

Soil health and ecosystem services in contaminated land management

Lessons from ISLANDR

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CENSE, CHANGE NOVA FCT; BRGM, Chalmers, GTK, CERTH, Green Decisions

REMTECH
Europe



What Does Soil Health Mean on Industrial and Urban Land?

- Considering different descriptors, how should soil health assessments vary across different land uses?
- What expectations exist for soil health across various land uses, and how do stakeholders' approaches differ?
- How to integrate soil health into sustainable community designs – climate adaptation and green infrastructures?
- What is the acceptance and financial impact/value driver of prioritizing soil health in industrial and urban areas?



From soil health to soil functionality

DECISION

- **Soil health** – emerges from the interaction of physical, chemical and biological properties
- **Soil functionality** – evaluates the capacity to perform functions under a given land use (Single indicators cannot capture soil functional performance)
- **Land use** – Threshold compliance $\neq$ functional integrity (Functional indicators support risk assessment, monitoring and remediation.)



Take-home message

Functionality makes soil health operational.

Soil functions underpin ecosystem services!

Considering future land use – indicators and soil functions

Physical

Soil Texture
Bulk Density
Porosity

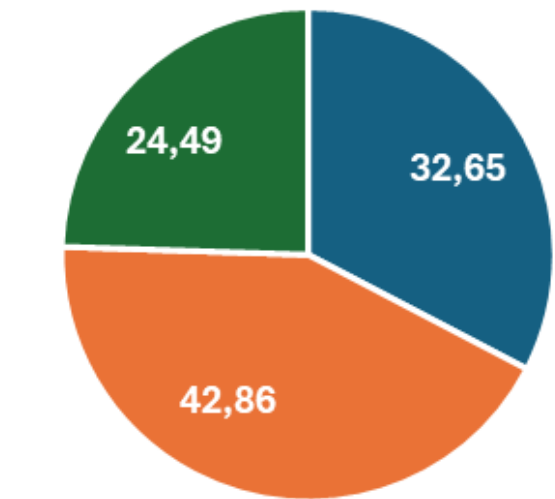
Chemical

pH Level
Electrical Conductivity
Organic Matter Content
Presence of Contaminants

Biological

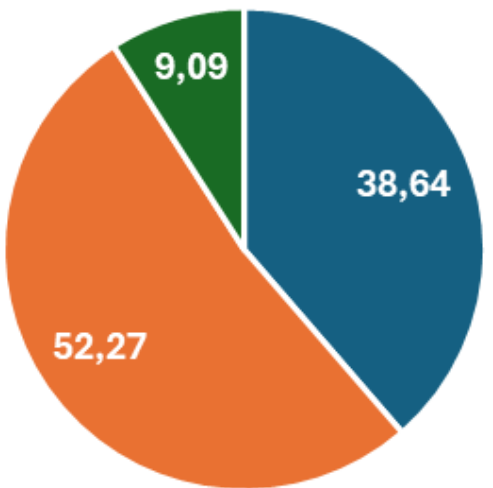
Microbial Biomass
Biodiversity
Basal Respiration

Urban land use



■ Physical ■ Chemical ■ Biological

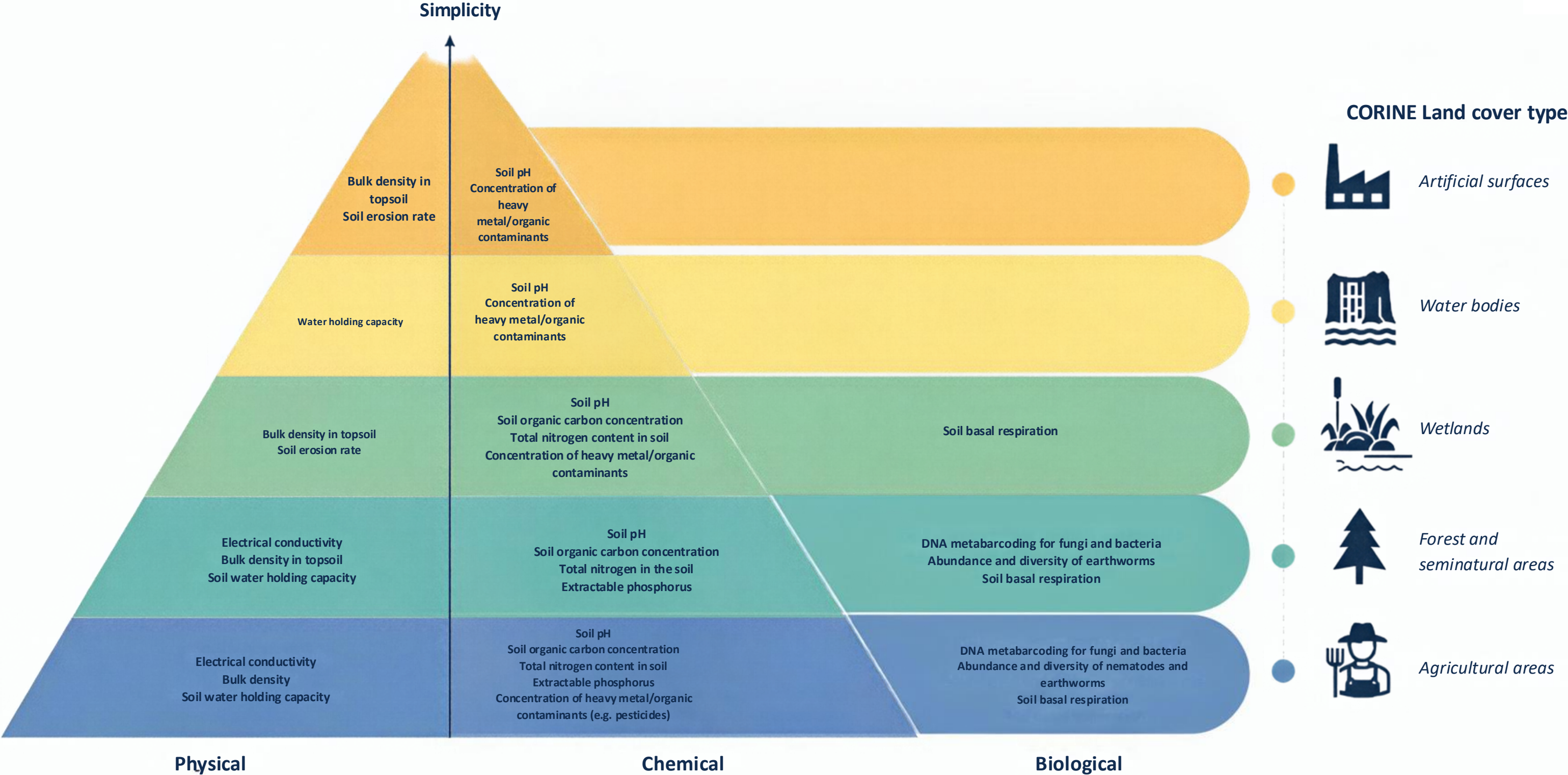
Industrial land use



■ Physical ■ Chemical ■ Biological

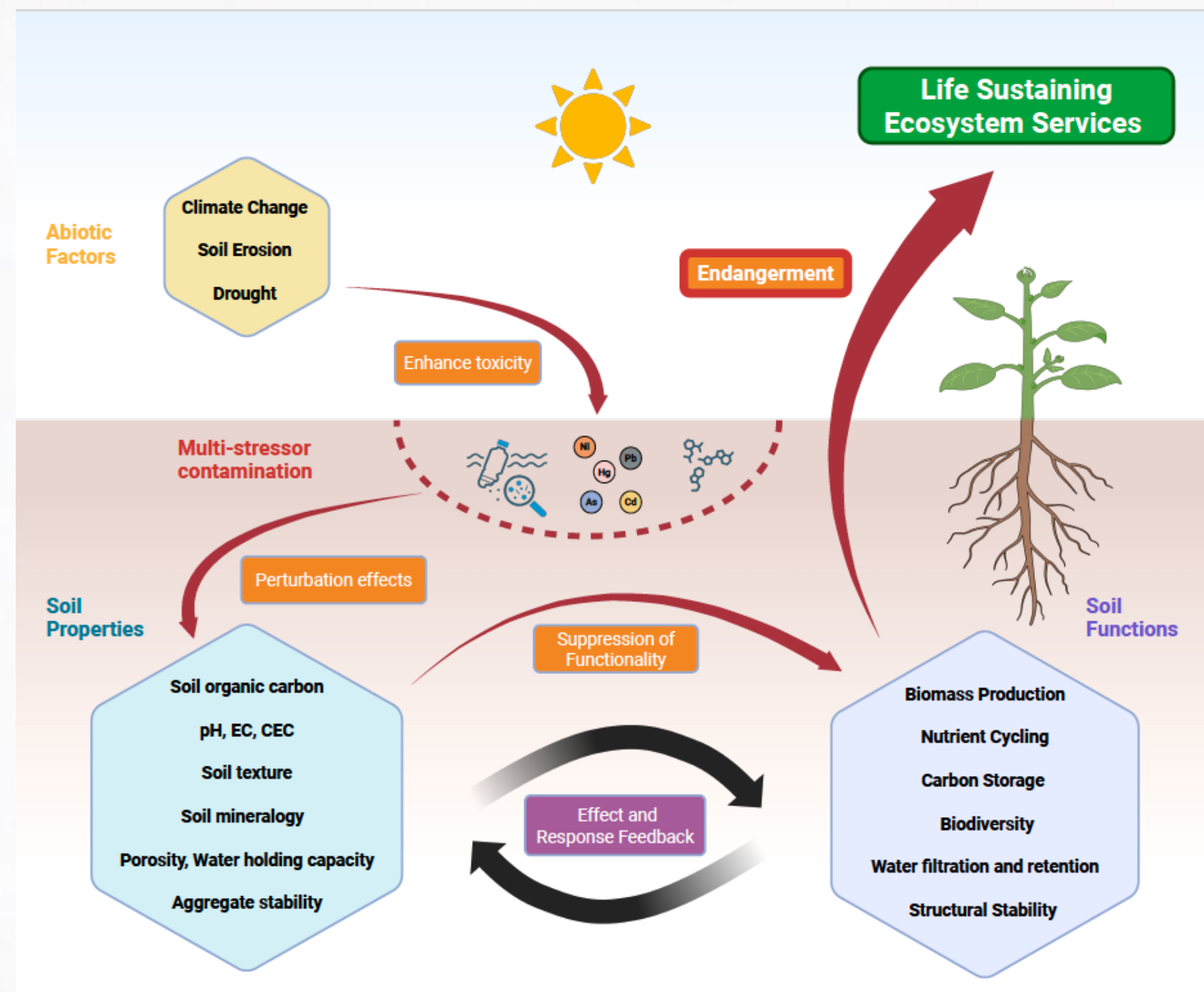
Soil health descriptors referred as relevant by the NICOLE workshop participants

Minimum Dataset (MDS): selecting the core indicators



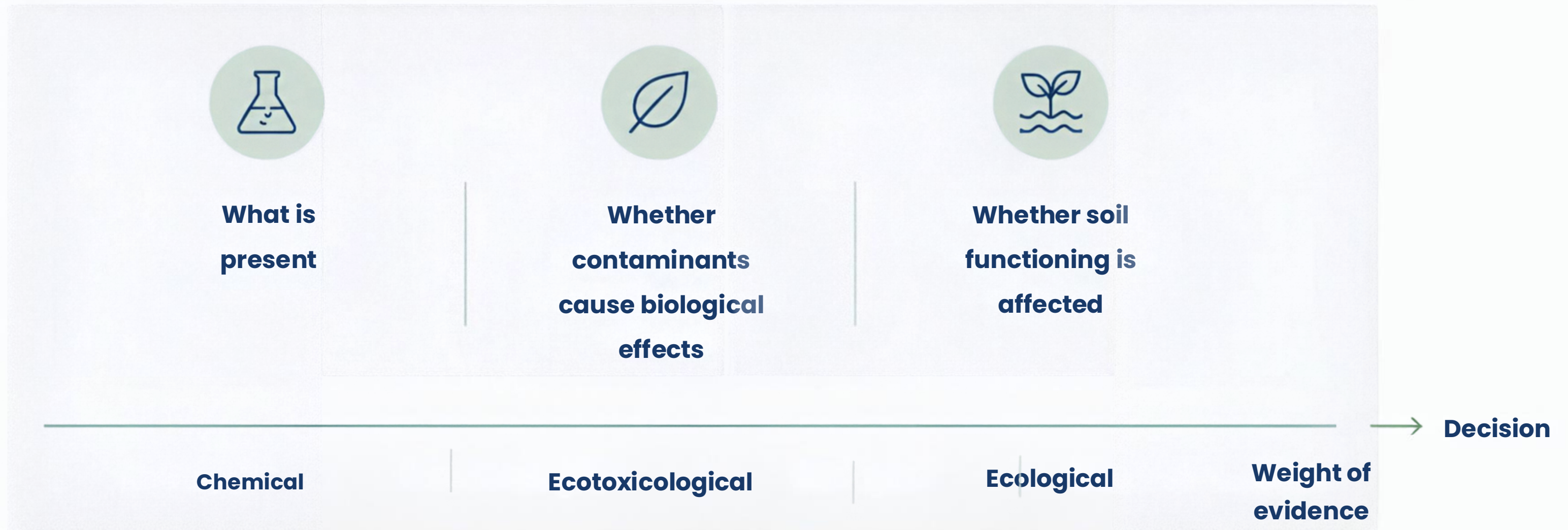
Proposed framework for selecting the Minimum Dataset (MDS) of soil health indicators according to land use. Source: ISLANDR Del 2.3

Effects of Environmental Contamination



Source: Djomerhi et al. 2026.

TRIAD: Integrating multiple Lines of Evidence (LoE)



Take-home message

Multiple Lines of Evidence reduce uncertainty

TRIAD as a tiered assessment framework

Screening

TIER 1

Total concentrations of contaminants present



Short term ecotoxicological assays

- mortality
- avoidance
- germination
- bioluminescence



Survey of vegetative cover

- density
- distribution



Edaphic fauna feeding bait lamina test



Refined assessment

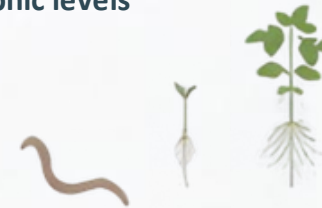
TIER 2

- Bioavailable concentrations → reagent extractions
- Physicochemical assays



Long term ecotoxicological assays across multiple trophic levels

- reproduction
- growth



Plant and edaphic fauna biodiversity



Soil microbial parameters

- respiration
- biomass
- enzymatic/metabolic activity



Detailed investigation

TIER 3

- Bioavailable concentrations → sequential extractions
- Physicochemical assays



Short/long term ecotoxicological assays with in situ organisms

- mesocosm experiments
- passive sampling



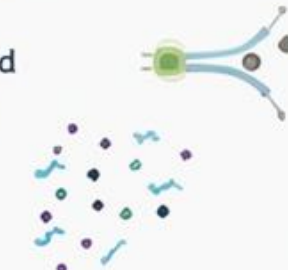
Structural and functional diversity of soil biome

- metagenomics
- metatranscriptomics



Contamination-triggered biochemical pathways

- metabolomics
- proteomics



Chemical LoE

Ecotoxicological LoE

Ecological LoE

Progressive TRIAD assessment Framework. *Source:* Djomerhi et al. 2026.

TRIAD helps us understand the effects of contamination.
But how do we define healthy soil?

Soil diffuse contamination

- Large areas
- Not confined to specific or identifiable sources
- Cannot be traced to a specific location
- Results from activities that disperse contaminants over large regions –e.g. Agriculture
- More difficult to control and remediate



Pesticides: an example of diffuse contamination

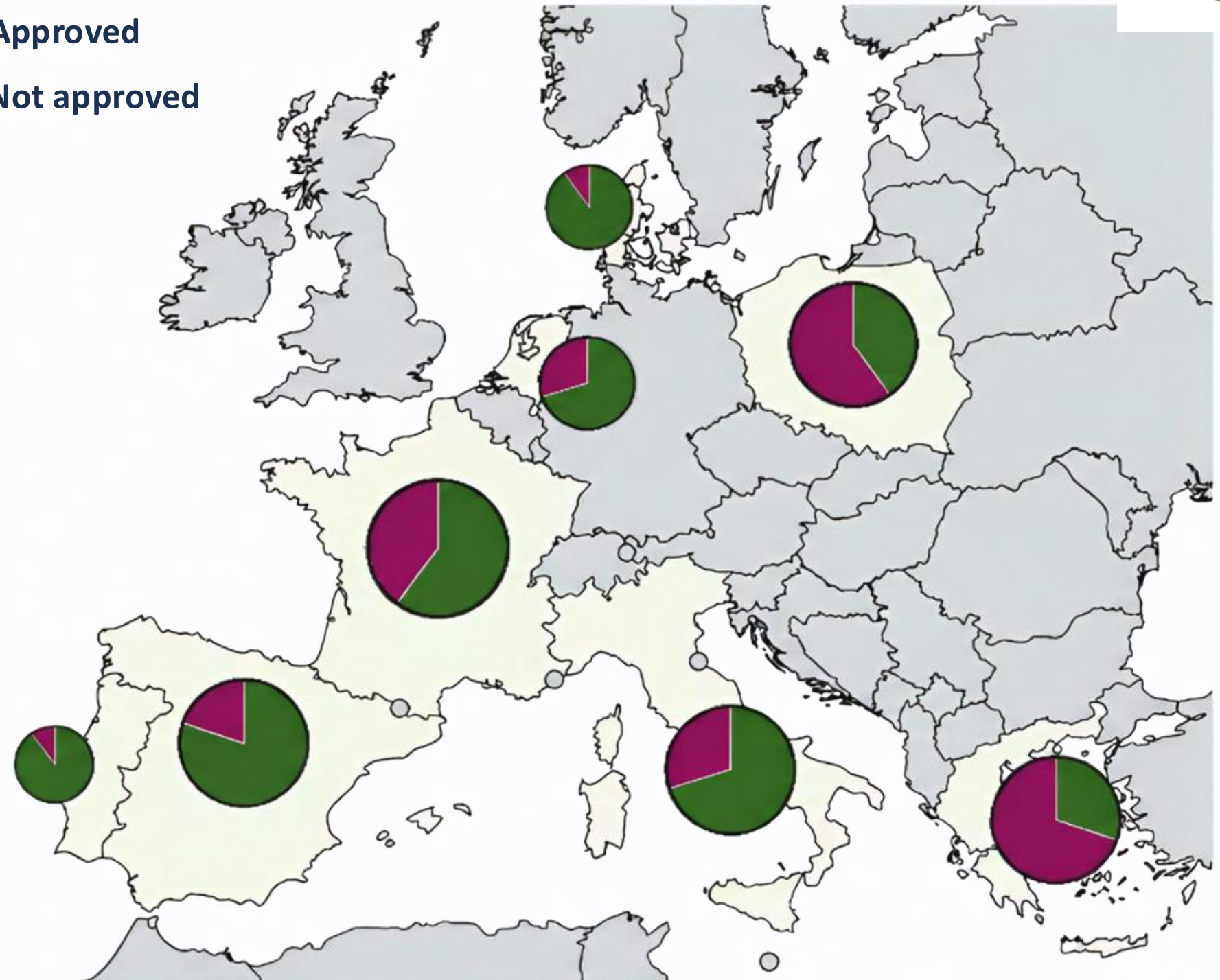
1 Persistent

2 Mobile

3 Spatially diffuse

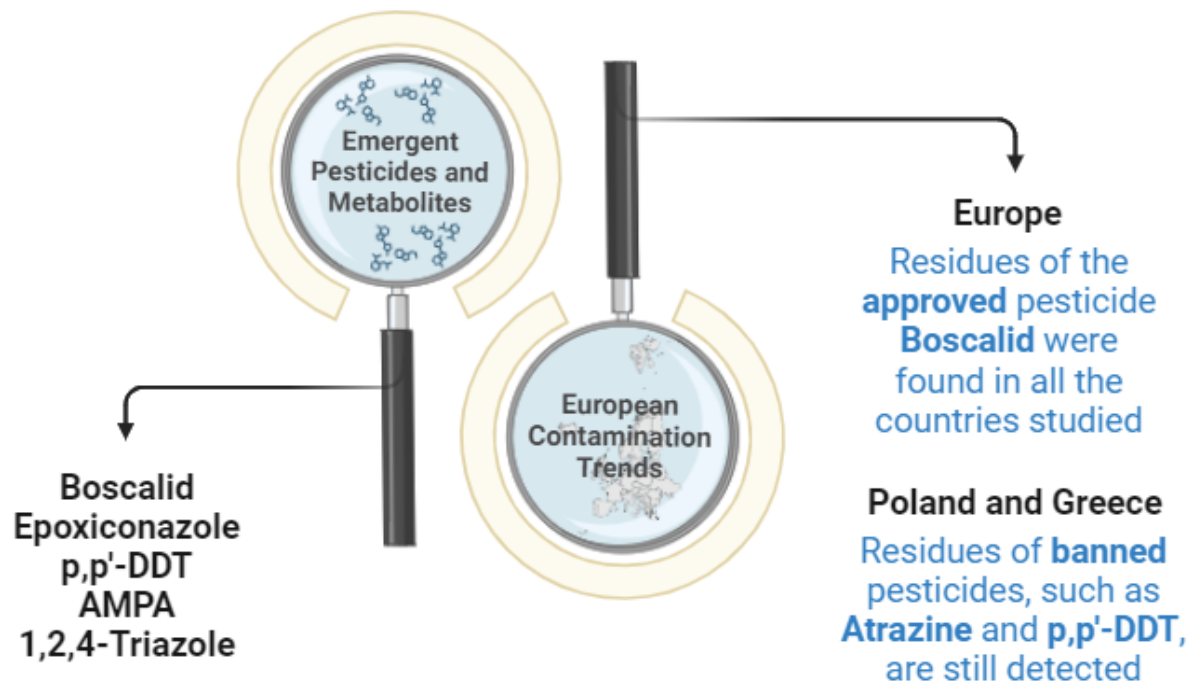
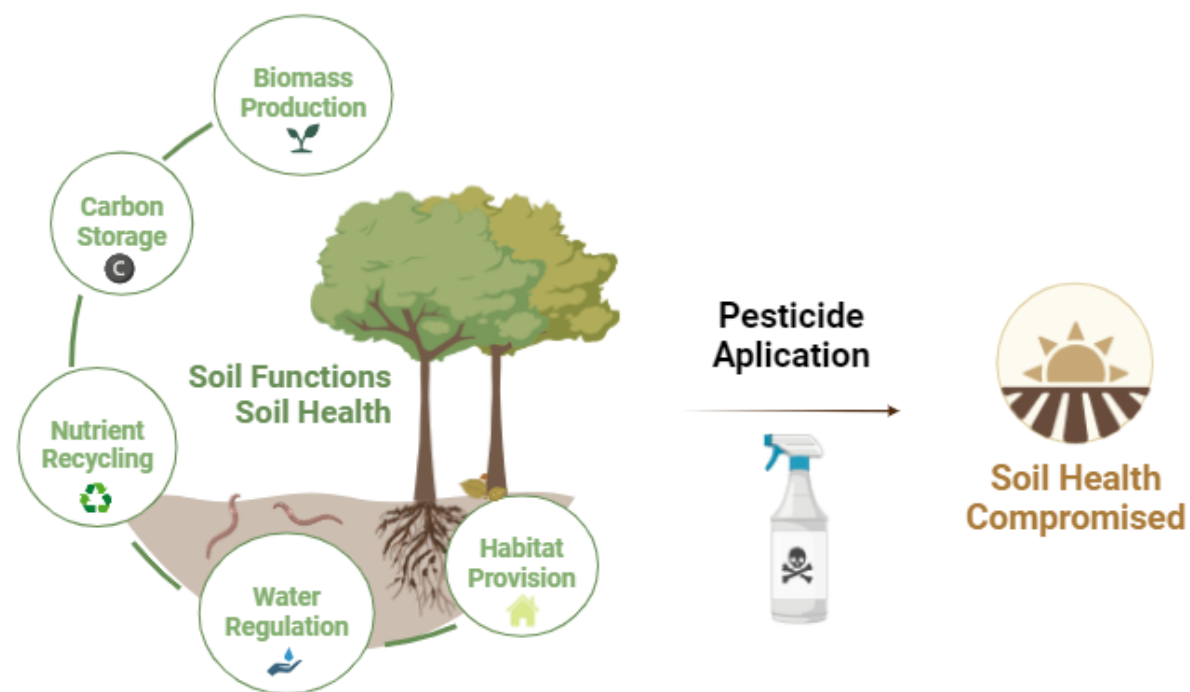
4 Difficult to manage

Approved
Not approved



Spatial distribution of approved and non-approved pesticides among the top 10 pesticides of concern in Europe. *Source:* adapted from Carvalho et al., 2025.

Tracing pesticide contamination across



Safeguard Soil Health



Source: Carvalho et al., 2025

From soil functionality to remediation decisions



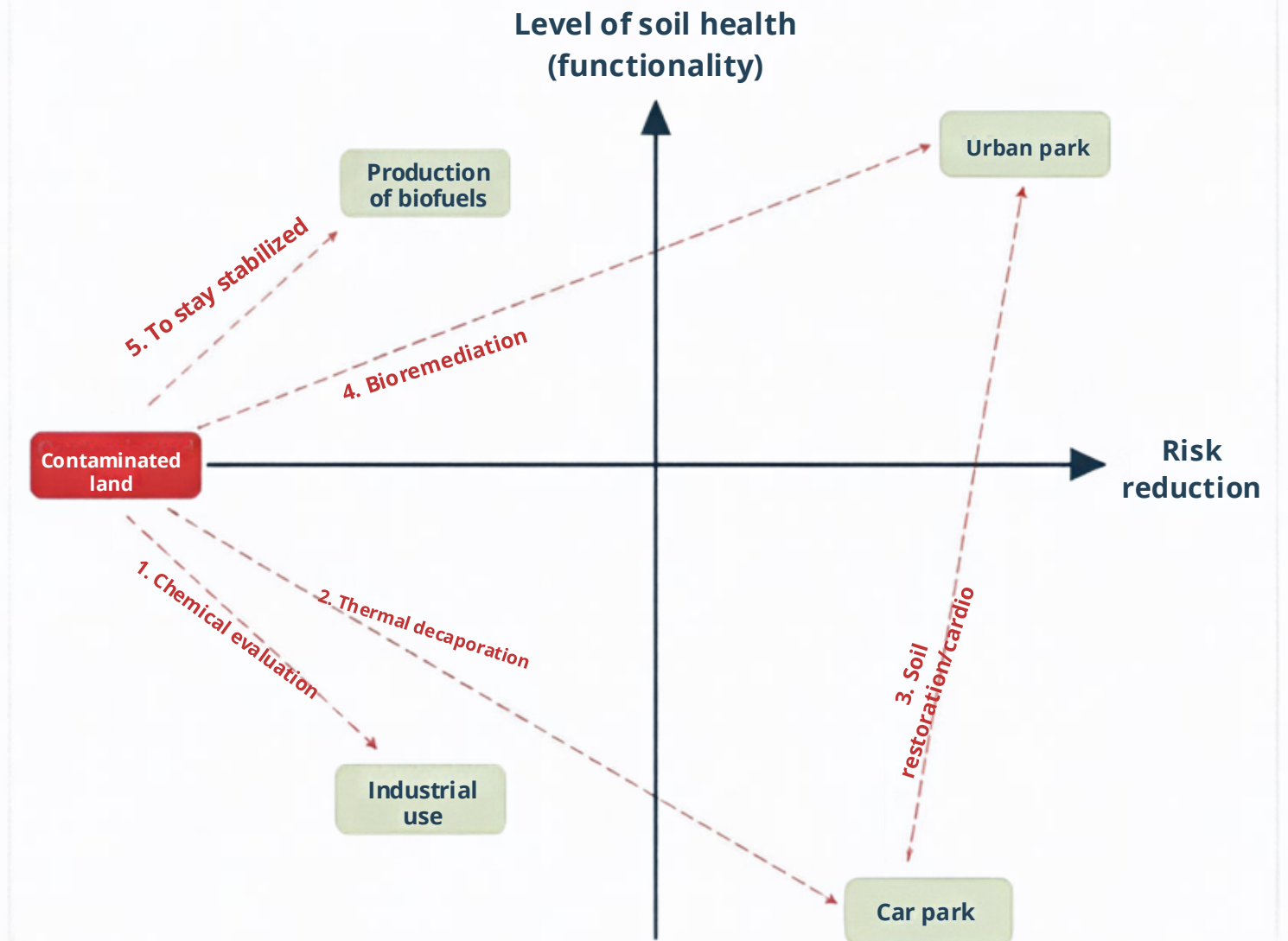
Function-oriented management

- Soil functionality is evaluated in relation to intended land use
- Regulatory compliance does not necessarily ensure soil functionality
- Different land uses require different soil functions



Different remediation trajectories

- Remediation objectives depend on the future land use
- Different trajectories balance risk reduction, soil functionality and feasibility
- The goal is to restore the functions required for the intended land use



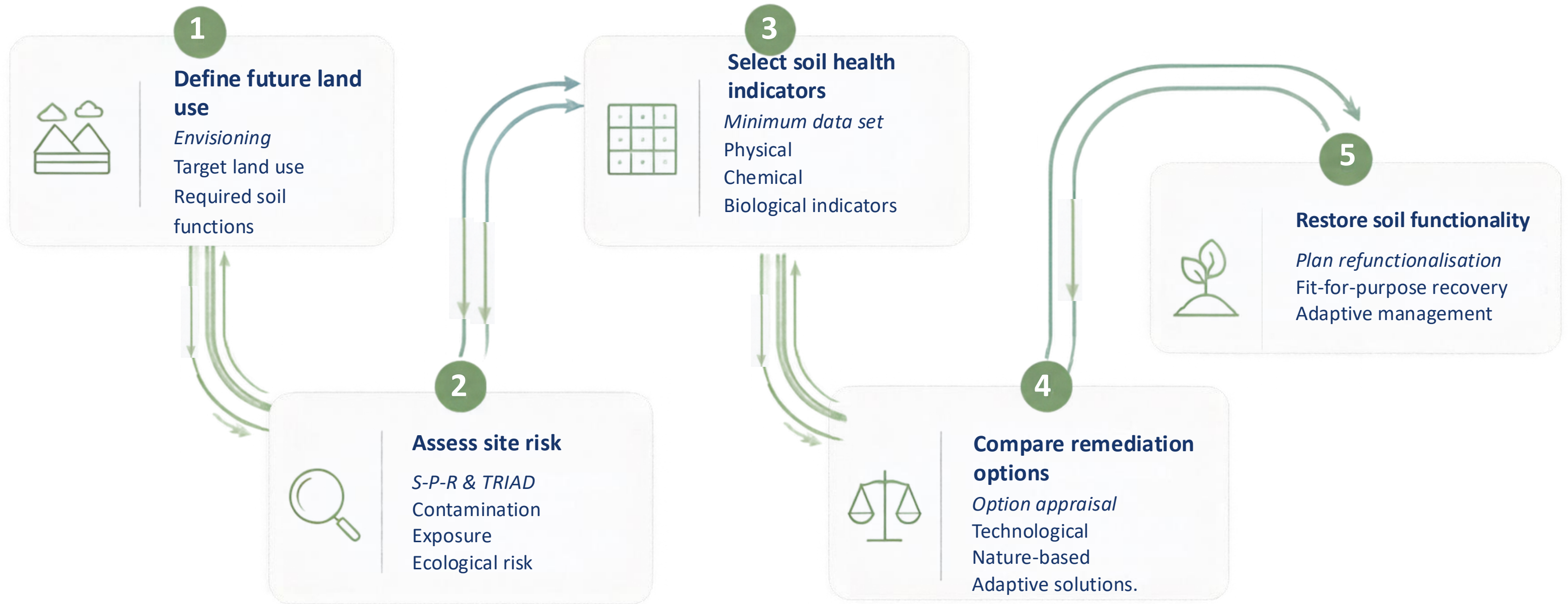
Source: ISLANDR Del 3.2



Take-home message

Remediation strategies should restore the functions required for the intended land use – not simply reduce contamination concentrations

The Stepwise Decision-Support Protocol



Integrated decision-making combines risk assessment, soil health indicators, remediation options and future land use to restore soil functionality.

Key take-home messages



“

**The future is not only cleaner soils.
It is functional soils.**

”

1. Paradigm shift

From concentration-based compliance



To function-oriented management

2. Integrated decision-making

Risk assessment



Soil health indicators



Decision support

3. Sustainable remediation

Fit-for-purpose restoration



Technological and nature-based solutions

Healthy soils deliver ecosystem services through their functions

Partners



Deltares



CHALMERS



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the European Union



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