BiOREST.
Life Cycle Assessment of the remediation model

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Strategie Green per la città de Futuro

BIORISANAMENTO DI SUOLI INQUINATI, RIDUZIONE DEL CONSUMO DI SUOLO
E USO SOSTENIBILE DELLE RISORSE

LIFE15 ENV/IT/000396

BIOREST

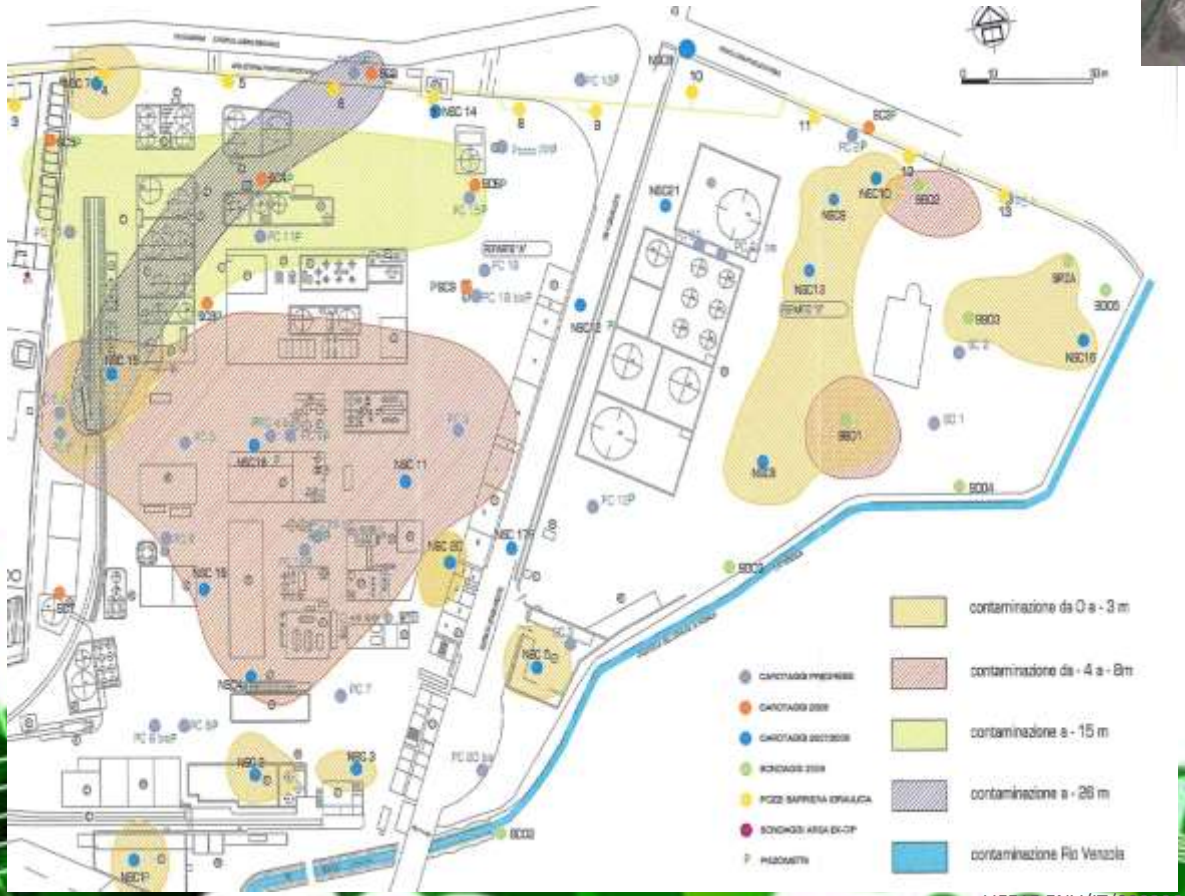
Bioremediation and revegetation to restor the public use of contaminated land

LIFE 2015 Environment and Resource efficiency

- **Total budget:** *1.710.267 €*
- **EC Contribution:** *968.274 €*
- **Duration:** *July 2016 – June 2019*
- **Coordination:** *Consorzio Italbiotec*
- **Associated beneficiaries:**
  Actygea Srl , ARPAE, CSIC,
  Università Cattolica del Sacro Cuore,
  Università degli Studi di Torino,
  SAAT GRAND-EST - WELIENCE

Testing site

Map of the polluted area



The bioaugmentation approach was tested in biopile in the Fidenza remedaton area

Were remediation activities based on biopiles, are currently on-going in this site, but they do not include bioaugmentation with selected microorganisms.

Testing area

LCA: Life Cycle Assessment

Life cycle assessment (LCA) is a multi-step procedure for calculating the environmental impact of a product or service.

LCA is now increasingly used to evaluate the environmental pros and cons of different options for the remediation of contaminated sites (Beames et al. 2015, Hauschild 2005, Toffoletto et al. 2005

It consists of tracking of all the flows in and out (inputs and outputs) of the system, including raw resources materials, energy, water, and emissions to air, water and soil by specific substance

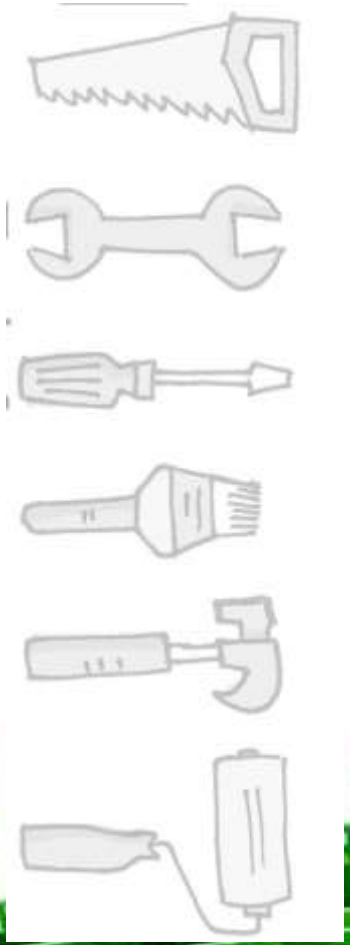
Environmental impacts: what they are and why they matter

The tragedy of the common: In economics is a situation in which several individuals use a common good for their own interests, but will not pay the cost

From the concept of common goods arises the need to quantify the use of environmental goods according to holistic approach

Hardin, G. (1968). "The Tragedy of the Commons". Science, 12(3859): 1243-1248.

What is LCA for ?



Describe an entire system in quantitative terms, according to a standardized structure

Identify hot spot and opportunities to reduce the burdens

Inform decision makers in industry, government, or nongovernmental organizations (e.g strategic planning, priority setting, and process design)

Outline the trade-offs of different decisions, mainly when different scenarios transfer burdens from one impact category to another

LCA for soil remediation

The net environmental consequences of remediation are not always a net positive achievement

The cost to the environment and human health in the form of increased greenhouse gas emissions, particle emissions, use of limited resources etc might outweigh the gain obtained by soil remediation.

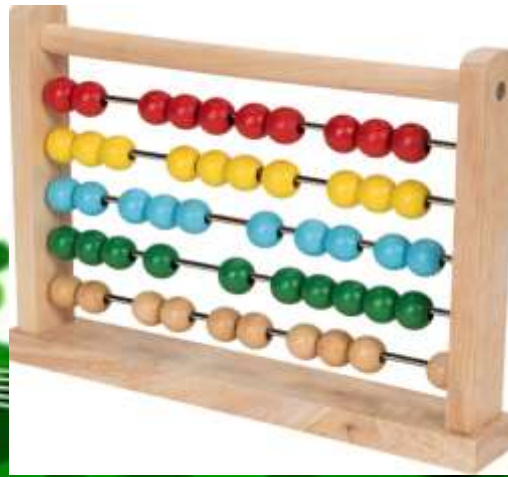
Specific priorities are to be set in order to deal the matter

LCA of soil remediation: what to account for?

primary impacts, local impacts related to the contamination of soil first, during and after remediation

secondary impacts, associated with the remediation process i.e. resource use and emissions arising in the remediation project

tertiary impacts, associated with the effects of the reoccupation of the site, thus accounting for the quality of the remediation process and the quality of delivered soil.



Primary impacts

ReCiPe method

Impact category	Unit
Human toxicity	kg 1,4-DB eq
Terrestrial ecotoxicity	kg 1,4-DB eq
Freshwater ecotoxicity	kg 1,4-DB eq
Marine ecotoxicity	kg 1,4-DB eq

USEtox

Impact category	Unit
Human toxicity, cancer	CTUh
Human toxicity, non-cancer	CTUh
Freshwater ecotoxicity	CTUe

Impacts related to toxicity to humans and the environment.

Unit in ReCiPe: toxic effects are expressed using the reference unit,

Kg 1,4-dichlorobenzene (1,4-DB) eq.

Unit in USEtox: comparative toxic unit.

Primary impact

Toxicity impact categories are

relatively young, not as robu

as classical LCA categories (e

Global Warming Potential)

Underestimation may occur

Secondary impacts

Numbers related to global and local effects raising from the remediation activity:

- Use of energy and fuels
- Use of chemicals and row materials

Recipe method

Impact category	Unit
Climate change	**kg CO2 eq**
Ozone depletion	**kg CFC-11 eq**
Terrestrial acidification	**kg SO2 eq**
Freshwater eutrophication	**kg P eq**
Marine eutrophication	**kg N eq**
Human toxicity	kg 1,4-DB eq
Photochemical oxidant formation	kg NMVOC
Particulate matter formation	kg PM10 eq
Terrestrial ecotoxicity	**kg 1,4-DB eq**
Freshwater ecotoxicity	**kg 1,4-DB eq**
Marine ecotoxicity	kg 1,4-DB eq
Ionising radiation	kBq U235 eq
Agricultural land occupation	m2a
Urban land occupation	m2a
Natural land transformation	m2
Water depletion	m3
Metal depletion	kg Fe eq
Fossil depletion	kg oil eq

Tertiary impacts

Numbers related to the use of soil before and after remediation

Accounts for the ecosystem services that will be restored by the remediation project

Recipe method

Impact category	Unit
Climate change	kg CO2 eq
Ozone depletion	kg CFC-11 eq
Terrestrial acidification	kg SO2 eq
Freshwater eutrophication	kg P eq
Marine eutrophication	kg N eq
Human toxicity	kg 1,4-DB eq
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Freshwater ecotoxicity	kg 1,4-DB eq
Marine ecotoxicity	kg 1,4-DB eq
Ionising radiation	kBq U235 eq
Agricultural land occupation	**m2a**
Urban land occupation	m2a
Natural land transformation	**m2**
Water depletion	m3
Metal depletion	kg Fe eq
Fossil depletion	kg oil eq

LCA.

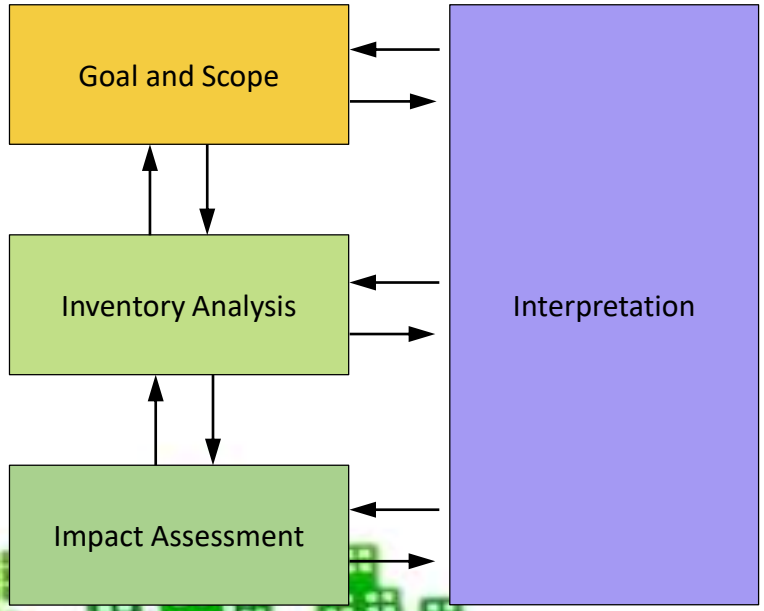
GLOBAL PERSPECTIVE

LCA studies the system as a whole, addresses and aggregates a large number of impacts on different geographical and temporal scales all toghether

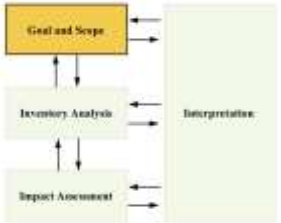
The LCA investigates global impacts and flattens the time scale

LCA provide a global frame of costs and benefits to compare scenarios, mainly when remediation scenarios are very demanding in term of energy and chemicals.

LCA phases


Goal and Scope
Inventory Analysis
Impact Assessment
Interpretation

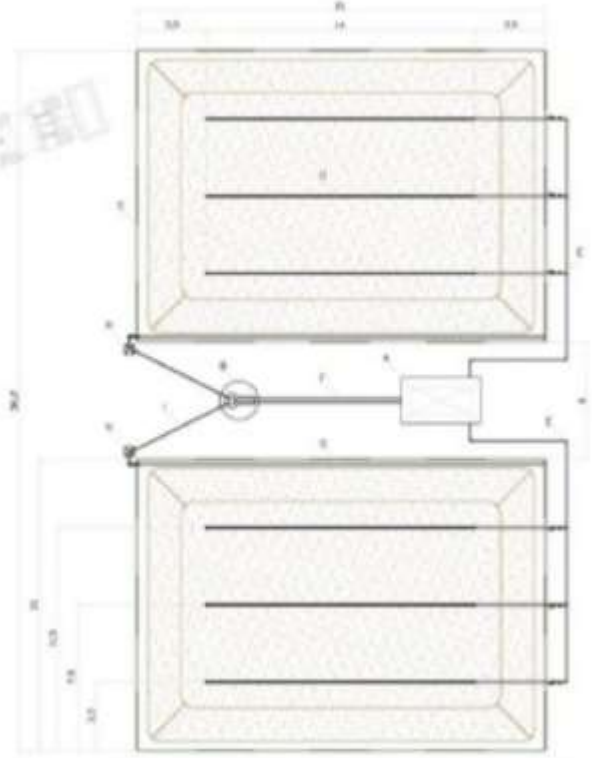
Functional unit



Functional unit in biorest is:

- **1 ton of soil, coming from 0 to 3 m depth**
- **Remediated up to the level provisioned in B table of Italian law**

Biorest System description



The biopile had a total volume of 400 m3 (ca 350 m3 of soil+ 50 m3 of mixed carrier material and inocula),

with an occupation of 315 m2 (21 m x 15 m) of field surface.

Hydrocarbons c>12	PAHs	Naphthalene	Benzene
(mg/kg s.s.)	(mg/kg s.s.)	(mg/kg s.s.)	(mg/kg s.s.)
1240	750	460	8

	sampling A	sampling B	sampling C
2-metilnaftalene	198	287	317
1-metilnaftalene	99.3	130	149
naftalene	178	288	301
acenaftilene	0.00	0.21	0.04
acenaftene	17.6	14.6	2.72
fluorene	12.0	7.5	6.13
fenantrene	36.8	26.5	37.4
antracene	3.16	2.66	2.76
fluorantene	13.6	7.87	13.7
pirene	12.1	5.95	11.0
benzo(a)antracene	2.18	0.69	1.84
crisene	3.28	2.07	2.79
benzo(b+j)fluorantene	1.86	0.89	1.40
benzo(k)fluorantene	1.06	0.53	0.89
benzo(a)pirene	0.45	0.17	0.22
indeno	0.43	0.31	0.33
dibenzo(ac+ah)antracene	0.14	0.08	0.10
benzo(ghi)perilene	0.67	0.38	0.47
dibenzo(al)pirene	0.00	0	0.00
dibenzo(ae)pirene	0.00	0	0.00
dibenzo(ai)pirene	0.00	0	0.00
dibenzo(ah)pirene	0.00	0	0.00
total_25_37	22.2	11.1	18.9
total_25_34	9.50	4.7	7.60
C>12	273	298	349

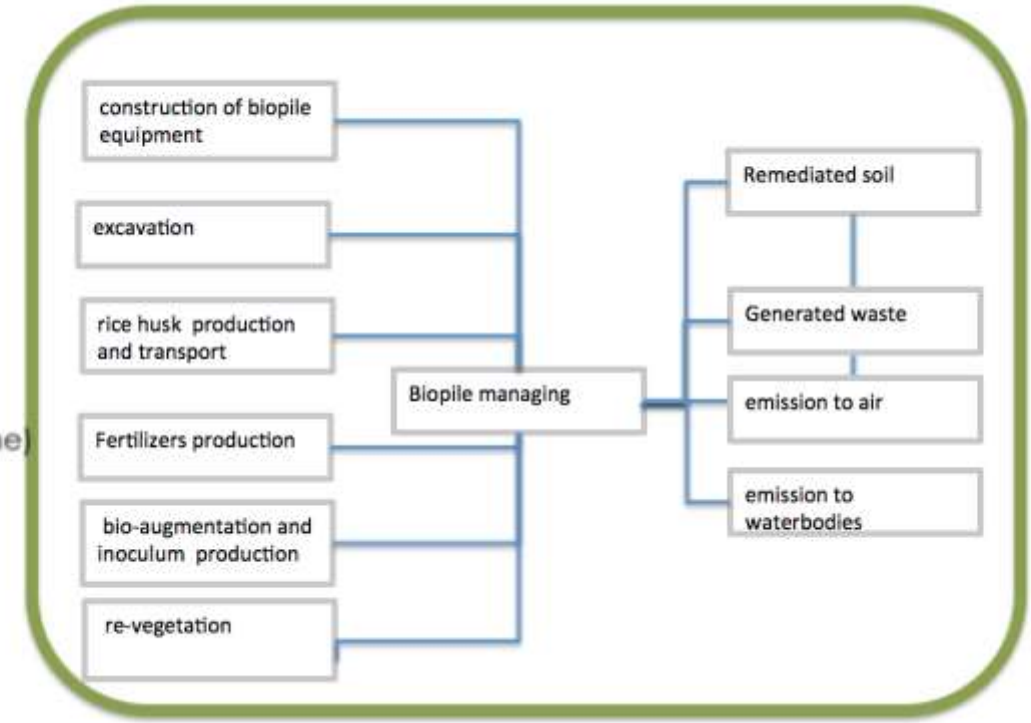
Biorest System Boundaries

Input

Water use
Land occupation
Row materials

Electricity
Fuel (operating machine)
Building materials

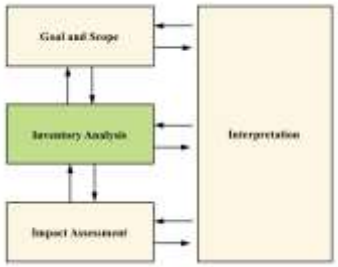
Chemicals



Output

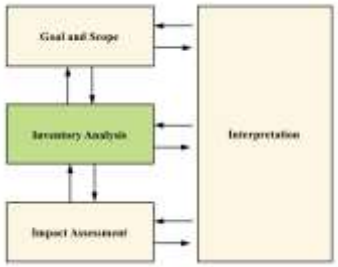
Products (bioremediated soil)
Emission to air
Emission to soil
Emission to water
Solid wastes
Other releases

Inventory



Parameter	Unit	Amount for 1 cycle of biopile process	Source of data
Hydrocarbons amount at site	mg/kg TS		As detected in sample at time 0
Hydrocarbons amount after remediation	mg/kg TS		Legal limits considered
Soil treated in a biopile	ton	2100	Management data
time of treatment	days	90	-
Cycle of treatment in one year performed in the structure	n	3	
Biopile equipment, lifetime	years	3	
Surface of soil involved in the remediation operation for each biopile -urban industrial	m2	875	soil exavated at 2m deep for remediation
Surface of soil used for the remediation **(soil on which biopile insist)**-urban industrial unoccupied	m2	1357	
Transformation			
Destination of soil use: urban industrial occupied (ecoinvent)	m2	2232	
High of biopile	m	1.3	
High of soil involved in the remediation (deep)	m	2	assumption (average)
Biopile structure			
HDPE basement and vessel	kg	15600	
HDPE pipe for water drainage	kg	900	
Total HDPE	kg	16500	
Steel (equipment/pumps)	kg	100	
Average distance for supply	km	60	
Biopile running			
Diesel consumed for excavation in site and biopile production	kg	1000	
Electricity consumed in the entire cycle	kwh	11000	
Water added to biopile	kg	3000	
Rice husk added (10-12% in volume of soil)	kg	17500	
Nitrogen fertilizer added	kg	1120	
P fertilizer added	kg	480	

Inventory



Bio-augmentation process, inoculum production (for at least 100 bio-pile)			
Lab selection			
Fuel for soil sampling operation: 600 km (return travel with small vehicle)	km	600	
Economic allocation of microbial selection on the lab activity	%	5%	
Electricity for lab maintenance (economic allocation)	kwh/year	43200	
Gas for lab maintenance (economic allocation)	m3/year	2000	
Inoculum production, industrial scale			
Fermenter production capacity	liter	200	
Heat needed for fermenter (gas to keep 25 degree for 3 days) methane gas	m3	2	
Electricity to produce industrial inoculum	kwh	216	
Amount of inoculum needed for 1 biopile	l/bipile	2	
Primary impacts			
HC Emission to water body	% of total	2.2-4.6%	Site data, and dispersion model

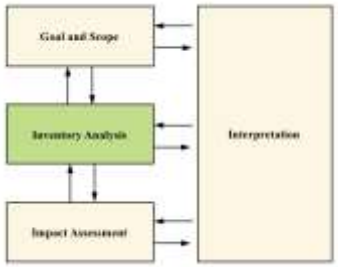
Inventory
Emission to air

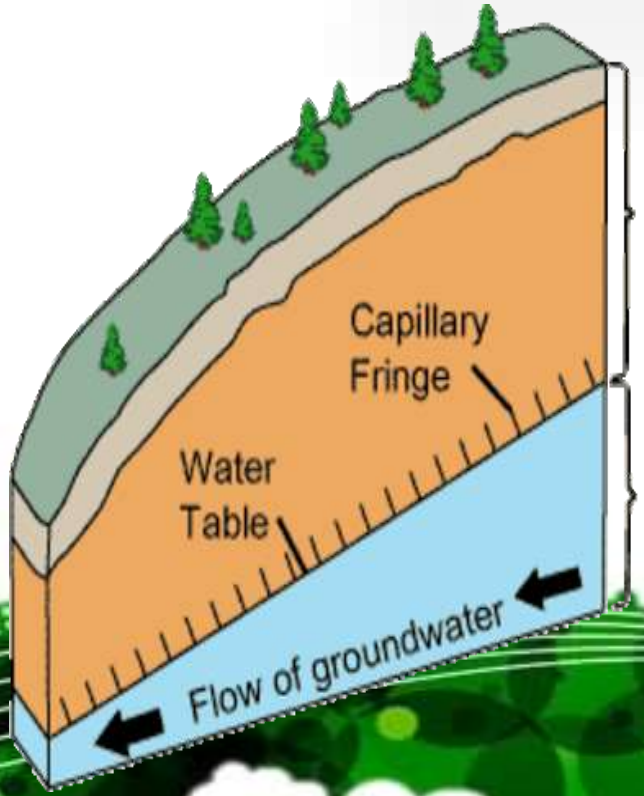
Air emission
Little information is available regarding the emission of HCs from bioremediation sites.

In the reference process the treatment is performed in bio-pile in closed vessel under depression and all the air is treated by carbon filters prior to discharge.

Thus the only possible emission to air refers to the excavation phase and is assumed to be negligible.

Inventory
Emission to waterbodies





The extent of pollutants that might be transferred to the groundwater can be modelled by

- site specific data during time , in situ investigation in the transition area from the unsaturated to the saturated zone,
- model calculations.

Land use and time

Without remediation it is assumed that the soil is unavailable for use at least for 50 years

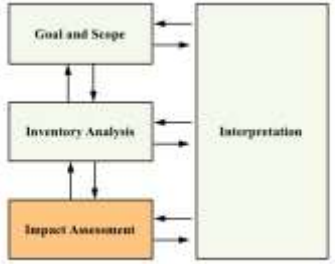
Two mechanisms of land-use in the Ecoinvent db

The occupation of land area used * by years of occupation.

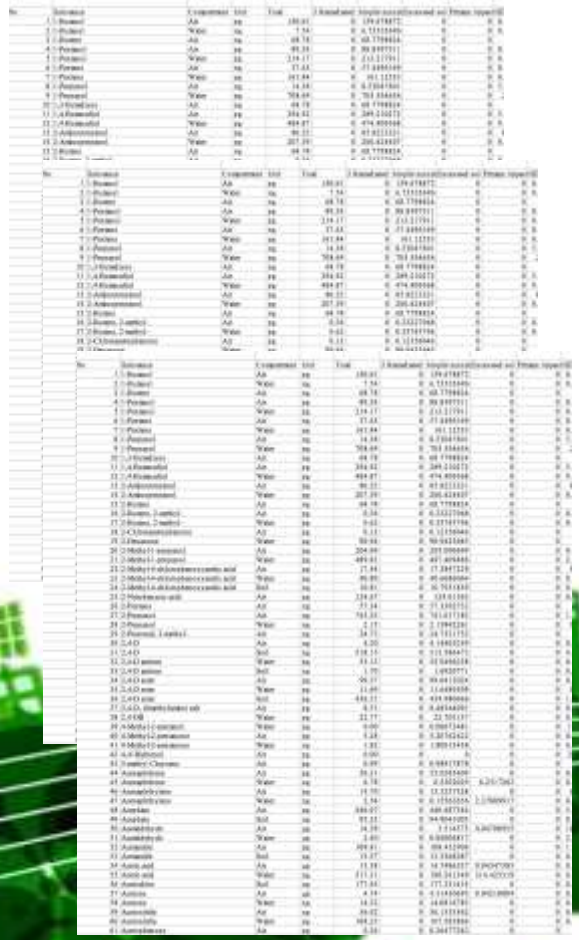
accounts for the duration of surface area made unavailable.

The transformation of land refers to the different types of land-use areas converted in the life cycle.

Impact assessment



PROVIDING MEANING TO THE NUMBERS…..



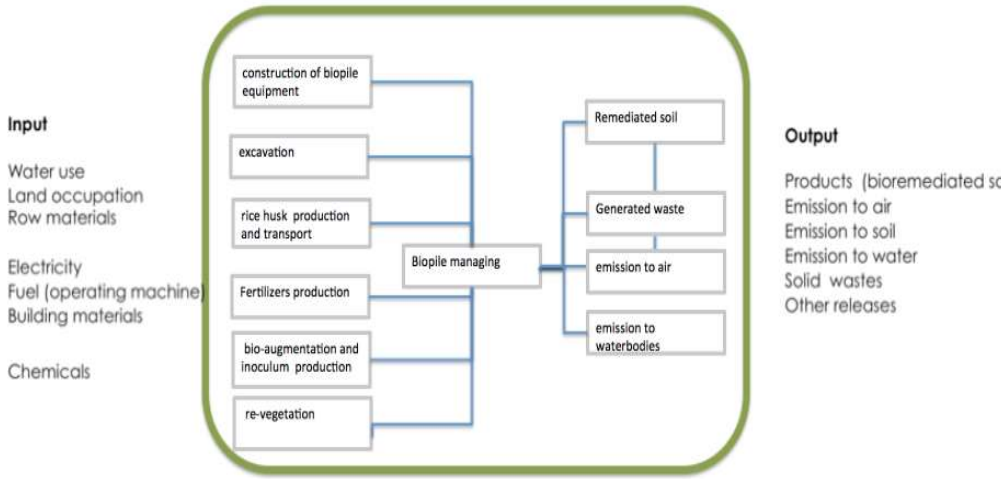
An inventory analysis provides information on all relevant energy and material inputs, and on the emission of toxic and non-toxic pollutants, but that alone does not provide enough information to guide decision-making.

To be able to understand the consequences of these inputs and emissions, we need to translate them into environmental impacts.

The impact assessment phase provides this translation.

Impact assessment

System



Substances inventory

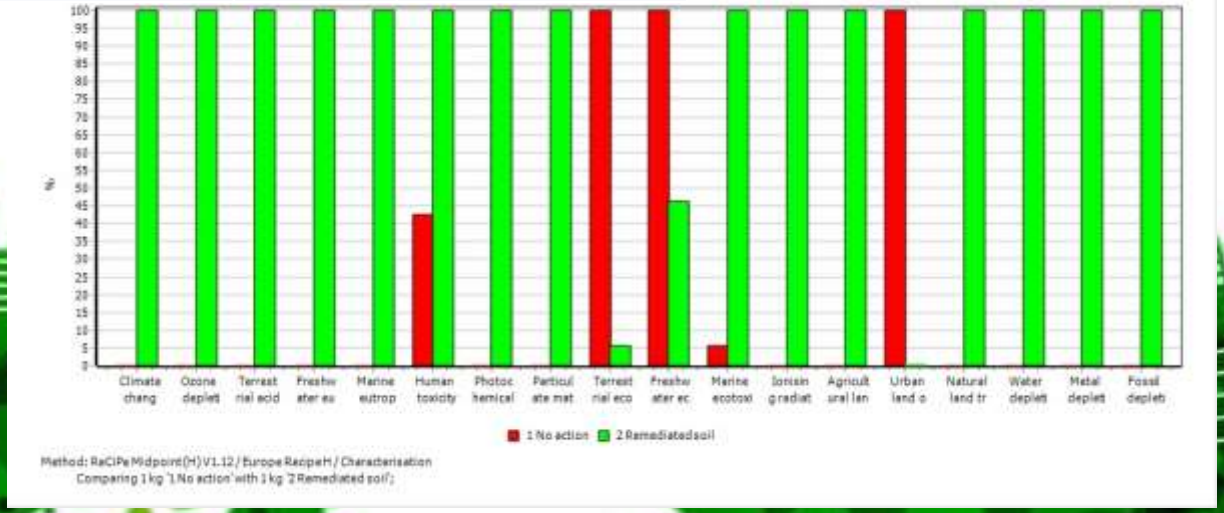
Raw Materials
Land use
CO^2
VOC
P
SO^2
NO_x
CFC
PAH
DDT

Impact categories

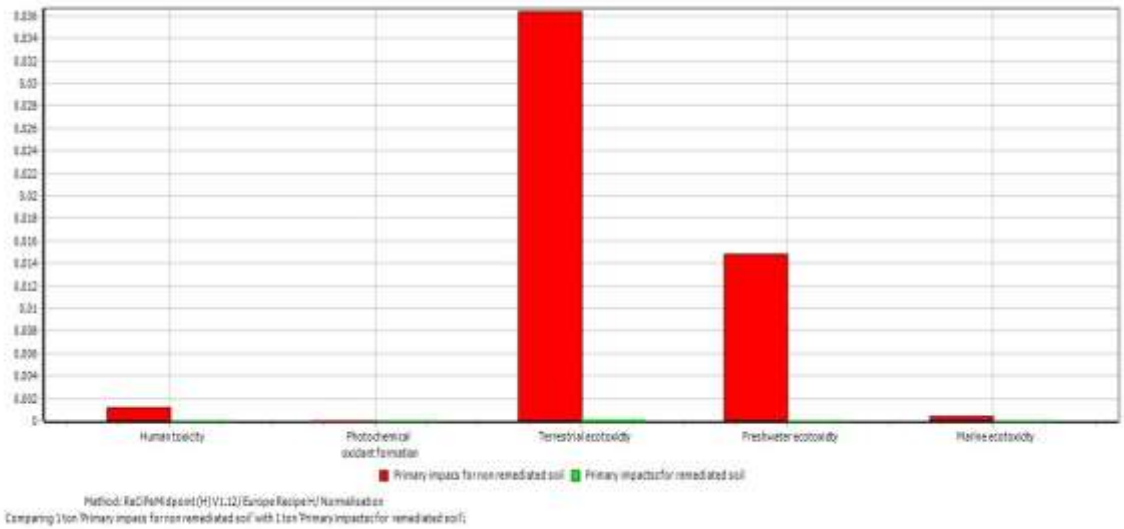
Ozone depletion
Human toxicity
Radiation
Ozoneformation
Particules form.
Climate change
Terr. ecotox
Terr. acidif.
Agr. land occ.
Urban. land occ.
Nat. land transf
Marine ecotox.
Marine eutr.
Freshwater eutr.
Freshw. Ecotox.
Fossil fuel cons
Mineral cons.
Water cons.

Global results of remediation and no action

Impact category	Unit	1 No action	2 Remediated soil
Climate change	kg CO2 eq	0	9.69
Ozone depletion	kg CFC-11 eq	0	7.72E-07
Terrestrial acidification	kg SO2 eq	0	4.49E-02
Freshwater eutrophication	kg P eq	0	1.64E-03
Marine eutrophication	kg N eq	0	3.74E-03
Human toxicity	kg 1,4-DB eq	1.27	1.69
Photochemical oxidant formation	kg NMVOC	0.04	0.03
Particulate matter formation	kg PM10 eq	0	0.02
Terrestrial ecotoxicity	kg 1,4-DB eq	0.30	0.00
Freshwater ecotoxicity	kg 1,4-DB eq	0.16	0.12
Marine ecotoxicity	kg 1,4-DB eq	0.01	0.07
Ionising radiation	kBq U235 eq	0	0.68
Agricultural land occupation	m2a	0	0.49
Urban land occupation	m2a	17.9	0.07
Natural land transformation	m2	0	0.00
Water depletion	m3	0	0.24
Metal depletion	kg Fe eq	0	0.38
Fossil depletion	kg oil eq	0	4.60



Primary impacts

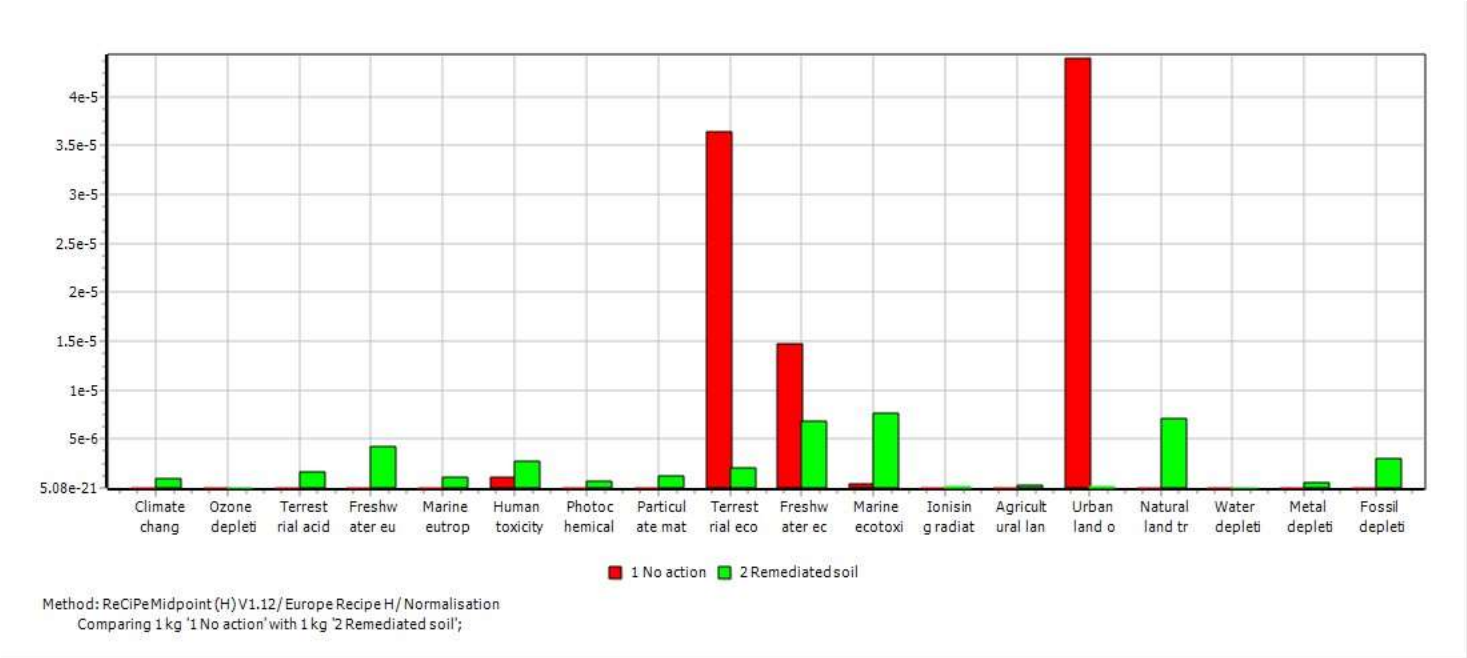


Impact category	Unit	Primary impacs for non remediated soil	Primary impactsc for remediated soil
Human toxicity	kg 1,4-DB eq	7.24E-01	4.24E-04
Photochemical oxidant formation	kg NMVOC	3.68E-05	0.00E+00
Terrestrial ecotoxicity	kg 1,4-DB eq	3.01E-01	6.96E-04
Freshwater ecotoxicity	kg 1,4-DB eq	1.63E-01	1.86E-05
Marine ecotoxicity	kg 1,4-DB eq	3.76E-03	8.06E-06

Toxicity impact categories are still “young”, less robust than older categories such as climate change. We do not expect to have the same reliability in results

Not all the pollutants have a characterization factor within the Impact assessment method used

Normalized on the basis of average EU inhabitant



Primary and secondary impacts

The assessment of primary impacts can also be used to compare the environmental impacts of a no action versus a remediation scenario to see whether remediation is an overall environmental benefit.

However, such comparisons entail a discussion of the internal weighting between primary and secondary impacts.

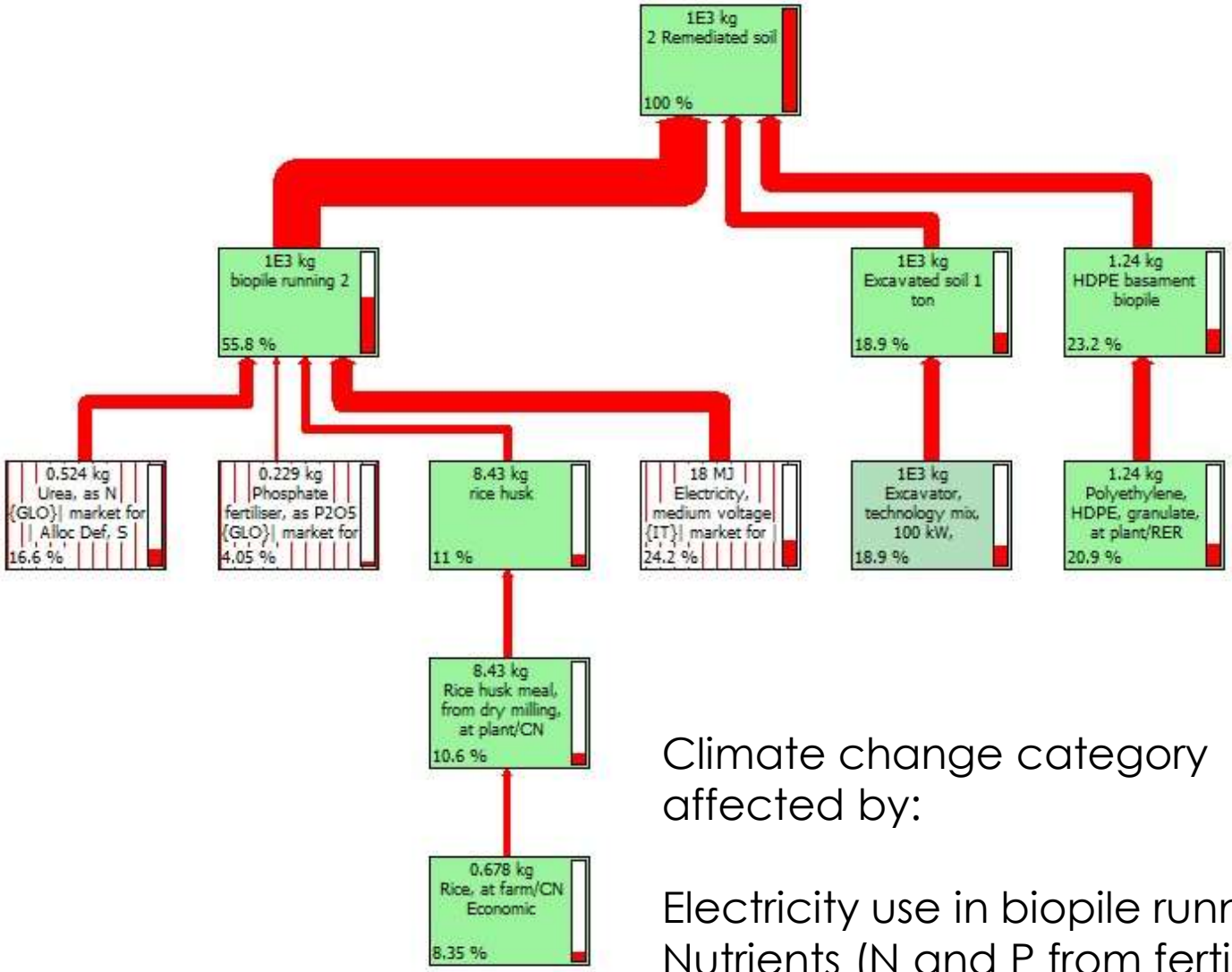
Primary impacts are local impacts

Secondary impacts are often global or far from site

Remediation results

Impact category	Unit	Total
Climate change	**kg CO2 eq**	9.69
Ozone depletion	kg CFC-11 eq	7.72E-07
Terrestrial acidification	kg SO2 eq	4.49E-02
Freshwater eutrophication	kg P eq	1.64E-03
Marine eutrophication	kg N eq	3.74E-03
Human toxicity	kg 1,4-DB eq	1.69
Photochemical oxidant formation	kg NMVOC	0.03
Particulate matter formation	kg PM10 eq	0.02
Terrestrial ecotoxicity	kg 1,4-DB eq	0.00
Freshwater ecotoxicity	kg 1,4-DB eq	0.12
Marine ecotoxicity	kg 1,4-DB eq	0.07
Ionising radiation	kBq U235 eq	0.68
Agricultural land occupation	m2a	0.49
Urban land occupation	m2a	0.07
Natural land transformation	m2	0.00
Water depletion	m3	0.24
Metal depletion	kg Fe eq	0.38
Fossil depletion	**kg oil eq**	4.60

Climate change hot spot



Climate change category is mainly affected by:

Electricity use in biopile running

Nutrients (N and P from fertilizer industry)

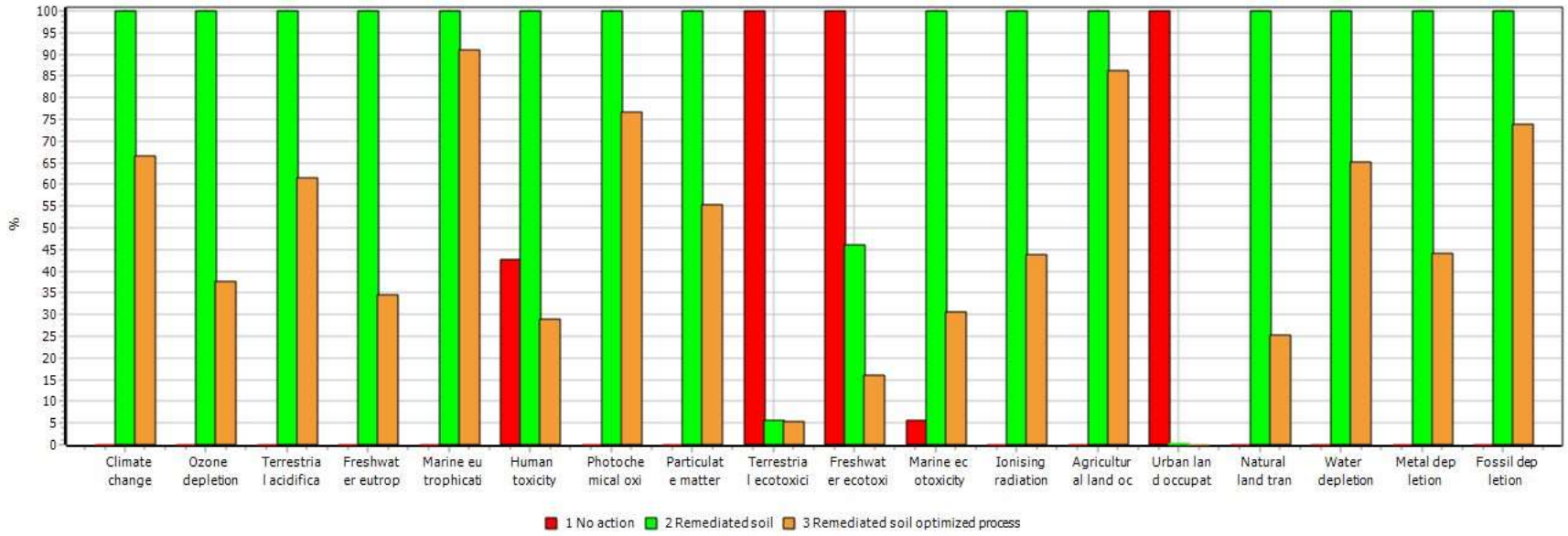
Scenarios

No action scenario, no remediation is considered and only primary impacts are accounted

Soil remediation: by treatment in bioaugmented biopile.

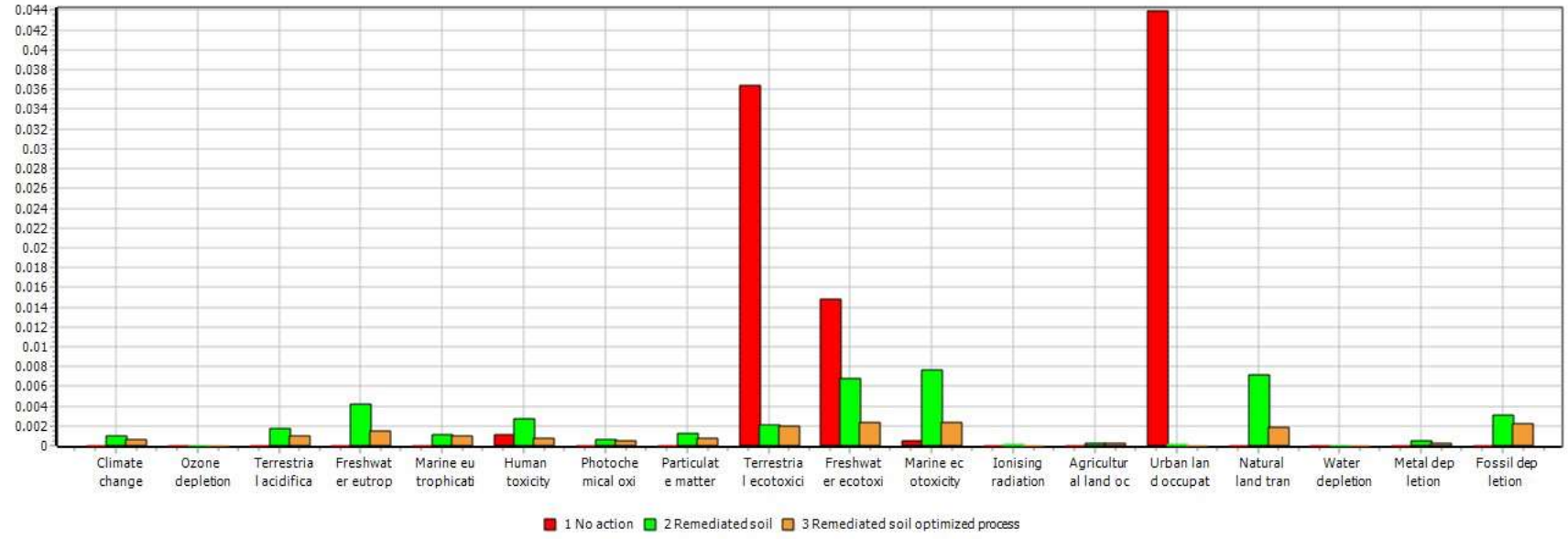
Soil remediation reduced input: by treatment in bioaugmented biopile and reduction of hot spot: electricity use reduced thanks to on-off aeration system based on O2 concentration, use of recovered nutrients available on site in place of fertilizers

Scenarios



Method: ReCiPe Midpoint(H) V1.12 / Europe RecipeH / Characterisation
Comparing 1 ton '1 No action', 1 ton '2 Remediated soil' and 1 ton '3 Remediated soil optimized process';

Normalized on the basis of average EU inhabitant



Method: ReCiPe Midpoint (H) V1.12 / Europe Recipe H / Normalisation
Comparing 1 ton '1 No action', 1 ton '2 Remediated soil' and 1 ton '3 Remediated soil optimized process';

Remediation scenario

Bioremediation scenario present the highest impacts in some categories related to the secondary impacts (operation of biopile venting and equipment construction) .

Climate change, photochemical oxidation, and particulate matter formation: related to the use of energy (fuel for excavation of soil and transport of materials, electricity for biopile running, energy for fertilizers production)

Freshwater and marine eutrophication: relative to the use of Fertilizers (N and P)

Agricultural land occupation: relative to the use of rice husk as by-products. In this case mass allocations of burdens among rice and husk was performed

No action

No action scenario: the impacts categories are related to the primary impacts, i.e.:

human toxicity, terrestrial eco-toxicity, terrestrial eco-toxicity, marine eco-toxicity.

These categories are related with the soil pollution and the consequences of the pollution on human health and environment

Primary impacts are local impacts

Conclusions

Primary impacts are tricky. Characterization factors sometime are missing and knowledge of cause –effect chain is not robust. Underestimation may occur!!

Remediation lessen local impacts and cause some impacts due to treatment at global level (secondary impacts)

The

LCA helps to highlight hot spots and look for better option in soil remediation