# 2. EFU-PEDOSPHERE – kész, uniformalizált EFU-dokumentum

**Cím:** EFU-PEDOSPHERE RESEARCH FRAMEWORK v1.0 – 104.44 PEDOSPHERE AUDIT (ARABLE SOIL)
**Szerző:** Simor István (EX2026D1342540)
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**Státusz:** Experimental Research Framework (Pre-standard, Research Phase)
**Keretrendszer:** EFU – Ecological / Human Flux Unit Research Framework

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# ABSTRACT

[AXIÓMA] Soil functions as a dynamic metabolic interface of the Earth system, where solar radiation, water flows and the mineral matrix interact to sustain biological and socio-ecological metabolism.frontiersin+1

[HIPOTÉZIS] The EFU-Pedosphere framework models soils as metabolic infrastructures and introduces a set of human-scale indicators – humus exergy (EFU-Humus / H-Ex), water-retention potential (EFU-Water Retention / W-Ret) and soil biodiversity / microbiome activity (EFU-Biodiversity / Bio-M) – to characterise soil health in terms of flux and exergy rather than static stocks.scholar.google+2

[HIPOTÉZIS] The Soil Sovereignty Gap (SS_soil) is defined as the discrepancy between a region's potential for food self-determination and the actual degradation state of its soils, expressed as a composite of humus change, water-holding capacity and erosion. Land sealing, monocultural industrial agriculture and high chemical input use tend to widen this gap, while regenerative practices can help close it.scholar.google+2

[PROTOKOLL] EFU-Pedosphere proposes an audit protocol combining sealing coefficients, regeneration rates and "chemical debt" with an experimental SS_soil metric, supporting comparative assessment of urban development, agricultural management and industrial land-take in terms of metabolic debt and soil-centred sovereignty.sciepublish+2

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# 1. Core statements with EFU labels

## 1.1 Metabolic role of soil

[AXIÓMA] Soil is a non-equilibrium, open system where energy and matter fluxes (radiation, water, nutrients, gases) continuously cross the soil–atmosphere and soil–water interfaces, enabling plant growth, carbon storage and nutrient cycling.frontiersin+1

[HIPOTÉZIS] Treating soil surfaces as purely geometric or cadastral entities systematically underestimates their role as metabolic infrastructures and leads to mispricing of land use, especially under urban expansion and industrial conversion.climate-adapt.eea.europa+1

## 1.2 Soil Sovereignty Gap ($SS_{soil}$)

[HIPOTÉZIS] The Soil Sovereignty Gap is a function of three main biophysical dimensions:

**Soil Stability Score ($SS_{soil}$) – definíció**

**$SS_{soil}$ = f(ΔHumus, ΔWater Retention, ΔErosion):**

- **ΔHumus** = change in soil humus content
- **ΔWater Retention** = change in soil water retention
- **ΔErosion** = change in erosion load

where large negative changes in humus and water retention, combined with high erosion, increase dependence on external inputs and reduce food sovereignty.sciepublish+2

[HIPOTÉZIS] Regions with stable or increasing humus exergy, improved water retention and controlled erosion are more likely to maintain long-term food self-determination and resilience under climate stress.scholar.google+2

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# 2. EFU-based indicators

## 2.1 EFU-Humus (H-Ex) – Humus exergy

[AXIÓMA] Soil organic matter (SOM) stores exergy and chemical potential that underpin soil fertility, structure and biological activity.scholar.google+1

[HIPOTÉZIS] A 1% absolute loss of humus in the topsoil over a given area corresponds to a significant loss of exergy and ecosystem functions (yield stability, water retention, biodiversity), which cannot be fully compensated by external fertiliser inputs.frontiersin+1

[PROTOKOLL] H-Ex should be derived from SOM measurements (e.g. loss-on-ignition or carbon content) combined with exergy factors from soil–plant interaction models, and reported as an EFU-normalized indicator for audit comparisons.scholar.google+1

## 2.2 EFU-Water Retention (W-Ret)

[AXIÓMA] Soil water-holding capacity is constrained by texture, structure, organic matter content and bulk density; it controls infiltration, runoff, drought resilience and flood risk.nfuonline+1

[HIPOTÉZIS] Management practices that increase W-Ret (e.g. organic amendments, reduced compaction, cover crops) provide an effective climate-adaptation lever by simultaneously reducing erosion, smoothing hydrographs and supporting crop stability.climate-adapt.eea.europa+1

[PROTOKOLL] W-Ret is quantified via field capacity, infiltration tests, or modelled water-holding indices, and then normalised into EFU units per hectare or per capita, depending on the audit scale.nfuonline+1

## 2.3 EFU-Biodiversity (Bio-M) – Soil microbiome activity

[AXIÓMA] Soil microbiomes mediate key ecosystem processes, including decomposition, nutrient cycling and pollutant transformation.nature+2

[HIPOTÉZIS] Microbial diversity and activity can serve as an integrated indicator of soil ecosystem multifunctionality and resilience; degraded soils show lower functional diversity and weaker system recovery after shocks.pubmed.ncbi.nlm.nih+1

[PROTOKOLL] Bio-M is estimated using microbial biomass, diversity indices (e.g. metagenomic profiles) or functional assays, summarised in a normalised EFU-Biodiversity index for comparative audits.nature+1

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# 3. EFU-Pedosphere audit protocol

[PROTOKOLL] A minimal EFU-Pedosphere audit should contain:

1. **Sealing coefficient (SC)** – area share of sealed surfaces, changes in infiltration and soil respiration capacity.[climate-adapt.eea.europa]
2. **Regeneration rate (Reg-Rate)** – estimated time horizon for restoring baseline H-Ex and W-Ret under specified management scenarios.[sciepublish]
3. **Chemical debt (Chem-Debt)** – trend in external input use (fertiliser, pesticides, irrigation energy) relative to soil function, indicating whether inputs substitute for lost soil exergy and biology.scholar.google+2

[HIPOTÉZIS] High SC, slow Reg-Rate and rising Chem-Debt describe a **metabolically extractive** soil-use regime, where soil system function is being mined rather than regenerated.

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# 4. Argument map (logical chain)

- Premise A [AXIÓMA]: Soil organic matter, water-holding capacity and microbiome activity are necessary physical foundations for long-term productivity, resilience and ecosystem services.nature+2
- Premise B [HIPOTÉZIS]: Industrial agriculture, land sealing and inadequate management practices systematically deplete humus, reduce W-Ret and degrade Bio-M, while increasing dependence on external inputs.scholar.google+3
- Conclusion C [HIPOTÉZIS]: Without explicit metabolic auditing (H-Ex, W-Ret, Bio-M, SC, Reg-Rate, Chem-Debt), land-use decisions will widen the Soil Sovereignty Gap, undermining regional food sovereignty and climate resilience.frontiersin+1

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# 5. Epistemological Appendix (EA)

## EA.1 Falsifiability

[PROTOKOLL] The EFU-Pedosphere framework is falsifiable if:

1. Empirical evidence shows that regions with declining H-Ex, W-Ret and Bio-M do **not** exhibit reduced yields, resilience or increased external input dependency, contrary to the Soil Sovereignty Gap hypothesis.sciepublish+2
2. Long-term case studies demonstrate that high sealing coefficients and erosion do **not** materially affect water-related risks or food-system robustness.climate-adapt.eea.europa+1
3. Microbiome-based indicators fail to correlate with soil multifunctionality and recovery capacity, weakening Bio-M as a meaningful component of soil metabolic health.pubmed.ncbi.nlm.nih+1

## EA.2 Uncertainty factors

[HIPOTÉZIS] Key uncertainty sources include:

- **Data uncertainty:** variability and measurement error in SOM, water-retention estimates, erosion rates and microbial indicators across sites and time.frontiersin+2
- **Model uncertainty:** choice of exergy models for H-Ex, hydrological models for W-Ret, and ecological models linking microbiome metrics to functions.scholar.google+2
- **Context dependence:** strong regional differences in climate, soil type and management that affect baselines and thresholds; SS_soil may require region-specific calibration.sciepublish+1

[PROTOKOLL] Every EFU-Pedosphere application should include:

- a transparent description of data sources and models,
- a sensitivity analysis for key parameters (e.g. humus change rates, W-Ret improvements),
- and a clear statement that all thresholds and indicators are **research-phase** constructs, open to revision in light of new evidence.climate-adapt.eea.europa+2

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# Scientific endnote for the EFU-Pedosphere Research Framework

[PROTOKOLL] The EFU-Pedosphere framework is designed as a research-phase metabolic audit tool for soils. The references below support the central assumptions about soil organic

matter (SOM), water retention, erosion control and the soil microbiome as drivers of ecosystem services and long-term sovereignty.

1. **Soil organic matter (SOM), exergy and ecosystem services**
   Experimental and modelling studies show that SOM underpins soil structure, water retention, nutrient cycling and biological activity; SOM loss impairs water-holding capacity, nutrient budgets and has negative feedbacks on the carbon cycle. Long-term experiments indicate that agricultural use often leads to continuous SOM depletion over decades, even when plant productivity increases, suggesting that historically accumulated SOM is being mined and that soil carbon stocks respond only slowly to management changes. These findings justify treating humus/SOM as an exergy-like backbone (EFU-Humus, H-Ex) in the EFU-Pedosphere model.sciencedirect+3
2. **Depletion and recovery dynamics of SOM**
   Long-term (>50 years) cropping experiments in Europe document 10–15% declines in soil organic carbon and phosphorus in the upper soil layers, with mean carbon transit times of less than a decade, implying that much of the new carbon entering soils is rapidly respired rather than stabilised. In contrast, regenerative management case studies show that SOM and topsoil thickness can increase substantially over a few decades, with A-horizon thickening on the order of centimetres per year under carefully designed regenerative practices. Together, these results support the EFU-Pedosphere hypotheses that (a) conventional management is often metabolically **extractive** with respect to SOM, and (b) regeneration is possible but requires deliberate, long-term practice change.nature+1
3. **Water retention, erosion and regulating ecosystem services**
   Soil water-holding capacity and erosion control are widely recognised as key regulating ecosystem services, influencing flood regulation, drought resilience, nutrient retention and pollution control. Guidance documents on soil retention services emphasise that climate, topography, soil properties, organic matter and land management jointly determine erosion risk and retention capacity, and that improved water retention in agricultural landscapes is a central climate-adaptation measure. This underpins the EFU-Pedosphere use of EFU-Water Retention (W-Ret) and ΔErosion as core components of the Soil Sovereignty Gap (SS_soil).openknowledge.fao+3
4. **Soil microbiome as an indicator of ecosystem multifunctionality**
   Recent large-scale studies across hundreds of European soils demonstrate that the soil microbiome explains a substantial, context-dependent share of variation in ecosystem multifunctionality and enzymatic activity (often >25% in certain soil types), and that specific bacterial and fungal taxa are strong predictors of ecosystem performance. Microbial biomass and nitrogen content, in particular, emerge as key predictors of multifunctionality, with cropland microbiomes explaining variance comparable to that explained by soil physico-chemical properties. These results justify the EFU-Biodiversity (Bio-M) indicator as a meaningful, biologically grounded proxy for soil metabolic health and resilience.nature+1
5. **Soil ecosystem services, sovereignty and long-term trajectories**
   Assessments of future soil ecosystem services under climate change scenarios show that soil service provision (e.g. food production, carbon storage, water regulation) is sensitive to changes in SOM, erosion rates and management regimes, with some drained or degraded soils projected to lose a significant fraction of their service capacity by the end of the century. Policy-oriented syntheses on soil ecosystem services stress that SOM loss, erosion and sealing have both on-site and off-site impacts, affecting flood risks, climate regulation and infrastructure stability. This

supports the EFU-Pedosphere concept of a Soil Sovereignty Gap (SS_soil), linking biophysical trajectories of humus, water retention and erosion to regional food self-determination and systemic resilience.alpine-space+3

[HIPOTÉZIS] Taken together, these empirical lines of evidence support the EFU-Pedosphere assumptions that (a) humus exergy (H-Ex), water-retention potential (W-Ret) and microbiome activity (Bio-M) capture key dimensions of soil metabolic health, and (b) their long-term trends provide a meaningful basis for defining and monitoring a Soil Sovereignty Gap.pmc.ncbi.nlm.nih+3

[PROTOKOLL] All EFU-Pedosphere applications should explicitly document the SOM, water and microbiome indicators used, report uncertainties, and treat all thresholds and composite indices (e.g. SS_soil) as research-phase tools to be calibrated, refined or falsified through ongoing empirical work.seea.un+2