-related impacts are responsible for more than a half of the total score
    - This result can be explained considering the massive amount of ZVI required to fill the gate (216 tons)
  - construction and transport related impacts are comparatively modest

LCA – Results and interpretation

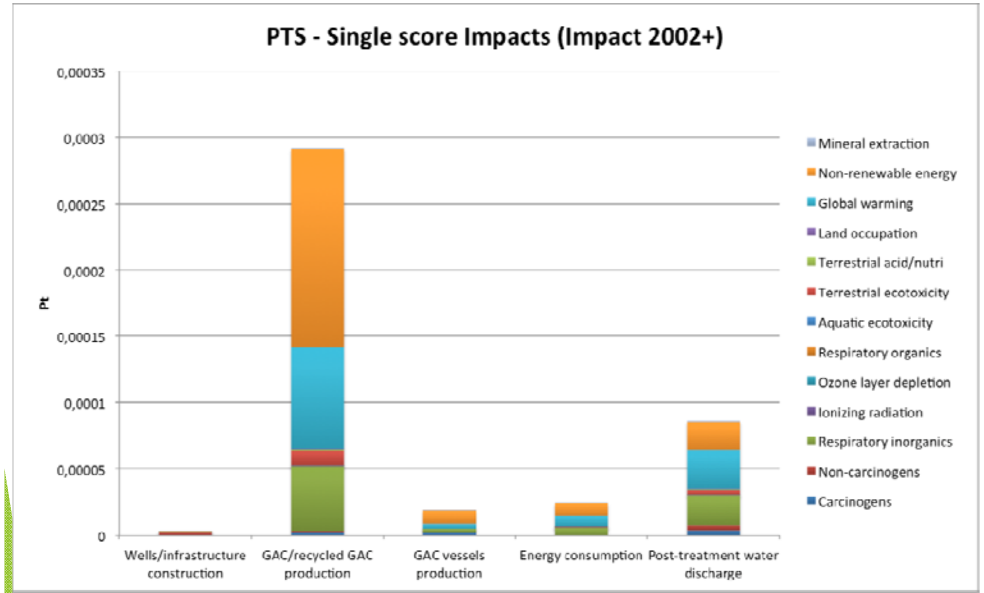


Figure 7: PTS - Single score impacts (IMPACT 2002+)

- ✓ The most affected impact categories are
  - ✓ Nonrenewable energies
  - ✓ Global warming
  - ✓ Respiratory inorganics

- PTS
  - the most relevant contribution is related to activated carbons production, which concurs to approximately 70% of total score
  - a smaller but non negligible contribution is due to the effect of post –treatment water discharge.
  - contrary to preliminary expectations, energy consumption related impacts had a small effect on overall environmental performance

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LCA – Technologies comparison

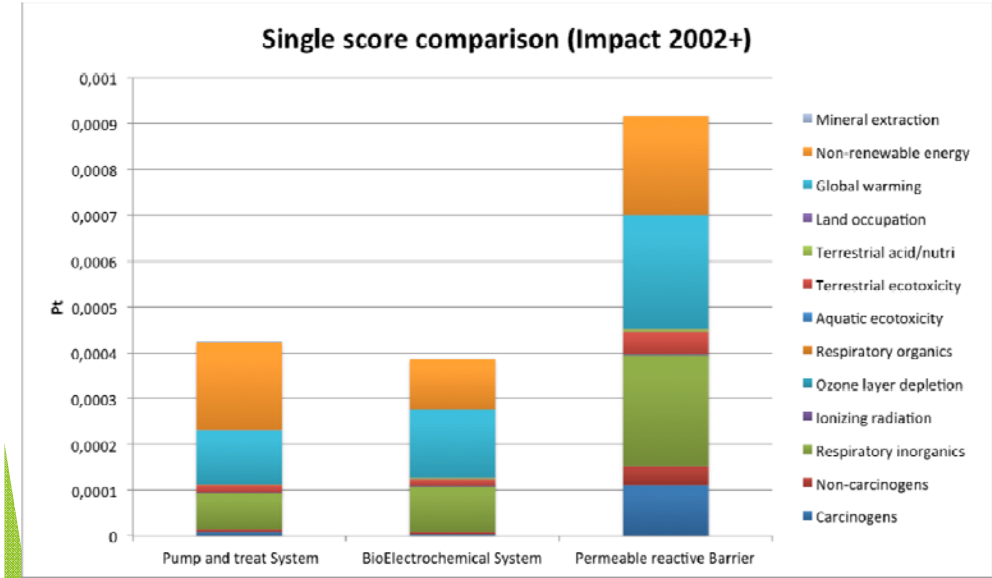

Figura 8: Single score comparison (IMPACT 2002+)

- The highest score is attributed to the Permeable reactive barrier
- Bioelectrochemical and Pump and Treat systems show a similar performance, resulting in a score about 50% lower than the PRB's.

As reactive media proved to be the most impactful subprocess for each of the investigated treatment options, it has been decided to look into their standalone environmental performance.

LCA – Technologies comparison

- Focusing only on the environmental performance of the reactive media:
  - granular activated carbon (PTS system), even in its recycled form, has by far the most penalizing production process, because of the considerable amounts of energy and heat involved
  - recycled cast iron (PRB system) production seems comparatively much more sustainable
  - graphite (BER) production-related impacts appear practically negligible.

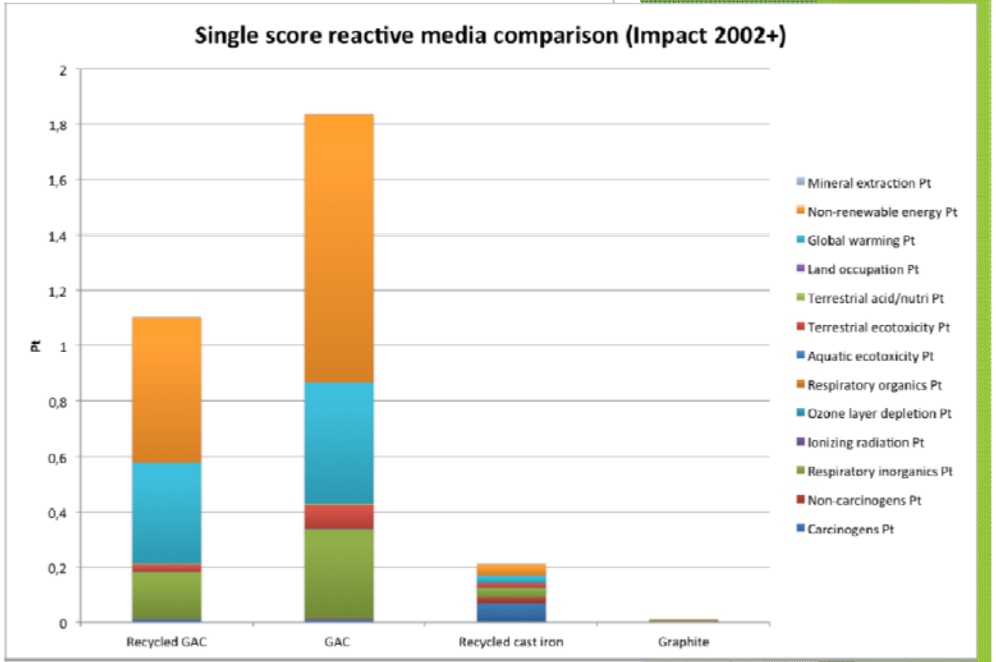

Figure 9: Single score comparison (REACTIVE MEDIA) (IMPACT 2002+)

A careful account of the media required should become a key element for the choice of a remediation technology

Conclusions

- **Reactive media production** proved to be a key factor for the three systems' overall performance
- The **bioelectrochemical system** showed a promising environmental performance, mostly because of the lighter environmental burden of graphite in respect of ZVI and granular activated carbon as a reactive medium
- Since BER technology was at an early stage of development, further analysis are to be performed once design assumption would have been backed up by **field data**
- The **permeable reactive barrier** showed the poorest environmental performance mainly because of the massive amount of reactive media required
- The **pump and treat system's** performance was close to the bioelectrochemical system's, but it could reach the remediation goal in shorter time.
- Impacts related to **groundwater discharge** after PTS treatment underlined a lack of an appropriate tool in the Eco Invent database which should be developed in further studies.

Final remarks

	BER	PRB	PTS
Strenght	✓ Graphite as reactive medium proved to be an eco-efficient choice ✓ Low energy consumption	Passive technology with low maintenance requirements	✓ It could reach the remediation goal in shorter time ✓ Process easy to control and maintain
Weakness	Remediation performance related to biological activity of local bacteria	Massive amount of reactive media (ZVI) required	Groundwater resource depletion
Most affected impact categories	✓ Global Warming, ✓ Nonrenewable energy ✓ Respiratory inorganics	✓ Global warming ✓ Nonrenewable energy ✓ Respiratory inorganics ✓ Carcinogens	✓ Nonrenewable energies ✓ Global warming ✓ Respiratory inorganics
Remarks	Design assumptions need to be backed up by field data	An effort towards eco-efficiency of the process should focus on ZVI production	A dedicated indicator must be studied to take into account the groundwater depletion

Aknowledgement

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Thank you for your kind attention

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