Biochar produced from wood waste for soil remediation in Sweden: Carbon sequestration and other environmental impacts

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Outline

I. **Background**
II. **Methods**
III. **MEFA Results**
IV. **LCA Results**
V. **Assessment of toxicity**
VI. **SFA Results**
VII. **Conclusions**

Biochar

Biochar is the solid carbonaceous product obtained from the thermochemical conversion of biomass in an oxygen-limited environment.

Thermo-chemical conversion processes:

- Pyrolysis, gasification, torrefaction and hydrothermal conversion.

Biomass feedstocks:

- wood and wood wastes,
- agricultural wastes (e.g. rice husk, manure, straw)
- food waste
- wastewater sludge
- …

Biochar systems

Biochar production systems are multifunctional systems that can be used:

- biowaste treatment
- bioenergy production
- biochar production

Biochar applications:

- application to soils (carbon sequestration + soil amendment)
- biofuel
- adsorbent for water purification and wastewater treatment
- substitute for coke in metallurgical processes
- for developing novel specialty materials (e.g. carbon nanosheets)
- …

Biochar for soil remediation

Soil contamination:

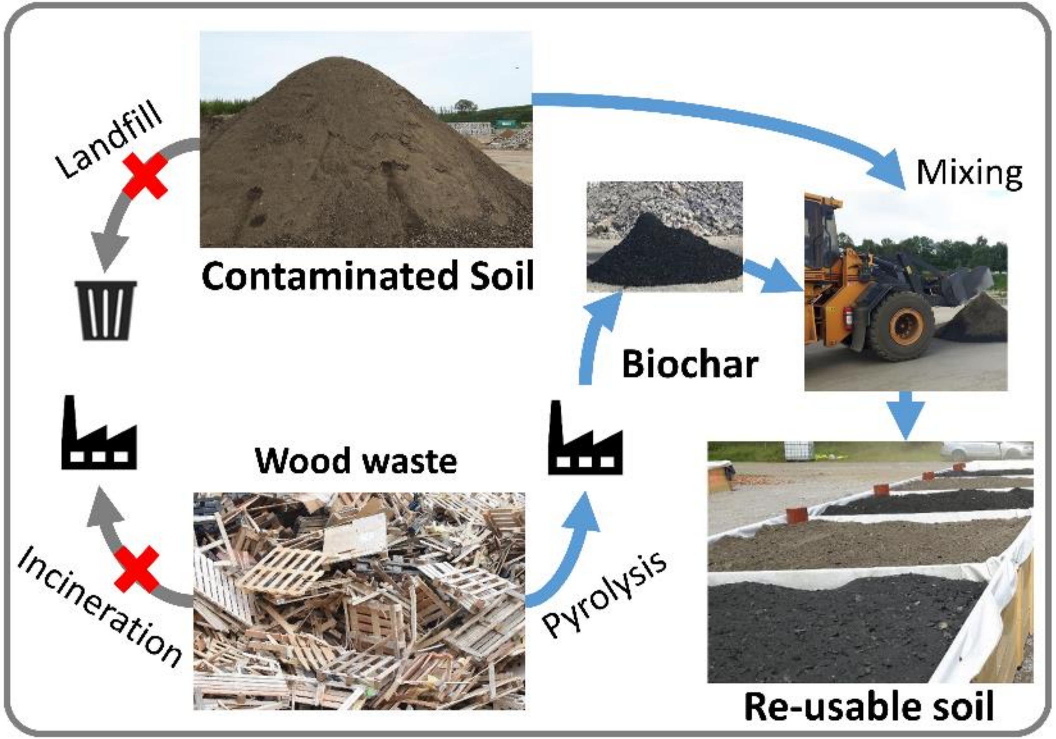
- 2.8 million potentially contaminated sites in EU-28
- 80,000 sites in Sweden
- Common handling technique: "dig and dump"

Source: Hodson (2010)

Biochar for remediation of contaminated soils:

- large sorption potential for organic (e.g. PAH) and inorganic (e.g. metals) substances
- porous structure, large surface area and cation exchange capacity
- the remediation effectiveness depends:
  - on the type and concentration of contaminants
  - the properties of the biochar determined by:
    - production conditions
    - type of feedstock

Biochar-RE:Source project



Biochar-RE:Source project

NSR waste site

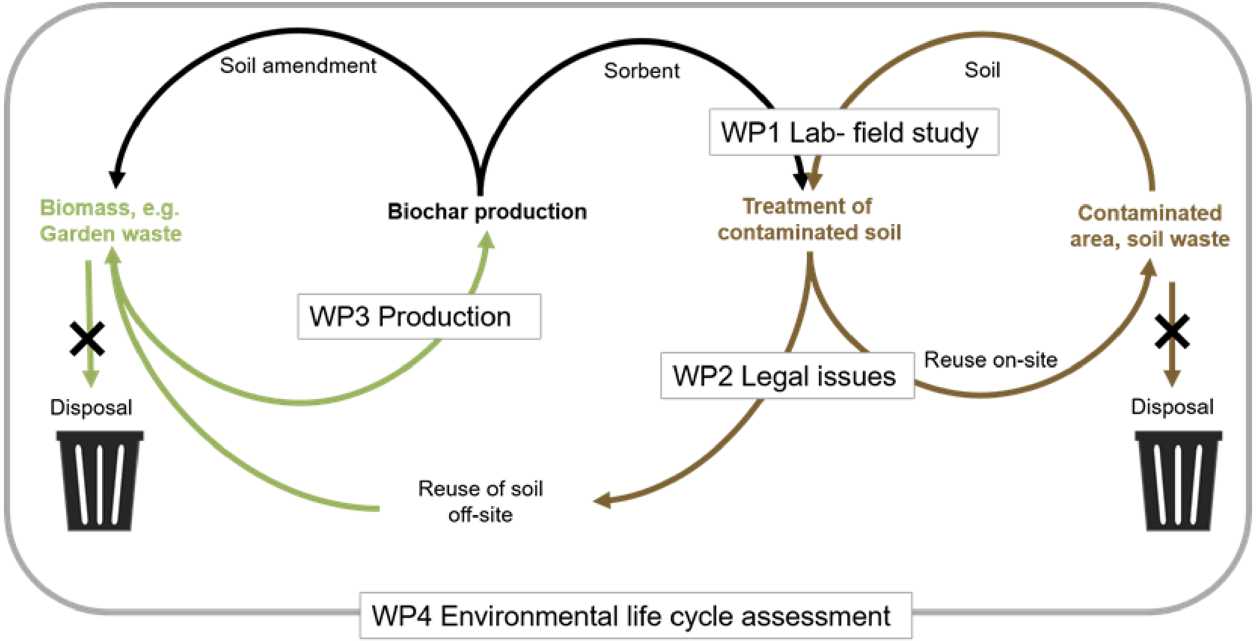
Source: Google (n.d.)

Biochar-RE:Source project

Source: Enell et al. (2020)

Biochar-RE:Source project

I. Background



Link: http://projects.swedgeo.se/biokol/index.php/publikationer-och-presentationer/

Aim

Aim: to assess the environmental impacts, from a life cycle perspective, of using biochar produced from wood waste to remediate soil contaminated with PAH, heavy metals and metalloids.

Two different options of soil remediation with biochar:

- on- site remediation
- off-site remediation.

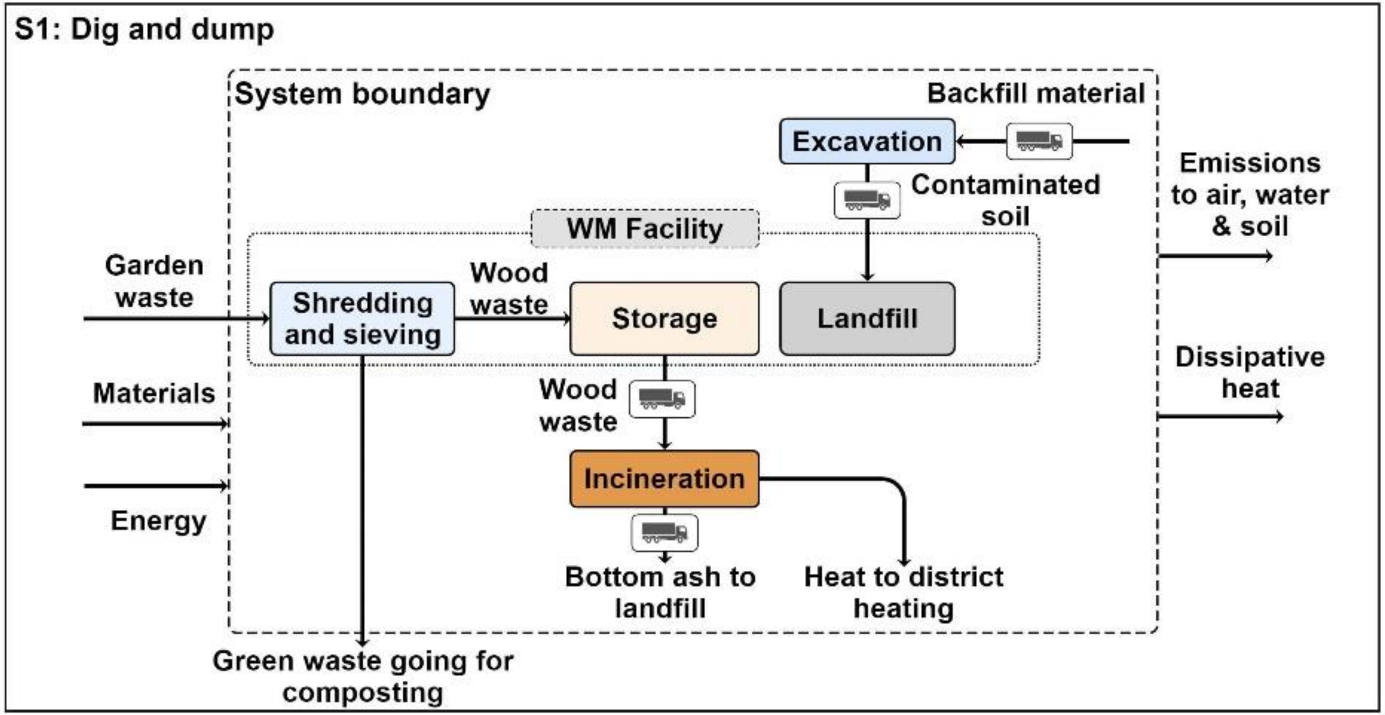
vs

- conventional "dig and dump" technique

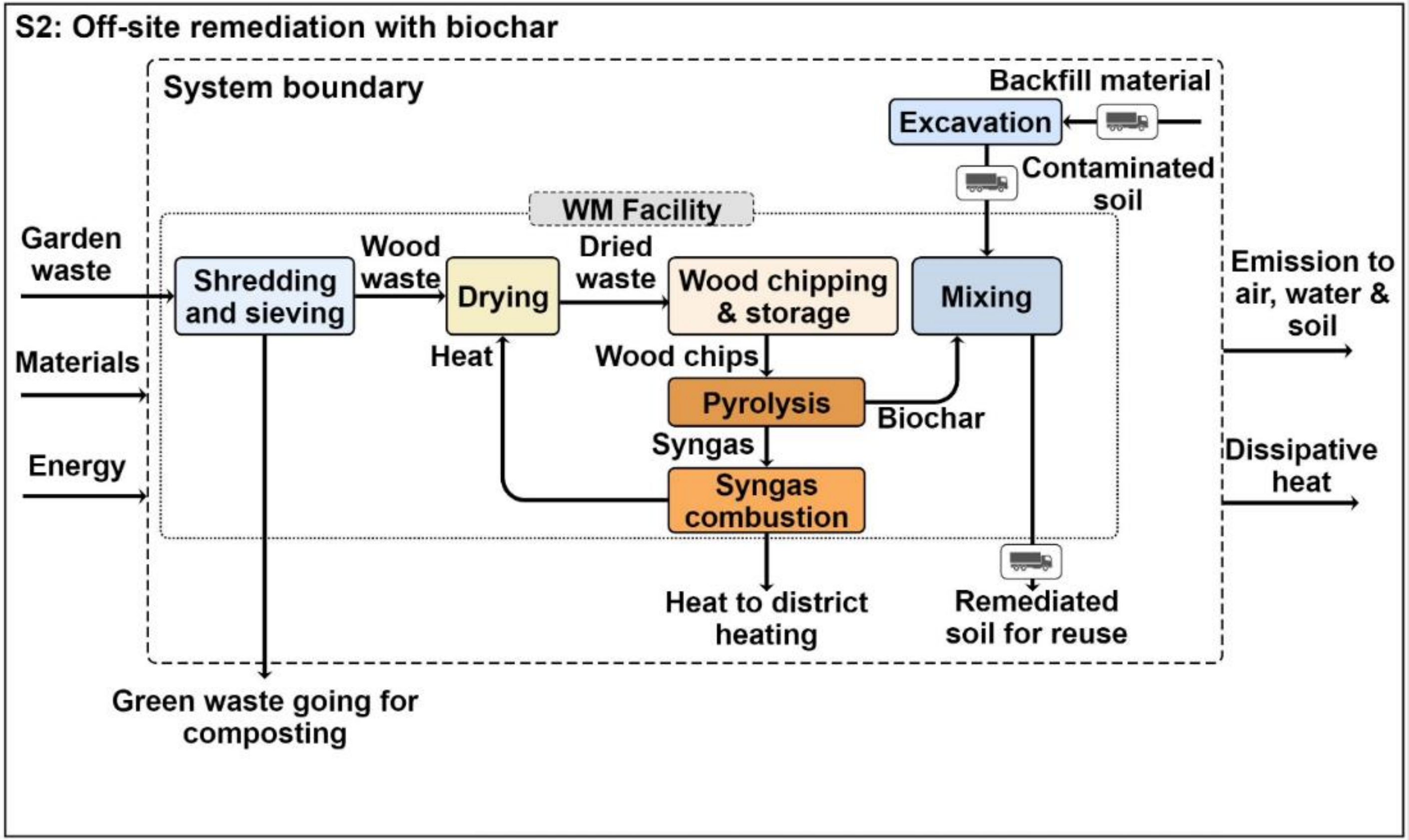
Methodological approach

- Material and Energy Flow Analysis.
- Life Cycle Assessment:
  - A comparative process-based LCA
- Substance Flow Analysis

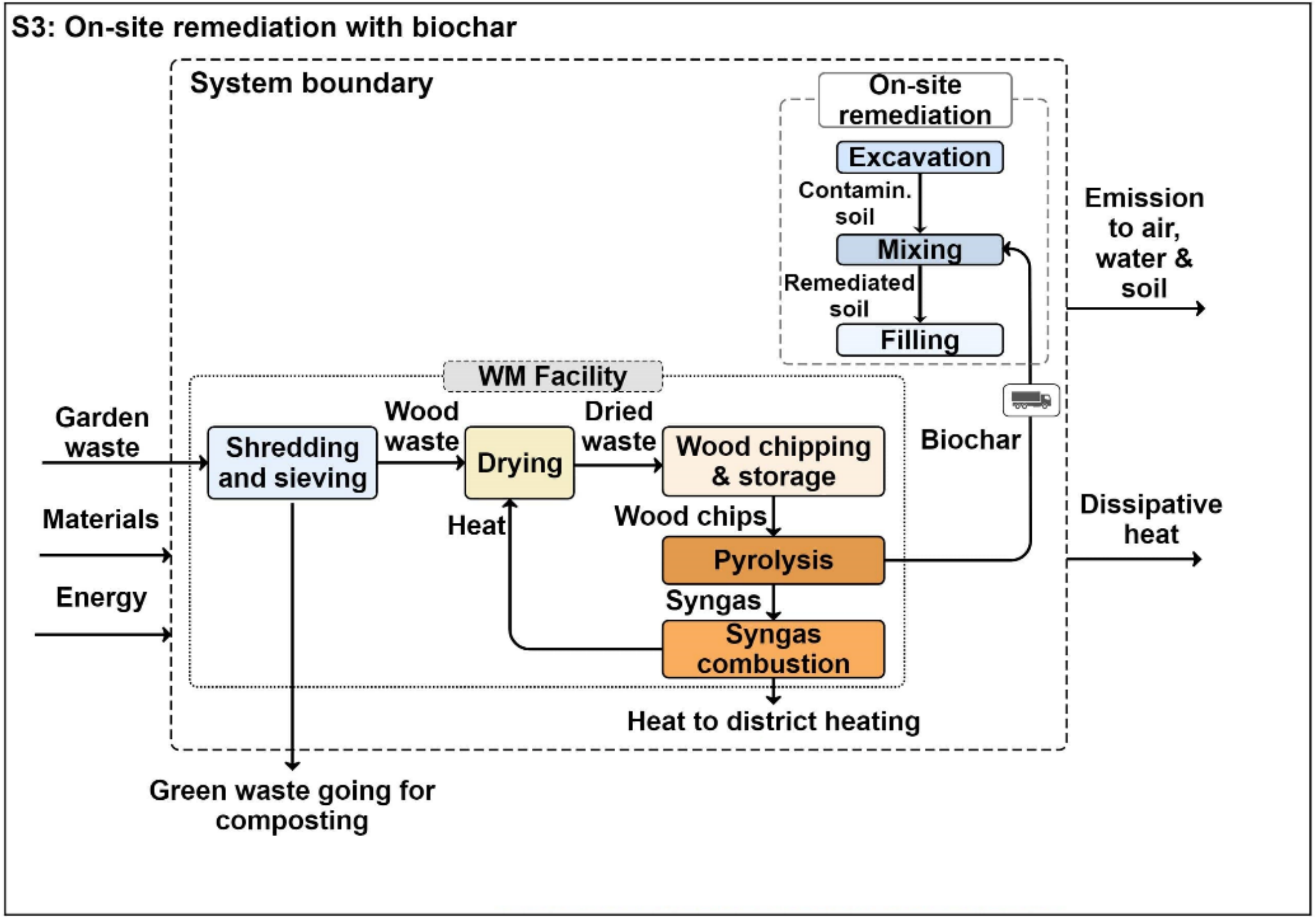
Scenarios


S1: Dig and dump
System boundary
Backfill material
Excavation
Contaminated soil
WM Facility
Garden waste
Shredding and sieving
Wood waste
Storage
Landfill
Emissions to air, water & soil
Materials
Wood waste
Dissipative heat
Energy
Incineration
Bottom ash to landfill
Heat to district heating
Green waste going for composting

Scenarios


S2: Off-site remediation with biochar
System boundary
Backfill material
Excavation
Contaminated soil
WM Facility
Garden waste
Wood waste
Dried waste
Shredding and sieving
Drying
Wood chipping & storage
Mixing
Materials
Heat
Wood chips
Pyrolysis
Biochar
Energy
Syngas
Syngas combustion
Emission to air, water & soil
Dissipative heat
Heat to district heating
Remediated soil for reuse
Green waste going for composting

Scenarios


S3: On-site remediation with biochar
System boundary
On-site remediation
Excavation
Contamin. soil
Mixing
Remediated soil
Filling
Emission to air, water & soil
WM Facility
Garden waste
Shredding and sieving
Wood waste
Drying
Dried waste
Wood chipping & storage
Biochar
Materials
Heat
Wood chips
Pyrolysis
Dissipative heat
Energy
Syngas
Syngas combustion
Heat to district heating
Green waste going for composting

LCA - Scope definition

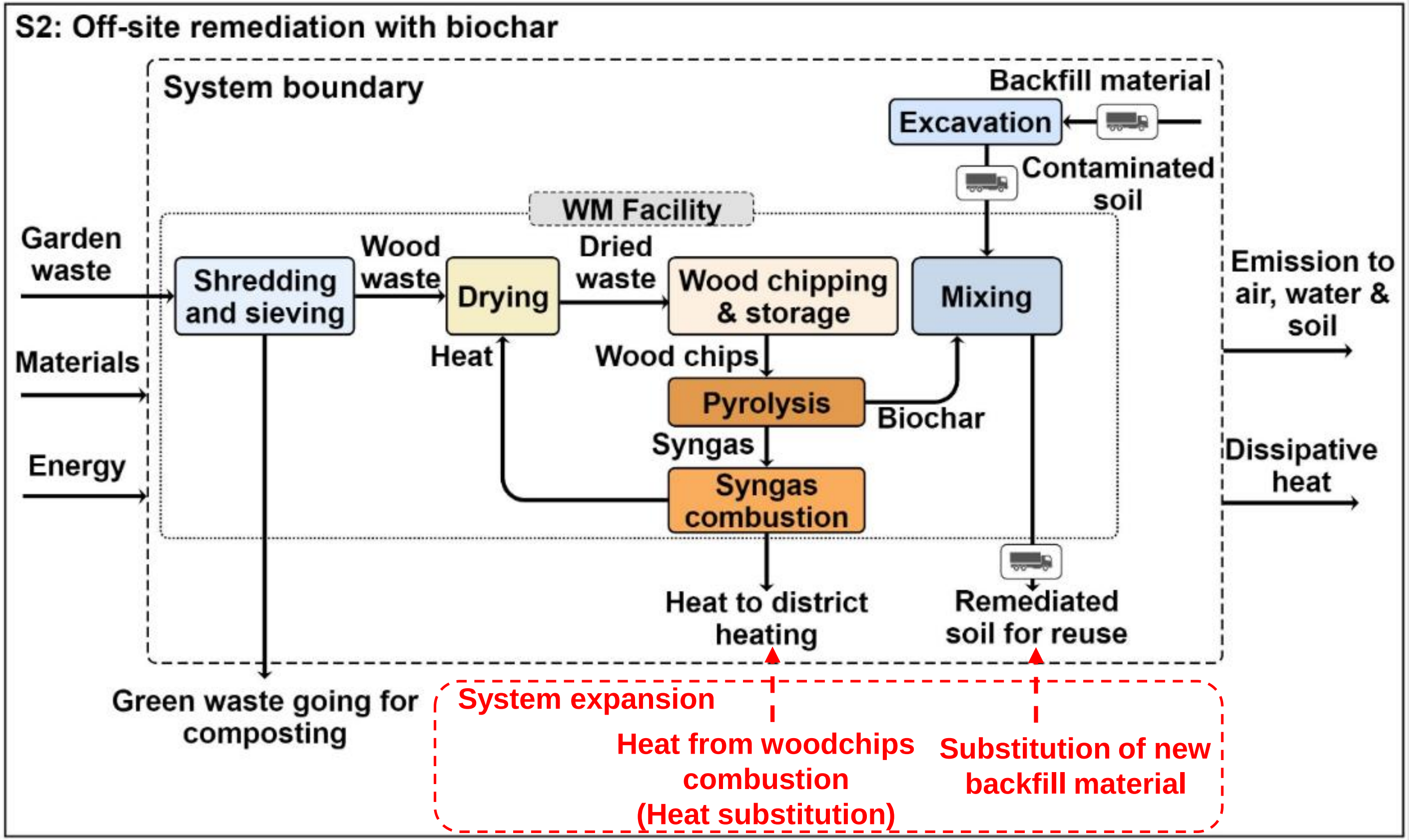
- Multi-functional systems:
  - Treatment of wood waste.
  - Production of heat for district heating.
  - Management of contaminated soil.

- Functional unit: 1 year of operation of the pyrolysis plant (800 kg/h dry wood, 1250 t/year biochar).
  - Treatment of 5,650 t of wood waste for district heating production (58,218 GJ of heat).
  - Management of 12,240 m^3 of lightly contaminated soil.

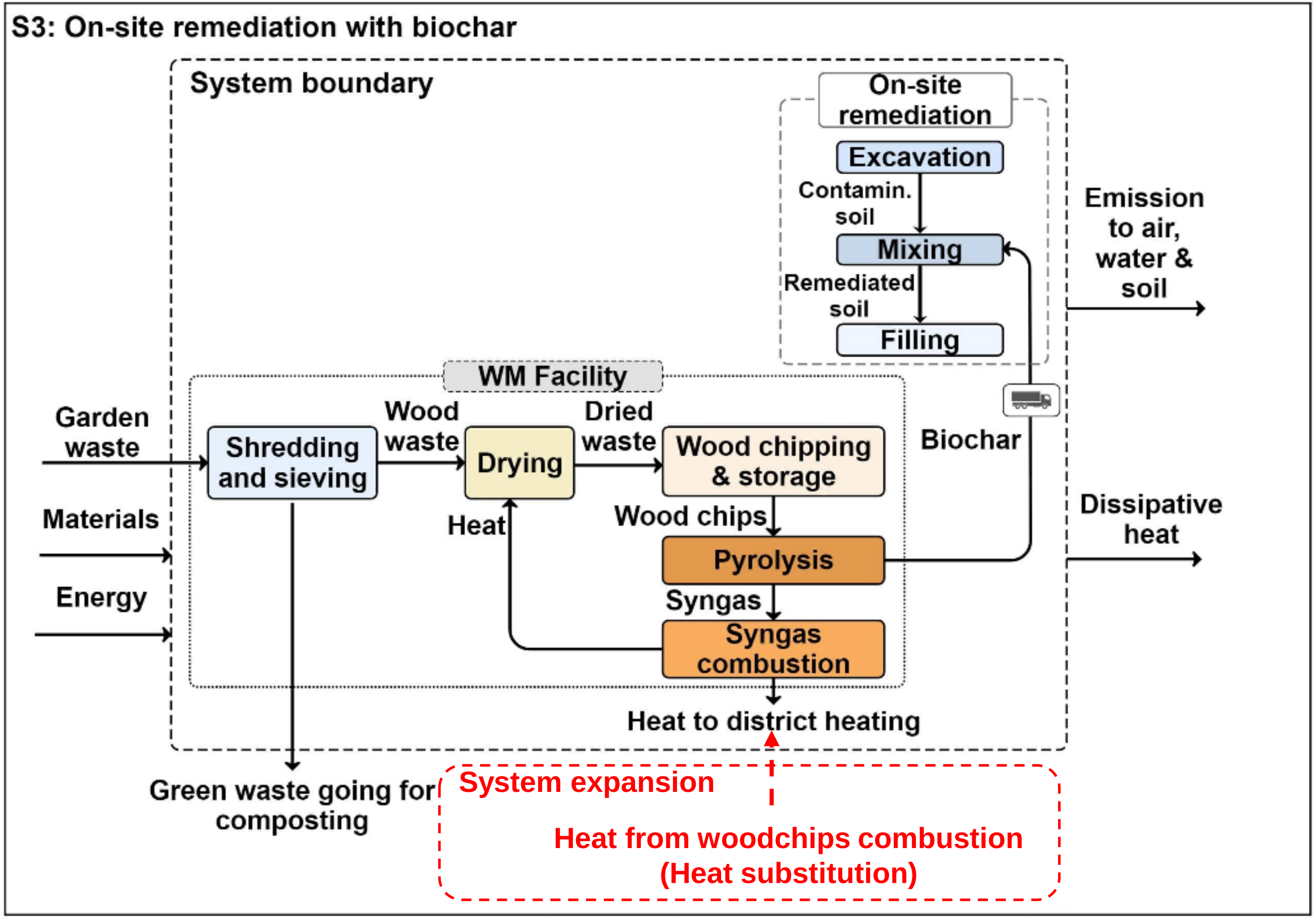
LCA - Scope definition

- Spatial boundaries:
  - Modelling based on the waste management site in Helsingborg.
  - Wood waste and contaminated soil from the area.
- Time boundaries: Annual
- Allocation: System expansion
- Impact assessment method: ILCD 2.0 midpoint (12 categories).

LCA - Scope definition

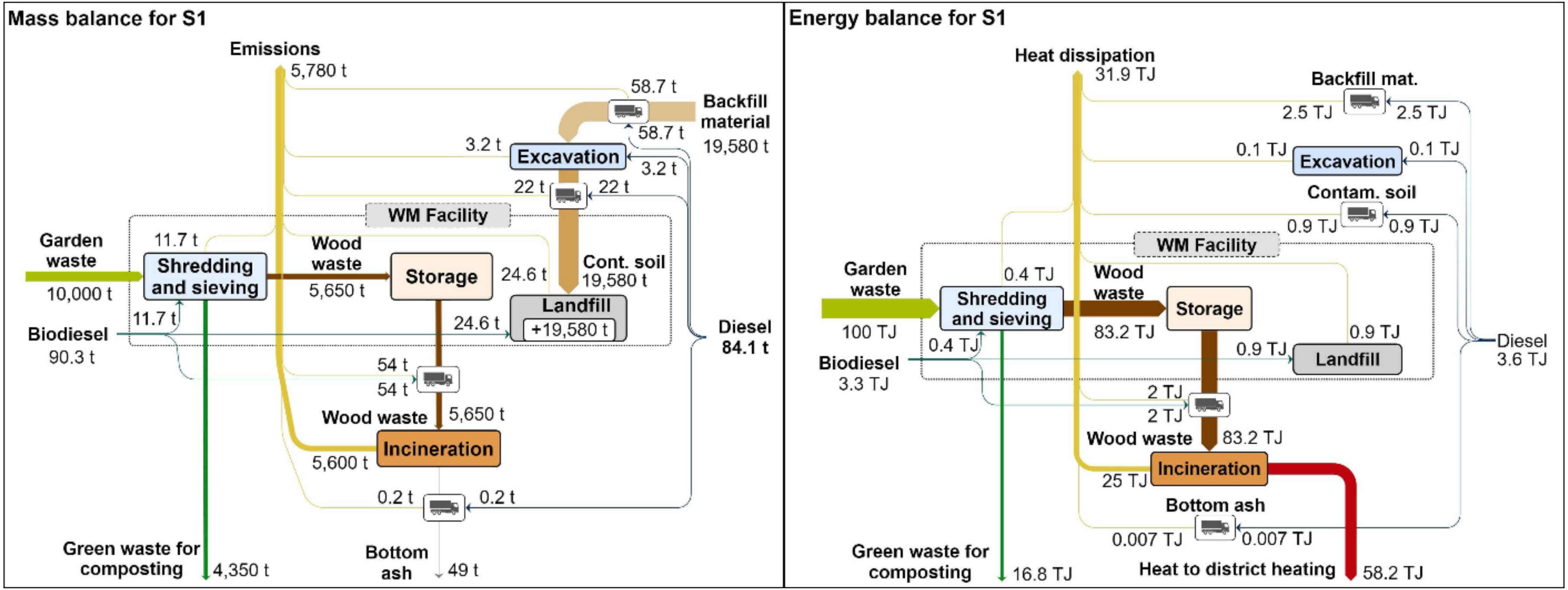


LCA - Scope definition



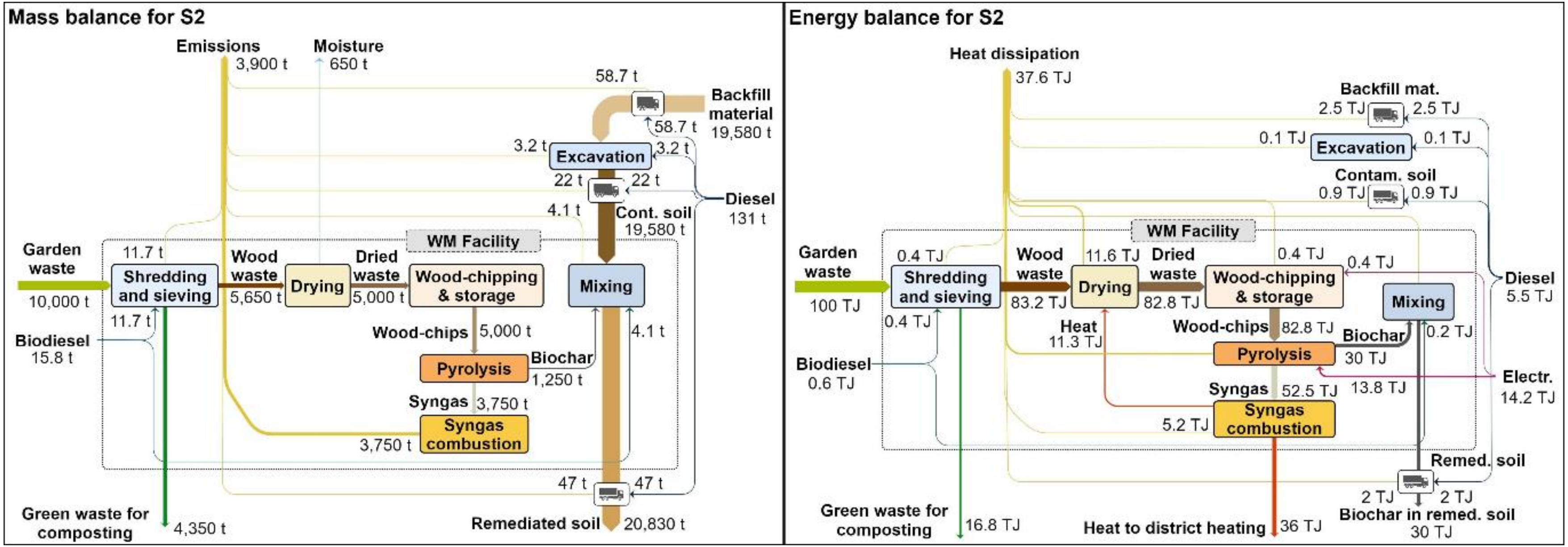
Mass and energy balances

S1: Dig and dump



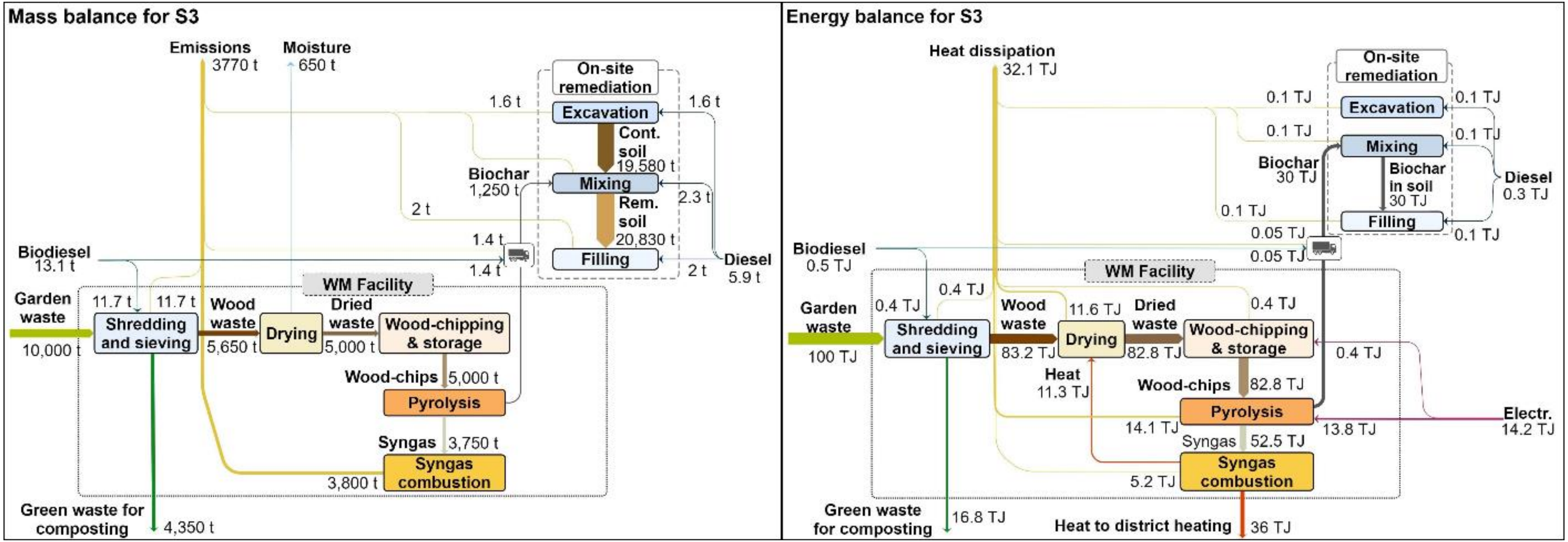
Mass and energy balances

S2: Off-site remediation with biochar



Mass and energy balances

S3: On-site remediation with biochar

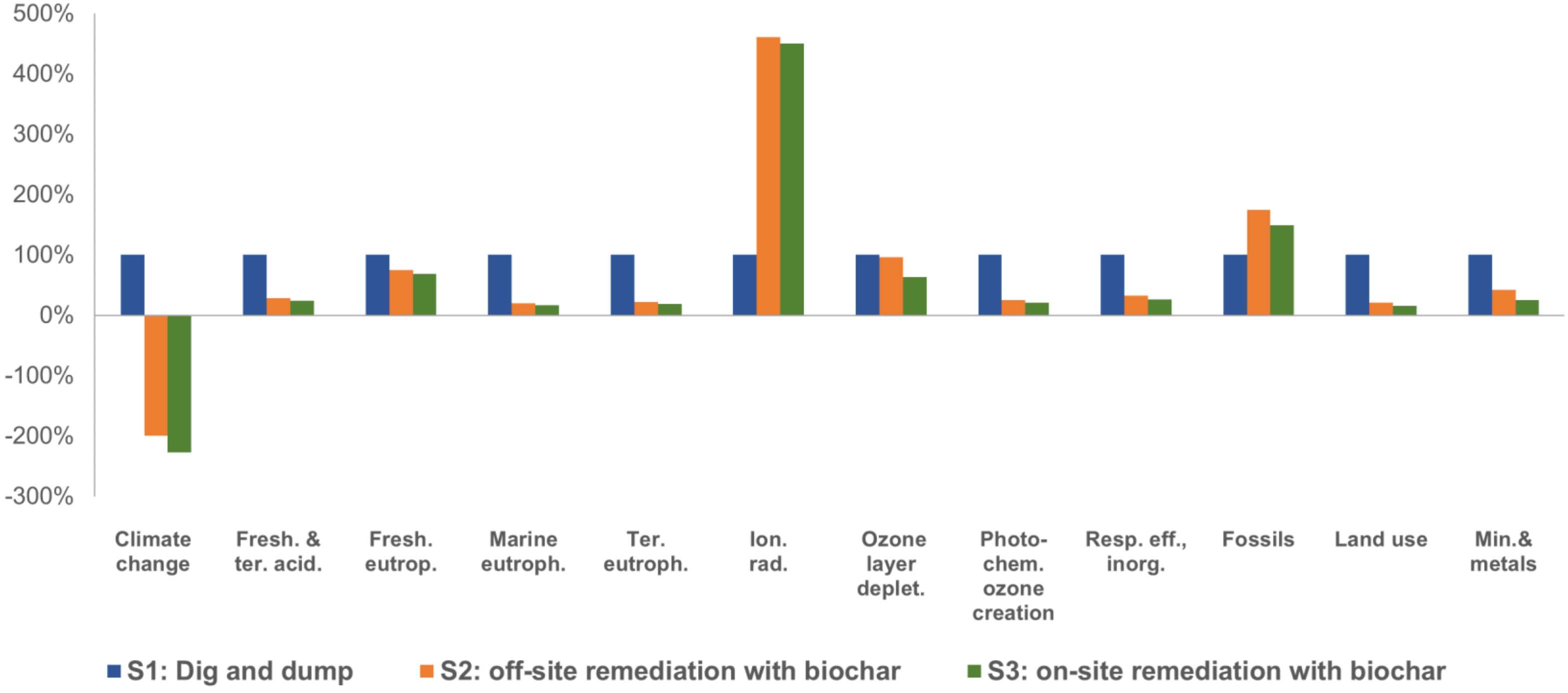


Main findings

- In S1 (dig and dump) and S2 (off-site remediation) there is increased consumption of fossil fuels due to transportation of materials (e.g. contaminated soil, inert material for backfilling)
- On-site remediation (S3) can provide fuel and inert material savings.
- Pyrolysis of wood waste for biochar production (in S2 and S3) generates less heat than incineration (38% lower) and requires a fair amount of auxiliary electricity.

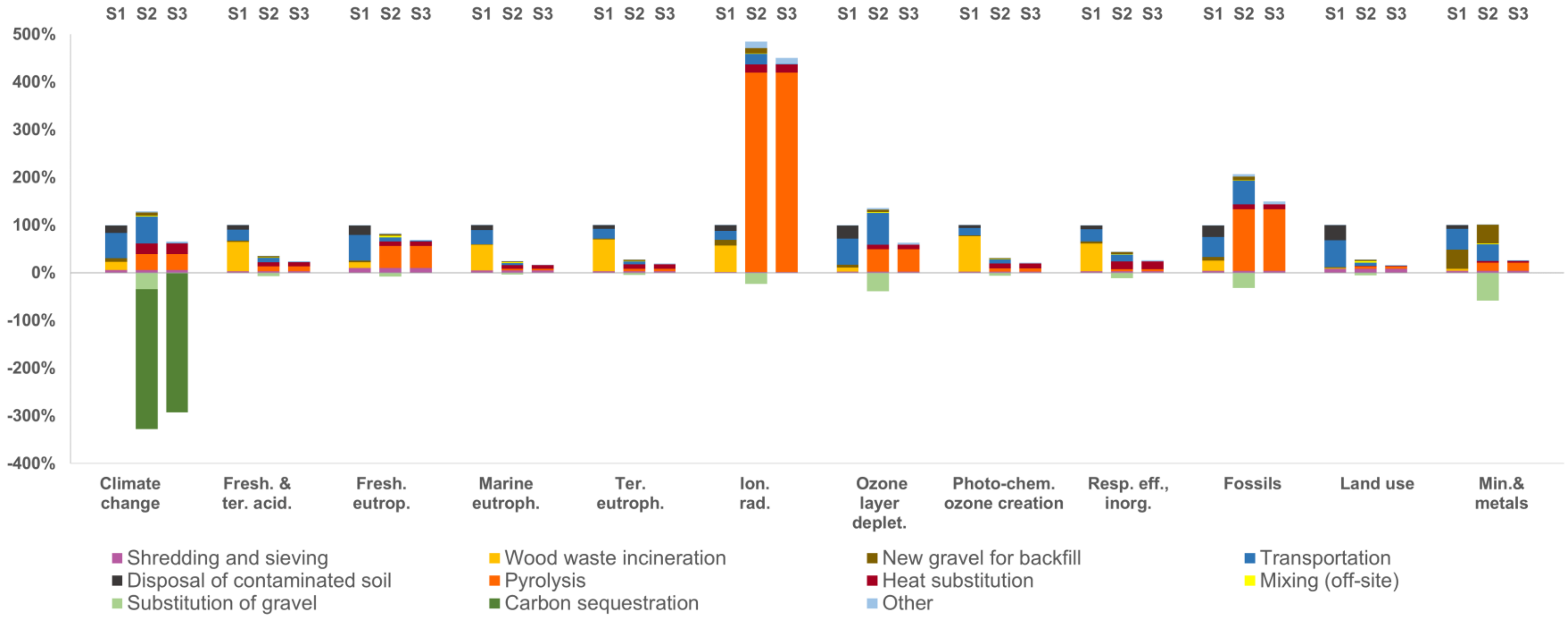
Environmental impacts

Environmental impacts of S2 and S3, normalized to S1 (S1=100%)



Environmental impacts

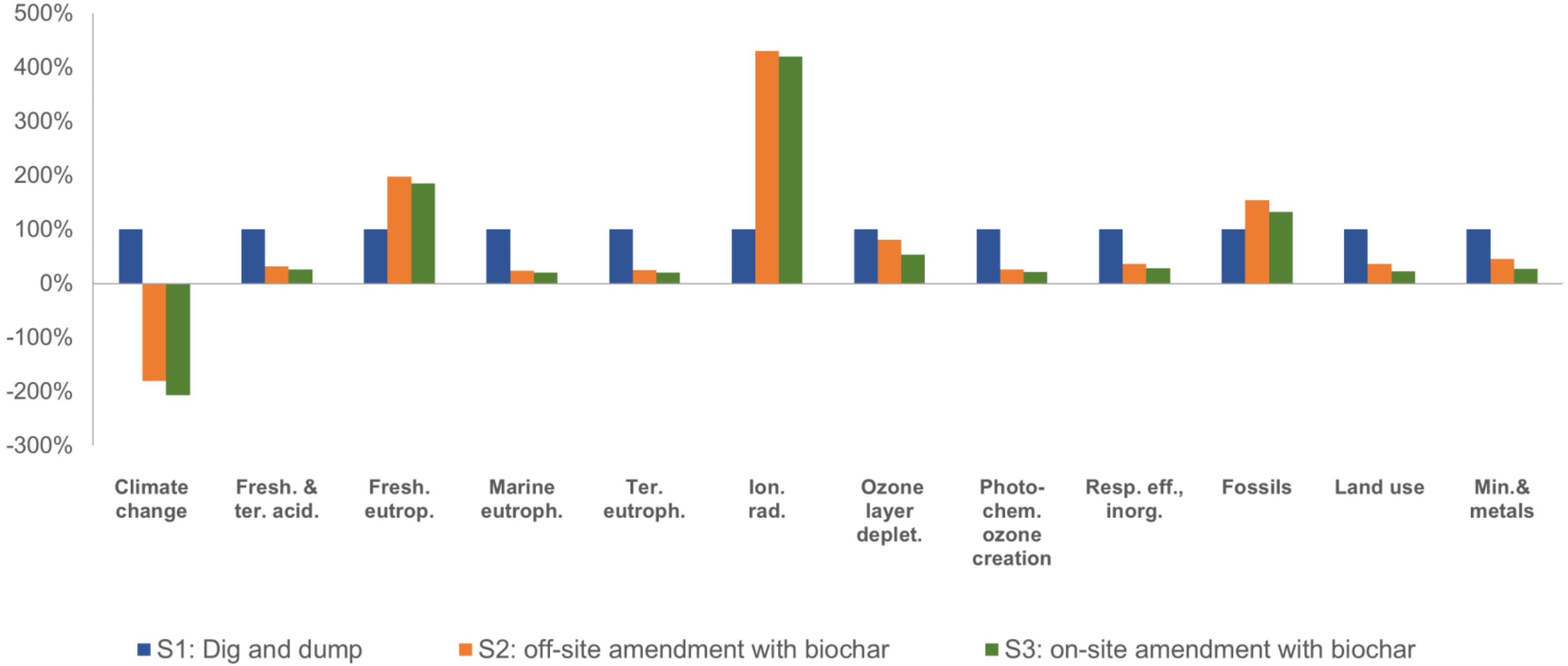
Process contribution



Environmental impacts of S2 and S3, normalized to S1 (S1=100%)

Environmental impacts

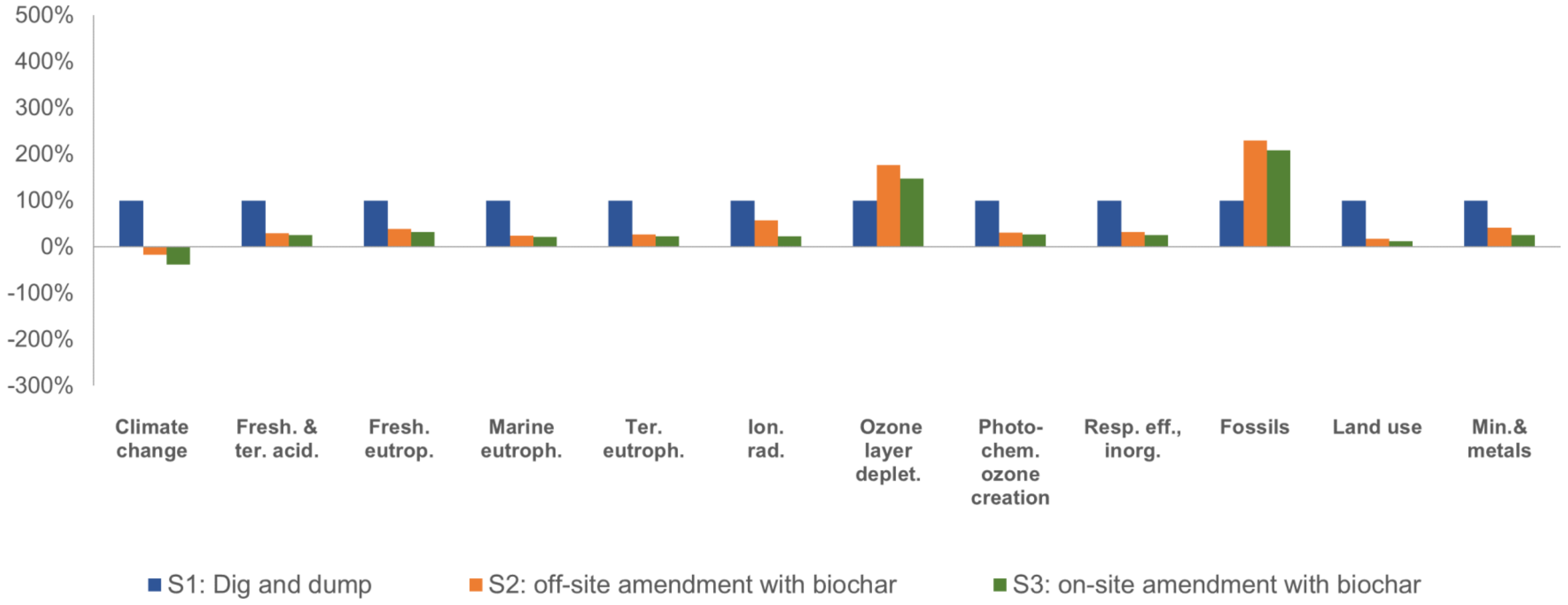
Sensitivity analysis 1: Fossil fuels instead of biodiesel



Environmental impacts of S2 and S3, normalized to S1 (S1=100%)

Environmental impacts

Sensitivity analysis 2: Fossil electricity



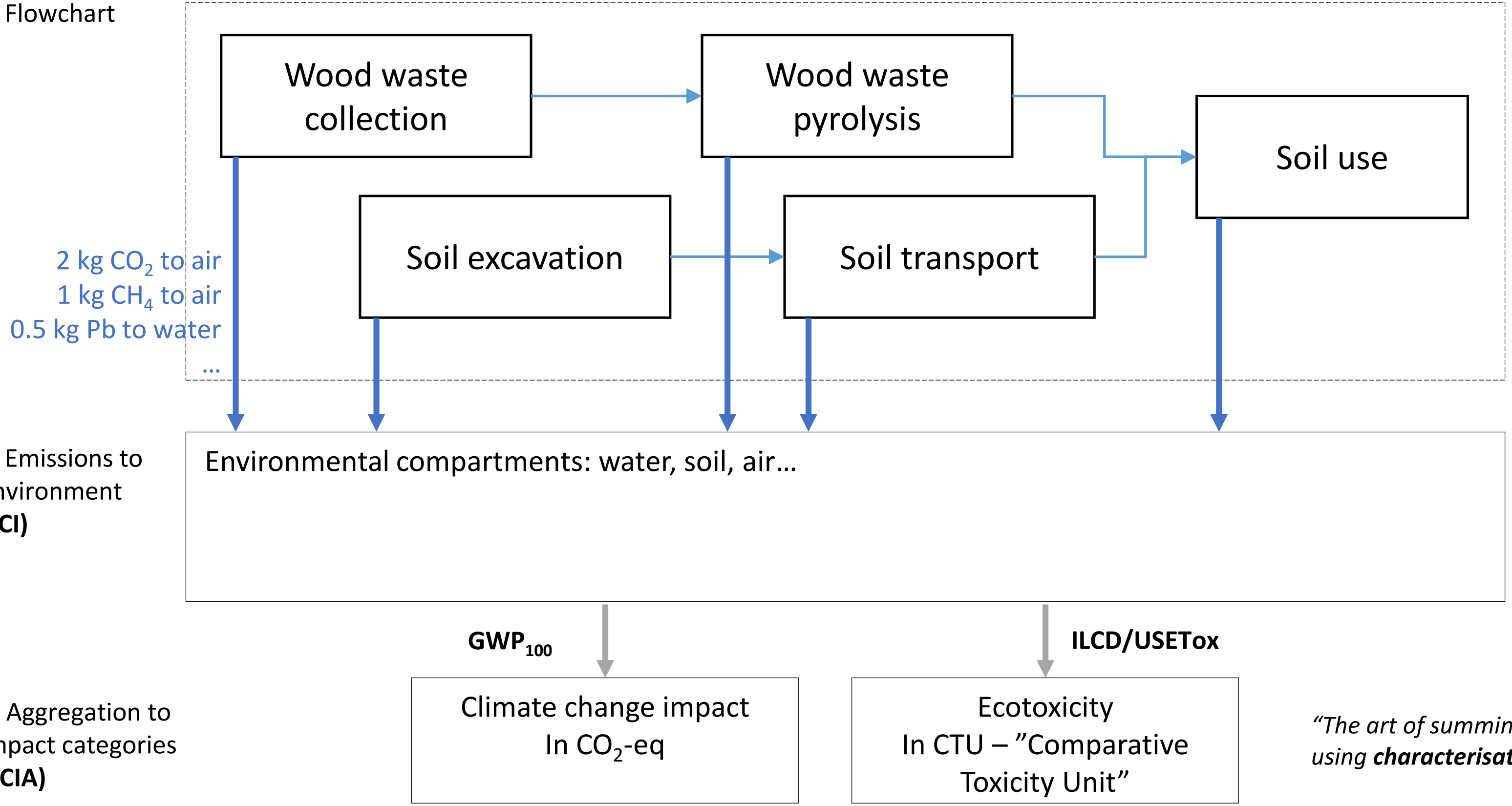
Environmental impacts of S2 and S3, normalized to S1 (S1=100%)

Toxicity.

1. Flowchart

2. Emissions to environment **(LCI)**

3. Aggregation to impact categories **(LCIA)**



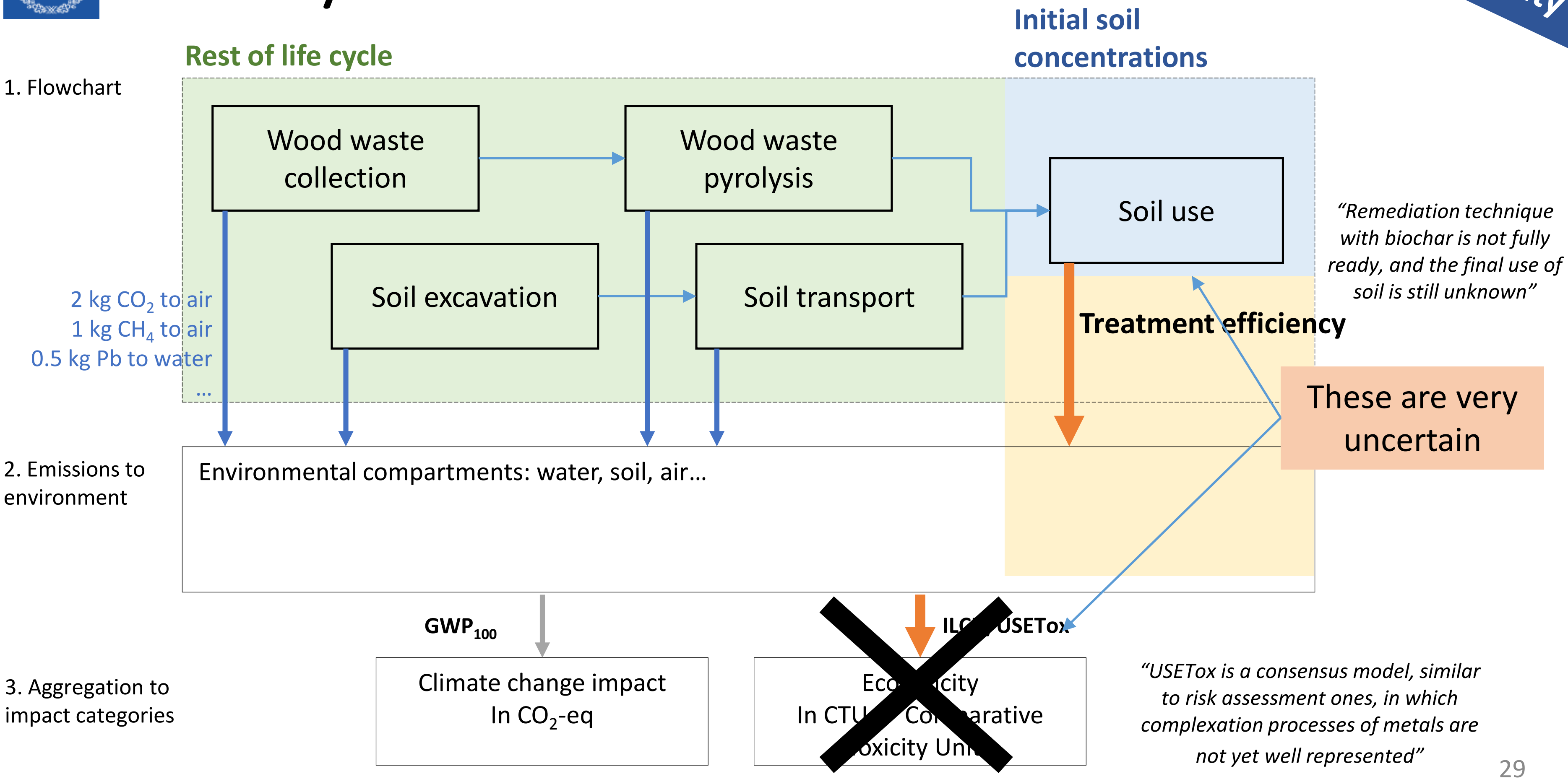
Functions provided:

- ✓ Waste treated
- ✓ Soil treated
- ✓ Heat produced

"A very long list of emissions"

*"The art of summing apples and pears using **characterisation factors**"*

Toxicity. But…



SFA

V. SFA

S1: Landfill

Rainwater
(30-80% infiltration depending on the top cover)

Landfilled soil

Collected leachate
(80% in the first 57 years, 0% afterwards)

Leachate treatment

Leached substances
(40%)

Leached substances
(20% in the first 57 years, 100% afterwards)

S2 and S3: biochar-remediated soil

Rainwater
(50% infiltration)

Remediated soil

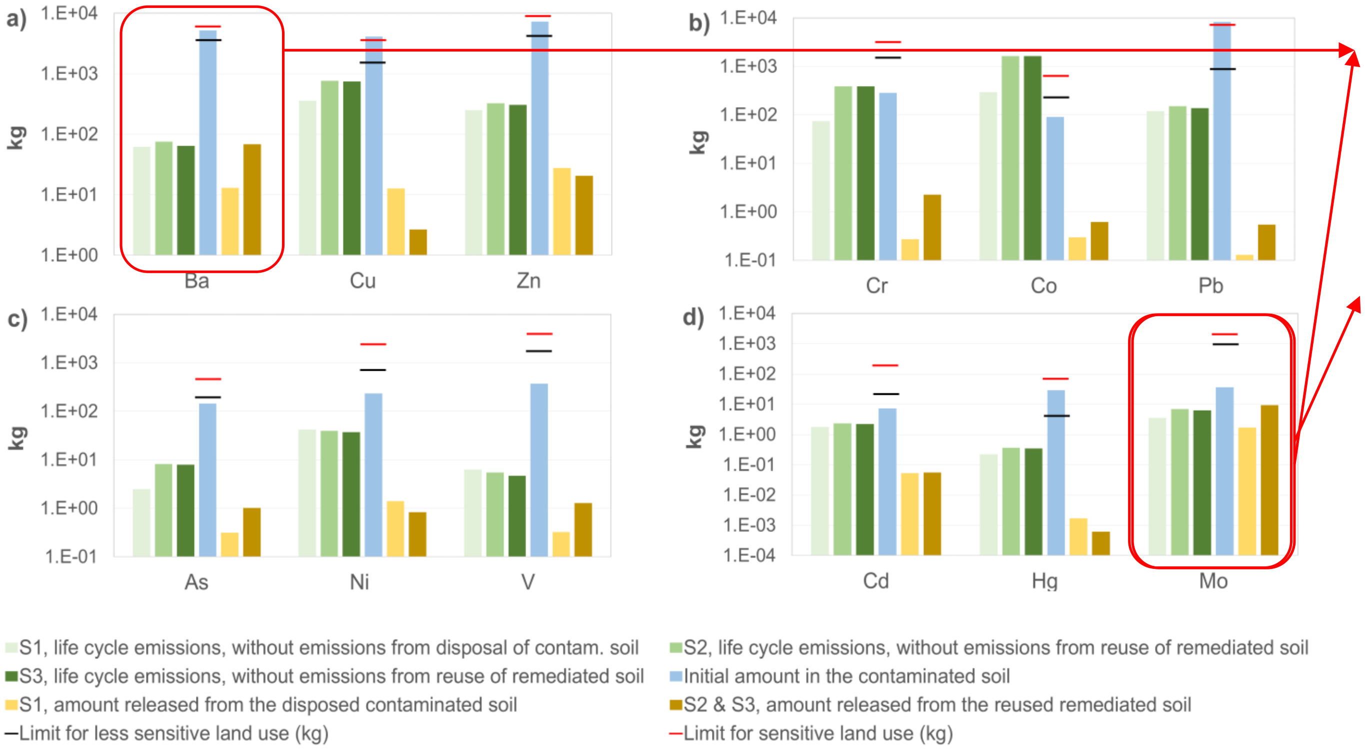
Leached substances

Data sources:
1) Field tests (lysimeters)
2) The Swedish Meteorological and Hydrological Institute

SFA

Rest of life cycle | Initial soil concentrations | Treatment efficiency

Metal(loid)s



Results of the SFA for metal(loid)s (in logarithmic scale)

The metal emissions from the landfilled or biochar-treated soil are significantly lower than the life-cycle emissions, except for Ba and Mo.

For most of the metal(loid)s (except Mo), only a small proportion (less than 1%) of their original content leaches into the soil.

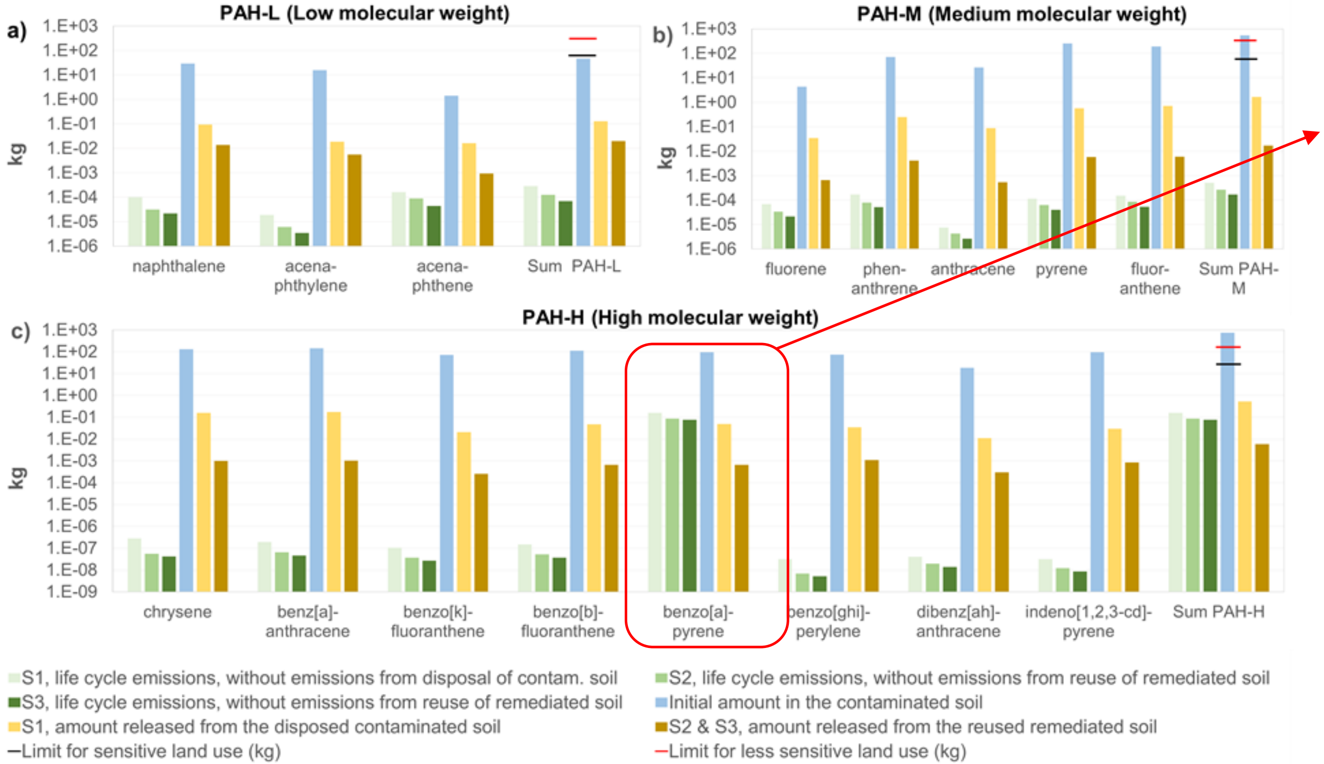
Smaller amounts of metals leach out from the biochar remediated soil for: Cu, Zn, Ni, Hg and Cd.

Higher amounts of metals leach out for: Ba, Cr, Co, Pb, As, V and Mo.

SFA

Rest of life cycle | Initial soil concentrations | Treatment efficiency

PAH



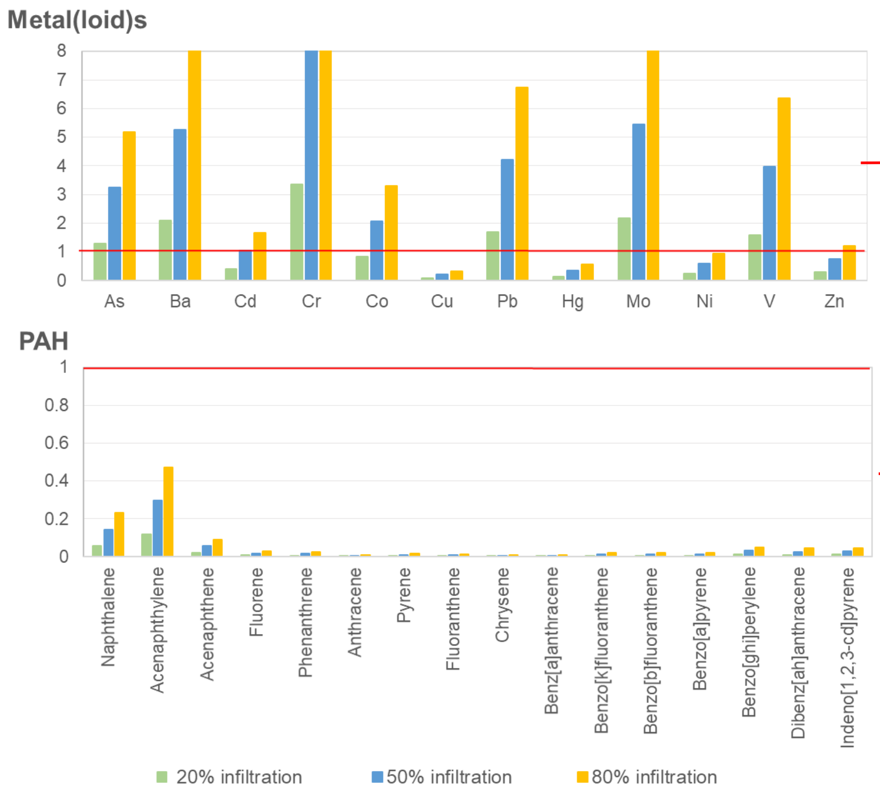
Emissions of PAHs from landfilled soil (S1) or treated soil (S2 and S3) are much higher than the life cycle emissions, except for benzo(a)pyrene.

PAH leaches out less from the biochar-treated soil than from the landfilled soil.

The amount of PAH that leaches out from both the landfilled soil and the treated soil is minimal compared to the total content of PAH in the soils.

Results of the SFA for PAH (in <u>logarithmic scale</u>)

Sensitivity analysis



The ratio of the amount of a substance leached from the remediated soil (S2 and S3) to the amount of the substance leached from the landfilled soil (S1), for different percentage of water infiltration in the remediated soil

For Cd, Co and Zn, the degree of infiltration determines whether the leached amount from the remediated soil is greater than that from landfilled soil.

For PAH, emissions from remediated soil are always significantly lower than emissions from landfilled soil, regardless of the assumption of rainwater infiltration.

Conclusions

- On-site remediation (S3) can provide fuel and inert material savings.
- On-site remediation (S3) has the lowest environmental impacts in almost all impact categories.
- Both off-site remediation (S2) and on-site remediation (S3) have negative climate change impacts thanks to carbon sequestration in biochar.
- Off-site remediation (S2) and on-site remediation (S3) perform worse than dig and dump (S1) only in:
  - ionising radiation
  - fossils

Conclusions

- The leaching of PAH from the remediated soil was lower than the landfilled soil, regardless of water infiltration level.
- For metal(loid)s, no straightforward conclusion could be made.
- In Sweden's current context, remediation with biochar is an environmentally promising alternative to "dig and dump".
- Further research is required to investigate the reuse of biochar-remediated soil.

Thank you for your attention!

Questions ?